Section IV

Access to Space

Introduction

Nothing has been more significant for the long-term development of the Space Age than the ability to reach Earth orbit. When *Columbia* was lost on Saturday morning, 1 February 2003, one of the issues the accident brought to the fore was the long and complex history of the Space Shuttle's origins, evolution, and operation, as well as the continuing challenge of space access. Even more, the accident opened the issue of space access from the dawn of the Space Age in the 1950s to the present. This is a rich and inviting history, requiring serious inquiry, critical thinking, and hard-edged analysis. The first-generation launchers were all ballistic-missile-derived vehicles that served well; with some upgrades over the years, they are still the backbone of the U.S. space launch fleet. Indeed, Redstone, Atlas, Titan, Delta, and Saturn were all scaled-up variants of the ICBMs, but with notable improvements. The Space Shuttle, the only human-carrying vehicle of the United States since the Apollo program of more than 30 years ago, followed those earlier space launch systems and has served many space-access needs for more than a quarter century.[1]

After more than four decades of effort, access to space remains a difficult challenge. Although space transport services should not be measured by terrestrial standards, if the grand plans of space visionaries and entrepreneurs are to be carried out, there is a real need to move beyond currently available technologies. Unfortunately, the high cost associated with space launch from 1950 to 2005 has demonstrated the slowest rate of improvement of all space technologies. Everyone in space activities shares a responsibility for addressing this critical technical problem. The overwhelming influence that space access has on all aspects of civil, commercial, and military space efforts indicates that it should enjoy a top priority.[2]

Of course, a key element in the spacefaring vision long held in the United States is the belief that inexpensive, reliable, safe, and easy spaceflight is attainable. Indeed, from virtually the beginning of the 20th century, those interested

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1. For a discussion of the overarching space-access history, see Roger D. Launius and Dennis R. Jenkins, eds., *To Reach the High Frontier: A History of U.S. Launch Vehicles* (Lexington: University Press of Kentucky, 2002).

2. More than 50 space-access studies have reached this conclusion over the last 40 years. See Roger D. Launius and Howard E. McCurdy, *Imagining Space: Achievements, Projections, Possibilities, 1950–2050* (San Francisco: Chronicle Books, 2001), chap. 4; United States Congress, Office of Technology Assessment, *Launch Options for the Future: Special Report* (Washington, DC: Government Printing Office, 1984); Vice President's Space Policy Advisory Board, "The Future of U.S. Space Launch Capability," Task Group Report, November 1992, NASA Historical Reference Collection, Washington, DC; NASA Office of Space Systems Development, *Access to Space Study: Summary Report* (Washington, DC: NASA, 1994).

in the human exploration of space have viewed as central to that endeavor the development of vehicles of flight that travel easily to and from Earth orbit. The more technically minded recognized that once humans had achieved Earth orbit about 200 miles up, the vast majority of the atmosphere and the gravity well had been conquered, and that persons were now about halfway to anywhere they might want to go.[3]

Although a large number of issues could be explored in the history of space access, five central legacies offer tantalizing possibilities for space history and represent critical issues in the field. These include the following:

1. The limitations of chemical rocket technology.
2. The ICBM legacy of space access.
3. The costly nature of space access.
4. Launch vehicle reliability.
5. The value of reusable launch vehicles (RLVs) versus expendable launch vehicles (ELVs).

The two chapters that follow review each of these legacies, sometimes explicitly but more often indirectly, and raise serious policy issues that must inform any debate concerning access to space.[4]

In chapter 9, John M. Logsdon asks the poignant question, why is there no replacement for the Space Shuttle despite the longevity of the issue on the national agenda? From almost the first flight of the Space Shuttle in 1981, NASA realized that planning should begin on an eventual replacement. Most observers in those early years of the program believed that the current fleet could remain operational for about 20 years but that by about the year 2000, replacement would probably be necessary. Understanding that it took most of a decade, sometimes even more, to carry a major spaceflight program to fruition, they thought it important to begin the process of building a successor second-generation reusable space-access vehicle capable of human launch. Yet, as of 2005 and despite a plethora of studies, little has been accomplished.[5]

Logsdon asserts that there was a fundamental "failure of national space policy over the past three plus decades, and that the lack of a replacement for the Space Shuttle is just one of the most obvious manifestations of that policy failure." At sum, he finds that the "lack of a clear 'mandate' for human spaceflight

3. G. Harry Stine, *Halfway to Anywhere: Achieving America's Destiny in Space* (New York: M. Evans and Co., 1996).

4. Roger D. Launius, "Between a Rocket and a Hard Place: Legacies and Lessons from 50 Years of Space Launch" (presentation in Lessons Learned Session of the 36th American Institute of Aeronautics and Astronautics [AIAA] Joint Propulsion Conference, sponsored by AIAA Solid Rocket Technical Committee [SRTC], Huntsville, AL, July 17, 2000).

5. See Roger D. Launius, "After Columbia: The Space Shuttle Program and the Crisis in Space Access," *Astropolitics* 2 (July–September 2004): 277–322.

over the past 35 years has meant that the U.S. human spaceflight program, and indeed the NASA program overall, has been sustained by a complex coalition of interests, not by a clearly articulated national goal and a stable political consensus in support of achieving that goal."[6] This is an important observation, for it gets to the heart of the overarching issue of rationales for human space exploration. Those rationales have not proven especially compelling, and NASA and its human spaceflight effort have been forced to deal with a lack of motivating reasons for the Agency's activities since the Apollo program.

Instead of developing a finely honed and convincing rationale for the necessity of humans in space, NASA has cobbled together a loose coalition of government interests, industry contractors, politicians of all stripes who are supportive because of "pork" for districts as well as patriotism, and spaceflight enthusiasts who dream of becoming a multiplanetary species. They came together to support the Shuttle as a means of achieving reliable, assured, and flexible access to space and have continued to support it to the present because of the lack of anything better—however "better" might be defined by the various interest groups—on the horizon.

Logsdon offers the bold assertion that the reason for undertaking human spaceflight was reconsidered by the nation soon after the United States began to fly astronauts in 1961 and that this reflection has led to a less supportive public commitment than NASA or the spaceflight community would like. "The people of the United States and their government have been willing over the past 35 years to continue a human spaceflight program," he writes, "but only at a level of funding that has forced it to constantly operate on the edge of viability." Logsdon concludes, "The lack of a replacement for the Space Shuttle is a symptom of this larger reality."

Logsdon goes on to ask how badly Americans want to fly humans in space and finds that the answer to that is "not very badly." Accordingly, at least by the time of post-Apollo planning, the United States, through the democratic process, had reached the conclusion that spaceflight in general, and human spaceflight particularly, had to stand behind a long list of other national needs. Its funding level would be something less than 1 percent of the federal budget per year, and within that budget, NASA should advance a useful space exploration agenda. Logsdon concludes that spaceflight enthusiasts have failed to align their vision of the future with the democratically arrived-at decisions relative to space policy. In other words, something less than the bold visions of the past are necessary in the realities of the present and the future.

At sum, Logsdon concludes that both the community of spaceflight advocates in the United States and the personnel of NASA have overemphasized

6. John M. Logsdon, "'A Failure of National Leadership': Why No Replacement for the Space Shuttle?" chap. 9 in this volume.

human spaceflight's centrality to the modern nation. Instead, he argues for a more realistic perspective that reduces the spaceflight agenda to a realm that might be successful with the funding available. But a question that must be asked is, despite an unwillingness by the public to open the treasury more fully to achieve the human spaceflight vision, would the American public accept a scaled-back program that is far less grandiose? More important for the policy debate concerning a replacement for the Space Shuttle, however, would the American public accept an end to the human spaceflight mission that NASA has conducted since 1961, since failure to replace the vehicle signals that end? Only time will tell if this is how the policy decisions relating to the Shuttle replacement effort will turn out.

In chapter 10, Andrew J. Butrica assesses the historical debate over reusable launch vehicles versus expendable launch vehicles. RLV advocates have been convincing in their argument that the only course leading to "efficient transportation to and from the earth" would be RLVs and have made the case repeatedly since the late 1960s.[7] Their model for a prosperous future in space is the airline industry, with its thousands of flights per year and its exceptionally safe and reliable operations. Several models exist for future RLVs, however, and all compete for the attention—and the development dollars—of the federal government.

Prior to the Mercury, Gemini, and Apollo programs of the 1960s, virtually everyone involved in space advocacy envisioned a future in which humans would venture into space aboard winged, reusable vehicles. That was the vision from Hermann Oberth in the 1920s through Wernher von Braun in the 1950s to the U.S. Air Force's X-20 Dyna-Soar program in the early 1960s.[8] Because of the pressure of the Cold War, NASA chose to abandon that approach to space access in favor of ballistic capsules that could be placed atop launchers originally developed to deliver nuclear warheads to the Soviet Union. NASA developed its human-rated ballistic launch and recovery technology at enormous expense and used it with a 100-percent success rate between 1961 and 1975. As soon as Apollo was completed, NASA chose to retire that ballistic technology, despite its genuine serviceability, in favor of a return to that earlier winged, reusable vehicle. The Space Shuttle was the result.[9]

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7. This was the argument made to obtain approval for the Space Shuttle. See *The Post-Apollo Space Program: A Report for the Space Task Group* (Washington, DC: National Aeronautics and Space Administration, September 1969), pp. 1, 6.

8. This quest has been well documented in Ray A. Williamson and Roger D. Launius, "Rocketry and the Origins of Space Flight," in *To Reach the High Frontier*, ed. Launius and Jenkins, pp. 33–69.

9. On this issue, see T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle* (Washington, DC: NASA SP-4221, 1999); Roger D. Launius, "NASA and the Decision to Build the Space Shuttle, 1969–72," *The Historian* 57 (autumn 1994): 17–34.

Then there is an alternative position that suggests that the most appropriate approach to space access is through the use of throwaway "big, dumb boosters" that are inexpensive to manufacture and operate. Although reusable rockets may seem to be an attractive cost-saving alternative to expendables because they allow repeated use of critical components such as rocket motors and structural elements, ELV advocates claim, they actually offer a false promise of savings. This is because all RLV savings are predicated on maximizing usage of a small number of vehicles over a very long period of time for all types of space launch requirements. Accordingly, cost savings are realized only when an RLV flies many times over many years. That goal is unattainable, they claim, because it assumes that there will be no (or very few) accidents in the reusable fleet throughout its lifespan.[10]

The reality, ELV advocates warn, is that the probability of all RLV components' operating without catastrophic failure throughout the lifetime of the vehicle cannot be assumed to be 100 percent. Indeed, the launch reliability rate of even relatively "simple" ELVs—those without upper stages or spacecraft propulsion modules and with significant operational experience—peaks at 98 percent with the Delta II, and that took 30 years of operations to achieve. To be sure, most ELVs achieve a reliability rate of 90 to 92 percent—again, only after a maturing of the system has taken place. The Space Shuttle, a partially reusable system, has attained a launch reliability rate of slightly more than 98 percent, but only through extensive and costly redundant systems and safety checks. In the case of a new RLV, or a new ELV for that matter, a higher failure rate has to be assumed because of a lack of experience with the system. Moreover, RLV use doubles the time of exposure of the vehicle to failure because the vehicle must also be recovered and be reusable after refurbishment. To counter this challenge, more and better reliability has to be built into the system, and this exponentially increases both R&D and operational costs.[11]

Designing for one use only, those arguing for ELV development suggest, simplifies the system enormously. One use of a rocket motor, guidance system, and the like means that it needs to function correctly only one time. Acceptance of an operational reliability of 90 percent or even less would

10. Barbara A. Luxenberg, "Space Shuttle Issue Brief #IB73091," Library of Congress Congressional Research Service Major Issues System, 7 July 1981, NASA Historical Reference Collection; *Economic Analysis of New Space Transportation Systems: Executive Summary* (Princeton, NJ: Mathematica, Inc., 1971); General Accounting Office, *Analysis of Cost Estimates for the Space Shuttle and Two Alternate Programs* (Washington, DC: General Accounting Office, 1973); William G. Holder and William D. Siuru, Jr., "Some Thoughts on Reusable Launch Vehicles," *Air University Review* 22 (November–December 1970): 51–58; Office of Technology Assessment, *Reducing Launch Operations Costs: New Technologies and Practices* (Washington, DC: U.S. Congress, Office of Technology Assessment, 1988).

11. Stephen A. Book, "Inventory Requirements for Reusable Launch Vehicles" (paper presented at the Space Technology & Applications International Forum [STAIF-99], Albuquerque, NM, copy in possession of the author).

further reduce the costs incurred in designing and developing a new ELV. Indeed, many experts believe that reliability rates cannot be advanced more than another 1.5 percent above the 90-percent mark without enormous effort, effort that would be strikingly cost-inefficient.[12]

The debate is far from decided. As Butrica shows in this essay, human spaceflight advocates seem driven toward RLVs for space access. This has been an enormously costly perspective over time and directly affects the search for a replacement for the Space Shuttle. Butrica recounts the depressing story of failed attempts to build new vehicles and their eventual cancellation.

Collectively, Logsdon and Butrica encapsulate a critical issue for both the history of NASA and the current policy arena as the space agency struggles to deal with an aging Shuttle fleet, a major reorientation of its mission, and prospects for a post-*Columbia*-accident spacefaring future.

12. B. Peter Leonard and William A. Kisko, "Predicting Launch Vehicle Failure," *Aerospace America* (September 1989): 36–38, 46; Robert G. Bramscher, "A Survey of Launch Vehicle Failures," *Spaceflight* 22 (November–December 1980): 51–58.

CHAPTER 9

"A FAILURE OF NATIONAL LEADERSHIP": WHY NO REPLACEMENT FOR THE SPACE SHUTTLE?

John M. Logsdon

If the policy for the future of U.S. civilian space activity first laid out by President George W. Bush on 14 January 2004 is pursued, the United States will retire the Space Shuttle from service in 2010. Ending Shuttle flights will leave the United States without its own capability to carry its astronauts into orbit until a replacement crew-carrying vehicle makes its first flight with astronauts aboard. According to the Bush "Vision for Space Exploration," this may not happen until 2014.[1] As leading space historian Roger D. Launius has commented, "The inability to ensure a continued capability for human space access has placed the United States in a situation that is unenviable and unfortunate as the twenty-first century begins."[2]

This essay attempts to set out the reasons why the United States has found itself in this "unenviable and unfortunate" situation, with a focus on why the country had not, by the time of the Space Shuttle *Columbia* accident on 1 February 2003, developed a replacement for the Shuttle as a U.S. means for carrying humans into space. That same question was asked by the Columbia Accident Investigation Board (CAIB) set up in the immediate aftermath of the *Columbia* tragedy. (I was a member of that 13-person group.) In addition to its investigation of the physical and organizational causes of the accident, CAIB, in its 26 August 2003 report, offered brief but pointed observations on the broader policy context within which the accident took place and on "future directions for the U.S. in space."[3] This kind of look ahead was not part of CAIB's original charter; it became part of the CAIB focus after members of Congress asked the Board Chair, retired Admiral Harold Gehman, to have the Board's report "set the stage" for a national debate on the future directions of the U.S. civilian space program. Including a discussion of national space policy in an accident investigation report was unprecedented; neither the internal NASA report following the Apollo 1 fire in January 1967 nor the Rogers Commission

1. White House, "A Renewed Spirit of Discovery," January 2004.

2. Roger D. Launius, "After *Columbia*: The Space Shuttle Program and the Crisis in Space Access," *Astropolitics* 2 (autumn 2004): 279.

3. Columbia Accident Investigation Board, *Report*, vol. 1 (Washington, DC: NASA and GPO, August 2003), p. 209.

investigation of the *Challenger* accident had gone beyond identifying and suggesting remedies for the immediate causes of those tragedies.

The brief section titled "Long-Term: Future Directions for the U.S. in Space" in chapter 9 of the CAIB report has had an impact well beyond the Board's expectations. It is not too grandiose a claim to suggest that it led to a fundamental change in national space policy. Staff members in the Executive Office of the President have confirmed that the Board's observation that there had been a "lack, over the past three decades, of any national mandate providing NASA a compelling mission requiring human presence in space" was the direct catalyst for the White House deliberations in fall 2003 that led to the 14 January 2004 announcement by President George W. Bush of the new space exploration vision. This "Vision for Space Exploration," with its call for a "sustained and affordable human and robotic program to explore the solar system and beyond," is explicitly intended as the "national mandate" that had been missing since Americans landed on the Moon in 1969.

The Board made a second set of general observations. The CAIB report noted that "following from the lack of a clearly-defined long term space mission," there had been no "sustained national commitment over the past decade to improving access to space by developing a second-generation space transportation system." The Board concluded that "*the United States needs improved access for humans to low-Earth orbit as a foundation for whatever directions the nation's space program takes in the future*." The CAIB report suggested that it was "*in the nation's interest to replace the Shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit*." Finally, it contained the following indictment: "*previous* [unsuccessful] *attempts to develop a replacement vehicle for the aging Shuttle represent a failure of national leadership*" (all emphasis in original).[4]

In his recent comprehensive and insightful analysis of U.S. policy towards access to space, Launius has used even stronger language than the Columbia Board. He suggests that "the lack of a firm decision to develop a Shuttle replacement represents the single most egregious failure of space policy in history."[5]

This essay will argue that there has been an even more fundamental and "egregious" failure of national space policy over the past three-plus decades and that the lack of a replacement for the Space Shuttle is just one of the most obvious manifestations of that policy failure. The series of decisions regarding a Shuttle replacement must be cast in the broader context of U.S. policy with respect to the reasons for sending people to space in the first place. The lack of a clear "mandate" for human spaceflight over the past 35 years has meant that the U.S. human spaceflight program, and indeed the NASA program overall, has been sustained by a complex coalition of narrow interests, not by a clearly

4. CAIB, *Report*, pp. 209–211.
5. Launius, "After *Columbia*," pp. 278–279.

articulated national goal and a stable political consensus in support of achieving that goal. As the CAIB report observed, without such a goal, NASA

> has found it necessary to gain the support of diverse constituencies. NASA has had to participate in the give and take of the normal political process in order to obtain the resources needed to carry out its programs. NASA has usually failed to receive budgetary support consistent with its ambitions. The result . . . is an organization straining to do too much with too little.[6]

It is this situation—"straining to do too much with too little"—that reflects the fundamental failure of U.S. space policy. In the 1969–1970 period, the administration of President Richard M. Nixon made a purposeful decision not to continue in the post-Apollo period the type of space effort that had taken Americans to the Moon. As Nixon stated in March 1970:

> Space expenditures must take their proper place within a rigorous system of national priorities. What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are important to us.[7]

This declaration was more than rhetorical. The NASA budget was rapidly reduced in the early 1970s to less than 1 percent of the federal budget, approximately one-fifth of its budget share at the peak of Apollo 10 years earlier. Outside of postwar demobilization, few government activities have seen such a rapid decline in the resources devoted to their implementation. More to the point of this essay, this lowered level of budget allocations has persisted to the current time.

WHAT DOES "REPLACING THE SPACE SHUTTLE" MEAN?

Many people talk of replacing the Shuttle as if the meaning of such an undertaking is quite clear. Such is not the case. There are several meanings that could be attributed to the term "replacing the Space Shuttle." They include the following:

6. CAIB, *Report*, p. 209.

7. Richard M. Nixon, "Statement About the Future of the United States Space Program," 7 March 1970, in U.S. President, *Public Papers of the Presidents of the United States: Richard Nixon, 1970* (Washington, DC: GPO, 1971), p. 251.

- Developing an advanced-technology, second-generation vehicle similar in its capabilities to the Shuttle, including the ability to carry both a sizable number of people and large and/or heavy cargo into low-Earth orbit, to provide living and working space for the crew for some period of time, and to be capable of various space operations such as payload deployment and retrieval and in-orbit servicing. Such a vehicle, presumably, would be as reusable as the Shuttle, preferably more so.

- Developing a vehicle that can carry either cargo or passengers to space and deliver its payload to an orbital destination such as the International Space Station; reusability would be a desired, but not necessary, characteristic.

- Developing a vehicle only to carry people to another destination in space and to return them to Earth, with limited or no cargo-carrying capacity. Again, reusability would be a desired, but not necessary, characteristic.

- Developing a vehicle capable of transporting people both to low-Earth orbit and to destinations beyond Earth orbit, such as the Moon, Mars, or a Lagrangian point.

Each of these types of vehicles could be considered a Shuttle replacement, and failure to differentiate among them has caused, and will continue to cause, policy confusion. For the purposes of this essay, the central meaning to be attributed to the term "Space Shuttle replacement" is a vehicle having the capability to transport humans to and from low-Earth orbit. Whether that vehicle would be reusable or not and whether it would be capable of going beyond Earth orbit are secondary considerations. This certainly was what the CAIB had in mind when it judged that "*it is in the nation's interest to replace the Shuttle as soon as possible as the primary means for transporting humans to and from Earth orbit*" (emphasis in original).

What did not happen, either during the CAIB's deliberations or since, was a corresponding adjustment in either the expectations placed on NASA by the nation's leaders or the ambitions of those committed to the vision of an expansive future in space. *The reality that national space policy did not bring ambitions and resources into balance in the 1970s, nor in the subsequent two decades, is the basic policy failure.* Either NASA should have been forced by the White House and Congress to plan and carry out a less ambitious program, or those national leaders should have been willing to provide the resources needed to carry out the ambitious program, with human spaceflight at its core, that NASA has proposed to implement.[8] By allowing NASA to try to "do too much with too little," national leaders failed in their responsibility as stewards of well-conceived national policy. The space sector has suffered as a result, most visibly with two Space Shuttle accidents and the loss of 14 astronaut lives.

An Album of Frustration

How has this "unenviable and unfortunate" situation come to be? The answer to this question can be portrayed by a set of "snapshots" taken at various times during the evolution of the U.S. human spaceflight effort.[9] This "photo album" of the steps towards the current situation will set the stage for a fuller analysis of *why* ensuring reliable, affordable, and safe human access has been a continuing policy problem for the past two decades:

1. From almost the start of serious thinking about human spaceflight, visionaries have expected that people would travel to and from space in a reusable, winged spacecraft; this image has continued to influence thinking about how to send people to space for most of the time since.

2. The pressures of Cold War competition drove the United States and the Soviet Union to abandon a winged approach to spaceflight and to develop instead crew-carrying ballistic capsules launched into space on top of expendable rockets, most of them derived from missiles designed to deliver nuclear warheads over intercontinental distances. Until the Space Shuttle was approved in 1972, only the U.S. Saturn family of boosters was designed from their start in the 1950s as space launch vehicles.

3. Once the United States had won the race to the Moon, the National Aeronautics and Space Administration in 1969 proposed an ambitious post-Apollo space effort beginning with the rapid development of a Saturn V–launched, 12-person space station. As a "logistics vehicle" for such a station, NASA proposed developing a reusable Earth-to-

8. In May 1992, then-new NASA Administrator Daniel S. Goldin did recognize this situation and told his senior officials to stop making plans that anticipated future budget increases. This was one of the foundations of Goldin's "faster, better, cheaper" guidance. But Goldin was also impatient and wanted to lay the foundation for human missions to Mars. This made his attempts to limit future ambitions not very effective.

9. In his *Astropolitics* article cited earlier, Roger Launius provides a parallel and well-stated account of this history.

orbit launch vehicle called the Space Shuttle. In NASA's 1970 budget presentation, the space station and Space Shuttle were presented to Congress as a single program. When the Nixon administration refused to approve the space station, NASA, in the fall of 1970, deferred—not canceled—its space station plans and directed its Shuttle contractors to design a vehicle capable of carrying pieces of a space station into orbit. This requirement defined the width of the Shuttle payload bay as no less than 14 feet. Thus the currently unbreakable link between the Space Shuttle and International Space Station programs actually has its roots in decisions taken 35 years ago.

4. In 1971, there was intense debate within the Executive Branch and its advisers of whether to approve Space Shuttle development. This debate led, in January 1972, to approval of Shuttle development as a product of "a series of political compromises that produced unreasonable expectations—even myths—about its performance," with a "technically ambitious design [that] resulted in an inherently vulnerable vehicle."[10] The Space Shuttle program was approved even in the face of a fundamental policy decision, made two years earlier, to reduce the priority of and resultant budget allocations for the civilian space program.[11] Based on that decision, the Office of Management and Budget forced NASA, in May 1971, to accept a $5.15-billion development cost ceiling for the Space Shuttle; this led NASA to abandon hopes for a two-stage, fully reusable vehicle and to quickly examine a wide variety of designs that could be developed within that cost cap.

5. In order to make the case that the investment in developing the Space Shuttle was cost-effective, NASA had to gain the agreement of the military and intelligence communities that when it became operational, the Space Shuttle would be the only launch vehicle for almost all government payloads, both human crews and robotic spacecraft. In order to gain this agreement, NASA had to design a Shuttle with specific performance characteristics that increased its technological risks. CAIB noted that "the increased complexity of a Shuttle designed to be all things to all people created inherently greater risks than if more realistic technical goals had been set from the start."[12] Certainly, if the

10. CAIB, *Report*, p. 21.

11. Accounts of the process that led to the decision to develop the Space Shuttle can be found in John M. Logsdon, "The Space Shuttle: A Policy Failure?" *Science* 232 (30 May 1986): 1099–1105; and T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle* (Washington, DC: NASA SP-4221, 1999).

