CHAPTER TWO

LAUNCH SYSTEMS

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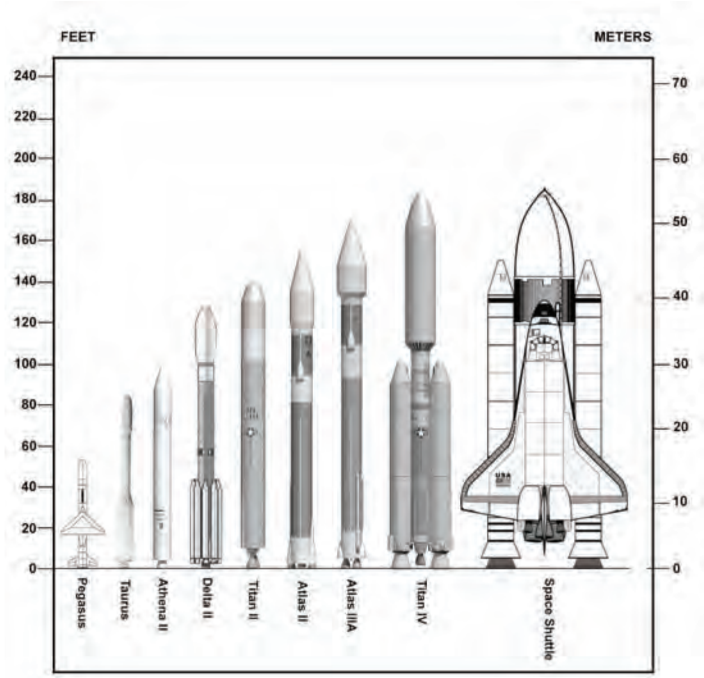
Introduction

Launch systems provide access to space, necessary for the majority of NASA's activities. During the decade from 1989–1998, NASA used two types of launch systems, one consisting of several families of expendable launch vehicles (ELV) and the second consisting of the world's only partially reusable launch system—the Space Shuttle. A significant challenge NASA faced during the decade was the development of technologies needed to design and implement a new reusable launch system that would prove less expensive than the Shuttle. Although some attempts seemed promising, none succeeded.

This chapter addresses most subjects relating to access to space and space transportation. It discusses and describes ELVs, the Space Shuttle in its launch vehicle function, and NASA's attempts to develop new launch systems. Tables relating to each launch vehicle's characteristics are included. The other functions of the Space Shuttle—as a scientific laboratory, staging area for repair missions, and a prime element of the Space Station program—are discussed in the next chapter, Human Spaceflight. This chapter also provides a brief review of launch systems in the past decade, an overview of policy relating to launch systems, a summary of the management of NASA's launch systems programs, and tables of funding data.

The Last Decade Reviewed (1979–1988)

From 1979 through 1988, NASA used families of ELVs that had seen service during the previous decade. NASA also introduced new models of ELVs and began using the fleet of Space Shuttles to launch satellites into space. NASA used three families of ELVs: the Scout, Delta, and Atlas. These ELVs were increasingly acquired from the private sector and were used to send commercial as well as scientific and other research satellites into space in compliance with national space policy. The success rate for ELV launches was high during this decade; there were only three ELV launch failures: 1984, 1986, and 1987.



*Space Shuttle shown for size (height) comparisons only

Figure 2–1. NASA's Fleet of Launch Vehicles (1989–1998). Not Pictured: the Scout and the Conestoga. The Scout stood 75 feet (23 meters) tall, placing it between the Pegasus and Taurus. The Conestoga stood 50 feet (14 meters), making it about the same height as the standard Pegasus.

This decade marked the Space Shuttle's debut as the world's first Reusable Launch Vehicle (RLV). The Space Shuttle fleet consisted of four orbiters: the *Columbia*, *Challenger*, *Discovery*, and *Atlantis*. An earlier orbiter, the *Enterprise,* was used as a test vehicle before the Space Transportation System's first spaceflight in 1981, but it did not fly in space.

The Space Shuttle flew 26 successful missions before January 28, 1986, when the *Challenger* exploded only a few seconds into flight, taking the lives of its crew. This single tragedy defined the decade and greatly obscured the program's achievements. It would be more than two years before the Space Shuttle returned to flight in 1988.

Government policy had initially stated its intention to replace ELVs with the Shuttle as the country's prime launch vehicle. However, as early as 1984, Congress had expressed reservations about relying solely on the Shuttle. During the two years following the *Challenger* accident, NASA used ELVs exclusively to launch the Nation's satellites. When Shuttle flights resumed in 1988, NASA implemented a "mixed fleet strategy." This strategy reserved the Shuttle for those flights requiring a human presence or where only the Shuttle could handle the payloads.

Overview of NASA's Launch Systems (1989–1998)

During 1989–1998, 281 U.S. launches occurred. Of these, 215 were ELV launches, and 66 were Space Shuttle missions.[1] Twenty-seven Shuttle missions did not deploy a payload, and several other Shuttle missions were used to deploy and quickly retrieve payloads sent into space to conduct experiments. All Shuttle and most ELV launches took place from Cape Canaveral, Florida. Polar missions usually launched from Vandenberg Air Force Base, California. ELV launches took place using Athena; Atlas; Conestoga; Delta; Pegasus; Scout; Taurus; and Titan launch vehicles. The Conestoga launch took place from Wallops Flight Facility on the Eastern Shore of Virginia. Figure 2–1 shows NASA's launch vehicles.

A wide range of payload types was launched. Most were either commercial or DOD payloads and had communications or navigation purposes, although some were reconnaissance satellites. Some of the launches carried satellites for other countries, among them Japan, the Philippines, the United Kingdom, Spain, India, Korea, Canada, and various international groups of satellite owners. A smaller number of launches deployed scientific satellites; these were usually NASA missions. The success rate for all types of launches during this decade was very high. All Shuttle launches succeeded. For ELVs, the total success rate was almost 94 percent.

National space policy and legislation, either in place by 1989 or promulgated during the decade, greatly determined the direction of space launch development and activities. During the administration of President George H. W. Bush, and with Vice President Dan Quayle's special interest in space policy, NASA and other agencies and organizations undertook a large number of space transportation studies. These studies grew partly out of Congress's desire to reduce the federal budget and, in particular, NASA's budget, and partly out of the view that new launch technologies were needed.[2] These studies, and the policies and legislation reflecting them, had three primary themes: a new heavy launch system was needed to augment or replace the Shuttle; an RLV needed to be developed; and ELV launches and launch services should largely be commercial enterprises.[3]

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[1] One joint U.S.-French launch took place from an Ariane launch vehicle.

