CHAPTER 10

REUSABLE LAUNCH VEHICLES OR EXPENDABLE LAUNCH VEHICLES? A PERENNIAL DEBATE

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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]

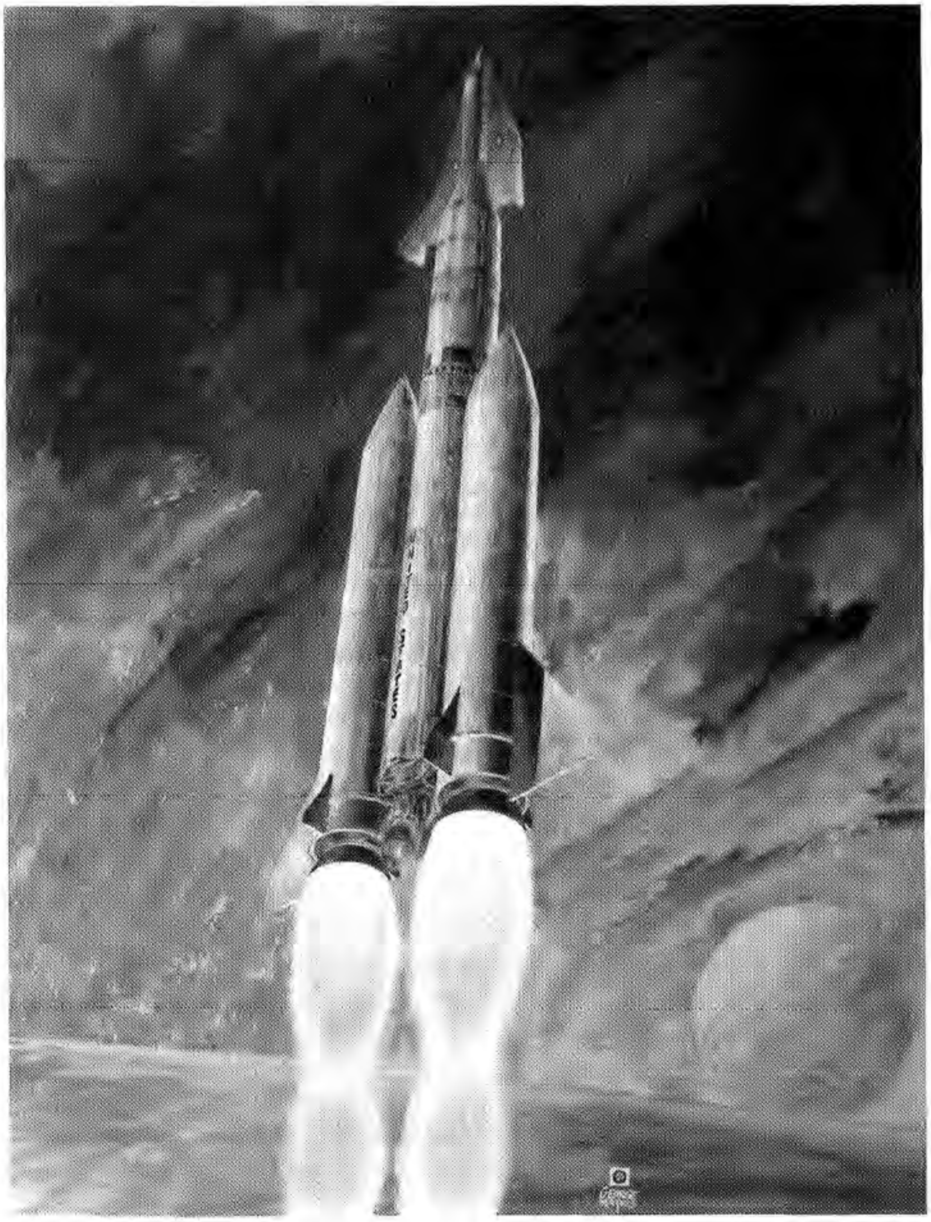
The Air Force's Dyna-Soar program emerged from a 1957 consolidation of the NACA's "Round Three" and several military hypersonic flight programs. Eventually, NASA participated in the project as well. Launched on an expendable booster, the Dyna-Soar X-20 would fly orbital or suborbital trajectories, perform 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]

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]

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;

continued on the next page

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.

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]

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-

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]

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.

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

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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.'"