12. CAIB, *Report*, p. 23.

Space Shuttle design had been optimized for its crew-carrying role, a less risky vehicle, with more provisions for crew safety, could have been designed.

6. A byproduct of the decisions to develop in the Space Shuttle a vehicle capable of launching all types of payloads was the drying up, beginning in the 1970s, of NASA funding for research and technology development related to any aspect of space transportation not associated with the Shuttle. Thus there was a limited base of technology from which NASA could draw when it did initiate or participate in Shuttle replacement efforts in the 1980s and 1990s.[13]

7. Soon after the first flight of the Space Shuttle in April 1981, the new NASA leadership set as its two top priorities bringing the Shuttle to operational status as soon as possible and getting presidential and congressional approval to develop a (Shuttle-launched) space station. No alternatives to using the Shuttle in this role were considered at the inception of the space station program.[14]

8. Also in 1981, after only two Shuttle flights, President Ronald Reagan approved a formal policy statement saying that the Space Shuttle "will be the primary space launch system for both United States military and civil government missions."[15] This policy was reinforced in a 1982 statement of National Space Policy, which said that "completion of transition to the Shuttle should occur as expeditiously as possible" and that "government spacecraft should be designed to take advantage of the unique capabilities of the STS [Space Transportation System, another designation for the Space Shuttle]."[16]

9. The U.S. Air Force, as the launch agent for both military and intelligence spacecraft, early on recognized the dangers of this "all eggs in one basket" policy. Soon after the Shuttle was declared operational on

13. This statement is not quite accurate. There continued to be some low-level efforts within NASA to examine future space transportation vehicles and technologies even as the Shuttle was being developed during the 1970s, but there was very limited financial support of these efforts.

14. For a discussion of the steps leading to President Reagan's approval of a space station program, see Howard E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice* (Baltimore, MD: Johns Hopkins, 1990).

15. John M. Logsdon, ed., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program*, vol. 4, *Accessing Space* (Washington, DC: NASA SP-4407, 1999), pp. 333–334.

16. John M. Logsdon, ed., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program*, vol. 1, *Organizing for Exploration* (Washington, DC: NASA SP-4407, 1995), pp. 591–592.

4 July 1982, after only four flights, the Air Force began to argue that the risks and costs of the system could be a detriment to its ability to perform its launch responsibilities for critical national security payloads. Most of those payloads had been designed since the late 1970s so that they could only be launched on the Shuttle. Beginning in 1983, the Air Force campaigned for approval of a backup to the Shuttle in order to provide assured access to space for such payloads. NASA fought this move. The dispute between the Air Force and NASA reached the White House in early 1985, where it was decided in favor of the Air Force.[17] This decision led to the development of the Titan IV expendable launch vehicle, which was capable of launching the largest military and intelligence spacecraft. After the 1986 *Challenger* accident, the Titan IV became the primary launcher for large national security missions, and those spacecraft that had been intended for Shuttle launch had to be redesigned at high cost.

10. Discussions within NASA about the need to develop a second-generation replacement for the Space Shuttle began even before the Shuttle was launched.[18] The first public statement of this need came in the report of the National Commission on Space in January 1986 (made public a few days after the *Challenger* accident). The Commission concluded that "the Shuttle fleet will become obsolescent by the turn of the century." It recommended separating cargo and "passenger" (its term) launches and developing, within 15 years, a new system for "passenger transport to and from low Earth orbit."[19] In contrast, an inside-the-government NASA-DOD National Space Transportation and Support Study during 1985–1986, while agreeing that in the future, separate human-carrying and cargo-carrying launch systems were desirable, concluded that "there was not an urgent need for an advanced manned vehicle; incremental improvements to the Space Shuttle would suffice."[20]

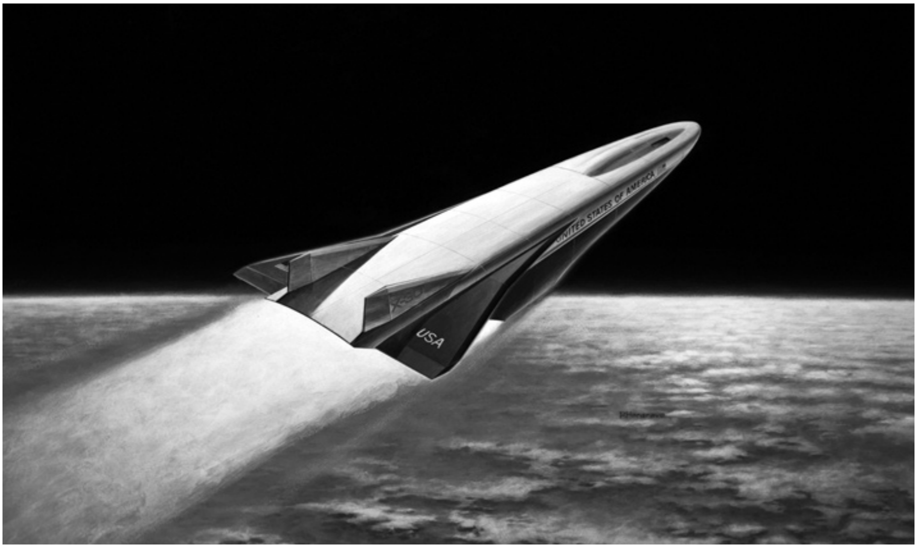
11. While NASA during the 1970s and early 1980s allocated only limited funding to advanced space transportation technology, the Department of Defense did support a fair amount of such research and technology

17. This dispute can be traced in John M. Logsdon, ed., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program*, vol. 2, *External Relationships* (Washington, DC: NASA SP-4407, 1996), documents II-40 through II-45.

18. Launius, "After *Columbia*," pp. 287–288.

19. *Pioneering the Space Frontier*, Report of the National Commission on Space, quoted in Launius, "After *Columbia*," p. 288.

20. Ivan Bekey, "Exploring Future Space Transportation Possibilities," in *Exploring the Unknown*, ed. Logsdon, vol. 4, pp. 505–506.



The National Aero-Space Plane (NASP) began as a NASA-DOD joint project in 1982. It called for the development of two vehicles capable of SSTO at Mach 25. It was intended to use a multicycle engine shifting from jet to ramjet to scramjet; it would use liquid-hydrogen fuel with oxygen scooped and frozen from the atmosphere. President Ronald Reagan had high hopes for it, announcing in the State of the Union Address in 1986: "We are going forward with research on a new Orient Express that could, by the end of the decade, take off from Dulles Airport, accelerate up to 25 times the speed of sound attaining low Earth orbit, or fly to Tokyo within two hours." It was canceled in 1992 without ever having flown. *(NASA KSC photo no. EL-2001-00432)*

development related to advanced-technology crew-carrying systems. By the early 1980s, these efforts were focused on a vehicle that used air-breathing engines to accelerate to hypersonic or perhaps even orbital velocity. The Air Force program was focused on a TransAtmospheric Vehicle (TAV), while a separate, highly classified, Advanced Research Projects Agency (ARPA) study was called Copper Canyon.[21] In late 1985, all Department of Defense research and development activity on hypersonic flight was consolidated into a program that became known as the National Aero-Space Plane (NASP); NASA joined the Department of Defense as a minority funder and comanager of the NASP effort. This program was given presidential endorsement in the 1986 State of the Union Address, delivered by President Ronald

21. The National Aero-Space Plane Program is discussed in Andrew J. Butrica, *Single Stage to Orbit: Politics, Space Technology, and the Quest for Reusable Rocketry* (Baltimore, MD: Johns Hopkins, 2003), chap. 4.

Reagan on 5 February of that year. In his address, the President spoke of an "Orient Express" that would, "by the end of the decade," be able to "take off from Dulles Airport [near Washington, DC], accelerate up to 25 times the speed of sound attaining low Earth orbit, or fly to Tokyo within two hours."[22]

12. The President's 1986 address came only a few days after the 28 January explosive burning and breakup of the Space Shuttle *Challenger*; seven crew members died in the accident. In the following months, policy toward use of the Space Shuttle came under intense scrutiny. First, the White House, on 15 August, announced that a new Shuttle orbiter would be built to replace *Challenger* but that the Shuttle would no longer be used to launch commercial payloads such as communication satellites. On 27 December, President Reagan signed a directive that established a "mixed fleet" concept for government payloads, with "critical mission needs" supported by both the Shuttle and expendable launch vehicles "to provide assurance that payloads can be launched regardless of specific launch vehicle availabilities." According to this directive, the Space Shuttle would only be used to support programs requiring "manned presence and other unique STS capabilities."[23] These decisions formally reversed the policy that had been one of the foundations of the decision to develop the Space Shuttle—that it could serve as a reliable, affordable launch vehicle for all U.S. payloads. It focused future Shuttle use on missions where the human presence was essential to the mission, not merely crew members delivering cargo to orbit. In 1987, the Air Force announced its support for resuming production of the Delta and Atlas expendable launch vehicles, with the clear implication that the military would in the future use the Space Shuttle only for those few missions that required its specific capabilities. The sum of these post-*Challenger* decisions meant that NASA became not only the operator, but also the main future user, of the Space Shuttle. With fewer missions to fly, with NASA having to pay all the costs of its operation, and with a flat or decreasing NASA budget for most of the 1990s, the Shuttle became a "mortgage" on the NASA budget that had to be paid. Funds for investing in its replacement could be made available only if the NASA budget were increased or the Shuttle program's budget were reduced.

22. Quoted in ibid., p. 65.

23. See the essay by Ray A. Williamson, "Developing the Space Shuttle," and documents II-42 and II-43 in *Exploring the Unknown*, ed. Logsdon, vol. 4, for an account of this policy shift.

13. While DOD-NASA work on NASP continued in the late 1980s, with DOD bearing some 80 percent of its costs, NASA gave top priority to returning the Space Shuttle to flight. Leading that effort was Admiral Richard H. Truly, a former Shuttle astronaut who was brought back to NASA in the weeks following the *Challenger* accident as Associate Administrator for Spaceflight.[24] Truly was a firm believer in the value of the Shuttle. When in 1989 the new administration of President George H. W. Bush selected him as NASA Administrator, the Space Shuttle gained a strong proponent at the top of the space agency. Then President Bush proposed an ambitious long-range vision for the nation's space program in July 1989. The NASA plan for implementing that vision did not include a proposal to replace the Shuttle as the means for taking people to orbit, even though the plan extended over several decades.

    Administrator Truly's personal embrace of the Shuttle as key to NASA's future was reflected by others in NASA, particularly those working on the Space Shuttle program in NASA Headquarters and at Johnson Space Center and Marshall Space Flight Center. Rather than respond to criticisms of the Shuttle and calls for its replacement, they strove to "impose the party line vision on the environment, not to reconsider it." Central to this behavior was the belief that the Space Shuttle could be made a safe and reliable system and should play a central role in NASA's human spaceflight efforts for many years to come. This behavior, in the judgment of the Columbia Board, led to "flawed decision-making, self deception, introversion and a diminished curiosity" about alternatives to the Shuttle.[25]

14. In 1990, the Advisory Committee on the Future of the U.S. Space Program, usually called the Augustine Committee after its chairman, aerospace executive Norm Augustine, concluded that "we are today overreliant on the Space Shuttle as the backbone of the civil space program." The Committee recommended rapid development of "an evolutionary, unmanned but man-rateable, heavy lift launch vehicle" to replace the Space Shuttle in supporting space station assembly and utilization. Noting that there was no alternative to the Shuttle for human transportation, the Committee recommended "expedited

24. See John M. Logsdon, "Return to Flight: Richard Truly and the Recovery from the Challenger Accident," chap. 15 in *From Engineering Science to Big Science*, ed. Pamela E. Mack (Washington, DC: NASA SP-4219, 1998).

25. Yale University organizational studies scholar Gary Brewer, quoted in CAIB, *Report*, p. 102.

development of a two-way [human] transportation capability" on such a launch vehicle "for use in the event of a Space Shuttle stand-down." The Augustine Committee was critical of the low level of NASA spending on space technology, including that related to advanced propulsion and aerodynamics, and called for a "two-to-three-fold enhancement" of NASA's space technology budget. It recommended an annual increase of 10 percent in the NASA budget if the nation was serious about wanting a successful space program.[26] The Committee concluded its report by recommending that the United States should reduce "dependence on the Space Shuttle . . . for all but missions requiring human presence."[27]

15. After receiving presidential endorsement in 1986, the NASP program over the subsequent several years struggled to achieve its technological and schedule goals. A 1988 Defense Science Board report concluded that the program's advocates had been overly optimistic in their initial promise of an early flight demonstration and suggested that the program should be "realistically presented to its sponsors." A year later, after the Air Force withdrew funding from the program, the White House, in 1989, approved a stretch-out of the program (rather than its cancellation as proposed by Secretary of Defense Richard Cheney), with a flight demonstration of the X-30 test vehicle to come only after relevant technologies had been developed.[28] In the face of competing budget priorities and slow technological progress, the NASP program was canceled in 1992, after $1.7 billion had been spent on it.[29] At that point, the cost of a full X-30 flight-test program was estimated at $17 billion, with another $10–20 billion to develop an operational vehicle.[30] No flight demonstration was attempted, but the program left a technological legacy for future advanced space transportation efforts.

Andrew Butrica observes that "the NASP concept was the wrong road." By pursuing an air-breathing approach to a single stage to orbit

26. The administration of George H. W. Bush took to heart the advice that the NASA budget should be substantially increased and proposed significant increases for FY 1992 and FY 1993. However, after coming to the White House in January 1993, the administration of President Bill Clinton reversed this upward trend in the NASA budget, which actually lost more than 10 percent in constant dollars during the eight years that Clinton was President.

27. *Report of the Advisory Committee on the Future of the U.S. Space Program* (Washington, DC: GPO, December 1990), pp. 21, 31, 33–34, 48.

28. Logsdon, *Exploring the Unknown*, vol. 4, documents IV-9, IV-10, quotation from p. 562.

29. Launius suggests that the costs were probably higher since some of the work on the NASP program was classified, and thus not all cost information was readily available ("After *Columbia*," p. 290).

30. Global Security.Org, "X-30 National Aerospace Plane (NASP)," *http://www.globalsecurity.org/military/systems/aircraft/nasp.htm* (accessed 13 January 2005).

vehicle rather than one using rocket power, NASA "propelled the nation into an expensive program that had no chance of success." Its failure "demonstrated unmistakably that an air-breathing, single-stage-to-orbit was not the road to travel." Ivan Bekey adds that "being airplane-like, the NASP concept attracted powerful backing because it was intuitively easy to grasp. The nation fooled itself into believing that because the NASP image was what was desired, the reality itself was therefore attainable."[31] Whatever the reason, the United States had lost several years and almost $2 billion in pursuing a failed path towards a Shuttle replacement.

16. On 1 April 1992, Daniel S. Goldin replaced the fired Richard Truly as NASA Administrator. In contrast to Truly, Goldin would prove to be no fan of the Space Shuttle, viewing its budget demands as a major barrier to initiating new, innovative NASA programs.[32] This was especially the case after 1993, when the new administration of President Bill Clinton retained Goldin as Administrator but declined to increase the NASA budget to both meet the demands of the Space Shuttle and the International Space Station programs and allow significant investments in major new efforts such as a Shuttle replacement. The Space Shuttle budget had peaked at over $5.5 billion per year as NASA recovered from the *Challenger* accident; the Bush administration, in early 1992, had proposed a $4.1-billion allocation. By the time Dan Goldin left office in November 2001, the Shuttle budget had been reduced by another 25 percent, to $3.2 billion per year. Goldin initiated the switch of Shuttle operations to private-sector management both as a cost-savings measure and as a way to encourage NASA engineers to focus on developing new capabilities. Until 1999, when he declared a "space launch crisis," Goldin was unwilling to allocate significant resources to Shuttle upgrades. Even so, Goldin, during his long tenure, came to recognize that successful and safe operation of the Shuttle was critical to political and public support of NASA's programs. His expectation was that by innovative partnerships with the private sector, the technological developments on which to base a Shuttle replacement could be achieved without a multibillion-dollar government investment. This unfortunately proved to be a false hope.

31. Butrica, *Single Stage to Orbit*, pp. 66, 81; Bekey, "Exploring Future Space Transportation Possibilities," p. 508.

32. As one indication of his attitude, it is reported that Goldin had removed from the cabin of the NASA Administrator's airplane all the pictures of the Space Shuttle that had been placed there under Richard Truly.

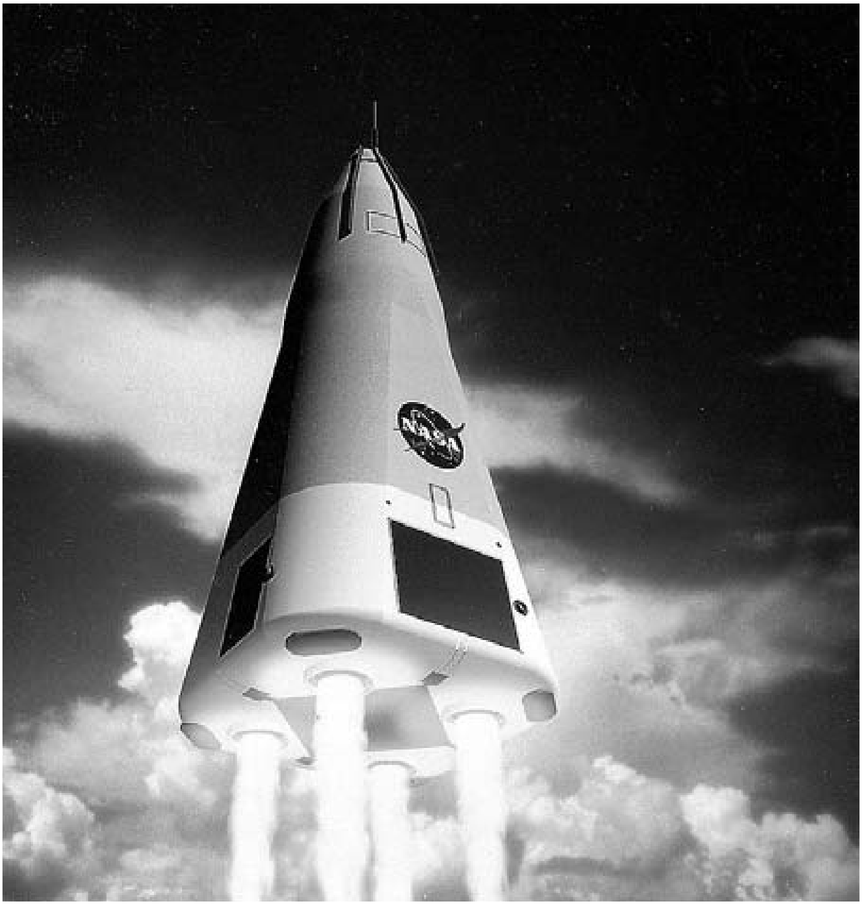
17. In 1992, during the last months of the George H. W. Bush administration, the Vice President's Space Policy Advisory Board, which advised the National Space Council, recommended the development by 2000 of an expendable "Spacelifter" launch vehicle, which would be human-rated, and also the development of a new Personnel Launch System for use with it. This would allow the government to "phase out the Space Shuttle at the earliest opportunity."[33] With the November 1992 election of a new administration, the recommendations contained in the Advisory Board's report were stillborn.

18. In 1993, both NASA Administrator Goldin and the U.S. Congress requested that the NASA staff carry out a comprehensive study of alternate approaches to accessing space through 2030. A principal goal of the study was "to make major reductions in the cost of space transportation (at least 50 per cent), while at the same time increasing safety for flight crews by at least an order of magnitude." The *Access to Space Study* examined three alternatives: 1) an upgraded Shuttle, 2) new expendable vehicles using conventional technologies, and 3) "new reusable vehicles using advanced technologies." The study concluded that "the most beneficial option is to develop and deploy a fully reusable single-stage-to-orbit (SSTO) pure-rocket launch vehicle fleet" that would allow the phasing out of the Space Shuttle, beginning in 2008.[34]

19. This conclusion of the *Access to Space Study* became formalized when President Clinton approved a new statement of National Space Transportation Policy in August 1994. That statement gave NASA the responsibility "to support government and private sector decisions by the end of this decade on the development of an operational next generation reusable launch system." NASA was to focus its research "on technologies to support a decision no later than December 1996 to proceed with a sub-scale demonstration which would prove the concept of single-stage-to-orbit." The policy envisioned that the private sector "could have a significant role in managing the development and operation of a new reusable space transportation system."[35] It was extremely unusual, if not unprecedented, for a specific technological solution such as the SSTO approach to be written into a presidential policy statement on space.

33. Logsdon, *Exploring the Unknown*, vol. 4, document IV-6, p. 550.
34. Ibid., document IV-14, pp. 585–586.
35. Ibid., document IV-16, p. 628.

20. Given the White House policy directive, NASA, over the following two years, organized a competition among potential developers of the subscale flight demonstrator. Three companies submitted proposals. Rockwell International proposed a vehicle that was in many ways a second-generation version of the Space Shuttle; Rockwell had been the prime contractor for the Shuttle. McDonnell Douglas proposed a version of the Delta Clipper vehicle that had been developed under



The McDonnell Douglas Delta Clipper-Experimental (DC-XA) reusable launch vehicle (RLV) was originally developed for DOD. NASA assumed control of the vehicle in the summer of 1995. The DC-XA was to have been an SSTO vertical takeoff/vertical landing launch vehicle concept, whose development would significantly reduce launch cost and provide a test bed for NASA RLV technology. *(NASA MSFC image no. MSFC-9513214)* the sponsorship of the Strategic Defense Initiative Organization to demonstrate simpler space operations techniques.[36] Lockheed Martin proposed an advanced-technology vehicle based on the use of a linear aerospike engine. On 2 July 1996, Vice President Al Gore announced that NASA had selected the most technologically advanced (and thus the riskiest) of these proposals, that from Lockheed Martin. The reasoning behind this decision has not been adequately explored.

At that time, the plan was to have the first flight of what was christened the X-33 by March 1999 and to complete a 15-flight test program by the end of that year. The goal was to demonstrate the technological foundation for a decision by Lockheed Martin to invest its own funds in a full-scale operational vehicle, which the company named VentureStar.™ The X-33 program would be a cooperative undertaking between NASA and Lockheed Martin, with NASA providing $941 million of the required funding and Lockheed providing $220 million. Once Lockheed Martin developed the VentureStar™ using private capital, the assumption was that NASA would be a major customer for its services, but also that a booming commercial space industry would emerge. The combination of government and commercial demand for access to space, it was claimed, would allow VentureStar™ to be a profitable undertaking.[37]

Although Lockheed Martin, over the following several years, promoted the VentureStar™ project as symbolic of its status on the cutting edge of future technologies, the X-33 program encountered technological difficulties almost from its inception. In November 1999, there was a major test failure of the vehicle's hydrogen fuel tank; by that time, the White House and NASA were losing confidence that the program would be able to overcome its technological hurdles. In March 2001, NASA announced that it would provide no more funding for the X-33, effectively killing it well before a flight demonstration could be attempted. At that point, NASA had spent $912 million on the project, while Lockheed Martin had exceeded its planned investment, having put $356 million into the X-33.[38]

21. Some in the Executive Office of the President and at NASA had, by at least 1998 (if not before), become skeptical that the X-33 pro-

36. See Butrica, *Single Stage to Orbit,* parts III and IV, for a discussion of the origins and fate of the Delta Clipper program.

37. NASA Marshall Space Flight Center, "Lockheed Martin Selected to Build the X-33," news release 96-53, 2 July 1996.

38. Leonard David, "NASA Shuts Down X-33, X-34 Programs," *Space.com*, 1 March 2001, *http://www.space.com/missionlaunches/missions/x33_cancel_010301.html* (accessed 5 February 2005).

gram would be able to overcome its technical challenges and would provide the information needed to decide when and how to replace the Shuttle. In 1998, the Office of Management and Budget asked NASA to fund the aerospace industry to carry out what were called Space Transportation Architecture Studies to determine 1) if the Space Shuttle system should be replaced; 2) if so, when the replacement should take place and how the transition should be implemented; and 3) if not, what is the upgrade strategy to continue safe and affordable flight of the Space Shuttle beyond 2010. Five industry teams examined these questions through 1999 and came up with a variety of approaches to meeting both NASA and commercial-sector launch requirements. Many of the suggested approaches for taking humans to space involved a capsule-type spacecraft launched on top of an expendable launch vehicle. NASA leadership viewed such proposals as not being adequately forward-looking.