[2] Andrew Butrica, "X-33 Fact Sheet #1, Part I: The Policy Origins of the X-33," *The X-33 History Project Home Page* (December 7, 1997), *http://www.hq.nasa.gov/office/pao/History/x-33/facts_1.htm* (accessed February 29, 2005).

[3] Advisory Committee on the Future of the U.S. Space Program, "Report of the Advisory Committee on the Future of the U.S. Space Program," December 17, 1990, *http://www.hq.nasa.gov/office/pao/History/augustine/racfup1.htm* (accessed March 14, 2005).

Executive policy statements and legislation emphasized the role of the private sector. Legislation took the government out of the business of building ELVs and supplying launch services for its primary payloads and required NASA to purchase them from commercial providers whenever possible. Policy and legislation directed the government to make national launch facilities available for private use and encouraged development of new launch systems by the private sector.[4] National policy also emphasized the importance of having a resilient and balanced launch capability so launch operations could continue even if any one system failed.

Further, restating policy set forth during President Ronald Reagan's administration,[5] Bush's policy dictated that the Shuttle would be reserved for launches requiring a human presence or the special capabilities of the Shuttle. It also stated that U.S. payloads must be launched from U.S. launch vehicles unless excepted by the President or a person designated by the President.[6]

In January 1993, William J. Clinton became President. In January 1994, the NASA Office of Space Systems Development released a study titled "Access to Space," undertaken in response to a congressional request in the NASA FY 1993 Appropriations Act. The goal of this study was to identify alternative approaches to space access that would reduce the cost of space transportation and increase safety for flight crews. The study concluded that the best option was "to develop and deploy a fully reusable single-stage-to-orbit pure-rocket launch vehicle fleet incorporating advanced technologies" and to phase out current systems "beginning in the 2008 time period."[7]

On August 5, 1994, President Clinton released a National Space Transportation Policy splitting the responsibility for space transportation between DOD and NASA. The policy gave DOD lead responsibility for improving ELVs and NASA lead responsibility for upgrading the Space Shuttle and developing and demonstrating new RLVs to replace the Space Shuttle.[8] In response, DOD initiated the Evolved Expendable Launch Vehicle program, and NASA initiated the RLV program to develop and flight-test experimental RLVs.

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[4] A *Bill to Facilitate Commercial Access to Space, and for Other Purposes,* 100th Congress, 2nd sess., H.R. 4399, (October 14, 1988); National Space Policy Directive, NSPD-1,"National Space Policy Directives and Executive Charter," November 2, 1989, *http://www.fas.org/spp/military/docops/national/nspd1.htm* (accessed March 1, 2005); NSPD-3, "U.S. Commercial Space Policy Guidelines," February 11, 1991, *http://www.fas.org/spp/military/docops/national/nspd3.htm* (accessed March 1, 2005).

[5] The White House Office of the Press Secretary, "Presidential Directive on National Space Policy," *Aeronautics and Space Report of the President, 1998 Activities* (Washington, DC: National Aeronautics and Space Administration, 1990), p. 190.

[6] National Space Policy Directive, NSPD-2, "Commercial Space Launch Policy," September 5, 1990, *http://www.hq.nasa.gov/office/codez/new/policy/pddnspd2.html* (accessed March 1, 2005).

[7] Office of Space Systems Development, NASA Headquarters, "Access to Space Study, Summary Report," January 1994, p. i (NASA History Office file 009830).

[8] The White House, Office of Science and Technology Policy, Presidential Decision Directive (PDD), National Science and Technology Council-4 (NSTC), *National Space Transportation Policy* (August 5, 1994), *http://www.au.af.mil/au/awc/awcgate/nstc4.htm* (accessed February 28, 2005).

Clinton's policy also set guidelines for the use of foreign launch systems and components and excess ballistic missile assets for space launches. His policy also encouraged an expanded private sector role in space transportation research and development.

In September 1996, the White House released a National Space Policy stating that NASA would work with the private sector to develop flight demonstrators to make a decision about the development of a new reusable launch system. The policy also stated that NASA would acquire launch vehicles from the private sector unless the Agency's special technical abilities were needed.[9] Legislation passed in 1998 stated that the federal government would acquire space transportation services from commercial providers, except when there was a reason to use the Space Shuttle or because it was not cost effective or in the best interests of the mission. The legislation also allowed the Federal Aviation Administration (FAA) to license firms to fly vehicles back from space. Since the 1980s, private firms had been able to acquire licenses for commercial space launches; but the licenses had not provided for return from space, which had been too expensive for all but government agencies. This bill also obligated NASA's Administrator to prepare for transferring operation and management of the Space Shuttle to the private sector.[10]

Management of NASA's Launch Systems

In the decade from 1989 through 1998, NASA's launch systems included both ELVs and the Space Shuttle. NASA's launch system programs also focused on developing new ways to provide access to space by using RLVs and other advanced technologies. As in the past, the offices managing these various activities frequently shifted among organizations as NASA reorganized in an effort to more efficiently achieve its objectives. At times, management of ELVs, the Space Shuttle, and developing launch programs were all in the same organization. At other times, they were spread among different areas of the Agency.[11] For part of NASA's fourth decade, management of NASA's expendable launch systems remained with the Office of Space Flight (Code M), although it did not receive the prominence it had in past decades because providing ELV services became more of a commercial function. Management of Space Shuttle activities always remained in the Office of Space Flight.

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[9] The White House National Science and Technology Council, "Fact Sheet–National Space Policy," PDD-NSTC-8 (September 19, 1996), *http://www.fas.org/spp/military/docops/national/nstc-8.htm* (accessed March 15, 2005).

[10] *Commercial Space Act of 1998,* 105th Congress., 1st sess., Public Law 105-303, Title II, (October 28, 1998).

[11] NASA assigned letters (called codes) as a quick way to refer to its top-level offices. The offices and codes applicable to launch systems during this decade were:
- Office of Space Flight–Code M
- Office of Space Systems Development–Code D
- Office of Advanced Concepts and Technology–Code C
- Office of Space Access and Technology–Code X
- Office of Space Science and Applications–Code E, later changed to Code S

Development programs were frequently located in other organizations. The sections that follow correspond to the major reorganizations and changes in the management structure of NASA's launch systems activities.

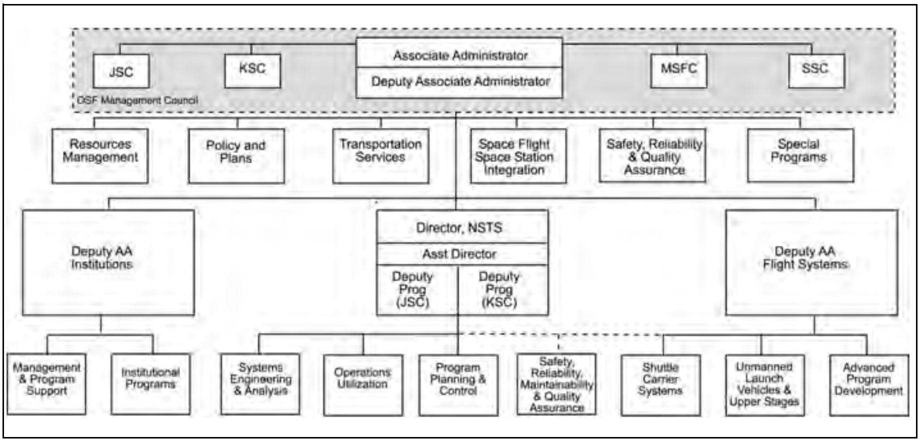

Figure 2–2. Office of Space Flight (Code M), February 1989.

Phase I: 1989–1990

The year 1989 and the first part of the 1990s saw three rapid reorganizations of the Office of Space Flight and changes in its leadership. In February 1989, the Office of Space Flight, led by Admiral Richard Truly, reorganized from its post-*Challenger* structure into an office consisting of three major divisions: 1) Institutions, headed by Richard J. Wisniewski; 2) Flight Systems, led by Joseph B. Mahon, and 3) the National Space Transportation System program (soon renamed the Space Shuttle program), headed by Arnold D. Aldrich (see Figure 2–2). Charles R. Gunn led the Unmanned Launch Vehicles and Upper Stages office in the Flight Systems Division. Aldrich left his post as head of the Shuttle program in October 1989 to become Associate Administrator of the Office of Aeronautics, Exploration and Technology and was replaced by Capt. Robert L. Crippen, initially as acting Director of the Space Shuttle program and as Director from February 1990.

Dr. William B. Lenoir, a former Space Shuttle astronaut, became Associate Administrator of the Office of Space Flight in July 1989, leaving his position as head of the Office of Space Station, a position he had held only since May 1989. In May, he had also been asked by Truly to develop a plan for consolidating the Offices of Space Flight and Space Station.[12] When President George H. W. Bush named Truly NASA Administrator, Lenoir took over leadership of the Office of Space Flight.

[12] "Space Station Program Leadership Selected by Truly," *NASA News* Release 98-77, May 19, 1989. (NASA History Office Folder 009610).

The February 1989 structure lasted less than a year because the office reorganized again in December and then made another small change in March 1990. The December 1989 reorganization consolidated the Office of Space Flight and Office of Space Station into a single organization consisting of four divisions that retained the name the Office of Space Flight (see Figure 2-3). Richard H. Kohrs took over the leadership of Space Station *Freedom*; Crippen, Wisniewski, and Mahon continued to head the Space Shuttle, Institutions, and Flight Systems divisions, respectively. Gunn continued as Director of Unmanned Launch Vehicles and Upper Stages. The March 1990 reorganization added a second Deputy Associate Administrator to the Office of Space Flight. In late 1990, Mahon was replaced by Michael T. Lyons as head of Flight Systems, and I. Duke Stanford became head of Institutions when Wisniewski retired from NASA. Around the same time, the heads of the divisions assumed the title of Deputy Associate Administrator of their respective organizations.

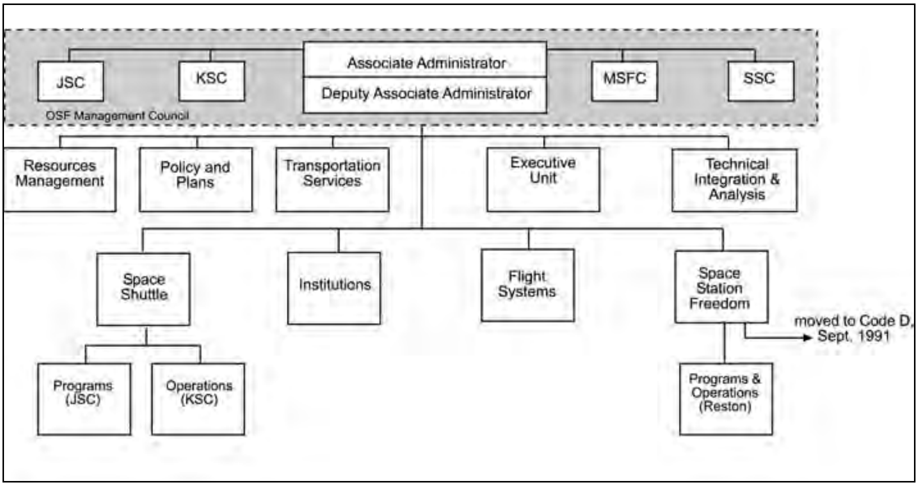

Figure 2–3. Office of Space Flight, December 1989.

Phase II: 1991–1992

The 1989 organizations remained in place until September 1991, when Administrator Truly followed the guidance of the Advisory Committee on the Future of the U.S. Space Program of December 1990, headed by Norman R. Augustine, and created a new Office of Space Systems Development (Code D).[13]

[13] NASA press release for September 13, 1991, that announced the formation of the new office referred to it as the Office of Space Flight Development; "New Office of Space Flight Development Announced," *NASA News* Release 91-148, September 13, 1991, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1991/91-148.txt* (accessed March 2, 2005). Beginning with an October 3, 1991, press release, the office was referred to as the Office of Space Systems Development." "NASA Administrator Announces Key Appointments," *NASA News* Release 91-161, October 3, 1991, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1991/91-161.txt* (accessed March 2, 2005). This name also appears on the NASA organization chart dated October 20, 1991, and in future references.

This reorganization moved several organizations from the Office of Space Flight to the new organization (see Figure 2–4). This new Space Systems Development office was responsible for Space Station *Freedom* development; large propulsion systems development, including the new National Launch System and its new space transportation main engine; other large spaceflight development; and the advanced transportation systems program planning function. Aldrich left the Office of Aeronautics, Exploration and Technology to lead the new Space Systems Development office. Dr. C. Howard Robins, Jr. was named Deputy Associate Administrator for the new office in October. The Flight Systems Division moved to the Office of Space Systems Development, with Lyons as its head. Kohrs was named head of the Space Station Freedom Division.