22. In 1999, NASA Administrator Daniel Goldin declared a "space launch crisis" and urged the White House to add funds to the NASA budget for necessary safety upgrades to the Shuttle. Substantial funds for this purpose were added to the NASA FY 2001 budget, submitted to Congress in early 2000. However, this upgrade initiative had a short lifespan. Within a year, funding for upgrades was reduced by over one-third in response to rising Shuttle operating costs and the need to stay within a fixed Shuttle budget.[39]

23. Based on the results of the Space Transportation Architecture Studies and the increasingly evident problems with the X-33 program, the NASA FY 2001 budget also contained a new Space Launch Initiative. This effort was to provide some $4.8 billion over five years to conduct studies and technology development to identify the most promising path to replacing the Space Shuttle and meeting other launch requirements. The hope was that this effort could provide the basis for a 2006 decision on what type of Shuttle replacement to develop, with a target date of 2012 for its initial launch. Three contractor teams—Boeing, Lockheed Martin, and a joint team of Orbital Sciences and Northrop Grumman—by early 2002 had identified 15 launcher concepts for detailed study.[40]

39. CAIB, *Report*, p. 114.

40. Leonard David, "Plans for Next Generation 'Shuttle' Ends First Phase; 15 Concepts Have Emerged," *Space.com*, 30 April 2002, *http://www.space.com/missionlaunches/sli_firstphase_020430.html* (accessed 5 February 2005).

24. The Space Launch Initiative was also short-lived. By the end of 2002, White House and top-level NASA optimism that it would provide the hoped-for basis for deciding to develop a second-generation, advanced-technology replacement for the Space Shuttle had evaporated. In November 2002, NASA announced that it was terminating the Space Launch Initiative and reallocating its funding to a new Integrated Space Transportation Plan. According to this plan, the Shuttle's life would be extended so that it could fly until 2020, and potentially to 2030. The Shuttle would be used for missions requiring its cargo-carrying and orbital-operations capabilities. However, for missions carrying only crew to and from the International Space Station, a new Orbital Space Plane (OSP) would be developed, but as a complement to, not a replacement for, the Shuttle. The OSP would not be an advanced-technology vehicle; the goal was to have it available for use as an ISS crew-rescue vehicle by 2010, eliminating dependence on the Russian Soyuz spacecraft to perform this function. The OSP would also become a crew-transfer vehicle by 2012, capable of carrying four or more astronauts to the International Space Station. The OSP would be launched either in the Shuttle's cargo bay or atop an expendable launch vehicle. A third element of the plan was funding of technologies and studies for an eventual next-generation vehicle to replace the Shuttle. No date was set for such a replacement vehicle to enter service.

    The Integrated Space Transportation Plan was also a reaction to the lack of a long-term plan for U.S. human spaceflight. Without knowing how long the International Space Station would operate, it was not possible to determine how long the Space Shuttle would be needed. Without a post-ISS goal for human spaceflight, particularly given the collapse of the commercial space launch market, it also was not clear what kind of "post-Shuttle" vehicle to develop.

25. On 1 February 2003, Shuttle orbiter *Columbia* broke up over Texas, and all seven crew members aboard died. As noted at the start of this essay, the August 2003 report of the Columbia Accident Investigation Board set off, in the following months, a sweeping review of national space policy. On 14 January 2004, President George W. Bush announced a new "Vision for Space Exploration" centered on "a sustained and affordable program of human and robotic exploration of the solar system."[41] The new Vision had as a key element the decision to retire the Space Shuttle as soon as the assembly of the International Space Station was declared

41. White House, "Renewed Spirit of Discovery."

> complete, in 2010 or soon thereafter. To replace the Shuttle, the Vision calls for the development of a Crew Exploration Vehicle (CEV) to carry humans into space, first to low-Earth orbit and eventually to the Moon and Mars. This vehicle will house the crew as they travel into space and thus will indeed replace the Shuttle as the means for U.S. human access to space. The CEV is the latest of the many attempts to develop a replacement for the Space Shuttle as a human transport vehicle. One can only hope that it will be become reality, unlike its predecessors.

One cannot escape the conclusion that these 25 "snapshots" add up to a portrait of failure—failure to provide for the United States' "assured access" to space for its citizens. Since 1981, there has been only one way for the United States to send people into space—at least using U.S. hardware. That way, of course, has been the Space Shuttle, and with its two fatal accidents, the United States lost human access to space twice—first for 32 months, and then for more than 30 months. The United States will not have independent access to space for humans between the time the Space Shuttle is retired in 2010 and the CEV begins crewed operations. This interval could be as long as four years, and during that time, the only way for U.S. astronauts to get to and from the International Space Station will be on Russian spacecraft.

It is worth noting that "assured access" for key national security and other robotic payloads *has* been a stated national policy since at least 1988. In its 1988 statement of National Space Policy, the Reagan administration declared that "United States space transportation systems must provide a balanced, robust, and flexible capability with sufficient resiliency to allow continued operations despite failures in any single system." The 1991 National Space Policy of President George H. W. Bush stated that "assured access to space is a key element of U.S. national space policy."[42] This policy continues in force today. President George W. Bush, on 21 December 2004, approved a new National Space Transportation Policy which stated that " 'assured access' is a requirement for critical national security, homeland security, and civil missions." To be fair, this most recent statement also suggests that assured access to space for humans is also a desired policy objective. It declares that "access to space through U.S. space transportation capabilities is essential . . . to support government and commercial human spaceflight."[43] If this objective were met, it would signify a strong commitment to human spaceflight on the part of the U.S. government. As the following analysis suggests, such a strong commitment has been missing for many years.

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42. Thor Hogan and Vic Villhard, "National Space Transportation Policy: Issues for the Future," RAND Science and Technology Working Paper WR-105-OSTP, October 2003, p. 7.

43. Office of Science and Technology Policy, Executive Office of the President, "National Space Transportation Policy," fact sheet, 6 January 2005.

THE ROOT CAUSES OF THE FAILURE TO DEVELOP A SHUTTLE REPLACEMENT

There can be no one explanation for why this complex chain of developments has taken place. But certainly it is possible to suggest some of the fundamental reasons for the lack of a Shuttle replacement more than 30 years after the original commitment to the Space Shuttle program.

W. D. Kay, in his book *Can Democracies Fly in Space*, suggests that the "space program's failures, like its earlier successes, have multiple causes, all of them ultimately traceable to the way the American political process operates." Space policy is "a political outcome, a product of the discussion, debates, competition, and compromises that attend all public issues." While there could be alternate frameworks within which to examine the reasons why there has been no replacement for the Space Shuttle, this essay will adopt the political perspective suggested by Kay. He sets out a framework that provides a useful way to analyze this situation. Kay suggests that it is possible to conceptualize the creation of space policy in terms of three levels of analysis:

1. An *organizational output*, produced by the hardware, procedures, and personnel developed and trained by NASA.

2. A *political activity*, an outgrowth of the ongoing debates, compromises, votes, and other decisions involving NASA, its contractors, the Congress, various executive agencies, and a number of other loosely coordinated (and in some cases competing) individuals, institutions, and organizations, both public and private.

3. A *national enterprise*, the product of a society and a people possessing not only a certain level of technical expertise, but also a high degree of consensus and a determination expressed through its political representatives . . . .[44]

These three levels of analysis, and particularly viewing space policy as the foundation of a national enterprise, help to understand was has happened in the space sector over the past three and one-half decades.

44. W. D. Kay, *Can Democracies Fly in Space? The Challenge of Revitalizing the U.S. Space Program* (Westport, CT: Praeger Publishers, 1995), pp. 33, 26–27.

Technological Hubris and Organizational Outputs

In the last 20 years, the aerospace community has been given two major opportunities by the national leadership to develop a Shuttle replacement; these opportunities were accompanied by significant (although not adequate) funding commitments. The first of these opportunities, the NASP program, was initially justified on national security grounds; NASA was a junior partner in the undertaking and was not able to continue it as a development effort leading to a flight-test vehicle once Department of Defense funding was withdrawn. The second opportunity was the SSTO effort initiated by NASA in 1996 in response to NASA's internal studies and then the 1994 National Space Transportation Policy.

With the benefit of hindsight, it is possible to see that these two efforts were very likely doomed to failure from their outset. In both cases, the approach selected depended on being able simultaneously to bring to an adequate level of maturity a variety of challenging technologies in areas such as aerodynamics, guidance and control, materials, and propulsion. Those responsible for both efforts within the Department of Defense, NASA, and the aerospace industry assured their leaders that they could overcome these technological challenges and move forward rapidly and with affordable costs. These assurances were at variance with what actually transpired.

As mentioned above, the reality that the NASP program was unlikely soon to result in a flight vehicle became rather quickly evident after President Reagan gave the program national visibility in 1986. By 1988, the Defense Science Board had raised major questions about the technological feasibility of the undertaking. In 1989, the RAND Corporation reported "reservations" with respect to NASP coming "anywhere near its stated/advertised cost, schedule, payload fees to orbit, etc. . . ." and suggested that the "primary NASP X-30 objective—manned single stage to orbit—is exceedingly sensitive to full success in technology maturation."[45] Ivan Bekey, a proponent of a rocket-based approach to space access rather than the NASP air-breathing approach, was less kind; he has characterized the NASP program as "the biggest swindle ever to be foisted on the country," "full of dubious . . . claims" and "hot air."[46]

When Vice President Al Gore announced in July 1996 that NASA had selected Lockheed Martin's proposal to develop an SSTO demonstrator, he made a point of noting that it was the most "technologically advanced" of the

45. Bruno Augenstein and Elwyn Harris, "Assessment of NASP: Future Options," RAND Working Draft WD-4437-1-AF, July 1989, p. 2.

46. Quoted in Butrica, *Single Stage to Orbit*, p. 79.

three competing proposals. The story of why this risky choice was made has yet to be told. But once again, an approach to replacing the Shuttle had been chosen that would require simultaneous maturation of challenging technologies.[47] And once gain, achieving that maturation, at least on the original timescale and in the face of an impatient NASA and national leadership, proved impossible.

Why were these two efforts given high-level approval to proceed and widespread publicity when, at the time of approval, their chances of success were known to be low to at least some observers? This is a question deserving of more attention than it has received to date.

In 1989, one veteran aerospace engineer wondered, with respect to NASP, "How could ideas that were so thoroughly explored thirty years ago, and so thoroughly found lacking in sufficient promise twenty years go, have suddenly become once again in vogue?" It was not technological progress that had brought the ideas to the fore, he concluded, but rather "blissful ignorance of the past." Only a few of the instigators of the NASP program had been involved in earlier efforts, and "they were the ones who not only had been infected by the dream of long ago, but who had, in the process, become addicted to it and, therefore, immune to any amount of contrary evidence."[48] One suspects that an informed independent assessment of those who advocated the X-33 program would not be much different in its conclusions.

The costs of a lack of historical perspective and unchecked technological optimism, bordering on hubris, have been high. Roger Launius has suggested that the X-33 program and the NASP program before it "have been enormous detours for those seeking to move forward with a replacement for the Space Shuttle. Expending billions of dollars and dozens of years in pursuit of reusable SSTO technology, the emphasis on this approach ensured the tardiness of development because of the strikingly difficult technological challenges."[49] The Columbia Board agreed, suggesting that one reason for the "failure of national leadership" related to the absence of a replacement for the Space Shuttle was "continuing to expect major technological advances" in a replacement vehicle.[50]

How are nontechnical decision-makers to be protected against the enthusiasm of technological optimists? That is a topic well beyond the scope of this essay, but clearly, in the case of NASP and X-33, the necessary checks and balances were missing or not influential.

47. It should be noted that although X-33 and then VentureStar™ were widely perceived as a path to Shuttle replacement, the original designs were for an automated, cargo-carrying vehicle. Presumably, humans could be carried as "cargo," i.e., passengers, as the reliability of VentureStar™ was demonstrated.

48. Carl H. Builder, "The NASP as a Time Machine," RAND Internal Note 25684-AF, August 1989, p. 1.

49. Launius, "After *Columbia*," p. 291.

50. CAIB, *Report*, p. 211.

The Political Process and the Strength of the Pro-Shuttle Coalition

As noted by the CAIB, the Space Shuttle is "an engineering marvel that enables a wide variety of on-orbit operations."[51] The Shuttle is also a program with a multibillion-dollar annual budget which employs thousands of people in various locations and is the focus of much of the activity at the Johnson Space Center, with a large astronaut corps located there; the Marshall Space Flight Center; and the Kennedy Space Center. Major and smaller aerospace firms across the United States work on the Shuttle program.

It is not surprising, then, that throughout the Shuttle program's history there has grown up a politically active coalition of government, contractor, local, and congressional supporters who argue that the Shuttle is a vehicle that continues to be superior in capabilities to any technologically feasible replacement, and who therefore have suggested that the preferred course of action is to invest scarce funds in upgrading and modernizing the Shuttle rather than seeking an early replacement. From the time when President Jimmy Carter (in 1979) considered terminating the Shuttle program, through the conflicts in the early 1980s with the Air Force on one hand and foreign and domestic competitors on the other, to the aftermath of the *Challenger* and *Columbia* accidents, and perhaps even to the current time, this coalition has argued that it would be a mistake to rush towards a Shuttle replacement. Ten years ago, a report from an advisory group headed by NASA veteran Christopher Kraft argued that the Shuttle was "a mature and reliable system . . . about as safe as today's technology will provide."[52] At the time of the 2003 *Columbia* accident, after the failure of the X-33 program and the Space Launch Initiative, NASA was planning to keep the Shuttle in operation until at least 2020 and potentially beyond.

The existence of an organized coalition of public and private interests with a stake in the Space Shuttle program is an entirely legitimate phenomenon. The whole system design of the American political process is intended to allow organized interests to contend for a favorable policy outcome. In this case, however, there was no organized alternative interest group pushing for an early Shuttle replacement, and thus the default outcome of annual policy debates was likely to favor the pro-Shuttle position, or, at a minimum, not result in outcomes opposing it. While, for example, there was opposition from the scientific community and some members of Congress in the 1980s and 1990s to the space station program, there has been no similar consistent opposition to the Space Shuttle.

51. Ibid., p. 25.
52. Quoted in ibid., p. 118.

There were, however, limits to the political strength of the Shuttle support coalition. Although it may have been powerful enough to raise questions about the wisdom of proceeding rapidly towards a Shuttle replacement, it did not have enough power within the political process to influence decision-makers to allocate adequate resources for upgrading the Shuttle and its associated infrastructure. The Shuttle program budget was cut by more than 40 percent in purchasing power between 1991 and 2000. Although some upgrades were introduced into the system, more were not funded or canceled soon after being approved, and the Shuttle's ground infrastructure was "deteriorating."[53] Especially in the decade before the *Columbia* accident, uncertainty about when the Shuttle might be replaced, as the politically weaker and not well organized advocates of such replacement contended with the pro-Shuttle coalition, created an ambivalent policy attitude towards the Shuttle program. This policy outcome was perhaps the worst possible situation—not enough funding for successful operation of the Shuttle, but also inadequate political commitment behind an effort to replace it. It was most fundamentally a reflection of the place that human spaceflight held, and perhaps continues to hold, in the list of national priorities—something that most Americans want to see continue but are unwilling to invest enough resources in to do well.

This is an attitude criticized by those committed to human spaceflight. Launius notes that "if the United States intends to fly humans in space it should be willing to foot the bill for doing so." He suggests that "if Americans are unwilling as a people to make that investment, as longtime NASA engineer and designer of the Mercury capsule spacecraft Max Faget [who died in 2004] recently stated, 'we ought to be ashamed of ourselves.'"[54] These are noble sentiments but do not reflect the long-standing reality of how the space program has been seen in terms of national priorities.

HUMAN SPACEFLIGHT AS A NATIONAL ENTERPRISE

Kay, writing a decade ago, observed that "three decades ago, the United States government made a decision to support space exploration—including human flight—on a rather large scale." He questions whether "our present institutional arrangements and political practices prevent us from carrying out that decision effectively," and thus there may be a need to "rethink our original policy decision."[55]

This essay asserts that at the national leadership level, the decision "to support space exploration—including human flight—on a rather large scale"

53. Ibid., p. 114.
54. Launius, "After *Columbia*," p. 295.
55. Kay, *Can Democracies Fly in Space?* p. x.

was rethought soon after it was made and that the outcome of that rethinking was a much more muted commitment to the civilian space program overall, including human spaceflight. The people of the United States and their government have been willing, over the past 35 years, to continue a human spaceflight program, but only at a level of funding that has forced it to constantly operate on the edge of viability. The lack of a replacement for the Space Shuttle is a symptom of this larger reality. In this context, the assertion that the lack of a Shuttle replacement is a "failure of national leadership" is the logical result of the halfhearted U.S. commitment to human spaceflight. If there is a "failure," then, it is the failure to reconcile the reality of limited support with this country's continuing commitment to sending people into space. Human spaceflight may indeed be a "national enterprise"—but it is one that for many years has not been central to important American interests, at least as they are expressed through the political process.

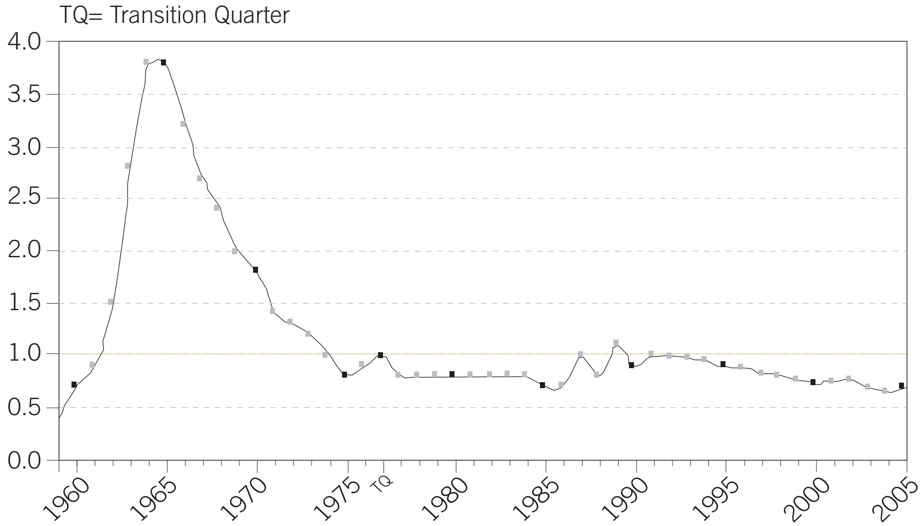
Kay ends his book with the question, "Can democracies fly in space?" His answer to this question is another question: "How badly do they want to?"[56] What will be argued below is that the answer to this second question is "not very badly."

Perhaps the single most convincing piece of evidence in support of this conclusion is the pattern of resources allocated to NASA over its history, as seen in the familiar figure repeated on the following page. Two things are remarkable about this pattern of resource allocation. The one most usually remarked upon is the rapid buildup of resources in the early 1960s in support of Project Apollo. This indeed was a peacetime mobilization of financial (and human) resources on a wartime scale. The Apollo buildup created an image of what a successful space program should be—one developing large-scale, expensive technology to take people into space.

Equally remarkable, however, and more fundamental to the argument of this paper is the rapid builddown of resources allocated to NASA between 1965 and 1974, and even more so the stability of that allocation over the past 30 years. It is impossible to escape the conclusion that, whatever the specific content of the NASA program at a particular time, the American public and their leaders, through the political process, have consistently decided to allocate less that 1 percent of the annual federal budget to the civilian space program as a national enterprise. This decision has been made, and reinforced, as the federal budget for each successive fiscal year has been assembled in the White House and approved or modified by the Congress. Within that allocation, national leaders have expected NASA to carry on a successful program of human spaceflight as well as its other activities. The result, as the CAIB

56. Ibid., p. 193.

NASA Budget as a Percentage of Federal Budget



observed with respect to the *Columbia* accident, has been an agency striving to "do too much with too little."

The basic decision that the United States, after succeeding in being first to land humans on the Moon, would not continue an ambitious program of human spaceflight in Earth orbit and beyond was made in 1969–1970 as the administration of President Richard Nixon formulated its post-Apollo policy for the civilian space program. It is a decision that has been reinforced by Presidents Ford, Carter, Reagan, and Clinton.

Up to 2004, only President George H. W. Bush (in 1989) suggested a reinvigoration of the human spaceflight program. Between President Bush's 1989 proposal for a "Space Exploration Initiative" and the time he was defeated in the 1992 election, it became clear, through the operation of the political process, that the country was not interested in a higher priority, more expensive human spaceflight effort.[57]

The first step in the process of formulating a policy to guide the space program after the end of the Apollo program was the creation in February 1969 of the Space Task Group, chaired by Vice President Spiro T. Agnew. This group was charged with preparing "definitive recommendations on the direction

57. See Thor Hogan, "Mars Wars: A Case History of Policymaking in the American Space Program" (Ph.D. diss., George Washington University, 2004), for a careful account of the origins and fate of the 1989 Space Exploration Initiative.

which the U.S. space program should take in the post-Apollo period."[58] In its 15 September 1969 report, the Space Task Group set out several options for the future and, "as a focus for the development of new capability," recommended that "the United States accept the long-term option or goal of manned planetary exploration with a manned Mars mission before the end of the century as the first target." This recommendation was actually a watered-down version of what the Group intended to recommend. President Nixon's advisers had intervened at the last minute, as the report was going into print, to make sure that the report did not contain the Group's planned recommendation that the initial mission to Mars be carried out in the 1980s, a recommendation that was politically unacceptable. The report proposed that whatever option was chosen by the President, the NASA budget by 1980 should be anywhere from the same as to twice that at the peak of the Apollo program.[59]

Accepting the Space Task Group's recommendations would have meant accepting a long-term national commitment to a robust program of human spaceflight, with repeated trips to the Moon and, eventually, forays to Mars. This was not at all what Richard Nixon and his advisers had in mind for the post-Apollo space effort. Rather than reward NASA for the success of the Apollo 11 landing, between October 1969 and January 1970, the NASA budget for fiscal year 1971 was severely reduced. In October, NASA requested White House approval of a $4.5-billion budget which would allow it to begin to implement the recommendations of the Space Task Group; by the time the President's budget was sent to Congress the following January, that amount had been reduced to $3.3 billion, a cut of over 25 percent from NASA's request and even $400 million less than the previous year's budget.

This outcome was not just the result of the Nixon administration's desire to submit a balanced budget; it reflected a major space policy choice. As Nixon's top adviser on space policy Peter Flanigan told the President in a 6 December 1969 memorandum:

> The October 6 issue of *Newsweek* took a poll of 1,321 Americans with household incomes ranging from $5,000 to $15,000 a year. This represents 61% of the white population of the United States and is obviously the heart of your constituency. Of this group, 56% think the government should be spending less money on space exploration, and only 10% think that the government should be spending more money.[60]

58. Logsdon, *Exploring the Unknown*, vol. 1, document III-22, p. 513.
59. Ibid., document III-25, p. 524.
60. Ibid., document III-27, p. 546.

NASA Administrator Thomas Paine, who had been touring both the United States and foreign countries to promote a post-Apollo space program as set out in the Space Task Group report, met with President Nixon on 22 January 1970 to make one last attempt to keep NASA on a path towards the approach laid out in the report. He had no success; Nixon told Paine that although he regretted the severe cuts to the NASA budget, "they were necessary in view of the overall budget situation—the reduced revenues and inflation." Nixon discussed "the mood of the country," which in the President's judgment "was for cuts in space and defense." Paine, ever an optimist, felt that the President "honestly would like to support a more vigorous space program if he felt the national mood favored it." But that was not the case, and Nixon wanted to make sure that he was not put in a position where "the opposition could invidiously compare his positive statements on space to problems in poverty and social programs here on Earth." Nixon did not want to appear to be "taking money away from social programs and the needs of the people here to fund spectacular crash programs out in space." Paine also noted that in their meeting, "the President didn't mention the Space Task Group Report."[61]

On 7 March 1970, the White House released a presidential statement on the future of the U.S. space program; Richard Nixon never addressed the subject in a public address. The statement was cast both as a response to the Space Task Group report and as an evaluation of where space fit into the country's future. Its message was clear:

> Space expenditures must take their proper place within a rigorous system of national priorities. What we do in space from here on in must become a normal and regular part of our national life and must therefore be planned in conjunction with all of the other undertakings which are important to us.[62]

The 1969–1970 interactions between NASA and the Nixon White House have been given detailed attention because they reflect a fundamental policy decision that has not been given adequate historical attention. In the months following the apex of U.S. success in human spaceflight with the Apollo 11 mission, the American President decided that it was neither in his political interest nor, more important, consistent with the desires of the American public to continue with a well-funded program of human spaceflight. This was not, as has been suggested, a case in which "the budget begat space policy

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61. Thomas Paine, "Meeting with the President, January 22, 1970," memo for record, 22 January 1970, Apollo Files, University of Houston–Clear Lake Library, Clear Lake, TX.