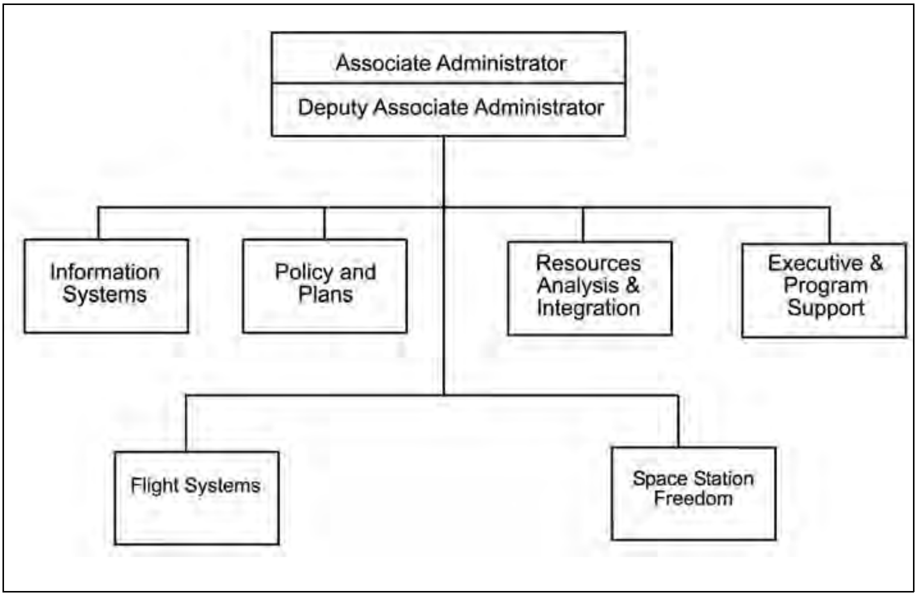

Figure 2–4. Office of Space Systems Development (Code D).

The scaled-down Office of Space Flight continued to focus on Space Shuttle operations and also retained responsibility for Space Station *Freedom*/Spacelab operations and utilization, ELV operations, and upper stages.[14] In December, Leonard S. Nicholson was named Director of the Space Shuttle program in the Office of Space Flight, replacing Crippen, who became Director of Kennedy Space Center. Lenoir remained as Associate Administrator of the Office of Space Flight until May 1992, when he resigned his leadership post and left NASA.

[14] "New Office of Space Flight Development Announced," *NASA New,* Release 91-148, September 13, 1991, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1991/91-148.txt* (accessed March 1, 2005).

In April 1992, Daniel S. Goldin replaced Truly and became NASA's new Administrator. Among his first hiring decisions was the appointment of Maj. Gen. Jeremiah W. Pearson, III as Associate Administrator of the Office of Space Flight. Bryan D. O'Connor, a former NASA astronaut, was named Deputy Associate Administrator for programs within the Office of Space Flight. In June, Pearson named Thomas Utsman, who had been serving as Deputy Associate Administrator for the Office of Space Flight since June 1990, as Program Director for the Space Shuttle. In March 1993, Pearson named Brewster Shaw, Deputy Director of Space Shuttle Operations, to the position of Space Shuttle Program Manager, replacing Nicholson, who left to take the position of acting Director of Engineering at Johnson Space Center.

In the summer of 1992, management of ELVs and upper stages, still under the leadership of Gunn, moved to the Office of Space Science and Applications (OSSA) Launch Vehicles Office. This was done largely because ELVs launched space and Earth science missions, and it seemed more efficient for all aspects of these missions to be in the same organization. The Launch Vehicles Office was responsible for managing the ELV and upper stages launch services program. It maintained the NASA ELV manifest and served as the primary interface with the U.S. Air Force, foreign governments, and the ELV industry.[15]

In November 1992, NASA moved the Space Technology program, led by Gregory Reck, out of the Office of Aeronautics and Space Technology (Code R) and merged it with the Office of Commercial Programs (Code C), creating a reformulated Code C, the Office of Advanced Concepts and Technology, under Reck's leadership (see Figure 2–5). The Transportation Division within the new Code C, led by Earl VanLandingham, included several space transportation technology efforts, among them the Solid Propulsion Integrity Program (SPIP), the Advanced Launch Technology effort, and Advanced Programs.[16]

[15] NASA *Management Instruction* (NMI) 1102.1H, "Role and Responsibilities—Associate Administrator for Space Science and Applications," July 30, 1992; NASA Management Instruction 1102.1I, "Role and Responsibilities—Associate Administrator for Space Science and Applications," June 28, 1993; "Goldin Announces Changes in NASA Organization To Focus and Strengthen Programs and Management," *NASA News* Release 92-172, October 15, 1992, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1992/92-172.txt* (accessed March 2, 2005).

[16] "General Statement," *National Aeronautics and Space Administration, Fiscal Year 1995 Budget Estimates*, p. AS-9.

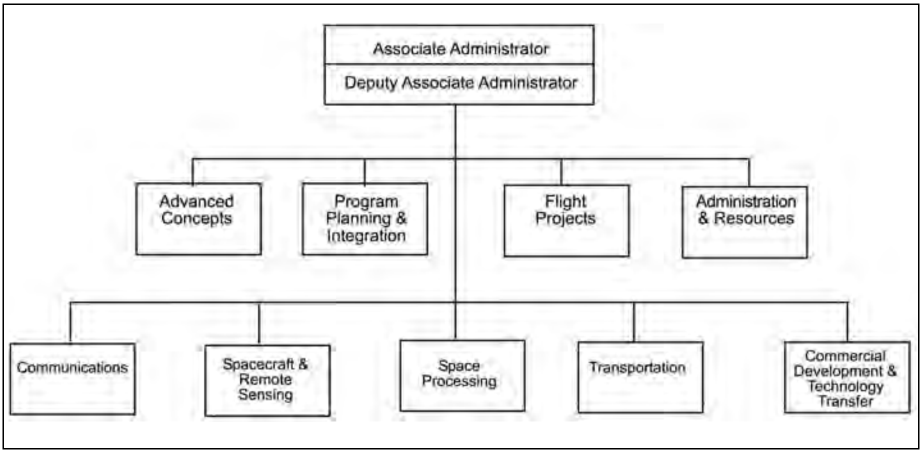

Figure 2–5. Office of Advanced Concepts and Technology (Code C).

Phase III: 1993–1996

In October 1993, Administrator Goldin announced that the Office of Space Flight would again assume responsibility for managing the Space Station Program because Space Shuttle flight activities were becoming increasingly more involved with Space Station planning.[17] This change moved the Space Station out of the Office of Space Systems Development, leaving that office without a major program to manage. O'Connor, Director of the Space Station transition since July 1993, became acting Space Station Program Director, replacing current Program Director Richard Kohrs, who retired in September 1993.[18] O'Connor remained in the position until January 1994, when Wilbur C. Trafton accepted the position.

Further changes in the Office of Space Flight took place in spring of 1994. Utsman left the position of Deputy Associate Administrator for Space Shuttle to return to Kennedy Space Center and become special assistant to the Associate Administrator in the Office of Space Flight. O'Connor, the Office of Space Flight Deputy Associate Administrator, replaced Utsman and also became the Space Shuttle Program Director, responsible for managing the Space Shuttle program. Wisniewski, who retired from NASA in 1990, returned to NASA and replaced O'Connor as Deputy Associate Administrator in the Office of Space Flight. He was responsible for resources, policy and plans, human resources, and management of the human spaceflight installations: Kennedy Space Center, Johnson Space Center, Marshall Space Flight Center, and Stennis Space Center.[19]

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[17] "Goldin Announces Key Space Station Management Moves," *NASA New,* Release 93-191, October 20, 1993, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1993/93-191.txt* (accessed March 1, 2005).
[18] See chapter 3, Human Spaceflight, for a description of space station transition to Johnson Space Center.
[19] "NASA Announces Space Flight Personnel Changes," *NASA News* Release 94-66, April 28, 1994, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1994/94-066.txt* (accessed March 1, 2005).

A reorganization in September 1994 consolidated the Advanced Concepts and Technology Office (Code C) and Office of Space Systems Development (Code D) into a new Office of Space Access and Technology (Code X), headed by John E. Mansfield. The divisions within Code X and their heads were: Flight Integration, Jack Levine; Advanced Concepts, Ivan Bekey; Launch Vehicles, Charles Gunn; Commercial Development, Robert Norwood; Space Systems, Samuel Venneri; Space Processing, Edward Gabris; Space Transportation, Col. Gary Payton; and Management Operations, Martin Stein (see Figure 2–6).

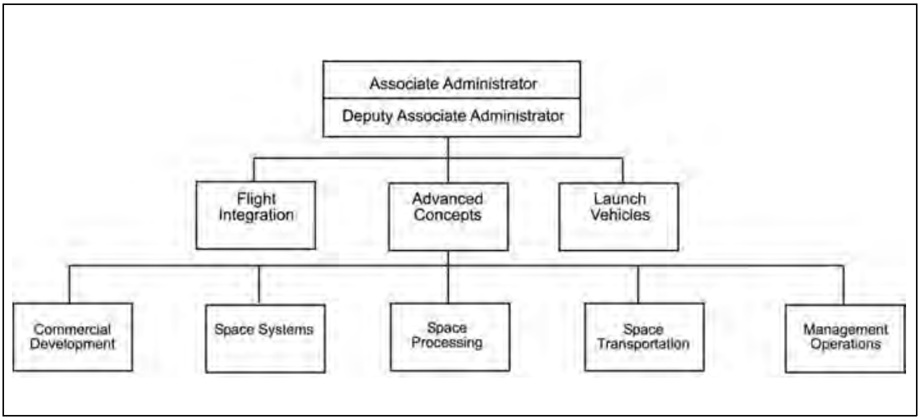

Figure 2–6. Office of Space Access and Technology (Code X), September 1994.

The Space Transportation organization in Code X managed transportation technology, advanced technology development for ELVs and the Space Shuttle, and NASA's efforts to develop an RLV. It also functioned as the single interface with DOD and other outside interests.[20] The Launch Vehicles Office consolidated NASA, the National Oceanic and Atmospheric Administration (NOAA), and international cooperative ELV mission requirements. Management and acquisition of launch services moved from the Office of Space Science and Applications to the Launch Vehicles Office as did acquisition of upper stages. Administration, procurement, and technical oversight of launch service delivery in the small and medium performance classes (Atlas E, Titan II, Pegasus, and Delta II) were handled by Goddard Space Flight Center. Launch services for the intermediate and large performance classes (Atlas I/IIAS and Titan IV/Centaur) were managed by Lewis Research Center. Kennedy Space Center had responsibility for technical oversight of vehicle assembly and testing at the launch site and for launch site spacecraft processing. Marshall Space Flight Center was responsible for managing upper stage missions.[21]

[20] "NASA Space Access and Technology Office Functions," *Aerospace Daily* (September 26, 1994): 480.
[21] "Office of Space Access and Technology," *National Aeronautics and Space Administration Fiscal Year 1996 Estimates*, pp. SAT 5–37.

In November 1994, Pearson resigned as Associate Administrator of the Office of Space Flight. He was replaced by NASA Chief Engineer and veteran manager Dr. Wayne Littles, who continued a review of the Shuttle work force begun by Pearson a few months earlier. At Administrator Goldin's direction, Littles was looking for any "unnecessary requirements" in the Shuttle program that could be cut and "to make sure that recent budget cuts have not affected safety."[22]

When Gunn retired in the spring of 1995, Charles J. Arcilesi took over as acting head of the Launch Vehicles Office. By summer, the Launch Vehicles Office had moved to the Office of Space Flight, and Karen Poniatowski was appointed to head the Expendable Launch Vehicles Office.

Later in the year, in October 1995, the Office of Space Flight reorganized with the goal of increasing efficiency and reducing the number of people in the organization (see Figure 2–7). In January 1996, Trafton, Director of the Space Station program, assumed additional responsibilities as the acting Associate Administrator for the Office of Space Flight, replacing Littles, who became Director of Marshall Space Flight Center. Trafton was formally named to the position in March. The position also placed Trafton in charge of the Human Exploration and Development of Space (HEDS) Enterprise, one of NASA's four Strategic Enterprises, whose mission was to "open the space frontier by exploring, using, and developing space; and to expand the human experience into the far reaches of the universe."[23] Andrew Allen became acting head of the Space Station program until Gretchen McClain took over in January 1997. In January 1996, the decision was made to transfer the ELV program from the Office of Space Access and Technology (Code X) back to the Office of Space Flight (Code M). In February 1996, O'Connor left his position of Space Shuttle Director, which he held since 1994.