62. Richard M. Nixon, "Statement About the Future of the United States Space Program," 7 March 1970, in U.S. President, *Public Papers of the Presidents of the United States: Richard Nixon, 1970* (Washington, DC: GPO, 1971), p. 251.

instead of space policy begetting the budget."[63] Rather, it reflected a deliberate, purposeful reversal of the space policy adopted by the Kennedy administration that had led to Project Apollo. That policy held that success in highly visible space projects was "part of the battle along the fluid front of the cold war"; that "dramatic achievements in space . . . symbolize the technological power and organizing capacity of a nation"; that it was "man, not machines, that captures the imagination of the world"; and that "*the nation needs to make a positive decision to pursue space projects aimed at national prestige*"[64] (emphasis in original). To Richard Nixon and his advisers, this was not an acceptable rationale for a post-Apollo space program. They did not want to put an end to human spaceflight, but they were unwilling to set an ambitious goal to guide that effort. Instead, they approved development of a means—the Space Shuttle—without stating clearly the objectives it was to serve.

The decision on the future of the space program, and particularly on the future of its most visible element, human spaceflight, taken by the Nixon administration 35 years ago has remained the core national space policy until recently. That decision viewed the space program as a national enterprise, to use Kay's term, but one of secondary priority compared to other areas of national activity such as a strong defense, adequate social welfare, and, since 2001, homeland security. Based on the priority assigned to space efforts in this policy, for more than 30 years there has been a remarkably consistent share of the federal budget allocated to NASA.

That budget share has also been consistently inadequate to support the aspirations of NASA and the space community. Neither the space agency nor its supporters have adjusted their aspirations to that reality. Instead, they have continued to hold on to the hope that either a technological breakthrough on the order of NASP or VentureStar™ or a shift in the national priority assigned to space will allow them to make their dreams reality.

It is understandable that those most directly involved in the space sector harbor expansive ambitions for the future. What is not acceptable as a basis for government policy is to allow those ambitions to remain unchecked when the resources for achieving them are not, and are not likely to be, available. It is up to the leaders of NASA and to those to whom they report in the White House and Congress to steer the organization in a direction consistent with its place in the public's priorities. As suggested earlier, those leaders have failed to do so.

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63. This is the argument put forth by Joan Hoff in her essay "The Presidency, Congress, and the Deceleration of the U.S. Space Program in the 1970s," in *Spaceflight and the Myth of Presidential Leadership*, ed. Roger D. Launius and Howard E. McCurdy (Urbana: University of Illinois Press, 1997), p. 106.

64. This quotation comes from the 8 May 1961 memorandum, signed by NASA Administrator James E. Webb and Secretary of Defense Robert S. McNamara, recommending that President Kennedy set a human lunar landing as a national goal. The memorandum can be found in Logsdon, *Exploring the Unknown*, vol. 1, p. 444.

This analysis seems to have wandered rather far from the focus of this essay on explaining why no replacement for the Space Shuttle has yet been developed. On the contrary—the answer to that question depends on understanding the context within which the human spaceflight program has operated for at least the last 35 years. Beginning with the Nixon administration (or perhaps even earlier),[65] the political process by which the United States sets priorities among various government activities has assigned a consistently secondary priority to the NASA space program. Operating within that priority, NASA was able to develop the Space Shuttle during the 1970s only by retiring all of the systems that had been developed for Project Apollo, with the exception of using surplus equipment for the 1973 Skylab and the 1975 Apollo-Soyuz missions. With these two exceptions, NASA accepted a lengthy hiatus in human spaceflight as an acceptable price to pay for being permitted to develop the Space Shuttle.

Once the Space Shuttle started flying in 1981 and a space station was approved in 1984, NASA has had no similar opportunity to stop what it was doing and invest the funds thereby made available in developing a Shuttle replacement. Instead, it has had to try both to continue its ongoing, Shuttle-based human spaceflight program and to develop new spaceflight capabilities within an unvarying share of the federal budget. This has, to date, proven an impossible challenge to surmount. Therein lies the fundamental reason why there is, today, no replacement for the Space Shuttle; it is a product of a space policy decision made many years ago and not reversed since.

So Has There Really Been a Failure?

Calling the lack of a replacement for the Space Shuttle "a failure of national leadership" is based on the assumption, as stated in the CAIB report, that "America's future space efforts must include human presence in Earth orbit, and eventually beyond."[66] If the United States is to continue human spaceflight, so this line of argument goes, it is essential to develop a Shuttle replacement rather than continue to rely on the aging and expensive Shuttle. To have come so far in space and not to have such a replacement ready or on the horizon must indeed be the result of a failure on the part of those responsible for allocating national resources to provide the support needed.

There is an alternative perspective: that a program of continuing human spaceflight, eventually leading to travel beyond Earth orbit, does serve the national interest. The rationales in support of human spaceflight are diffi-

65. The NASA budget actually began its rapid decline from the 1965 peak of spending on Apollo while Lyndon B. Johnson was President. Although Johnson was committed to completing Apollo, he apparently gave post-Apollo spaceflight lower priority in the context of the other issues facing him in the 1965–1968 period.

66. CAIB, *Report*, p. 210.

cult to articulate to the unconvinced in convincing fashion; Launius calls the rationale for human spaceflight "highly problematic."[67] For example, one member of the space community recently commented that taking "as axiomatic that space's highest and true calling is achieving societal goals of research and exploration into the unknown" is the "burdensome baggage of an aristocratic calling, now bankrupt both ideologically and financially."[68]

What appears to be needed is some form of a national debate on the future of human spaceflight that will allow these and other conflicting perspectives to be fully articulated and the long-standing policy of assigning space efforts a secondary priority as a national enterprise to be reassessed. As suggested above, the current policy that assigns space such a priority has resulted in a human spaceflight effort that has struggled now for many years to be a viable undertaking. As one recent analysis suggests, the fact that the vision of human spaceflight, including the resumption of human voyages of exploration, has not resonated "with the American public to the point where it inspires action is a reflection of a larger problem: the U.S. currently has no larger shared vision" into which a space exploration vision can fit.[69]

The policy of assigning secondary priority to space is thus not a "failure" in a basic sense; the policy is the consistent result of a democratic political process and thus can be said to represent the will of the American public. It is also difficult to say that national leaders have failed when they have acted in accordance with the public will as expressed through established institutions and processes.

Who then—or what—has failed? As suggested above, there has been a leadership failure in the sense that space ambitions and the resources to accomplish them have not been brought into balance. But perhaps the failure also lies with those who continue to advocate the original space dream, which was based on "adventure, mystery, and exploration." To date, they have failed to convince enough others that this dream is worth realizing to make it a focus of a higher priority national (or international) enterprise. Most Americans appear not to care very much about a future that includes a vigorous space effort. Advocates have not adjusted their hopes to reflect the resources society is willing to provide them. Rather, "the dreams continue, while the gap between expectations and reality remains unresolved."[70]

67. For a discussion of the difficulty in stating a compelling rationale for human spaceflight, see John M. Logsdon, "A Sustainable Rationale for Human Spaceflight," *Issues in Science and Technology* (winter 2004); Launius, "Beyond *Columbia*," quotation from p. 308.

68. Rick Fleeter, "Contemplating Which Direction in Space," *Space News* (18 October 2004): 7.

69. Center for Cultural Studies & Analysis, "American Perception of Space Exploration: A Cultural Analysis for Harmonic International and the National Aeronautics and Space Administration," report to NASA, 1 May 2004, p. 3.

70. Howard E. McCurdy, *Space and the American Imagination* (Washington, DC: Smithsonian Institution Press, 1997), p. 243.

EPILOGUE: AN ACHIEVABLE VISION?

On 14 January 2004, President George Bush laid out what has become known as the Vision for Space Exploration. In his speech announcing this new vision, the President called for a "journey, not a race." In the formal language of the policy directive underlying the Vision, the objective is a "sustained and affordable program of human and robotic exploration of the solar system and beyond."[71]

Those planning this new approach to the U.S. space program appear to have recognized the reality described in this essay: any major new space initiative, if it is to be achievable, must be planned so that it can be carried out within a level of funding consistent with the pattern of more than three decades. The Vision gives highest priority within the NASA program to those activities related to exploration; other activities will receive lower priority and thus less funding in the future. A firm deadline has been set for retiring the Space Shuttle from service, and NASA's activities aboard the International Space Station will be gradually phased out. A replacement for the Space Shuttle in its role of carrying Americans into space, the Crew Exploration Vehicle, is a key part of the new Vision. In order to stay within a politically feasible budget, the first crew-carrying flight of the CEV is not scheduled until the 2012–2014 timeframe, and the first human mission to the Moon is planned for 2018–2020. A several-year period during which the United States will have to depend on Russia for human access to space is accepted. Cost of achieving the Vision will be minimized by substantial international and private-sector involvement. According to the Vision's financial projections, the NASA budget between 2004 and 2020 will increase only by 1.5 percent in the first five years of the new effort and not at all in constant dollars in the subsequent decade.

Is this a vision that the country will support on a stable basis? Can its objectives be achieved within the resources projected?[72] These are questions that cannot be answered now. What can be said is that the Vision for Space Exploration in its conception reflects the realities described in this essay. Whether its aspirations can become reality remains to be seen.

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71. White House, "Renewed Spirit of Discovery."

72. See U.S. Congress, Congressional Budget Office, "A Budgetary Analysis of NASA's New Vision for Space Exploration," September 2004, for a skeptical response to this question.

Chapter 10

Reusable Launch Vehicles or Expendable Launch Vehicles? A Perennial Debate

Andrew J. Butrica

The decades-long debate over reusable launch vehicles (RLVs) versus expendable launch vehicles (ELVs) has been less a reasoned debate than a sustained argument for the building of reusable launchers instead of the standard throwaway rocket. The single greatest touted advantage of reusable launch vehicles is that they reduce launch costs.[1] Comparing reusable and expendable rockets is not simple; it is a rather complicated task not unlike the proverbial comparing of apples and oranges. To compare the costs of the two types of rockets, we must consider two types of costs, recurring and nonrecurring. Nonrecurring costs entail those funds spent on designing, developing, researching, and engineering a launcher (called DDR&E costs). Recurring costs fall into two categories: expenses for building the launcher and the costs of its operation and maintenance.

Outlays for designing, developing, researching, and engineering reusable launchers are necessarily higher than those for expendable launchers because reusable rockets are technologically more challenging. For example, a reusable launch vehicle must have advanced heat shielding to allow it to reenter the atmosphere not once, but many times. Throwaway rockets have no need for such heat shielding. In addition, we possess a profound knowledge of expendable rocket technologies thanks to our long experience (over a half of a century) with ICBMs and other single-use rockets, while many of the technologies needed to build a fully reusable launcher remain in the elusive future. Construction costs, however, favor reusable launchers. For each launch, the cost of building a new expendable rocket is a recurring expense. For reusable launchers, construction costs are part of the upfront costs amortized over each launch.

Because reusable launch vehicles must fly many times in order to amortize startup costs, they have to be a lot more reliable than throwaway rockets,

1. Another cost-comparison method, but one that applies to specific launchers rather than launcher types and is considered to be more like comparing apples to apples (rather than oranges), is to determine the cost of delivering a pound of payload into orbit using a given launch system.

as well as more robust, so that on any given flight the craft does not suffer significant deterioration. The reliability of throwaway launchers is about 95 percent—that is, on average, 1 launch in 20 fails. A reusable launcher with equal reliability would not be able to recoup the higher investment needed to develop and build it. Achieving the necessary increased robustness and reliability also increases the cost and decreases the useful payload weight for reusable launchers.

The result of these intrinsic differences between the two launcher types leads to a tradeoff between the lower development costs of expendable rockets and the lower recurring costs of reusable launchers. In making that tradeoff, one must take into account a number of other realistic factors that favor expendable launchers. For example, although one can amortize reusable vehicle construction costs over many flights, they are far more expensive to build than expendable rockets. Building a full-scale version of the VentureStar™, Lockheed Martin's failed attempt at a reusable, single stage to orbit (SSTO) launch vehicle, would have cost (conservatively) more than the $1 billion NASA spent on the X-33 program, the intent of which was to build a prototype of the VentureStar™ craft.[2] That same amount of money might have bought 10 expendable rockets at $100 million each. Also, the knowledge gained in manufacturing a large number of a given type of disposable launcher actually can help to lower construction costs. Thus, in order to compete with the low development and construction costs of the established expendable industry, a reusable launcher would have to fly more than 50 times.

The gamble of the reusable launcher is that a small fleet of three to five vehicles could put payloads into orbit for less than the cost of the number of expendable rockets required to lift similar payloads. A commercial builder and operator of reusable launchers, however, would be burdened by the need to amortize development and construction costs over each mission. An obvious solution would be to have the government pay for most or all of the development costs and for government (NASA and the Air Force) to buy one or two reusable launchers for its exclusive use.

The preceding discussion applies to a comparison of expendable rockets with fully reusable launchers. The economics of launching a reusable vehicle atop an expendable booster are rather different. Such hybrid systems are technologically more achievable than fully reusable single-stage or two-stage rockets. A variety of launchers that combine reusable and expendable stages have been under development by companies and government, and they appear to promise reductions in the cost of placing payloads in orbit. Throughout

2. NASA canceled plans to have a history of the X-33 written. To date, the best brief description of the project's evolution is General Accounting Office, *Status of the X-33 Reusable Launch Vehicle Program*, GAO/NSIAD-99-176 (Washington, DC: GPO, August 1999), pp. 2–8.

the decades-long quest for reusability, the configuration of a reusable reentry vehicle atop a throwaway booster (a so-called boost-glide system) has dominated launcher thinking. In these boost-glide systems, the upper stage vehicle, once released from its booster rocket, climbs into orbit on its own power, then glides to a landing. Some reusable suborbital vehicles launch from a large jet, such as a B-52 or an L-1011.

Cost has not been the only factor favoring one launch technological system over another. Emotional and political considerations are certainly key, as is the pull on the imagination exercised by the promise of reusable launchers. RLV enthusiasts believe that a fully reusable rocket would provide the low-cost, reliable transport to space necessary to realize the seemingly endless possibilities of exploiting space—the "final frontier"—for colonization, mining, tourism, manufacturing, or just exploration.

The history of the debate over reusable versus expendable launchers is complex, and one can explore it from a variety of perspectives. The most obvious is a narrative of the enduring endeavor to conceive and develop a reusable launch vehicle. This chapter begins with such an account, then discusses the evolution of space transportation policy regarding reusable and expendable launchers. A third section raises historiographical questions about launch vehicle history as well as space history in general.

THE SPACEPLANE CONCEPT

One of the earliest reusable vehicle concepts was that of the spaceplane.[3] They are like airplanes in a rather simplistic and literal way. They have wings and take off and land horizontally like an airplane; a pilot and copilot sit in a cockpit. They usually (but not always) feature a kind of air-breathing engine known as a scramjet.[4] Their appeal is rather similar to that of jet aircraft, namely, the urge to go faster and higher than before that permeates the history of flying. Indeed, spaceplanes are little more than aircraft that fly into space.

One of the first spaceplane concepts was that of the American rocketeer Robert Goddard. In a *Popular Science* article published in December 1931, he described a spaceplane ("stratosphere plane") with elliptically shaped wings and propelled by a combination air-breathing jet and rocket engine. The rocket engine drove the vehicle while it was outside the atmosphere, and two turbines moved into the rocket's thrust stream to drive two large propel-

3. I am excluding all of those reusable launch vehicles described in science fiction literature.

4. *Scramjet* is a truncation of "supersonic combustion ramjet." Ramjets are jet engines that propel aircraft at supersonic speeds by igniting fuel mixed with air that the engine has compressed. Scramjets achieve hypersonic velocities.

lers on either wing, thereby powering the vehicle while in the atmosphere.[5] German researcher Eugen Sänger, in his 1933 book on rocket flight, described a rocket-powered suborbital spaceplane known as the *Silbervogel* (Silver Bird), fueled by liquid oxygen and kerosene and capable of reaching a maximum altitude of 160 kilometers (100 miles) and a speed of Mach 10. Later, working with his future wife, the mathematician Irene Bredt, and a number of research assistants, Sänger designed the Rocket Spaceplane, launched from a sled at a speed of Mach 1.5. A rocket engine capable of developing 100 tons of thrust would boost the craft into orbit, where it could deploy payloads weighing up to 1 ton.[6]

The appearance of ideas for craft capable of flying into space is not surprising. They reflected the interwar enthusiasm for the airplane, as well as excitement over rocketry, and projected those technological enthusiasms into space. New technologies often look like older technologies. For example, James Prescott Joule's electric motor resembled a steam engine, and Samuel F. B. Morse built his first telegraph from a canvas stretcher, a technology he knew as an artist.[7] Inventors necessarily proceed from the known to the technologically unknown. The passion for spaceplanes continued for decades more, feeding off the exciting advances in technology that propelled aircraft faster and faster to supersonic, then to hypersonic, speeds.

Spaceplanes remained largely fictional concepts until 1957, when the Air Force initiated what became the Aerospaceplane program to develop a single stage to orbit vehicle powered by an air-breathing engine. By 1959, the project had evolved into the Recoverable Orbital Launch System (ROLS), an SSTO design that would take off horizontally and fly into a 300-mile-high (483-meter-high) orbit. The ROLS propulsion system collected air from the atmosphere, then compressed, liquefied, and distilled it in order to make liquid oxygen, which mixed with liquid hydrogen before entering the engines.

5. Russell J. Hannigan, *Spaceflight in the Era of Aero-Space Planes* (Malabar, FL: Krieger Publishing Company, 1994), p. 71. Materials in file 824 of the NASA Historical Reference Collection at NASA Headquarters, Washington, DC, indicate that the article appeared in the December 1931 issue, pp. 148–149, and was titled "A New Turbine Rocket Plane for the Upper Atmosphere."

6. Irene Sänger-Bredt, "The Silver Bird Story: A Memoir," file 7910, NASA Historical Reference Collection, Washington, DC; Hannigan, *Spaceflight in the Era of Aero-Space Planes*, pp. 71–73; Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (New York: The Free Press, 1995), pp. 7–10; Richard P. Hallion, "In the Beginning Was the Dream . . . ," in *The Hypersonic Revolution: Eight Case Studies in the History of Hypersonic Technology*, ed. Richard P. Hallion, vol. 1, *From Max Valier to Project Prime, 1924–1967* (Dayton, OH: Special Staff Office, Aeronautical Systems Division, Wright-Patterson AFB, 1987), pp. xi–xv.

7. Brooke Hindle, *Emulation and Invention* (New York: New York University Press, 1981), pp. 85–108, 120–121; Lewis Coe, *Telegraph: A History of Morse's Invention and Its Predecessors in the United States* (Jefferson, NC: McFarland, 1993); J. M. Anderson, "The Invention of the Telegraph: Samuel Morse's Role Reassessed," *IEEE Power Engineering Review* 18 (July 1998): 28–29.

This complicated propulsion system, dubbed LACES (Liquid Air Collection Engine System), later renamed ACES (Air Collection and Enrichment System), as well as various scramjet engine concepts, underwent Air Force evaluation over time. Faced with the uncertainties of the single-stage design, the Air Force shifted the focus of the Aerospaceplane to two stage to orbit concepts in 1962, and following the program's condemnation by the Scientific Advisory Board, the Aerospaceplane died in 1963. Congress cut fiscal 1964 funding, and the Pentagon declined to press for its restoration.[8]

Dyna-Soar

A rather different reusable vehicle concept was the boost-glide system. The Peenemünde rocket group under Wernher von Braun originally planned to develop a much larger missile, the A-10/A-9, capable of delivering a 1-ton bomb over 5,000 kilometers (3,125 miles) away. The A-10 first stage was a conventional booster rocket, while the A-9 upper stage was a winged vehicle that could glide at supersonic speeds before hitting its target. Other Peenemünde work, kept secret from the Nazis, included a piloted version of the A-9 that would launch vertically and land horizontally, like the Space Shuttle. An even larger vehicle, the A-12, was a fanciful three-staged launcher whose top stage was a reusable winged reentry vehicle.[9] None of these concepts, however, were orbital vehicles.

At the end of World War II, as is widely known, Wernher von Braun and much of the German rocket program became a vital part of the United States' own missile program and contributed to the development of boost-glide systems.[10] Walter Dornberger, a key Nazi rocketeer and later a consultant for Bell Aircraft, persuaded that firm to undertake a study of boost-glide technology. In 1952, that study led to the joint development by Bell and the Wright Air Development Center, Dayton, Ohio, of a piloted bomber missile and reconnaissance vehicle called BoMi. A two-stage rocket would lift BoMi, which would operate at speeds over Mach 4. By 1956, the BoMi study work had evolved into a contract for Bell to develop Reconnaissance System 459L, commonly known as Brass Bell, a piloted two-stage boost-

8. Hannigan, *Spaceflight in the Era of Aero-Space Planes*, pp. 77–78; T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle* (Washington, DC: NASA SP-4221, 1999), pp. 75–78; Hallion and James O. Young, "Space Shuttle: Fulfillment of a Dream," in *The Hypersonic Revolution: Eight Case Studies in the History of Hypersonic Technology*, ed. Hallion, vol. 2, *From Scramjet to the National Aero-Space Plane* (Dayton, OH: Special Staff Office, Aeronautical Systems Division, Wright-Patterson AFB, 1987) pp. 949–951.

9. Neufeld, *Rocket and the Reich*, pp. 92–93, 121, 138–139, 156–157, 283; Hallion, "In the Beginning Was the Dream . . . ," p. xviii; Hannigan, *Spaceflight in the Era of Aero-Space Planes,* p. 73.

10. Linda Hunt, *Secret Agenda: The United States Government, Nazi Scientists, and Project Paperclip, 1945 to 1990* (New York: St. Martin's Press, 1991).

glide reconnaissance system, while the bomber part of the BoMi work became RoBo, a piloted hypersonic, rocket-powered craft for bombing and reconnaissance missions.[11]

A major step in orbital boost-glide systems was the Dyna-Soar (for Dynamic Soaring) program. It was the final stage of a three-stage study of rocket-powered hypersonic flight initiated by the National Advisory Committee for Aeronautics (NACA) with Air Force participation. The study used a series of experimental aircraft ("X" vehicles) lifted into the sky by reusable aircraft. "Round One," to use the NACA nomenclature, consisted of the Bell X-1 series, the Bell X-2 series, and the Douglas D-588-2 Skyrocket. "Round Two" was the series of flights eventually undertaken by the X-15. "Round Three" called for testing winged orbital reentry vehicles.[12]

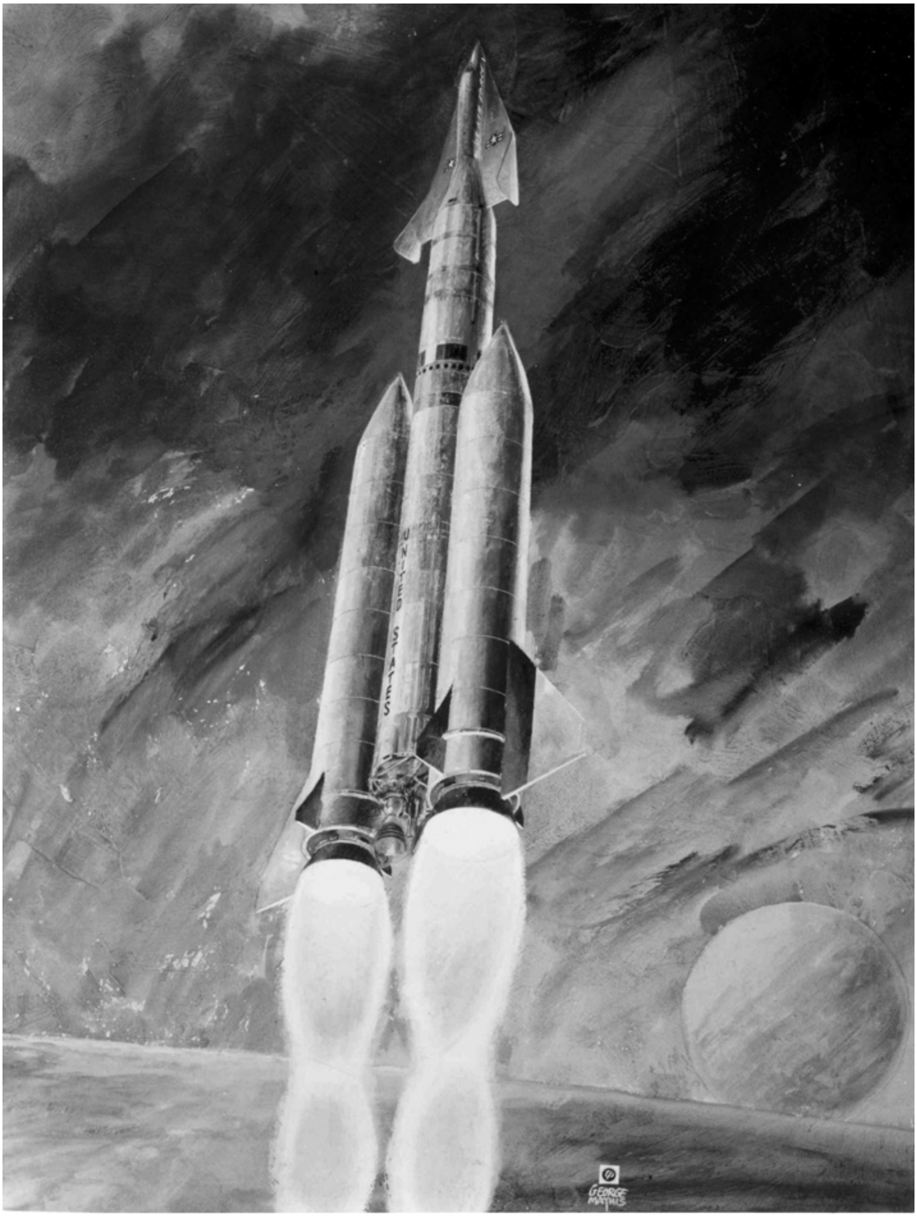
The Air Force's Dyna-Soar program emerged from a 1957 consolidation of the NACA's "Round Three" and several military hypersonic flight programs. Eventually, NASA participated in the project as well. Launched on an expendable booster, the Dyna-Soar X-20 would fly orbital or suborbital trajectories, perform reconnaissance at hypersonic speeds, and land horizontally like an aircraft at many U.S. air bases. Although the Dyna-Soar vehicle was never built, a prototype was near completion when Secretary of Defense Robert McNamara terminated the program on 10 December 1963, only eight months before drop tests from a B-52. The first piloted flight had been scheduled for 1964.[13]

Dyna-Soar had a lot to offer the Air Force and the nation and might have changed history. The military might have benefited economically by possessing the world's first reusable orbital vehicle, and the Pentagon would not have

11. Clarence J. Geiger, "Strangled Infant: The Boeing X-20A Dyna-Soar," in *The Hypersonic Revolution*, ed. Hallion, vol. 1, pp. 189, 191–198, a manuscript copy of which is in file 11326, NASA Historical Reference Collection, Washington, DC, as Geiger, "History of the X-20A Dyna-Soar," October 1963; additional items from files 495 and 11923, NASA Historical Reference Collection, Washington, DC; Hallion, "Editor's Introduction," in *The Hypersonic Revolution*, ed. Hallion, vol. 1, p. II-xi.