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[22] Ben Iannotta, "Littles Takes Over Space Flight Post as Pearson Quits," *Space News* (November 21–December 4, 1994): 29.

[23] Sharon M. Wong, "Strategic Management: Opening the Space Frontier," *NASA HQ Bulletin* (April 15, 1996): 5.

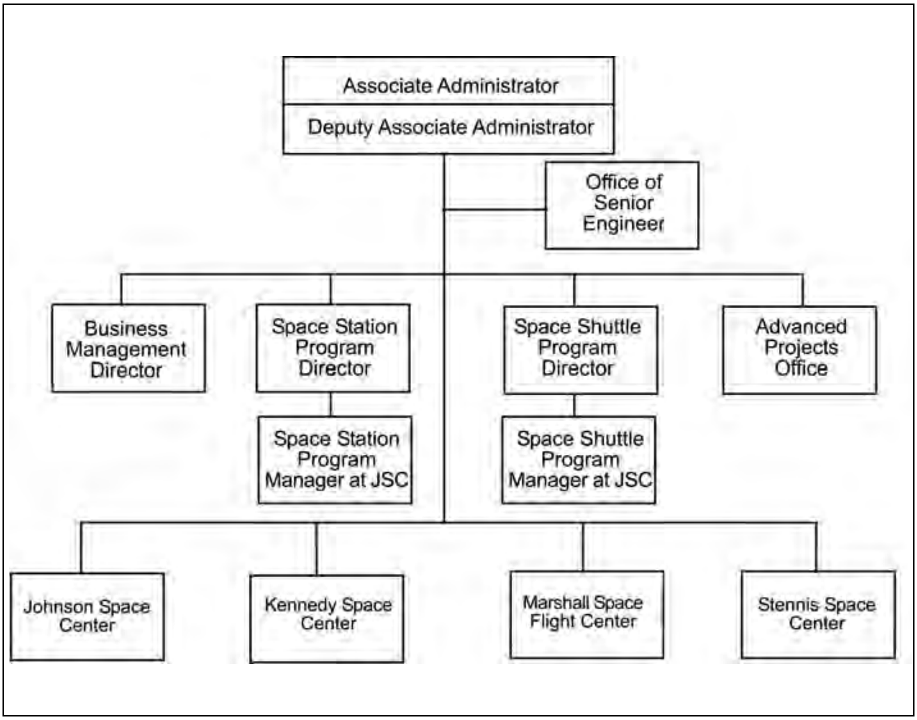

Figure 2–7. Office of Space Flight, October 1995.

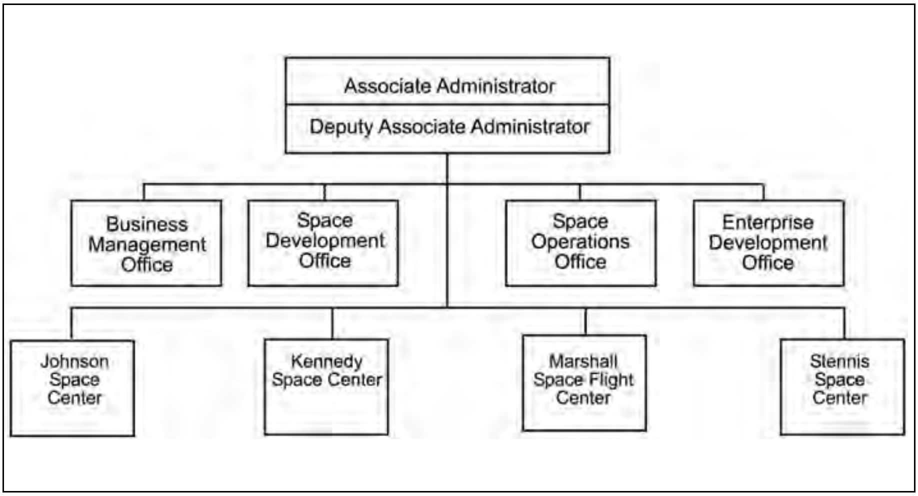

Figure 2–8. Office of Space Flight, July 1998.

Phase IV: 1996–1998

In April 1996, NASA announced plans to accelerate the downsizing of NASA Headquarters. Agency officials had previously identified more than 200 positions that could be moved from Headquarters to NASA's Field Centers; about half of the positions had already moved or were in the process of moving. In October 1996, a major Agency-wide restructuring took place that aimed to reduce NASA Headquarters staffing and transfer most technology development and commercialization activities to individual program offices and Field Centers.[24] The Office of Space Communications (Code O) merged into the Office of Space Flight, becoming another division at the same level as the Space Station program, Space Shuttle program, and Advanced Projects office.[25] The new Communications Division was headed by David W. Harris, who had previously led the Program Integration Division in the Office of Space Communications.

At the same time, the Office of Space Access and Technology (Code X), where the RLVs program was located, was disbanded. Work into space research and technology returned to Code R, now renamed the Office of Aeronautics and Space Transportation Technology. A Space Transportation Technology organization was created as well as a Space Transportation Division, both headed by Payton, who had headed the Space Transportation division in Code X. The Advanced Space Transportation office, charged with NASA's X-33 and X-34 launch vehicle technology development programs, was relocated to Code R.

Trafton resigned as Associate Administrator of the Office of Space Flight in November 1997. Joseph H. Rothenberg, Director of Goddard Space Flight Center, was appointed to the position in January 1998, becoming NASA's fourth Associate Administrator for the Office of Space Flight in little more than three years. In July 1998, the Office of Space Flight reorganized into four functional offices: 1) Operations, headed by William Readdy, which included ELVs, led by Karen Poniatowski; Space Communications, headed by Robert Spearing; and Space Operations Utilization, led by Robert L. Elsbernd; 2) Enterprise Development, led by Darrel Branscome, which included Advanced Projects, Strategic Planning, and Outreach 3) Business Management, led by Michael Reilly; and 4) Development, led by Gretchen McClain; (see Figure 2–8).

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[24] Anne Eisele, "Restructuring Would Slash Headquarters," *Space News* (July 1–7, 1996): 4.

[25] Charles T. Force, Associate Administrator for the Office of Space Communications (Code O), had resigned from NASA in May 1996, before the announcement of the merger of Code O into Code M. "Force To Leave NASA," *NASA News* Release 96–88, May 3, 1996, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1996/96-88.txt* (accessed March 3, 2005).