12. Hallion, "In the Beginning Was the Dream . . . ," p. xxi; Hallion, "Editor's Introduction," in *The Hypersonic Revolution*, ed. Hallion, vol. 1, pp. I-iv–I-v, II-xi.

13. R&D Project Card Continuation Sheet, 23 August 1957, file 11325, NASA Historical Reference Collection, Washington, DC; additional items in file 11340, NASA Historical Reference Collection, Washington, DC; Geiger, "Strangled Infant," pp. 198–199, 201–204, 261, 263, 266, 276–278, 296–297, 299–301, 305, 308–309. A number of studies are available on the Dyna-Soar program. See, for instance, Terry Smith, "The Dyna-Soar X-20: A Historical Overview," *Quest: The History of Spaceflight Magazine* 3, no. 4 (1994): 13–18, 23–28; Matt Bacon, "The Dynasoar Extinction," *Space* 9 (May 1993): 18–21; Roy Franklin Houchin II, "The Rise and Fall of Dyna-Soar: A History of Air Force Hypersonic R & D, 1944–1963" (Ph.D. diss., Auburn University, 1995); Houchin, "The Diplomatic Demise of Dyna-Soar: The Impact of International and Domestic Political Affairs on the Dyna-Soar X-20 Project, 1957–1963," *Aerospace Historian* 35 (December 1988): 274–280.



Artist's concept of a Dyna-Soar manned space glider being launched into space by a modified Titan ICBM. The glider, riding on the nose of the Titan, would be separated from its booster, leaving the spacecraft in piloted, near-orbital flight. The pilot could glide to a conventional landing at an Air Force base. The Boeing Company was the prime contractor for the glider, which was a U.S. Air Force program. Only a prototype of the glider was built before the program was terminated on 10 December 1963. *(Boeing drawing S-5938, dated 22 September 1960)* been forced to become NASA's political ally in the space agency's political struggle to win funding for its Space Shuttle program. Also, Dyna-Soar could have provided NASA a less expensive, but two-stage, orbital shuttle. The knowledge gained from the research program, which included over 14,000 hours of wind tunnel tests, could have been applied to a number of applications from glide bombers to future spacecraft. Moreover, after termination of the program, Boeing carried out a small "X-20 continuation program" for several more years that involved testing various X-20 components and design features both in ground facilities and on flight research vehicles. The René 41 high-temperature nickel alloy developed for the X-20 reappeared in the 1970s as part of the airframe structure and heat shielding for Boeing's Reusable Aerodynamic Space Vehicle (RASV).[14]

Lifting Bodies

Also of note among these early boost-glide systems was a group of reusable suborbital vehicles known as lifting bodies. A lifting body is a wingless aerodynamic shape that develops lift—the force that makes winged craft fly—because of its peculiar body shape. Research on lifting bodies began in early 1957 at the NACA's Ames Aeronautical Laboratory (now NASA's Ames Research Center). Following NASA's success with its wooden M2-F1, the Air Force joined NASA at Edwards AFB in the test-flight program of the rocket-powered M2-F2, launched from a B-52 from 1966 until its crash in 1967.[15]

The most prominent of these lifting-body craft was the Air Force's X-24B, built by Martin Marietta in 1972. A modified X-24B powered by aerospike engines became Lockheed's Space Shuttle design concept in the latter 1960s, the StarClipper, while the X-24B's shape also inspired the design of what eventually became Lockheed skunk works' X-33 launch vehicle. Despite the apparent name similarity, the X-24B had rather different shapes and distinct origins from the X-24A lifting body built for NASA, though both had a role in the Air Force's lifting-body program.[16]

The RASV

Even as NASA and industry were building the Space Shuttle, the search for a reusable Shuttle replacement was under way. As with lifting-body research,

14. Geiger, "Strangled Infant," pp. 319–320, 369; Andrew K. Hepler interview, tape recording and transcript, Seattle, WA, by Butrica, 11 July 2000, NASA Historical Reference Collection; Hepler and E. L. Bangsund, Boeing Aerospace Company, Seattle, WA, *Technology Requirements for Advanced Earth Orbital Transportation Systems*, vol. 1, *Executive Summary* (Washington, DC: NASA Contractor Report CR-2878, 1978).

15. R. Dale Reed, *Wingless Flight: The Lifting Body Story* (Washington, DC: NASA SP-4220, 1997), pp. 9, 67, 69–72, 75, 87, 91, 96–98, 102, 106–109, 116; John L. Vitelli and Hallion, "Project PRIME: Hypersonic Reentry from Space," in *The Hypersonic Revolution*, ed. Hallion, vol. 1, p. 529.

16. Vitelli and Hallion, "Project PRIME," pp. 558, 566, 571, 577–596, 694–695, 699, 702–704, 711.

NASA led the way. In 1972, the Langley Research Center, with the approval of NASA Headquarters, set up a small group to study the possibility of growing an aircraft known as the Continental/SemiGlobal Transport (C/SGT) into a single stage to orbit vehicle. The C/SGT would take off, almost attain orbit, then land, delivering people or cargo to any place on Earth in less than 2 hours. Langley researchers' analyses of the vehicle suggested that with just a little bit more speed, the C/SGT could achieve orbit.[17]

Using Shuttle technology as the starting point for their study of the structures, materials, and engines needed for a Shuttle replacement, the Langley analysis team evaluated the impact of improving structures and materials (such as composites) beyond the Space Shuttle on various configurations. The improved materials promised to reduce overall vehicle weight significantly, thereby seeming to bring SSTO transport within the realm of the possible.[18] Then, in 1975, Langley funded two industry studies of SSTO rocket concepts carried out by teams from Martin Marietta Denver and Boeing Seattle. The stated purpose of the study was to determine the future technology development needed to build an operational rocket-powered, single stage to orbit Space Shuttle replacement by the year 1995. Each team concluded that such a vehicle was feasible using technology available in the near term.[19]

Next, Boeing tried to sell their vehicle design from the Langley 1975 study to the Air Force. The company's interest in the reusable SSTO vehicle was "based on the belief that the reusable airplane type operation of earth orbit transportation vehicles will allow considerable improvement in cost per flight and flexibility."[20] The vehicle would have incorporated both proven and unproven technologies. The cylindrically shaped, delta-winged, reusable single stage to orbit craft, powered by Space Shuttle Main Engines, would have take off with the help of a sled and land horizontally on a conventional runway. It would have used a combination of aluminum-brazed titanium and René 41, a high-temperature nickel alloy developed for the Dyna-Soar X-20, for both its structure and heat shielding. The vehicle would have stored liquid-hydrogen fuel in its body and liquid oxygen in its wings. The integration of the liquid-hydrogen and liquid-oxygen tanks into the load-carrying

17. Alan Wilhite interview, tape recording and transcript, NASA Langley Research Center, Hampton, VA, by Butrica, 22 May 1997, NASA Historical Reference Collection, Washington, DC.

18. Charles H. Eldred interview, tape recording and transcript, NASA Langley Research Center, Hampton, VA, by Butrica, 20 May 1997, NASA Historical Reference Collection, Washington, DC.

19. The two studies were Rudolph C. Haefeli, Earnest G. Littler, John B. Hurley, and Martin G. Winter, Denver Division, Martin Marietta Corporation, *Technology Requirements for Advanced Earth-Orbital Transportation Systems: Final Report* (Washington, DC: NASA Contractor Report CR-2866, October 1977); and Andrew K. Hepler and E. L. Bangsund, Boeing Aerospace Company, Seattle, WA, *Technology Requirements for Advanced Earth Orbital Transportation Systems*, vol. 1, *Executive Summary*, and vol. 2, *Summary Report* (Washington, DC: NASA Contractor Report CR-2878, 1978).

20. Hepler and Bangsund, *Technology Requirements for Advanced Earth Orbital Transportation Systems*, 1:13–14.

structure (that is, the wings and the main body of the craft), combined with the metallic shell made of honeycomb panels, went far in reducing overall vehicle weight.[21]

Boeing soon interested the Air Force Space and Missiles System Organization (Los Angeles Air Force Station) in this vehicle concept. The Air Force dubbed it the Reusable Aerodynamic Space Vehicle (RASV) and, in 1976, provided funding for a seven-month preliminary feasibility study of the RASV concept. It concluded (not surprisingly) that the RASV was feasible and that it would fulfill Air Force requirements. Among those requirements were flying 500 to 1,000 times "with low cost refurbishment and maintenance as a design goal" from a launch site in Grand Forks, North Dakota, into a polar orbit or once around the planet in a different orbit. The vehicle would have to reach "standby status within 24 hours from warning. Standby to launch shall be three minutes."[22]

In all, the Air Force invested $3 million in the project for technology development. The service had become convinced that the RASV potentially could provide a manned platform that could be placed above any point on the planet in less than an hour and could perform a variety of missions, including reconnaissance, rapid satellite replacement, and general space defense. In December 1982, Boeing Chairman T. A. Wilson gave the RASV effort the go-ahead to propose a $1.4-billion prototype vehicle to the Air Force.[23] Boeing, however, would not build the RASV.

The problem was not the steep technological hurdles that the firm would have to leap, such as development of the sled to accelerate the RASV to a speed of 600 feet per second or achievement of fast turnaround time (24 hours or perhaps as short as 12 hours) for the Strategic Air Command (SAC).[24] The Air Force ordered two classified studies of single stage to orbit technologies, "Science Dawn" (1983–1985) and "Have Region" (1986–1989), conducted by industry partners Boeing, Lockheed, and McDonnell Douglas. They inter-

21. Ibid., 1:14–16, 2:191; Hepler interview.

22. Boeing Aerospace Company, *Final Report on Feasibility Study of Reusable Aerodynamic Space Vehicle*, vol. 1, *Executive Summary* (Kent, WA: Boeing Aerospace Company, November 1976), pp. 5, 35.

23. Hallion, "Yesterday, Today, and Tomorrow: From Shuttle to the National Aero-Space Plane," in *The Hypersonic Revolution*, ed. Hallion, vol. 2, p. 1334; P. Kenneth Pierpont, "Preliminary Study of Adaptation of SST Technology to a Reusable Aero-space Launch Vehicle System," NASA Langley Working Paper NASA-LWP-157, 3 November 1965; Boeing RASV proposal, December 1982, file 256, X-33 Archive, record group 255, accession number 255-01-0645, Washington National Records Center, Suitland, MD (hereafter, X-33 Archive); Jess Sponable interview, tape recording and transcript, NASA Headquarters, Washington, DC, by Butrica, 19 January 1998, NASA Historical Reference Collection, Washington, DC; Gary Payton and Jess Sponable, "Designing the SSTO Rocket," *Aerospace America* (April 1991): 40.

24. Hepler interview.

preted the study results as demonstrating the technological feasibility of the RASV for SAC.[25] But instead of proceeding with further RASV studies, the Air Force chose to develop a space vehicle that not only operated like an aircraft, as the RASV did, but had air-breathing jet engines, too. That space vehicle would be known as the National Aero-Space Plane (NASP).

The National Aero-Space Plane

With NASP, the spaceplane quest returned.[26] The milestone moment was President Ronald Reagan's State of the Union Address, delivered on 4 February 1986, just days after the *Challenger* disaster. Reagan declared: "We are going forward with research on a new Orient Express that could, by the end of the decade, take off from Dulles Airport, accelerate up to 25 times the speed of sound attaining low Earth orbit, or fly to Tokyo within two hours."[27] As portrayed by the President, the Orient Express would be both a high-speed aircraft and a single stage to orbit vehicle, powered by air-breathing engines. The program merged two existing efforts.

One was the TransAtmospheric Vehicle (TAV) program, set up in 1982 as an Air Force study of Space Shuttle replacement concepts. Air-breathing engines were a serious, though not exclusive, consideration. The program considered a variety of both single- and two-stage vehicle configurations, powered by either rocket or jet engines.[28] Interest in the TransAtmospheric Vehicle grew as a direct result of the increased need for launchers driven

25. Raymond L. Chase, "Science Dawn Overview," March 1990, file 235, X-33 Archive; Major Stephen Clift, "Have Region Program: Final Brief," September 1989, file 235, X-33 Archive; Sponable interview.

26. For background information on NASP, see the materials in file 106, box 4, X-33 Archive; Larry Schweikart, "Command Innovation: Lessons from the National Spaceplane Program," in *Innovation and the Development of Flight*, ed. Roger D. Launius (College Station: Texas A&M University Press, 1999), pp. 299–323; Hannigan, *Spaceflight in the Era of Aero-Space Planes*, passim; Schweikart, "The National Spaceplane: Evolving Management Approaches to a Revolutionary Technology Program," *Essays in Economic and Business History* 12 (1994): 118–33; Alan W. Wilhite, Richard W. Powell, Stephen J. Scotti, Charles R. McClinton, S. Zane Pinckney, Christopher I. Cruz, L. Robert Jackson, James L. Hunt, Jeffrey A. Cerro, and Paul L. Moses, "Concepts Leading to the National Aero-Space Plane Program" (paper read at the 28th Aerospace Sciences Meeting, Reno, NV, 8–11 January 1990), file 703, box 23, X-33 Archive.

27. Quoted in Scott Pace, "National Aero-space Plane Program: Principal Assumptions, Findings, and Policy Options," RAND publication P-7288-RGS, December 1986, p. 1. Reagan's speechwriters confused the NASP reusable single stage to orbit vehicle with the Orient Express, a McDonnell Douglas hypersonic aircraft design in which Federal Express had shown interest. The confusion probably screened the flight vehicle's military mission, though the McDonnell Douglas prototype claimed to be capable of performing either a NASP single stage to orbit or an Orient Express mission, depending on the vehicle's propulsion system. See Paul Czysz interview, tape and transcript, NASA Langley Research Center, Hampton, VA, by Erik M. Conway, 17 July 2001, pp. 1–5, 8–9, 11.

28. Hallion, "Yesterday, Today, and Tomorrow," pp. 1337, 1340–1341, 1345.

by the Strategic Defense Initiative (SDI) and Space Station *Freedom*.[29] The second program was the classified three-phase Copper Canyon program of the Advanced Research Projects Agency (ARPA), which funded research on scramjet hypersonic vehicles.[30] The Copper Canyon and TransAtmospheric Vehicle efforts merged to form a larger program that comprised the gamut of government agencies involved in hypersonic air-breathing engine studies at one time or another: NASA, ARPA, the Air Force, the Navy, and the Strategic Defense Initiative Organization (SDIO). On 1 December 1985, the title National Aero-Space Plane (NASP) replaced all earlier designations.[31]

The NASP program initially proposed to design and build two research craft, the X-30, at least one of which was to achieve orbit by flying in a single stage through the atmosphere at speeds up to Mach 25. The X-30 would use a multicycle engine that shifted from jet to ramjet and scramjet speeds as the vehicle ascended, burning liquid-hydrogen fuel with oxygen scooped and frozen from the atmosphere. The engine and vehicle designs had come from Tony DuPont, an aerospace designer who had developed a multicycle jet and rocket engine under contract with NASA, then ARPA.[32] DuPont's vehicle design rested on a number of highly questionable assumptions, optimistic interpretations of results, and convenient omissions (such as landing gear).[33]

NASP, like the Aerospaceplane program, fell victim to budget cuts, but this time as a result of the end of the Cold War. Congress canceled NASP in 1992, during fiscal 1993 budget deliberations. Although the program never came near to building or flying hardware, NASP contributed significantly to the advance of materials capable of repeatedly withstanding high temperatures (on the vehicle's nose and body) or capable of tolerating repeated exposure to extremely low temperatures (the cryogenic fuel tanks).[34]

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29. Ibid., pp. 1336–1337, 1340–1341.

30. John V. Becker, "Confronting Scramjet: The NASA Hypersonic Ramjet Experiment," in *The Hypersonic Revolution*, ed. Hallion, vol. 2, pp. VI.xii, VI.xiv, 765, 786–789, 824, 841; Heppenheimer, *The National Spaceplane* (Arlington, VA: Pasha Market Intelligence, 1987), p. 14; Hallion, "Yesterday, Today, and Tomorrow," p. 1361; Larry Schweikart, "The Quest for the Orbital Jet: The National Aerospace Plane Program, 1983–1995," manuscript, pp. I.30–I.31, NASA Historical Reference Collection, Washington, DC. For background on these and other hypersonic research projects, see Erik Conway, *High-Speed Dreams: NASA and the Technopolitics of Supersonic Transportation, 1945–1999* (Baltimore, MD: Johns Hopkins, 2005).

31. Heppenheimer, *The National Spaceplane*, p. 14; Hallion, "Yesterday, Today, and Tomorrow," pp. 1334, 1362–1364; Schweikart, "The Quest for the Orbital Jet," pp. I.30–I.31; Becker, "Confronting Scramjet," in *The Hypersonic Revolution*, ed. Hallion, vol. 2, p. VI.xv.

32. Robert Jones interview, tape and transcript, NASA Langley Research Center, Hampton, VA, by Erik M. Conway, 25 June 2001, pp. 8–9; Conway to Butrica, e-mail message, 5 April 2002; Schweikart, "The Quest for the Orbital Jet," pp. I.19–I.20, I.23, I.28, III.31, III.43–III.44; Hallion, "Yesterday, Today, and Tomorrow," pp. 1346, 1351, 1379.

33. Schweikart, "The Quest for the Orbital Jet," pp. I.11–I.12, I.19–I.20, I.23, I.28, III.43.

34. Ibid., pp. III.37–III.38, III.41–III.42.

The Delta Clipper

The end of NASP was not the end of efforts to realize a fully reusable launch vehicle. In parallel with, but never in competition with, NASP was the SSTO Program of the SDIO. This program differed radically from its predecessors that had attempted to develop flight technology; instead, it tested the flight operations of a single stage to orbit vehicle, the Delta Clipper Experimental (DC-X). Its intent was not to develop technology, but to demonstrate "aircraft-like" operations, which included autonomous operations, minimal launch and operational crews, ease of maintenance, abort capability, and short turnaround time. The novelty of the SSTO Program also was to combine the goal of "aircraft-like" operations with the use of an "X" vehicle and a "lean" management approach by both government and industry in the hope of expediting the project and keeping costs low.

In early 1990, the Strategic Defense Initiative Organization started the SSTO Program. The 10-month-long Phase I consisted of design studies and the identification of critical technologies by Boeing, General Dynamics, McDonnell Douglas, and Rockwell International.[35] In June 1991, following a review of Phase I concepts by NASA's Langley Research Center, the SDIO solicited proposals for Phase II. The Statement of Work described the capabilities of the full-scale operational single stage to orbit vehicle—which would loft SDI Brilliant Pebbles payloads into orbit—and the Phase II small suborbital "X" vehicle, its support infrastructures (such as the launchpad), and operational concepts.[36] Of the three contractors competing—General Dynamics, McDonnell Douglas, and Rockwell International—the SDIO selected McDonnell Douglas in August 1991 to build its Delta Clipper Experimental (DC-X) in 24 months. The firm clearly understood the need to demonstrate operations rather than develop technology.[37]

McDonnell Douglas rolled out the 111-foot (34-meter) DC-X in record time, four months ahead of schedule, in April 1993. The company built the Delta Clipper out of modified existing hardware, some of which, such as welding rods and hinges, they purchased literally from local hardware stores. Pressure regulators and cryogenic valves came from Thor missiles formerly positioned in Europe, and the manufacturer of the alu-

35. McDonnell Douglas Space Systems Company, "Single Stage to Orbit Program Phase I Concept Definition," 13 December 1990, file 267, X-33 Archive; General Dynamics Space Systems Division, "Concept Review Technical Briefing," 13 December 1990, file 265, X-33 Archive; Space Transportation Systems, Boeing Defense and Space Group, "Single Stage to Orbit Technology Demonstration Concept Review Technical Briefing," 12 December 1990, file 264, X-33 Archive; Rockwell International, "SDIO Single Stage to Orbit Concept Review," 12 December 1990, file 259, X-33 Archive.

36. "NASA Evaluation of SDIO Phase I SSTO Concepts," n.d., file 294, X-33 Archive.

37. Sponable interview.

minum liquid-oxygen and -hydrogen tanks was not an aerospace firm, but Chicago Bridge and Iron (CBI) of Birmingham, Alabama.[38] More importantly, McDonnell Douglas sought to achieve SSTO Program operational goals. The Flight Operations Control Center at the White Sands Missile Range, New Mexico, consisted of a compact, low-cost, 40-foot (12-meter) mobile trailer. Three people operated the ground support equipment and launched the DC-X, not the hundreds typically used for NASA or military rocket launches. Former astronaut Pete Conrad was the "flight manager." McDonnell Douglas designed the DC-X so that they could fly it again after only three days. Eventually, on 8 June 1996, the Clipper team demonstrated a one-day (26-hour) turnaround.[39]

By the time the DC-X undertook its first flight on 18 August 1993, the world had changed dramatically. The Cold War was over, and defense cuts were the order of the day. As DC-X flight trials took place, the future of funding for those flights, as well as for completion of the program, grew less certain. Money for Phase III disappeared, and various bureaucratic maneuvers stymied White House and congressional approval of financing. The predicament grounded the Clipper after only three flights, until the NASA Administrator intervened financially in January 1994.[40]

NASA's "X" Vehicles

By January 1994, NASA Administrator Daniel S. Goldin had become interested in single stage to orbit and other kinds of reusable launchers. His interest did not arise from any internal NASA studies, such as those conducted by the Langley Research Center as early as the 1970s, nor from the influence of high-level individuals at NASA Headquarters, such as Ivan Bekey, Director

38. Paul L. Klevatt interview, tape recording and transcript, Tustin, CA, by Butrica, 14 July 2000, NASA Historical Reference Collection, Washington, DC; William Gaubatz interview, tape recording and transcript, Huntington Beach, CA, by Butrica, 25 October 1997, NASA Historical Reference Collection, Washington, DC; Klevatt, "Design Engineering and Rapid Prototyping for the DC-X Single Stage Rocket Technology Vehicle," AIAA-95-1425 (paper read at AIAA-ASME-ASCE-AHS-ASC Structures, Structural Dynamics, and Materials Conference, New Orleans, LA, 10–12 April 1995).

39. Klevatt interview; McDonnell Douglas Space Systems Company, "Single Stage to Orbit Program Phase I Concept Definition," 13 December 1990, file 267, X-33 Archive; Charles "Pete" Conrad interview, tape recording and transcript, Rocket Development Company, Los Alamitos, CA, by Butrica, 22 October 1997, NASA Historical Reference Collection, Washington, DC; Luis Zea, "The Quicker Clipper," *Final Frontier* (October 1992): 4, file 267, X-33 Archive; Mark A. Gottschalk, "Delta Clipper: Taxi to the Heavens," *Design News* (September 1992), file 292, X-33 Archive; Leonard David, "Unorthodox New DC-X Rocket Ready for First Tests," *Space News* (11–17 January 1993): 10.