Money for NASA's Launch Systems

Budget Structure

The federal appropriation categories funding NASA space transportation and launch programs and activities changed in the mid-1990s. For the first four years of the 1989–1998 decade, they were funded by R&D and SFC&DC appropriations. With the FY 1993 budget year, NASA changed its appropriation categories to HSF, which included all Space Shuttle activities, and SAT, which included experimental or development initiatives.[26] ELVs also fell within the SAT appropriation until 1998, when it moved to HSF.

When NASA began using HSF and SAT appropriations, the names and descriptions of many of the subordinate programs and budget categories remained as they had been with the R&D and SFC&DC budget structure. Exceptions are noted below each table. If it is unclear whether a new budget category was merely a name change or whether it indicated a new or modified program, the new name is treated as a new budget category.

A large portion of NASA's budget went to fund Space Shuttle activities, and most space transportation budget categories in the annual budget relate to the Space Shuttle. Expendable launch systems received relatively little attention because NASA obtained most expendable launch services from the commercial sector. The main focus of non-Shuttle launch services in the annual budget related to the mission is to develop new and alternative reusable launch systems and reduce the cost of access to space.

In most cases, the authorization and appropriations bills funding NASA's programs addressed only major budget categories and did not provide much detail regarding where funds should be spent. Authorization bills provided more detail than appropriations bills, at least showing amounts for Space Transportation Capability and Development in the R&D appropriation and for Space Shuttle Production and Operational Capability and Space Shuttle Operations in the SFC&DC category. When the appropriation categories changed to HSF and SAT, the authorization bills typically provided amounts for Payload and Utilization Operations; Space Shuttle Safety and Performance Upgrades; Shuttle Production and Operational Capability; and Space Shuttle Operations in the HSF appropriation. In the SAT appropriation, Congress provided amounts for Advanced Concepts and Technology (Space Access and Technology). Congress only occasionally indicated that a particular amount was authorized for a specific project. Amounts for ELVs and launch services were occasionally provided separately, but many were not budgeted separately from the larger categories.

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[26] These appropriations funded additional NASA programs.

Authorization bills provided more detail than appropriations bills, which provided almost no detail. Appropriations bills generally gave a total amount only for R&D and another for SFC&DC. After the change in appropriation categories, they gave an amount for HSF and one for SAT.

Congress based total authorized and appropriated funding on NASA's annual budget estimates provided to the President and presented to Congress. These detailed estimates formed the basis for NASA's operating plan and the amounts each program would actually spend. The House and Senate subcommittees and committees used these budget estimates for their discussions and often prepared reports dealing with the estimated amounts; but except where specific amounts were included in the authorization or appropriations bills, these reports did not legally require NASA to spend funds in a certain way except in very broad categories.

Phase I: FY 1989–FY 1992

During this period, the R&D and SFC&DC appropriations funded NASA's launch systems, as well as other NASA programs. The R&D appropriation funded Space Shuttle programs in the Space Transportation Capability Development category. These included activities such as the Tethered Satellite System; Spacelab; development and procurement of upper stages; engineering and technical base support at the human spaceflight NASA Centers (Johnson Space Center, Kennedy Space Center, Marshall Space Flight Center, and Stennis Space Center); payload operations and support equipment; studies into advanced launch systems; and other advanced programs and development activities. Space Transportation Capability Development also funded all Space Station activities (discussed in chapter 3).

The SFC&DC appropriation funded the operational activities of the Space Transportation System. The system's two major elements were Shuttle Production and Operational Capability and Space Transportation (Shuttle) Operations. Shuttle Production and Operational Capability provided for the fleet of orbiters; main engines; launch site and mission operations requirements; spares; production tooling; and related supporting activities. The appropriation also provided funds for development of an Advanced Solid Rocket Motor. Space Transportation Operations included standard operational support services for the Space Shuttle and the procurement of ELVs. This budget category funded the production of flight hardware, overhaul and repair of equipment, and labor and materials needed for flight and ground operations. The SFC&DC appropriation also was used to fund the tracking and communication systems used for all NASA flight projects.

Phase II: FY 1993–FY 1998

In FY 1993, R&D and SFC&DC budget items involving space transportation were placed into a new HSF appropriation or into the Science, Applications and Technology appropriation. The HSF appropriation included the on-orbit infrastructure (Space Station and Spacelab), transportation capability (Space Shuttle program, including operations, program support and performance, and safety upgrades), and the Russian Cooperation program (which included flight activities associated with the cooperative research flights to the Russian *Mir* Space Station). HSF appropriation activities were funded in the following major budget line items: 1) Space Station, 2) Russian Cooperation, 3) Space Shuttle, and 4) Payload Utilization and Operations. The Space Shuttle budget had two major categories: Safety and Performance Upgrades and Space Shuttle Operations. Safety and Performance Upgrades corresponded most closely with the old SFC&DC Shuttle Production and Operational Capability budget category. Payload Utilization included funding to support payloads flying on the Shuttle and Spacelab, as well as advanced technology projects and engineering technical base support for the Field Centers supporting HSF flight activities. Space Station, Russian Cooperation, and Spacelab are discussed in chapter 3. Space Shuttle and the Payload Utilization and Operations activities are discussed in this chapter.

The new SAT appropriation provided funding for NASA's research and development activities, in particular, "to extend knowledge of the Earth, its space environment, and the universe; and to invest in new technologies, particularly in aeronautics."[27] The two categories in the SAT appropriation most directly related to space transportation or launch systems were 1) Advanced Concepts and Technology (as it was called in FY 1995) or Space Access and Technology (beginning in FY 1996), and 2) Launch Services, consisting primarily of the ELV budget formerly included in the SFC&DC appropriation. Launch Services sometimes appeared in budget documents as a separate budget category under the SAT appropriation. At other times, it was shown as a subcategory in the Office of Space Science and Applications. Notes below the funding history tables that follow identify items funded from the SAT appropriation.

Funding History

For the 1989–1991 fiscal years, funding increased for launch systems and, in particular, the Space Shuttle. Payload operations and support declined slightly as did upper stages. Space Transportation Capability Development in the R&D appropriation peaked in 1991 at $763,400,000. In the SFC&DC appropriation, Space Shuttle Production and Operational Capability reached its

[27] "General Statement," *National Aeronautics and Space Administration, Science, Aeronautics and Technology, Fiscal Year 1995 Estimates*, p. SAT SUM-1.

high of $1,364,000,000 in 1991. Funding for Space Transportation Operations continued to rise for two more years, reaching its high of $3,085,200,000 in 1993. ELV funding, which had dropped in 1993, rose in 1994 to $300,300,000.