40. George E. Brown, Jr., to Les Aspin, 31 January 1994, file 293, X-33 Archive; Ben Iannotta, "DC-X Hangs by Thin Thread Despite Short-term Reprieve," *Space News* (7–13 February 1994): 4; Iannotta, "Pentagon Frees Funds for More DC-X Flights," *Space News* (9–15 May 1994): 4; Warren E. Leary, "Rocket: Program Faces Budget Ax," *New York Times* (31 January 1994): 13A.

of Advanced Programs in the Office of Space Flight, although Bekey was to play a role.[41] Rather, the Administrator was reacting to a September 1992 mandate from Congress to assess national space launch requirements, particularly in light of declining federal budgets.[42]

The NASA *Access to Space Study* considered NASA, military, and commercial launch needs for the period between 1995 and 2030. It examined three different launcher alternatives ("options")[43] and strongly concluded in favor of pursuing the development of a single stage to orbit replacement for the Space Shuttle, especially because it appeared to be the best approach to reducing overall launch costs.[44] Indeed, the single stage to orbit zeal of the *Access to Space* team was so strong that they proposed a NASA technology development program using an "X" vehicle—the X-2000 (for the program's final year of operation)—to be built entirely by NASA with joint funding from the Pentagon. The X-2000, not by chance, closely resembled the Phase III vehicle of the Delta Clipper program.[45]

NASA, however, was not going to build the X-2000. In April 1994, the White House released a draft National Space Transportation Strategy that made NASA "the lead agency for technology development and demonstration for advanced next generation reusable launch systems."[46] It also decreed, in section III, paragraph 2(b): "Research shall be focused on technologies to support a decision, no later than December 1996, to proceed with a subscale flight demonstration which would prove the concept of single-stage to orbit."[47] In this way, the new space transportation policy committed NASA to the development of reusable and single stage to orbit space launch vehicles.

Because that policy designated NASA as the lead agency for reusable launchers and the Department of Defense as the lead agency for expendable

41. Ivan Bekey interview, tape recording and transcript, NASA Headquarters, Washington, DC, by Butrica, 2 March 1999, NASA Historical Reference Collection, Washington, DC.

42. U.S. House of Representatives, *Conference Report*, 102nd Cong., 2nd sess., Report 102-902 (Washington, DC: GPO, 1992), pp. 69–70.

43. Arnold D. Aldrich and Michael D. Griffin to Daniel S. Goldin, "Implementation Plan for 'Access to Space' Review," 11 January 1993, file 197, X-33 Archive; Office of Space Systems Development, NASA, "Access to Space Study: Summary Report," January 1994, pp. 2–5, 8–58, file 100, X-33 Archive; Access to Space Study Advanced Technology Team, "Final Report," vol. 1, "Executive Summary," July 1993, pp. iii, 38, file 85, X-33 Archive. According to Bekey in the aforementioned interview, the study initially was to compare Space Shuttle upgrades and a new expendable, or partially reusable, launcher. These alternatives ultimately became Option 1 and Option 2.

44. Bekey interview.

45. Ben Iannotta, "Winged X-2000 Project Considered," *Space News* (15–28 November 1993): 14; "Single Stage to Orbit Advanced Technology Demonstrator (X-2000)," briefing, August 1993, file 122, X-33 Archive; "Single Stage to Orbit: Advanced Technology Demonstrator: SSTO Concept Proposal, X-2000," August 1993, file 162, X-33 Archive.

46. Draft, National Space Transportation Strategy, April 26, 1994, file 153, X-33 Archive.

47. Cited in NASA news release 95-1, 12 January 1995.

systems,[48] the DC-X was transferred to NASA, where it formed the initial component of the Agency's Reusable Launch Vehicle (RLV) Program. While NASA's DC-XA (where "A" stood for Advanced) tested certain key operational concepts, such as a critical rotational maneuver and a 72-hour turnaround time, the vehicle also was a technology demonstrator.[49]

In addition to the DC-XA, NASA's new RLV Program consisted of two additional "X" vehicles. One, the X-34, also known as the Reusable Small Booster Program, would demonstrate certain technologies and operations useful to smaller reusable vehicles launched from aircraft. Among those were autonomous ascent, reentry, and landing; composite structures; reusable liquid-oxygen tanks; rapid vehicle turnaround; and thermal-protection materials.[50] The other was the X-33, known also as the Advanced Technology Demonstrator Program, which proved far more challenging technologically. Among the operations and technologies it would demonstrate were reusable composite cryogenic tanks, graphite composite primary structures, metallic thermal-protection materials, reusable propulsion systems, autonomous flight control, and certain operating systems, such as electronics for monitoring vehicle hardware.[51]

The X-33 program experienced insurmountable difficulties. After seeming to overcome weight and control problems, the X-33 project encountered one delay after another because of complications and obstacles encountered in the design and construction of the linear aerospike engines and the construction and testing of the composite liquid-hydrogen tanks. The vehicle's launch was postponed from the original March 1999 date to sometime in 2003. However, with program expenditures totaling over $1.4 billion, construction of the vehicle halted and the components were divided up among NASA and the contractors.[52]

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48. Department of Defense, "Space Launch Modernization Plan: Executive Summary," April 1994, p. 29; Iannotta, "Congress, NASA Dueling Over Reusable Rocket Management," *Space News* (23–29 May 1994): 25.

49. After the death of General Graham, the DC-XA took on the name Clipper Graham. The DC-XA differed from the DC-X in six main areas: 1) a switch from an aluminum oxygen tank to a Russian-built aluminum-lithium alloy cryogenic oxygen tank with external insulation, 2) an exchange of the aluminum cryogenic hydrogen tank for a graphite-epoxy composite liquid-hydrogen tank with a low-density reinforced internal insulation, 3) a graphite-epoxy composite intertank structure, 4) a graphite-epoxy composite feedline and valve assembly, 5) a gaseous-hydrogen and -oxygen auxiliary power unit to drive the hydraulic systems, and 6) an auxiliary propulsion system for converting liquid hydrogen into gaseous hydrogen for use by the vehicle's reaction control system. See Delma C. Freeman, Jr., Theodore A. Talay, and R. Eugene Austin, "Reusable Launch Vehicle Technology Program," IAF 96-V.4.01 (paper read at the 47th International Astronautical Congress, Beijing, China, 7–11 October 1996), p. 3, file 92, X-33 Archive.

50. John W. Cole, "X-34 Program," in "X-33/X-34 Industry Briefing, October 19, 1994," file 12, X-33 Archive, especially slide 1A-1216.

51. X-33 announcement in *Commerce Business Daily* (29 September 1994), file 276, X-33 Archive.

52. Several other serious troubles emerged along the way, but I have mentioned only the best known of the numerous X-33 problems. See NASA news release 00-157, 29 September 2000;

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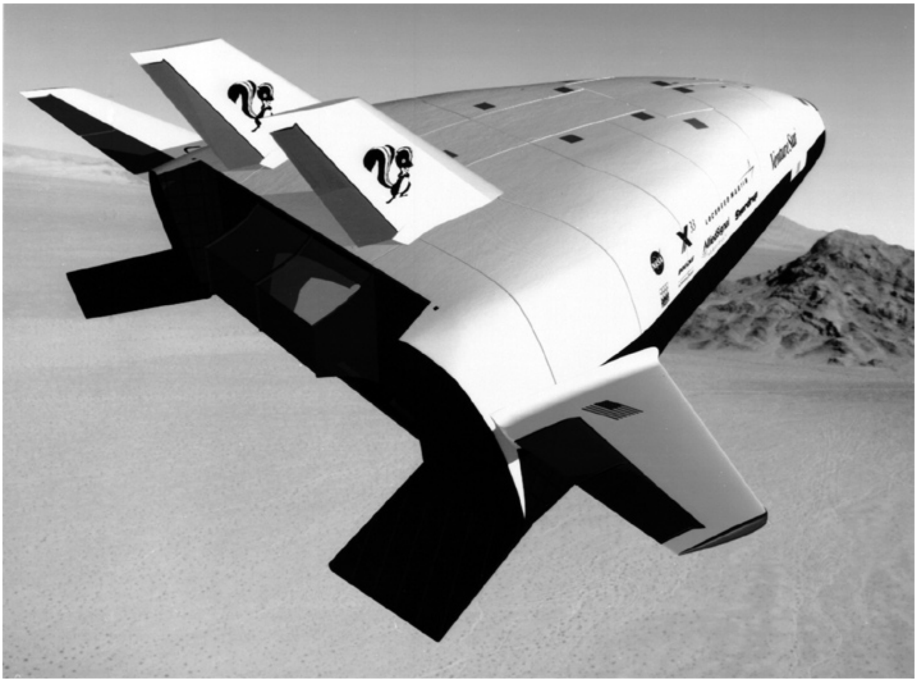

This artist's concept shows the X-33 Advanced Technology Demonstrator, a subscale prototype reusable launch vehicle (RLV), in its 1997 configuration. Named the VentureStar™, this vehicle was to have been manufactured by Lockheed Martin's "skunk works." The VentureStar™ was one of the earliest versions of the RLVs developed in an attempt to replace the aging Shuttle fleet. The X-33 program was discontinued in 2001 without flight. *(NASA MSFC image no. MSFC-9711197)*

Shortly after the start of the RLV Program, NASA also initiated the Pathfinder and Trailblazer programs to develop low-cost reusable space transport. Pathfinder involved technology experiments conducted on existing flight vehicles, such as the Space Shuttle. Trailblazer, on the other hand, entailed the construction of entirely new "X" vehicles to demonstrate advanced space transport technologies and operations. In August 1998, NASA solicited proposals for Future-X, the first of the Trailblazer vehicles,[53] and, in December, announced that it had entered into negotiations with

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"Development Troubles Push First X-33 Flight Back to July '99," article 34208 in *Aerospace Daily* (24 June 1997, electronic edition), hard copy in file 225, X-33 Archive; Brian Berger, "Activists Say Lockheed Should Not Compete for X-33 Funds," *Space News* 11 (16 October 2000): 21.

53. NASA news release 98-141, 3 August 1998.

Boeing to design and build the Advanced Technology Vehicle (ATV), the first "X" vehicle to fly in orbit and to reenter the atmosphere.[54]

The Advanced Technology Vehicle soon became the X-37. The Shuttle would carry the craft into space, then release it. The X-37 would orbit the planet, then return to Earth through the atmosphere, testing heat shielding and other advanced space materials and technologies. The vehicle's shape derived from that of the X-40A, an unpowered Air Force craft designed and built by Boeing's Phantom Works. In August 1998, the Air Force drop-tested the X-40A from an Army Black Hawk helicopter above Holloman Air Base, New Mexico, and the vehicle landed under remote control on a runway. The Air Force provided partial funding for the X-37 in the hope of realizing some of the objectives of its Space Maneuver Vehicle (SMV), a reusable winged craft capable of deploying satellites, weapons, and antisatellite devices; inspecting enemy satellites; and other military missions. The Space Maneuver Vehicle could have remained in orbit for up to a year and would have been capable of a 72-hour turnaround.[55]

No discussion of NASA's reusable "X" vehicles would be complete without at least a mention of the defunct Crew Recovery Vehicle (CRV), which would have served as a lifeboat for the International Space Station (ISS). Drop tests of the X-38, an experimental 80-percent scale version of the vehicle, at increasing altitudes from a B-52 began in 1999. The basic design for the X-38 and CRV originated at NASA's Langley Research Center as the HL-10 (Horizontal Lander) lifting body. The initial HL-10 design derived from photographs of the BOR-4 (Unpiloted Orbital Rocketplane in Russian), a Russian reusable rocket, that had landed in the Indian Ocean. Renamed the HL-20 by NASA Headquarters, the vehicle concept subsequently became popular in NASA launcher studies.[56]

54. NASA news release c98-w, 8 December 1998.

55. NASA news release 99-139, 14 July 1999; Frank Sietzen, Jr., "Air Force's Needs Shape Newest NASA X Rocket," *Space.com*, 25 August 1999, *http://www.space.com/businesstechnology/business/x37_briefing.html*, hard copy in file 386, X-33 Archive; "Space Maneuver Vehicle Drop Test Planned for Early August," article 110718 in *Aerospace Daily* (21 July 1998, electronic edition), hard copy in file 226, X-33 Archive; "USAF Sets Aug. 4 Test of Space Maneuver Vehicle," article 111407 in *Aerospace Daily* (30 July 1998, electronic edition), hard copy in file 226, X-33 Archive; "Competition Likely for Space Maneuver Vehicle Demonstrator," article 111904 in *Aerospace Daily* (6 August 1998, electronic edition), hard copy in file 226, X-33 Archive.

56. Theodore A. Talay interview, tape recording and transcript, NASA Langley Research Center, by Butrica, 21 May 1997, NASA Historical Reference Collection, Washington, DC; Doug Stanley interview, tape recording and transcript, Orbital Sciences Corporation, Dulles, VA, by Butrica, 25 February 1999, NASA Historical Reference Collection, Washington, DC; "NASA's X-38 Station Lifeboat Testbed Completes a Drop Test," article 124222 in *Aerospace Daily* (9 February 1999, electronic edition), hard copy in file 386, X-33 Archive; Andrew Bridges, "Space Station Lifeboat Sails to Success in Desert Test," *SpaceViews* (2 November 2000), hard copy available in file 854, X-33 Archive.

Commercial Launchers

NASA and the Air Force were not the only developers of reusable launchers during the 1990s. As the global market for satellite launches grew throughout the decade, small startup companies entered the field with plans for a variety of two-stage reusable vehicles. Among those was Kelly Space & Technology, initially headed by Michael S. Kelly. Starting in 1993, with funding from NASA and the Air Force, the firm began developing the Astroliner, a reusable glider towed to launch altitude by a Boeing 747 aircraft using patented Eclipse towing technology. An expendable stage launched from the Astroliner would place payloads in orbit. Subsequently, Kelly received NASA funding to develop its reusable launcher.[57]

A comparable two-stage system that combined a reusable first stage with a throwaway second stage was Pioneer Rocketplane's Pathfinder. The two-seat Pathfinder aircraft powered by air-breathing and (RD-120) rocket engines would have taken off from Vandenberg AFB, taken on additional liquid oxygen in midair from a Boeing 747 freighter, then climbed outside the atmosphere, where it would release an upper stage and its payload, then reenter the atmosphere and land like an aircraft.[58] Pursuing development of a different two-stage launch system known as the K-1 is the Kistler Aerospace Corporation. The K-1 was an unpiloted vehicle powered by surplus Russian NK-33 and NK-43 engines. It would launch vertically and be capable of a turnaround of nine days. A system of parachutes and air bags (field-tested in 1998) would allow the company to recover and reuse both the booster and orbital stages.[59]

The only single stage to orbit vehicle under commercial development—Rotary Rocket Company's Roton—also was the only one that did

57. Kelly news releases for 7 October 1996, 22 May 1997, and 2 February 1998, file 373, X-33 Archive.

58. "RLV Startups Have Enough Capital, But Worry About Regulation," article 37503 in *Aerospace Daily* (13 February 1998, electronic edition), hard copy in file 226, X-33 Archive; "Rocketplane System," *Pioneer Rocketplane* Web site, *http://www.rocketplane.com*.

59. "RLV Startups Have Enough Capital"; "Kistler May Shift Flight Tests to Australia," article 37615 in *Aerospace Daily* (23 February 1998, electronic edition), hard copy in file 226, X-33 Archive; "Developments in the Field of Space Business are Briefly Noted," article 109711 in *Aerospace Daily* (7 July 1998, electronic edition) and article 111101 (27 July 1998), hard copies in file 226, X-33 Archive; Frank Morring, Jr., "Tight Money Forces Slowdown at Kistler Aerospace," article 122111 in *Aerospace Daily* (8 January 1999, electronic edition), hard copy in file 386, X-33 Archive; "Northrop Grumman Increases Stake in Kistler's K-1 Vehicle," article 127002 in *Aerospace Daily* (22 March 1999, electronic edition), hard copy in file 386, X-33 Archive; "Kistler Has a Line on Remaining Financing, But Much Rests on Contingent Funds," article 132104 in *Aerospace Daily* (2 June 1999, electronic edition), hard copy in file 386, X-33 Archive; "NASA Taps Kistler to Evaluate ISS Access Options," article 163106 in *Aerospace Daily* (28 August 2000, electronic edition), hard copy in file 854, X-33 Archive; additional materials in file 179, X-33 Archive.

not receive NASA funding. The firm's founder, Gary Hudson, with funding from the private sector, has pursued single stage to orbit concepts since the 1980s. A staunch believer in private enterprise, Hudson received substantial backing for the Roton from author Tom Clancy, along with other investors. Like the Delta Clipper, the Roton would take off and land vertically but would use rocket-powered rotors for the final descent and touchdown, much like a helicopter.[60]

Analysis of a Perennial Debate

The quest for reusability certainly has had its losses, mistakes (NASP), overly ambitious projects (X-33), and seemingly fruitful routes taken but abandoned (Dyna-Soar, RASV). Success has been partial for three major reasons: 1) the major technological challenges of achieving full reusability and "aircraft-like" operations; 2) the lack of an ongoing technology development program; and 3) the toll on the search for a new launch system taken by past space policy and political decisions. Current policy does not redress these issues, but rather appears to exacerbate, not assuage, them.

POLICY

The Era of Space Transportation

Space transportation policy obviously did not begin to include reusable launch vehicles until reusable launchers were about to become a reality. The evolution of launchers as a means for transporting people was gradual, beginning with the recoverable, but not reusable, craft used for the Mercury and Gemini missions.[61] Similarly, the means for transporting astronauts to the Moon were the recoverable, single-use Apollo spacecraft. These vehicles differed from ordinary transportation in that they could not be used more than once. Aircraft, for instance, can fly over and over again, and that reusability is an essential characteristic of any form of transportation. We therefore can think of the advent of the Space Shuttle as ushering in a new era or phase of space history, as well as a new period of space policy that would address issues related to space transportation.

In this new era, everything—whether reusable or expendable—that carried a payload conceptually was transportation. The Shuttle held a privileged

60. Materials relating to Gary Hudson and the Roton rocket are in file 348, X-33 Archive.

61. Starting in 1959, the Air Force's ASSET (Aerothermodynamic/elastic Structural Systems Environmental Tests) boost-glide system involved lofting small, reusable hypersonic gliders from Cape Canaveral on top of expendable rockets. The gliders were recovered, and though they potentially were reusable, none ever flew more than once. See Hallion, "ASSET: Pioneer of Lifting Reentry," in *The Hypersonic Revolution*, ed. Hallion, vol. 1, pp. 449–450, 510, 512–513, 515–516, 518, 523–524.

place in the constellation of space transporters. It was not only the only reusable launch vehicle, but also *the* Space Transportation System (STS). Despite the de facto mix of expendable and reusable launchers, government policy leaned toward domination by the reusable Space Shuttle. Driving this policy were claims and assurances—made as early as the 1960s[62]—that the Shuttle would be a low-cost, reliable launcher (a space "bus" or space "truck"). In addition, NASA aggressively marketed the Space Shuttle as a vehicle that could place any satellite into orbit.[63] Ironically, the Shuttle would not only inspire and empower space policy, it would impede it as well.

President Ronald Reagan made this "one-size-fits-all" strategy national policy through National Security Decision Directive 8, "Space Transportation System," dated 13 November 1981. It stated, succinctly, that "the STS will be the primary space launch system for both United States military and civil government missions." Moreover, its language, that the Shuttle would "service all authorized space users," left the door open for a subsequent enlargement of this basic space policy.

The issuance of National Security Decision Directive 42, "National Space Policy," on 4 July 1982, reiterated the "one-size-fits-all" policy and, more importantly, defined the "authorized space users" of the Space Shuttle as "domestic and foreign, commercial, and governmental."[64] In effect, the new space policy called for making the Shuttle available to all commercial users, provided no conflicts with national security resulted. The directive marked a dramatic policy shift, indeed, a redefinition of space policy, not seen since the launch of Sputnik in 1957, because for the first time in the history of the U.S. space program, a high-level official document made a direct reference to the American business community.[65] Between November 1982 and January 1986, the Space Shuttle carried 24 communication satellites into orbit on 11 flights. Five were for private corporations: Westar 6, two Telstars, and two SATCOMs. Others were for foreign clients, including Canada (four Aniks),

62. *The Post-Apollo Space Program: A Report for the Space Task Group* (Washington, DC: NASA, September 1969), pp. 1, 6.

63. Hans Mark, *The Space Station: A Personal Journey* (Durham: Duke University Press, 1987), pp. 61–65; Heppenheimer, *Space Shuttle Decision*, pp. 275–280; David M. Harland, *The Space Shuttle: Roles, Missions and Accomplishments* (Chichester, U.K.: Praxis Publishing, Ltd., 1998), pp. 411–412.

64. Christopher Simpson, *National Security Directives of the Reagan and Bush Administrations: The Declassified History of U.S. Political and Military Policy, 1981–1991* (Boulder, CO: Westview Press, 1995), pp. 136–143 (classified version) and pp. 144–150 (unclassified version); "National Space Policy," 4 July 1982, file 386, X-33 Archive. An NSDD 42 innovation of at least equal significance was the establishment of the National Security Council Senior Interagency Group (Space), usually referred to as simply SIG (Space), as the primary forum for the formulation of space policy. Chaired by the Assistant to the President for National Security Affairs, SIG (Space) was the locus of policymaking throughout the two terms of Ronald Reagan's presidency.

65. W. D. Kay, "Space Policy Redefined (Again)," chap. 7 in *Defining NASA: The Historical Debate over the Agency's Mission* (Albany: State University of New York Press, 2005).

Australia (two AUSSATs), Indonesia (two Palapas), India (INSAT), and Saudi Arabia (ARABSAT).[66]

The 1972 decision by President Richard Nixon to build the Space Shuttle short-circuited debate on the desirability of investing in new expendable launch vehicles and facilities and froze them in 1970s technologies. NASA no longer ordered Delta or Atlas launches, and the Air Force began shutting down production lines for the Titan.[67] Expendable launch systems began to age and became increasingly expensive to build and operate (which added to the cost of military and NASA space programs) because needed improvements in launch technology had been set back some two decades. The Shuttle already was expensive to operate and soon would show its grounding in yesterday's technology. Space transportation came to be perceived as consuming too large a share of the federal budget, thereby shutting out opportunities for new science and technology initiatives. Eventually, the government would have to spend over $12 billion to restore abandoned ELV operations and to transfer satellites designed for the Shuttle back to these aging launchers.[68]

A Mixed Fleet

National space transportation policy, however, soon crashed on the rocks of reality—and on the launchpad. Following a launch failure of a Titan 34D on 28 August 1985, the Air Force temporarily suspended Titan launches until after an investigation.[69] Five months later, the *Challenger* accident, on 28 January 1986, grounded the STS for two years, a watershed moment for the U.S. space program, for NASA, for the Department of Defense, and for space commerce. What made the accident so damaging, aside from the loss of human life, was the policy that placed NASA, military, and commercial payloads aboard the Shuttle. The dependence on the Space Shuttle as the nation's "primary" launch system impaired the ability of the nation's defense and intelligence agencies to place payloads into orbit, and it stymied the development of a commercial launch industry which had been struggling against both the Shuttle and its European ELV competitor, Ariane.

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66. Dennis R. Jenkins, *Space Shuttle: The History of Developing the National Space Transportation System* (Marceline, MO: Walsworth Publishing Co., 1992), pp. 286–287.

67. For a discussion of the process leading up to Nixon's decision, see Heppenheimer, *Space Shuttle Decision*; Dorsey Oles Boyle, "The Nixon Space Policy, 1969–1974" (M.A. thesis, University of Maryland at Baltimore County, 1993).

68. National Space Council, "Final Report to the President on the U.S. Space Program," January 1993, pp. 5, 33, file 017, box 1, X-33 Archive; John M. Logsdon and Craig Reed, "Commercializing Space Transportation," in *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program*, ed. John M. Logsdon, vol. 4, *Accessing Space* (Washington, DC: NASA SP-4407, 1999), pp. 408–409.

69. William Boyer, "Titan IV Explosion Halts Launch Program," *Air Force Times* 54 (16 August 1993): 33.

Shortly after the *Challenger* tragedy, additional expendable launcher failures took place. A more disastrous Titan 34D launch accident on 18 April 1986 effectively grounded military space operations on both coasts until the military and industry could ensure the Titan's reliability. The rocket exploded only 8 seconds after lifting off. Upper sections of its solid rockets and fuel showered the launchpad, causing severe damage to nearby launch facilities. In some instances, large steel fragments were blown 3,000 feet from the explosion, which also created a toxic cloud that rose to an altitude of 8,000 feet before being blown over the Pacific Ocean. The following month, on 3 May 1986, a Delta carrying the $57-million GOES-G weather satellite broke up about 90 seconds after liftoff from Cape Canaveral, Florida. The root cause of the failure (a lightning strike) needed to be determined before more Deltas could fly.

The lessons learned (or that ought to have been learned) from these various launch accidents were that NASA needed to reduce its dependence on the Space Shuttle and that the nation needed a variety of launchers, both reusable and expendable, as well as a variety of disposable rockets. Collectively, these incidents brought home the dangers of relying on one or two launch systems. Subsequently, National Security Decision Directive 254, "United States Space Launch Strategy," 27 December 1986, took NASA and the Space Shuttle out of competition with potential commercial launch providers. Specifically, the directive stipulated that "NASA shall no longer provide launch services for commercial and foreign payloads subject to exceptions for payloads that: (1) are Shuttle-unique; or (2) have national security or foreign policy implications." By "Shuttle-unique," the directive meant payloads requiring either human intervention or facilities available only on the Space Shuttle.[70]

President Reagan approved a revised national space policy on 5 January 1988. It too overthrew the long-standing notion of the Shuttle as the nation's "primary" launch system and established the de facto mixed fleet of launchers as policy.[71] Essentially, NASA henceforth would use the (partially) reusable Space Shuttle, and the Department of Defense would rely on expendable

70. James A. Baker III to Economic Policy Council, "Presidential Policy Directive—Space Commercialization," 6 October 1986, file 387, X-33 Archive; "Presidential Directive on National Space Policy," fact sheet, 11 February 1988, p. 9, file 386, X-33 Archive.

71. The classified space policy was not released until 11 February 1988, following completion of a parallel review of commercial space policy being conducted by the Economic Policy Council. See NSDD 293, "Presidential Directive on National Space Policy," 5 January 1988; "Presidential Directive on National Space Policy," fact sheet, 11 February 1988, pp. 7, 9–10, file 386, box 15, X-33 Archive. The essential parts of the 1988 national space policy that attempted to foster a domestic launch industry made their way into legislation as the Commercial Space Launch Act Amendments of 1988 (Public Law No. 100-657). See Kim G. Yelton, "Evolution, Organization, and Implementation of the Commercial Space Launch Act and Amendments of 1988," *Harvard Journal of Law & Technology* 4 (1989): 34.

launchers.[72] This institutional division between expendable and reusable launchers based on whether or not the launcher carried humans remained in effect over the following years, buttressed by intervening space policy declarations, despite partisan and ideological changes in White House leadership. The policy was based not on any study of expendable versus reusable launch vehicles, but on the exigencies of national security and the promotion of (space) business, not to mention the underlying assumption (and fact) that the only "human-rated" launcher was the partially reusable Space Shuttle.

A New World (Dis)Order?

The period of George H. W. Bush's presidency, 1989–1993, was marked more by change than by continuity with the past. The biggest change—the winding down of the decades-long Cold War—had many consequences for space transportation, especially for the use of reusable and expendable launchers, as well as for the federal budget, the economy, and strategic planning. For starters, the budget reality that emerged at the end of the Cold War meant that fewer government dollars were available for space transportation. The government would have to find cheaper ways to launch payloads. The pressure to reduce launch costs was reflected in the December 1992 study "A Post Cold War Assessment of U.S. Space Policy." It called for the scaling back of all NASA, Defense Department, and Department of Energy space facilities, whether operated by the government or a contractor; the elimination of all duplication within governmental agencies with space programs; and the formation of a nonpartisan commission modeled after the Base Closure Commission to suggest consolidation measures.[73]

The end of the Cold War also raised new questions about the usefulness of President Reagan's quixotic Strategic Defense Initiative, which had its own launcher needs. Additionally, with the Soviet Union no longer a military foe, to what extent was it now feasible (or legal) for the United States government and launch industry to acquire Russian technology, such as rocket engines, or even Russian launchers? By the end of George H. W. Bush's presidency, space policy also began to accommodate new space launch trade agreements with Russia as well as China.[74]

72. There have been exceptions. Typically, Defense Support Program (DSP) satellites are launched into geosynchronous orbit by a combination of a Titan IV booster and an Inertial Upper Stage. However, one DSP satellite was launched using the Space Shuttle on mission STS-44 (24 November 1991). Also, policy excluded NASA specifically from maintaining its own expendable launchers. If the Agency wanted to launch on an ELV, it would have to turn to the Pentagon or industry.

73. Vice President's Space Policy Advisory Board, "A Post Cold War Assessment of U.S. Space Policy," December 1992, pp. 39–43, file 016, box 1, X-33 Archive.

74. See National Space Policy Directive 2, "Commercial Space Launch Policy," 5 September 1990, in National Space Council, "Final Report to the President on the U.S. Space Program."

Similarly, a surfeit of now-useless missiles and hardened silos became available for nonmilitary uses. Could those Minuteman II ICBMs be used to conduct scientific research, as the United States had done with V-2 rockets brought back from Germany after World War II?[75] That is exactly what the Universities Space Research Association wanted to do with the surplus missiles. Specifically, the association proposed conducting a pilot program to demonstrate low-cost, short-duration, small scientific satellite missions in support of university research and technology development. The initial problem was getting the missiles transferred from the military to NASA.[76]

Into this mix of questions and problems President Bush threw a new space program that would require the development of its own launch system. The Space Exploration Initiative (SEI) was a grandiose plan to return to the Moon, set up a lunar base, and send astronauts to Mars by 2019. Like space station *Freedom*, it would require development of a heavy-lift expendable rocket.[77] As a result, both NASA and the Defense Department were in the market for an expendable launcher, but the Senate Commerce Committee essentially zeroed out its funding before the program even began.[78]

In addition to supporting the development of medium- and heavy-lift ELVs by and for both NASA and the Defense Department, the Bush administration funded two programs to create innovative reusable launch vehicles: the National Aero-Space Plane and the SDIO's Single Stage to Orbit Program (DC-X). Both were the most technologically challenging kind of reusable transport to build: single stage to orbit launchers. Technological change generally occurs incrementally, not in giant leaps, and an operational single stage to orbit vehicle is too much of a leap. To date, no single stage to orbit craft has taken off or landed on this planet. These launchers likely will remain in the domain of science fiction and fantasy for a long time into the future, like the *Star Trek* transporter or the Stargate.

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75. See David H. DeVorkin, *Science with a Vengeance: How the Military Created the U.S. Space Sciences after World War II* (New York: Springer, 1992); William R. Corliss, *NASA Sounding Rockets, 1958–1968: A Historical Summary* (Washington, DC: NASA SP-4401, 1971).

76. Materials in file 130, box 5, X-33 Archive, relate to the use of excess DOD ballistic missiles by the Universities Space Research Association.

77. Synthesis Group on America's Space Exploration Initiative, "America at the Threshold: America's Space Exploration Initiative," n.d., p. 31, file 104, box 4, X-33 Archive; William Piland, "Space Transportation in the Future: Practical Considerations," presentation to Access to Space Red Team, 4 June 1992, file 430, box 16, X-33 Archive. Piland pointed out that SEI could be accomplished with existing ELVs and the Russian Energia launcher. National Space Policy Directive 6, Space Exploration Initiative Strategy, dated 13 March 1992, dealt with Bush's SEI. A copy is in National Space Council, "Final Report to the President on the U.S. Space Program," appendix III, "National Space Policy Directives."

78. Lyn Ragsdale, "Politics Not Science: The U.S. Space Program in the Reagan and Bush Years," in *Spaceflight and the Myth of Presidential Leadership*, ed. Launius and Howard E. McCurdy (Urbana: University of Illinois Press, 1997), pp. 161, 163–164.

The Vision Thing

The undertaking of these single stage to orbit, as well as expendable launch vehicle, programs required for the Strategic Defense Initiative, the Space Exploration Initiative, and Space Station *Freedom* shaped space transportation policy during George Bush's presidency. In addition, the search for a Space Shuttle replacement continued, and the nation's aging launchers and launch facilities—the heritage of the "one-size-fits-all" Shuttle policy—demanded attention.[79] The basis for the institutional division that made NASA responsible for reusable launchers and the Defense Department responsible for single-use rockets continued to be the implicit assignment of the role of human spaceflight to NASA and its Space Shuttle.[80] In the future, however, those roles might change, as reusable launchers began to supply the nation's launch needs.

Bush's National Space Launch Strategy, released 24 July 1991, laid the groundwork for that change to take place. The strategy charged the Defense Department and NASA with joint development, funding, and management of a new suite of expendable rockets capable of lifting medium and heavy payloads for both civil and military use and set the first flight of the new system for 1999. Reflecting the stringent budgetary environment and the new direction of space commercialization, the space launch strategy called for the two agencies to explore potential participation by the private sector.[81] The 10-year space launch technology plan mandated by the space launch strategy, issued in October 1991 by NASA and the Departments of Defense and Energy, painted a picture of what the nation's fleet of launchers would look like a decade later, as well as the technologies needed to get there.

By then, the United States would have a new family of expendable launchers, known as the National Launch System (NLS), including a heavy-lift rocket for the Space Exploration Initiative. Reusable launchers continued to be the technological system of choice for human spaceflight, although the expendable launchers under development would have the capability and high reliability required to boost a crew into orbit as part of a Space Shuttle–replacement launch system. Starting in 2005, Reusable Aerospace Vehicles, in the language

79. See, for example, National Research Council, *From Earth to Orbit: An Assessment of Transportation Options* (Washington: National Academy Press, 1992), p. 3, copy available in file 102, box 4, X-33 Archive.

80. "National Space Policy," 2 November 1989, file 374, box 15, X-33 Archive; White House, Office of the Press Secretary, "U.S. National Space Policy," fact sheet, 16 November 1989, file 374, box 15, X-33 Archive; National Space Policy Directive 3, "U.S. Commercial Space Policy Guidelines," issued 12 February 1991 in National Space Council, "Final Report to the President on the U.S. Space Program," appendix III, "National Space Policy Directives."

81. Interagency Working Group on Space Transportation, "Current National Space Policy on Space Transportation," p. 2; National Space Policy Directive 4, "National Space Launch Strategy," in National Space Council, "Final Report to the President on the U.S. Space Program," appendix III, "National Space Policy Directives," pp. III-27–III-28.

of the plan, would complement and later replace the Shuttle. The plan included a reusable military launcher known as the Military Aerospace Vehicle, which also would be operable around 2005, just in time to replace the Space Shuttle. Initially, a robotic version of the craft could be launched to address commercial launch needs, and a later version could be equipped to carry a crew. By merging NASA, military, and commercial launch needs, the 10-year plan envisioned the possibility of a low-cost-per-flight reusable vehicle that would satisfy all of the nation's launcher needs.[82] In effect, the plan for implementing Bush's launcher strategy would have committed the same mistake as his predecessor's space policy, which put all of its launch eggs in a single, reusable basket.

The NASA *Access to Space Study*

The election of William Jefferson Clinton as President in November 1992 opened the door to a significant change in launcher policy. The new Democratic administration would want to shape space policy to suit its own agendas, which were certain to be different from those of its Republican predecessors. Three studies formed the basis for the new space transportation policy, and they came to different conclusions about the future of reusable launchers, especially single stage to orbit rockets. The most important of those was NASA's *Access to Space Study*. Mandated by the House Subcommittee on Space of the Committee on Science, Space, and Technology in 1992, *Access to Space* focused on future launch systems, analyzed the launcher needs of NASA, Defense, and industry, and developed various alternatives for addressing those needs for the period 1995 to 2030.[83]

Option 1 involved retaining the Space Shuttle until 2030. The Option 1 team endorsed fresh studies of flyback, fully reusable liquid-fueled Shuttle boosters in order to increase safety and to reduce costs. Option 2 replaced the Shuttle in 2005 with a new expendable launcher using state-of-the-art technology. Option 3 was more daring. It would replace the Space Shuttle in 2030 with "an unspecified . . . next-generation, advanced technology system . . . a 'leapfrog' approach, designed to capitalize on advances made in the NASP and SDI [the DC-X] programs to achieve order-of-magnitude improvements in the cost effectiveness of space transportation."[84]

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82. National Space Council, "Ten-Year Space Launch Technology Plan," October 1992, pp. ES-1, ES-2, 1-1, 2-8, 2-10, 2-11, file 103, box 4, X-33 Archive.

83. Ivan Bekey, "Access to Space," IAF-94-V.1.515 (paper read at the 45th Congress of the International Astronautical Federal, Jerusalem, Israel, 9–14 October 1994), p. 3, copy available in file 098, box 3, X-33 Archive, summarizes the *Access to Space Study* more succinctly than the study's own executive summary.

84. Office of Space Systems Development, NASA Headquarters, "Access to Space Study: Summary Report," January 1994, p. 71, file 100, box 3, X-33 Archive; Arnold D. Aldrich, "NASA's

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The Option 3 team considered three launcher architectures. The first was a rocket-powered SSTO ship. The second was a single stage to orbit craft powered by a combined rocket and air-breathing propulsion system. A combination of rocket and air-breathing engines propelled the third architecture, which was a two stage to orbit launcher. As part of the Option 3 study, the team specifically compared a generic rocket-powered single stage to orbit launcher with the NASP, looking at such factors as cost, risk, and development schedule. They concluded against NASP and all other air-breathing vehicles because their technological difficulty would drive up costs and require a longer period of development. The Option 3 team report concluded that reusable launchers could replace medium-load throwaway rockets, leaving expendable launchers to lift heavy payloads in the short term, and that in time, reusable vehicles would replace even those.[85]

Once each team selected the best vehicle design from the range of alternatives considered, the *Access to Space Study* then compared all of the winning designs. This comparison necessarily included weighing expendable rockets against reusable launchers. The study concluded that the most beneficial option was to develop and deploy a fleet of fully reusable, rocket-powered single stage to orbit vehicles and recommended phasing out current throwaway rockets—as well as the Shuttle—beginning around 2008. The new reusable launch vehicles would be able to accommodate all conceivable NASA, military, and commercial payloads, and—despite their need for a large upfront investment, especially in technological development—they would cut government launch costs by up to 80 percent while increasing vehicle reliability and safety by about an order of magnitude.[86]

After the *Access to Space Study*, several of the NASA officials involved in it began to proselytize their belief in the near-term feasibility of SSTO rockets in various venues, including such popular journals as *Aerospace America*.[87] Furthermore, the Space Frontier Foundation—dedicated to human colonization

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Access to Space Study," 21 November 1993, file 101, box 4, X-33 Archive; Arnold D. Aldrich and Michael D. Griffin to Daniel S. Goldin, "Implementation Plan for 'Access to Space' Review," 11 January 1993, file 197, box 7, X-33 Archive. According to Ivan Bekey in his interview cited earlier, the study initially was to compare Shuttle upgrades and a new expendable, or partially reusable, launcher. These alternatives ultimately became Option 1 and Option 2.

85. Access to Space Advanced Technology Team, "Final Report," vol. 1, "Executive Summary," July 1993, file 85, box 3, X-33 Archive; Office of Space Systems Development, NASA Headquarters, "Access to Space Study: Summary Report," p. 71; "Integration of Existing ELVs into the Option 3 Architecture," in Access to Space Advanced Technology Team, "Final Report," vol. 1, "Executive Summary."

86. An order of magnitude is a tenfold increase. See Aldrich, "NASA's Access to Space Study," pp. 8–12.

87. See, for example, Bekey, "SSTO Rockets: A Practical Possibility," *Aerospace America* 32 (July 1994): 32–37; Robert E. Austin and Stephen A. Cook, "SSTO Rockets: Streamlining Access to Space," *Aerospace America* 32 (November 1994): 34; and Austin, "Studies Show SSTO Plan is Feasible," *Space News* (31 July 31–6 August 1995), among others in file 352, box 14, X-33 Archive.

of space—organized a congressional briefing in the spring of 1996 that they called Cheap Access to Space. The message to Congress was to support single stage to orbit vehicle programs as the only way to get low-cost space launchers, and in particular to fund the DC-X (then a NASA program) and NASA's X-33. With generous funding from NASA Headquarters, the foundation organized the Cheap Access to Space symposium in July of 1997 with the same message.[88]

Defense Department Studies

The NASA *Access to Space* enthusiasm for reusable and single stage to orbit rockets was missing from the two Defense Department studies that contributed to the formulation of Clinton administration space transportation policy. Instead, they proposed to keep launching the existing disposable rockets. Such, for instance, was the conclusion of the so-called "Bottom-Up Review." Completed in 1993, the "Bottom-Up Review" of military launchers, like NASA's *Access to Space*, considered three alternatives. Alternative 1 was to extend the life of current military expendable rockets, while Alternative 2 was to develop a new launch system. Alternative 3 funded the development of advanced reusable launch vehicle technologies and maintained current expendable launchers until the Pentagon could switch to reusable vehicles. Alternative 3 evaluated four reusable launcher concepts chosen for their level of increasing technological complexity, ranging from a flyback first stage to a fully reusable two stage to orbit craft, plus two different single stage to orbit designs, one powered by rockets and the other by a combination of rockets and air-breathing engines. Ultimately, the study team eliminated Alternative 3 but shifted the SSTO rocket to Alternative 2 for consideration. Unlike NASA's *Access to Space*, the "Bottom-Up Review" did not embrace single stage to orbit rockets or reusable launchers in general. Rather, it concluded that the current fleet of expendable boosters was fulfilling the Defense Department's launcher needs and selected Alternative 1.[89]

The other key Defense Department launcher study stemmed from a congressional mandate, like NASA's *Access to Space*. Section 213 of the National Defense Authorization Act for 1994 directed the Defense Secretary to develop a plan for modernizing its launchers and launch facilities, lowering the costs of manufacturing current single-use rockets, and developing a new launch sys-

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88. The presentations from the Cheap Access to Space congressional briefing are in file 360, box 14, X-33 Archive. Notes and other materials from the Cheap Access to Space Symposium held in Washington on 21–22 July 1997, including the $100,000 in underwriting from NASA, are in file 705, box 24, X-33 Archive, and more detailed information on the NASA underwriting is in file 842, box 28, X-33 Archive.

89. Director, Strategic & Space Systems, "Space Launch Systems Bottom-Up Review," 4 May 1993, file 233, box 8, X-33 Archive; "Executive Summary," in *Space Launch Modernization Study*, April 1994, pp. 5–6, file 142, box 5, X-33 Archive.

tem. Issued in April 1994, the *Space Launch Modernization Study*, better known as the Moorman Report after its chairman, Air Force Lieutenant General Thomas S. Moorman, Jr., considered four launcher options.[90]

Option 1 would have maintained the current fleet of ELVs—Delta, Atlas, Titan—and the Space Shuttle while NASA funded a technology program that eventually would lead to the development of a reusable launcher to replace the Shuttle. In Option 2, NASA also funded development of an RLV and continued using the Shuttle, but the current throwaway rockets were upgraded. Option 3 involved developing a new expendable launcher. One version would launch only cargo and eventually would replace current systems, while the other would carry either cargo or passengers, one day replacing both the current expendable rockets and the Space Shuttle. Option 4 involved developing a reusable vehicle in cooperation with NASA, plus setting up a government-mandated launch corporation. The arrangement would bring together public and private financing; government and contractors would share the costs.[91]

Although directed to select the "most attractive" option, the Moorman Report simply presented the four options without stating a preference for any of them.[92] Despite its apparent ambiguity, the report contained a number of suggestions that soon became part of national space policy. For instance, it recommended that NASA—because of its need to continue human spaceflight and to replace the Shuttle—be assigned the lead for developing RLVs, with the Defense Department maintaining a cooperative reusable launcher program that would include experimental flight demonstrations. The X-33 program embodied that suggestion. Meanwhile, the Defense Department would take the lead in developing single-use rockets, and each agency would manage and fund efforts within their area of responsibility. That recommendation became policy. The Moorman Report, however, was not immune to the raging enthusiasm for reusable launch vehicles, especially for the growing commercial launch industry. It proclaimed that once reusable vehicles reduced launch costs by a factor of 10, they would "ignite a commercial space boom."[93] They were not alone in that belief.

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90. "Executive Summary," in *Space Launch Modernization Study*, April 1994, pp. 1–2, 15–23, file 142, box 5, X-33 Archive; Lieutenant General Thomas S. Moorman, Jr., "DoD Space Launch Modernization Plan," briefing to the Commercial Space Transportation Advisory Committee (COMSTAC), 10 May 1994, file 588, box 29, X-33 Archive; Bekey, "Access to Space," p. 14.

91. "Executive Summary," in *Space Launch Modernization Study*, pp. 15–19; Moorman, "DoD Space Launch Modernization Plan"; Bekey, "Access to Space," p. 14.

92. Nonetheless, on the question of developing a new launcher, it recommended that the Defense Department develop a heavy-lift launcher. See "Executive Summary," in *Space Launch Modernization Study*, p. 25.

93. "Executive Summary," in *Space Launch Modernization Study*, p. 29; Moorman, "DoD Space Launch Modernization Plan."

The 1994 Space Transportation Policy

The Moorman Report, the "Bottom-Up Review," and the *Access to Space* studies quickly became the foundation for the preparation of a new space launch policy by the Clinton White House Office of Science and Technology Policy (OSTP), which had absorbed the duties of the National Space Council.[94] Its goal was to piece together a single, coherent space transportation policy[95] that addressed the various launch vehicle needs of NASA, the Pentagon, and industry, while taking into account the changing character of the era following the Cold War. Signed by President Clinton in August 1994, the new space transportation policy addressed the range of ills afflicting the country's launchers and facilities.

It ruled, for instance, on the use of excess Minuteman missiles[96] and gave Russian launch vehicles a larger role by involving that country in the space station program.[97] The policy also proposed the modernization of existing launch systems (both expendable rockets and the Shuttle) and facilities and the development of a new reusable launch vehicle that would reduce "greatly" the cost of putting payloads in orbit. In addition, it extended and expanded the standing policy of fostering the commercialization of space, as well as the international competitiveness of the U.S. commercial launch industry.[98]

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94. The actual work of preparing the policy was carried out by the Interagency Working Group on Space Transportation. Established by the Office of Science and Technology Policy, it consisted of representatives of the various agencies with an interest in space policy: NASA; the Defense Department; the Joint Chiefs of Staff; the National Security Council; the Director of Central Intelligence; the Departments of State, Commerce, Treasury, and Transportation; the Council of Economics Advisors; the Nuclear Energy Commission; the Office of Management and Budget; the Office of the Vice President; and the United States Trade Representative. See Office of Science and Technology Policy, Executive Office of the President, "Interagency Working Group on Space Transportation Representatives," May 1994, file 147, box 5, X-33 Archive.

95. The National Space Transportation Policy replaced National Space Policy Directive (NSPD) 2, NSPD 4, and National Security Directive (NSD) 46, "Cape York," as well as the portions that pertain to space transportation of NSPD 1/NSD 30, "National Space Policy"; NSPD 3, "U.S. Commercial Space Policy Guidelines"; and NSPD 6, "Space Exploration Initiative Strategy." See Interagency Working Group on Space Transportation, "Current National Space Policy on Space Transportation," p. 1; National Space Transportation Policy, draft, 10 May 1994, file 147, box 5, X-33 Archive.

96. Office of Science and Technology Policy, White House, "Statement on National Space Transportation Policy," 5 August 1994, file 147, box 5, X-33 Archive; Presidential Decision Directive National Science and Technology Council (NSTC) 4, 5 August 1994, file 147, box 5, X-33 Archive.

97. The Joint Statement on Cooperation in Space, signed by Vice President Albert Gore, Jr., and the Russian Prime Minister in September 1993, laid the foundation for the two countries to cooperate on the Station project. The 1 November 1993 addendum approved by President Clinton declared that the Russian launchers (as well as the Shuttle) would carry the various Station segments and that Russia was a full partner in the project. See "Use of foreign launch vehicles for the Space Station has already been approved by the President," file 149, box 6, X-33 Archive.

98. Richard DalBello, Office of Science and Technology Policy, White House, to multiple addressees, "May 17, 1994 Meeting of the Interagency Working Group on Space Transportation," 11 May 1994, file 147, box 5, X-33 Archive.

The 1994 National Space Transportation Policy continued the standing decision to utilize a mixture of expendable and reusable launchers but added the notion of a lead agency for each type of launch technological system, as the Moorman Report had recommended. The new language shifted the basis for distinguishing institutional responsibilities from the nature of the payload (human spaceflight) to the type of technological system utilized (expendable versus reusable launch vehicle). Thus, NASA would be the lead agency in developing the "next generation" of reusable launchers—including single stage to orbit rockets—while the military would implement improvements in expendable rockets on behalf of the entire national security sector.[99]

Even though the Space Transportation Policy made NASA the lead agency for the development of reusable launchers, individuals within the Air Force, such as Simon P. Worden, and Congress, especially Representative Dana Rohrabacher (R-California), wanted to continue work on such reusable military craft as the TransAtmospheric Vehicle and the Space Maneuver Vehicle.[100] The position of the Defense Department, however, was that the 1994 Space Transportation Policy clearly gave NASA the responsibility for reusable launchers, not the Department, and the Pentagon preferred to split the funding the same way. The Air Force recently had started the Evolved Expendable Launch Vehicle (EELV) program to develop a low-cost heavy-lift expendable rocket in collaboration with Boeing and Lockheed Martin. As a result, Paul G. Kaminski, Under Secretary of Defense for Acquisition and Technology, explained, the Department had "no requirement to initiate an additional program." NASA Administrator Dan Goldin agreed with Kaminski on splitting launch vehicle funding in the same way that the space transportation policy divided up launch vehicle responsibilities.[101]

99. Office of Science and Technology Policy, White House, "Statement on National Space Transportation Policy," 5 August 1994; Presidential Decision Directive NSTC 4, 5 August 1994. The DOD, in cooperation with NASA, could use the Shuttle to meet national security needs. Launch priority would be provided for national security missions as governed by appropriate NASA/DOD agreements. Launches necessary to preserve and protect human life in space would have the highest priority except in times of national emergency. NASA would maintain the Shuttle until a replacement became available.

100. Rohrabacher to members of the House Appropriations National Security Subcommittee, "A request for assistance on this week's markup," 11 July 1995, file 506, box 19, X-33 Archive; "Department of Defense Appeal: FY 1996 Defense Authorization Bill," 15 June 1995, file 506, box 19, X-33 Archive; Jeffrey M. Lenorovitz, "Reusable Launcher Backers Push X-Plane Test Program," *Aviation Week & Space Technology* (25 July 1994): 24–25, copy available in file 180, box 7, X-33 Archive; Warren Ferster, "U.S. Air Force Awards 2 Study Contracts for Space Plane," *Space News* 8 (8–14 September 1997): 19, copy available in file 192, box 7, X-33 Archive; James Cast to Gary Payton, e-mail message, 4 September 1997, copy available in file 192, box 7, X-33 Archive.

101. Paul G. Kaminski, Under Secretary of Defense for Acquisition and Technology, to Goldin, 4 May 1995, file 506, box 19, X-33 Archive; Goldin to Kaminski, 12 June 1995, file 506, box 19, X-33

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What is striking about the 1994 Space Transportation Policy is that it was the first space policy statement to contain language regarding a specific program, NASA's X-33 project. That peculiarity was the direct result of strong NASA lobbying. One set of proposed language made NASA focus on developing technologies "to support a decision no later than December 1996 to proceed with a subscale flight demonstration which would prove the concept of SSTO."[102] Later, the Agency suggested wording that supported its single stage to orbit project by authorizing technology development leading up to a June 1997 decision to proceed with a subscale flight demonstration to "prove the concept of Single Stage To Orbit (SSTO)."[103] Another iteration of draft policy added: "The technology development program will lead to the full-scale development of a next generation reusable space transportation system by the end of the decade."[104] NASA subsequently made a point of holding back the release of the Cooperative Agreement Notice for the X-33 program until after the White House reviewed NASA's plans for implementing the 1994 space policy and responded to NASA in writing.[105] Thus, the Space Transportation Policy represented a clear victory for NASA's pursuit of single stage to orbit launchers and reusable launch vehicles in general.

The RLV Bubble Bursts

The same enthusiasm for reusable launchers translated to the commercial launch industry, too. Government policy—the 1994 Space Transportation Policy—and government investment in such projects as the NASP and the DC-X, followed now by the X-33, favored the development of reusable launch vehicles. In part, too, this enthusiasm resulted from one of the touted advantages of reusable launch vehicles, namely, their lower operating costs. This advantage took on new importance because of the considerable, in fact unprecedented, number of launches projected to take place in the near future. Setting up the Milstar, Teledesic, Orbcomm, Intermediate Circular Orbit (ICO), Globalstar, and Iridium networks would involve launching literally hundreds of satellites.

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Archive; "Memorandum of Agreement between Air Force Space Command, the Air Force Research Laboratory, and the National Aeronautics and Space Administration for Cooperative Technology Development Support of NASA Reusable Launch Vehicles and Air Force Military Spaceplanes," 12 October 1997, file 506, box 19, X-33 Archive.

102. Office of Science and Technology Policy, White House, "Statement on National Space Transportation Policy," 5 August 1994; Presidential Decision Directive NSTC 4, 5 August 1994.

103. "NASA Comments on the Draft National Space Transportation Strategy Directive and on May 17 Interagency Comments," 19 May 1994, file 147, box 5, X-33 Archive.

104. Gary Krier to Jeff Hofgard, "NASA Comments to the OSTP National Space Transportation Strategy Draft of 8 April 1994," 20 April 1994, file 151, box 6, X-33 Archive.

105. Richard DalBello, Technology Division, OSTP, to Jack Mansfield, NASA, 8 November 1994, file 153, box 6, X-33 Archive.

Commercial launch firms' enthusiasm for reusable launch vehicles was reflected in the technological shift that took place between 1989 and 1999 within the industry. In 1989, when the Department of Transportation issued the first commercial launch licenses,[106] expendable rockets based on 1950s technology and established companies with deep roots in the military-industrial complex dominated the industry. These included Martin Marietta, manufacturer of the Titan; McDonnell Douglas, maker of the Delta rocket; and General Dynamics, which built the Atlas-Centaur. The nation's smaller startup launch providers also were utilizing expendable launchers: the Conestoga rocket of Space Services, Inc. (SSI); the Industrial Launch Vehicle (ILV) of the American Rocket Company (AmRoc); and Conatec, Inc., and E'Prime Aerospace Corporation used various sounding rockets.[107]

The picture in 1999 was quite different. Reusable vehicles were now the space launcher *du jour*, thanks mainly to the enthusiasm of a half dozen relatively small startup launcher companies that were developing RLVs for commercial and government payloads. Among these were the Astroliner of Kelly Space and Technology, the K-1 of Kistler Aerospace Corporation,[108] the Pathfinder of Pioneer Rocketplane, Rotary Rocket Company's Roton C-9, Space Access's SA-1, and Vela Technology Development's Space Cruiser System.[109] Meanwhile, with NASA funding, Lockheed Martin was developing its single stage to orbit VentureStar™, as well as the X-33 prototype; Orbital Sciences Corporation was building and testing the X-34; Boeing was working on the Future X Trailblazer; and Scaled Composites was involved in the X-38 Crew Return Vehicle program.[110] The Space Maneuver Vehicle, moreover, was under development by the Air Force Space Command in conjunction with McDonnell Douglas, Lockheed Martin, and the Boeing Phantom

106. Stephanie Lee-Miller, "Message from the Director," October 1989, in Department of Transportation Office of Commercial Space Transportation, *The U.S. Office of Commercial Space Transportation Fifth Annual Report* (Washington, DC: GPO, 1990), copy available in file 393, box 15, X-33 Archive.

107. U.S. Department of Transportation, Office of Commercial Space Transportation, "Annual Report to Congress: Activities Conducted under the Commercial Space Launch Act," 1987, pp. 5–6, file 391, box 15, X-33 Archive.

108. Walter Kistler, Bob Citron, and Thomas C. Taylor, "A Small, Reusable Single Stage to Orbit Rocketship," IAF-94-V.3.536 (paper read at the 45th Congress of the International Astronautics Federation, Jerusalem, Israel, 9–14 October 1994), file 179, box 7, X-33 Archive; Kistler Aerospace Corporation, "K-1 Aerospace Vehicle Overview," December 1997, file 179, box 7, X-33 Archive.

109. Unless indicated otherwise, the following discussion of RLV projects is from Associate Administrator for Commercial Space Transportation, "1999 Reusable Launch Vehicle Programs & Concepts," January 1999, pp. 7, 22–29, file 564, box 20, X-33 Archive; and Bill Sweetman, "Rocket Planes," *Popular Science* 232 (February 1998): 40–45, file 180, box 7, X-33 Archive.

110. The vehicle would be attached to the International Space Station as a means of returning to Earth if an emergency required an immediate evacuation of the Station, if an astronaut had a medical emergency, or if the Shuttle were grounded and the astronauts had to return to Earth. Strictly speaking, the X-38 was not an RLV; that is, it was not intended to be a launch vehicle but was capable of multiple flights nonetheless.

Works.[111] Nor was RLV fever confined to the United States. Similar efforts were under way in the United Kingdom, India, and Japan.[112]

This RLV bubble burst in 2000, just as various high-technology industries were beginning to soften. Space commerce, because of its high capital requirements, was one of the first to falter, starting with the failure of Motorola's Iridium communication satellite constellation. The possibility of winning the Ansari X Prize encouraged some firms to keep trying, however.[113] Meanwhile, NASA terminated its RLV programs: the X-33 and the X-34 on 1 March 2001, followed by the Future X Trailblazer,[114] and the X-38 prototype Crew Return Vehicle on 29 April 2002. The space agency was out of the business of developing reusable launchers.

The New Bush

George W. Bush brought about major changes in Clinton space policy largely through his appointee to head NASA, Sean O'Keefe. Within a month of taking charge, O'Keefe embarked on a series of measures that brought NASA and the Defense Department into closer collaboration on technology development, including a possible jointly developed reusable launch vehicle.[115] While O'Keefe was drafting NASA once again into military service, Defense Secretary Donald Rumsfeld announced the revival of President Reagan's space-based missile defense system and elevated the agency's status from the Ballistic Missile Defense Organization to the Missile Defense Agency (MDA) on 4 January 2002 in recognition of the high national priority that the President gave to missile defense.[116] Bush, however, did not give space commercialization the same status, perhaps because his policy advisers believed that the major downturn in the market for commercial launch services had undermined the

111. The Air Force gave study contracts to both Lockheed Martin and McDonnell Douglas Space Division to develop concept designs for the suborbital vehicle. McDonnell Douglas based its design on the DC-X. The Boeing Phantom Works was developing the SMV.

112. Associate Administrator for Commercial Space Transportation, "1999 Reusable Launch Vehicle Programs & Concepts," January 1999, pp. 7, 22–29, file 564, box 20, X-33 Archive; Sweetman, "Rocket Planes," pp. 40–45, file 180, box 7, X-33 Archive.

113. The X Prize was a $10-million prize offered to the first entrant able to launch a vehicle capable of carrying three people to a 100-kilometer suborbital altitude and repeating the flight within two weeks. See Associate Administrator for Commercial Space Transportation, "1999 Reusable Launch Vehicle Programs & Concepts," pp. 30–32; Rebecca Anderson and Michael Peacock, "Ansari X-Prize: A Brief History and Background," NASA History Division Web site, *http://history.nasa.gov/x-prize.htm* (accessed 24 March 2005).

114. The goal of Future X was to develop vehicles more technologically advanced than the X-33. It consisted of a series of experimental flight demonstrators called the Pathfinder and Trailblazer series. Material on the Future X program can be found in file 184, box 7, X-33 Archive.

115. Marc Selinger, "Air Force, NASA Studying Joint Development of New Reusable Launch Vehicles," article 197714 in *Aerospace Daily* (25 January 2002, electronic edition), hard copy in file 854, X-33 Archive.

116. "BMDO's Name Changed to Missile Defense Agency," article 196406 in *Aerospace Daily* (7 January 2002, electronic edition), hard copy in file 854, X-33 Archive.

ability of industry to recoup the considerable investments needed to develop launch systems.[117] Instead, on 14 January 2004, he revived his father's failed Space Exploration Initiative as the Vision for Space Exploration.[118]

Later that year, on 21 December 2004, the White House released a new space transportation policy. It raised more questions than it answered. The policy made no basic changes in existing space commerce policy, but it did throw up barriers to the commercial launch industry by allowing the government to use excess ballistic missiles when their use was cheaper than flying on a commercial launcher. It also made it harder for companies to put payloads on foreign launchers (despite the reliance on Russian launchers following the *Columbia* disaster). Furthermore, the new space transportation policy did not make reusable and expendable launcher responsibility the basis for distinguishing the institutional responsibilities of NASA and the Defense Department. Instead, it made the Defense Secretary responsible for national security launchers and facilities, and the NASA Administrator responsible for "the civil sector," without any mention of reusable or expendable launchers or even which agency had responsibility for human spaceflight.

The central issue addressed by the policy was the need for launchers to achieve the Vision for Space Exploration. It declared that the Space Shuttle would return to flight, complete assembly of the Space Station by the end of the decade, then retire. Concurrently, NASA would develop a new "crew exploration vehicle" for human spaceflight.[119] Furthermore, it declared that the Evolved Expendable Launch Vehicle (EELV) program was now "the foundation for access to space" for intermediate and heavy payloads serving both military and civilian missions. The policy also directed NASA and DOD to develop jointly a version of the EELV suitable for "space exploration."

In January 2004, NASA announced that it would begin developing the Crew Exploration Vehicle, a piloted vehicle to carry humans into orbit "and beyond," as well as to ferry astronauts to and from the Space Station following the retirement of the Shuttle. Different versions of the vehicle could operate in Earth orbit or near the Moon or even on the surface of Mars. The Crew Exploration Vehicle effort was part of what the space agency was calling its Constellation Systems Theme, a set of projects to develop, test, and deploy the various systems needed to prosecute the Vision for Space Exploration. In addition, NASA planned to use an established military acquisition process known as spiral or evolutionary acquisition to develop space exploration hardware.

117. "U.S. Space Transportation Policy," fact sheet, 6 January 2005, p. 2.

118. Office of the Press Secretary, White House, "Executive Order President's Commission on Implementation of United States Space Exploration Policy," 30 January 2004.

119. The following section is from "U.S. Space Transportation Policy," fact sheet, 6 January 2005, except where noted.

The first spiral or stage would deliver humans to orbit in a Crew Exploration Vehicle by 2014. The second would land humans on the Moon's surface by 2020, followed by extended lunar visits in the third stage.[120] All of these proposed systems would be launched on top of an EELV.

In the end, the 2004 Space Transportation Policy and its implementation seemed to assign reusable vehicles the same role played by Mercury, Gemini, and Apollo capsules: sitting atop expendable boosters. This time, though, the rocket of choice was the Evolved Expendable Launch Vehicle and its future variants. Implicit in the decisions underlying the latest space transportation policy was the assumption of a reduced launch rate. Reusable launch vehicles only make economic sense if they have numerous payloads to launch, and their absence in the 2004 Space Transportation Policy can be interpreted as an admission (or at least an assumption) that launch rates for the foreseeable future will be low. One must wonder, then, what the thinking is that lies behind the current Russian effort to build the Kliper reusable launch vehicle for transporting crew and cargo to the Space Station. Do they see launch rates rising? Is the purpose of the Kliper just to bring down launch costs below those for the Soyuz for the cash-starved Russian space effort?[121]

In the relatively brief period between 1980 and 2005, the status of reusable launch vehicles in national space transportation policy waxed and waned more than once. The perception that there was something called space transportation began as people started to fly into space on a reusable, rather than a recoverable, craft; that is, the notion of transportation involved both reusability and human spaceflight. Thus, the advent of the Space Shuttle engendered and dominated (monopolized) space transportation policy. Beginning in 1986, however, reusable craft took their place alongside expendable launchers in a mixed fleet. The dividing line between NASA and Defense Department institutional responsibilities was human spaceflight, but that did not give NASA responsibility for all reusable and the Pentagon responsibility for all expendable launchers. Nonetheless, the 1994 Space Transportation Policy explicitly did enunciate that technological separation of institutional responsibilities, and it created the framework within which a tremendous commercial and governmental enthusiasm for reusable launch vehicles thrived. That policy also broke new ground by mentioning—for the first time—specific space programs. Following the collapse of enthusiasm that began in 2000, reusable launch vehicles disappeared from space transportation policy.

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120. NASA, fiscal year 2006 budget request, *http://www.nasa.gov/pdf/107488main_FY06_low.pdf*, pp. SAE 5-2, SAE 5-3, SAE 6-1, SAE 6-4 to 6-6. On spiral acquisition, see, for example, Alexander R. Slate, "Evolutionary Acquisition: Breaking the Mold—New Possibilities from a Changed Perspective," *Program Manager* 31 (May–June 2002): 6–13. It is from the lingo of spiral acquisition that NASA has picked up the phrase "system of systems."

121. Anatoly Zak, "Russians Propose a New Space Shuttle," *IEEE Spectrum* 42 (February 2005): 13–14.

HISTORIOGRAPHY

A Question

The history of air travel in the United States can be traced back to a time over two centuries ago. A symposium held at the National Air and Space Museum attempted to deal with the subject, a sort of "bicentennial survey" held in the year of the U.S. bicentennial, specifically on 4 November 1976.[122] The history of motorized winged flight is much shorter, of course, and the first Sputnik launches took place scarcely two decades before the symposium. Several of the speakers lamented the chore of condensing 15 or 70 years of history into 20 minutes. In placing their talks in a broader context, historian Thomas Parke Hughes noted that 70 years was not a large amount of time. Nor did he find aeronautics and astronautics to be "an overwhelmingly significant" subject. "We are dealing here with a very short period of time and one episode in a long history of man and technology."[123]

Little has changed in the intervening two decades since Hughes made that observation. The year 2007 will mark only the 50th anniversary of the Sputnik launches, followed by NASA's 50th anniversary. Fifty years is a short historical span; it is certainly not *histoire à longue durée*. Furthermore, during the past two decades, the amount of printed literature and unpublished talks on space history has multiplied swiftly, confirming once again the de Solla Price curve.[124] Despite this growth, we lack a "big picture" understanding of space history. A different, but associated, question is how space history fits into general histories, such as those of the United States, or into specialized histories, such as the history of transportation. Is space history such a peculiar topic of study that it does not lend itself to integration into other histories, into larger historical questions?

A recent joint publication of the American Historical Association and the Society for the History of Technology[125] that surveyed U.S. transportation history ended with a chapter on "airways," but not a mention of space travel. Is going into space such a peculiar human endeavor that its history must be segregated from the other categories into which we parse history? Is it because many space and space history enthusiasts act as if the space program were a nontheistic religion? Or should we be asking whether space transportation is

122. Eugene M. Emme, ed., *Two Hundred Years of Flight in America: A Bicentennial Survey*, AAS History Series, vol. 1 (San Diego: Univelt, Inc., for the American Astronautical Society, 1977). The symposium sponsors were NASM, the AIAA, SHOT, and AAS, which published the proceedings.

123. Hughes, "Perspectives of a Historian of Technology: A Commentary," in *Two Hundred Years of Flight in America*, ed. Emme, p. 257.

124. Derek de Solla Price, *Science Since Babylon*, 1st edition (New Haven, CT: Yale University Press, 1961).

125. Robert C. Post, *Technology, Transport, and Travel in American History* (Washington, DC: American Historical Association, 2003).

really a form of transportation? Was there anything of substance to the transportation references common to space travel—such as the Space *Transportation* System and National Space *Transportation* Policy—or were they just figures of speech, similar to the analogies with aircraft and ships reflected by the terms *spacecraft*, *spaceplane*, *rocket ship*, and *spaceship*[126] or, say, the maritime analogies used by presidential speechwriters[127] and space advocates?[128]

One of the peculiar aspects of space launch vehicles is their origins in rocketry, which for centuries served largely military purposes. The aerospace engineer Maxwell W. Hunter II captured the difference between the two uses of rocket technology with his use of the terms "ammunition" and "transportation." Expendable rockets, he wrote, were ammunition, while reusable launch vehicles were transportation.[129] The shift from "ammunition" to "transportation" was not just one of application, but also a change of perception that occurred once people replaced the bombs, electronic instrumentation, and other inanimate objects that had served for decades as the sole payloads carried into space or the uppermost reaches of the atmosphere. The transformation of a military technology into a mode of transport is rather unique in world history, perhaps as unique as turning swords into plowshares.

The reverse, turning transportation into a weapon, is certainly not unique, but rather a common occurrence in history. In recent times, we have witnessed aircraft turned into weaponry on 7 December 1941 and 11 September 2001, for example. Automobiles and trucks also have become bomb delivery systems in the hands of Timothy McVeigh and colleagues on 19 April 1995, against the Murrah Federal Building in Oklahoma City, and Ramzi Yousef and his fellow coconspirators on 26 February 1993, against the World Trade Center in New York City. Any form of transpor-

126. Another term that evokes the maritime analogy is *spacefaring*. Much can be written on the analogy between moving through outer space and sailing, as I suggested in *Single Stage to Orbit: Politics, Space Technology, and the Quest for Reusable Rocketry* (Baltimore, MD: Johns Hopkins 2003), pp. 21–22, 217.

127. For example, President Kennedy told a crowd at the Rice University stadium, "We intend to be first . . . to become the world's leading space-faring nation" (John F. Kennedy, address at Rice University, 24 September 1962, *Public Papers of the Presidents* [Washington, DC: National Archives and Records Service, 1963], p. 329).

128. Lieutenant Colonel Daniel O. Graham, the well-known proponent of what became the Strategic Defense Initiative, believed that a U.S. space-based global defense system would bring about a Pax Americana similar to the Pax Britannica induced by Britain's domination of the world's oceans. See Erik K. Pratt, *Selling Strategic Defense: Interests, Ideologies, and the Arms Race* (Boulder, CO: Lynne Rienner Publishers, 1990), p. 96.

129. See, for example, Hunter to E. P. Wheaton, vice president for research and development, Lockheed, "Orbital Transportation," 28 October 1965, pp. 1–2, file 338, box 13, X-33 Archive. The distinction between ammunition and transportation appears throughout Hunter's oeuvre. See, for instance, Hunter, "The SSX: A True Spaceship" (manuscript, 2000), pp. 17, 18, 22; and Hunter, "The SSX: A True Spaceship" (manuscript, 4 October 1989), pp. 2, 6, both in file 338, box 13, X-33 Archive.

tation can undergo this transformation, yet we cannot imagine any bomb delivery system or other form of weapon system being turned into a form of transportation. Although certain military-use vehicles have found civilian applications—such as the Jeep of World War II and the High Mobility Multipurpose Wheeled Vehicle (more commonly known as the Hum Vee or Hummer)—they always served as military transport vehicles, never as weapon systems. One could stretch the point and argue that the Bradley M2 Fighting Vehicle or the Abrams M1 tank could be turned into transport, but their high maintenance and operational costs, frequent need for maintenance and repairs, lack of reliability, and poor performance only highlight the absurdity of the proposition.

If we define space transportation as human flight into space via reusable launch vehicles (the key being the combination of *reusability* and humans in space), then the real question historians need to answer is not whether space transportation is really transportation and therefore part of transportation history. Space travel clearly has many characteristics in common with the various forms of terrestrial transportation. One can point to numerous aspects of space transportation shared by other forms of transportation, from the model-building of amateurs to the carrying of cargo and passengers (both astronauts and tourists) to desired destinations. Even the inherent danger of space travel has had its precedents in the boiler explosions that pervaded early steam-powered transporters. Like other forms of transportation, travel to places off the planet requires a complex infrastructure.

For instance, one can compare the launch infrastructure required by rocketry with the infrastructures that support automobile or truck travel. In addition to the nation's vast network of roads, signage (and the systems needed to maintain and operate them), and facilities for refueling and repairing vehicles (gas and repair stations), these include such legal and regulatory elements as driving rules and laws, driver license and registration facilities, driver education, vehicle inspections and inspection stations, and various regulatory agencies from the local motor vehicle agency to the Interstate Commerce Commission and the Department of Transportation. Infrastructure issues also are relevant to the choice between using a solid-fueled or a liquid-fueled rocket. Similarly, in the early history of the automobile, different engine types (electric, steam, gas) required a dedicated infrastructure. Reusable and expendable launch vehicles similarly have different infrastructure needs.

Historians often claim that one properly cannot write the history of a subject until the passage of a certain amount of time. The subject, like a bottle of wine, must age and somehow achieve a certain degree of ripeness before it is suitable for historical inquiry. Space history, as measured from Goddard's first liquid-fueled rocket near Auburn, Massachusetts, on 16 March 1926 to the present, does not span a very long period, just eight decades—even less if one counts from Sputnik forward. In comparison, Georg Agricola, nearly a half millennium ago, recounted the use of railways in mining operations,[130] and the Appian Way is centuries older still. And yet, histories that cover periods as short as five years or less have been—and are continually being—written. The challenge is not the relatively short length of the space travel era nor its topical nature. Historians routinely research and write about events that have taken place only a few years earlier—or investigate history as it happens.[131] The real question is a challenge, the challenge for space historians to integrate their work into the larger historical context, with its rich fabric of political, economic, social, and cultural threads.

130. Georg Agricola, *De Re Metallica* (Basil, Switzerland: H. Frobenium and N. Episcopium, 1556), trans. and annotated by Herbert Clark Hoover and Lou Henry Hoover (London: *The Mining Magazine*, 1912).

131. This was the subject of a recent panel, "Doing the History of the Recent Past: Historiography, Sources, Disciplinary Boundaries . . . ," held by the Society for the History of Technology in 1997. The panel's contributors consisted of Joseph N. Tatarewicz, "In from the Cold or Out in the Cold? Warriors and Nuclear Weaponeers Search for their Place in History"; Pascal Griset, "Oral History and Recent Evolutions in the History of French Industry"; and Butrica, "From the X-Files: Some Source and Historiographical Problems of the X-33 History Project, or 'History Made While You Wait.'"