In 1992, the downward slide for Space Shuttle operations began as rising costs for the Space Station drained the budget. The SFC&DC Space Shuttle Production and Operational Capability authorization dropped from $1,364,000,000 in FY 1991 to $1,328,900,000 in FY 1992. The amount authorized for Space Transportation Capability Development dropped from $763,400,000 in the FY 1991 authorization to $679,800,000 in FY 1992; it rose somewhat in FY 1993 to $733,700,000 and almost to its FY 1991 level in FY 1994, reaching $7,509,300,000. The amount for Space Shuttle Operations continued to rise until FY 1994, when it dropped from $3,085,200,000 to $3,006,500,000.

In FY 1995, appropriated amounts used the new HSF appropriation categories, which covered the operational end of launch systems, and SAT for developmental areas of space transportation. It was clear that, beginning with FY 1995, the HSF budget dropped considerably. Between FY 1995 and FY 1997, the appropriated amount decreased from $5,592,900,000 to $5,362,000,000. This included a $94 million general reduction taken from Space Shuttle operations.[28] The decline reflected a concerted Clinton administration effort to reduce the deficit while dealing with greater costs for the Space Station. The FY 1996 appropriation, coming at the end of an arduous six months of discussions that included 14 continuing resolutions and two government shutdowns, allotted HSF 1 percent less than NASA's request and 1.1 percent less than its FY 1995 amount. This decrease took place even though the Space Station received 1.1 percent more than it had in FY 1995, making the cuts to the Space Shuttle program even more pronounced.[29] The amount appropriated to SAT, which handled work on new RLVs, rose in FY 1997, but dropped in FY 1998 from $711,000,000 to $696,000,000. At the same time, in FY 1998, the appropriation for HSF rose again to $5,506,500,000.

The following tables reflect the budget categories as broken down by NASA and authorized by Congress. Table 2–1 shows congressional action. Notes below the table indicate when amounts were appropriated rather than authorized. Table 2–2 shows programmed amounts. These amounts formed NASA's operating plan, i.e., what NASA budgeted for particular activities during a fiscal year. On both these tables, the reader should not assume that subordinate amounts below a major budget category equal the amount shown above in the major budget category. Some subordinate budget categories are not launch-related and are not included in these tables.

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[28] "Senate Appropriators Approve $14.4 Billion for NASA," *Aerospace Daily* (July 15, 1994): 79.

[29] "Results of FY 1996 Appropriations Process," *The American Institute of Physics Bulletin of Science, Policy News,* no. 86 (May 30, 1996), *http://www.sdsc.edu/SDSCwire/v2.12/FY96results.html* (accessed March 14, 2005).

The following series of tables show the amounts NASA submitted in its annual budget estimates (see Tables 2–3 through 2–57). NASA submits a budget estimate two years before the start of each fiscal year and then a revised estimate a year later. The tables show both the original and revised estimates, separated by a forward slash. If only one amount is shown (either before or after the forward slash), NASA's budget estimate documents referenced that budget category only once—either in its original budget estimate, shown before the forward slash. or in the revised budget estimate, shown after the forward slash. If a category was mentioned in an authorization bill, that amount is shown.

Authorized and appropriated amounts come from the appropriate authorization or appropriations bill.[30] If no authorized or appropriated amount is shown for a particular category, then the bills did not address that category. Submitted and programmed amounts come from the annual NASA budget estimates. NASA appropriations were included with the Department of Veterans Affairs, Housing and Urban Development, and Independent Agencies appropriations bills for the fiscal year. If no programmed amount is shown, that year's budget did not include a programmed amount for the particular budget category. See the individual budget tables for details.

Expendable Launch Vehicles

Overview

By NASA's fourth decade, America's ELVs were obtained either from the DOD stockpile of retired rockets and modified for space launch purposes or were procured from the private sector according to criteria in NASA's FY 1991 Authorization Act and Launch Services Purchase Act (LSPA) of 1990.[31] The LSPA required NASA to purchase launch services for its primary payloads from commercial providers. This legislation quickly opened up a new market to American industry as the government no longer competed as a launch services provider. Within six months after its passage, one launch services provider, General Dynamics, had decided to fund the construction of 60 new Atlas launch vehicles although it did not yet have a single buyer for the vehicles. Other launch vehicle providers followed suit. In November 1990, NASA signed a contract with McDonnell-Douglas to provide at least three Delta IIs. In September 1991, a contract with Orbital Sciences Corporation was signed for seven Pegasus vehicles. NASA contracted with Martin Marietta in 1994 for intermediate-class launch services on Atlas vehicles, and Orbital Sciences was selected to provide ultra-lite ELV launch services the same year.

[30] Authorization and appropriations bills are available at *http://thomas.loc.gov.*

[31] The Launch Services Purchase Act of 1990 was Title II of the FY 1991 Authorization Act. *National Aeronautics and Space Administration Authorization Act, Fiscal Year 1991*, 101st Congress, 2nd sess., Public Law 101-611 (November 16, 1990).

In the first years following NASA's 1988 return to flight, NASA acquired ELVs noncompetitively for the scientific missions remanifested onto ELVs from the Space Shuttle. NASA acquired all subsequent ELV launch services competitively from the private sector in the small, medium, and intermediate-performance classes, which could launch payloads up to 30,000 pounds (13,600 kilograms). Larger payloads up to 39,000 pounds (17,690 kilograms) were launched aboard the Titan IV/Centaur launch vehicle, developed by Martin Marietta Corporation (later Lockheed Martin). These were acquired from the U.S. Air Force by means of a contract the Air Force had with Martin Marietta since large class launch services were not available directly from the private sector.[32]

During NASA's fourth decade, 215 launches on American ELVs and one joint U.S.-French ELV launch on a European Ariane rocket took place. Almost 94 percent of these launches succeeded. Eight families of ELVs: Athena; Atlas; Conestoga; Delta; Pegasus; Scout; Taurus; and Titan were used. They each had impressive success rates with very few failures. The large majority carried either DOD or commercial payloads. Launch vehicle performance is shown in Figure 2–9 and Table 2–58. ELV activities are summarized in the following section. Some references use the term "partial failure" to discuss specific launches. To allow inclusion in this table and in the graph that follows, each launch is classified as either a success or failure. Partial failures are explained in footnotes below the table.

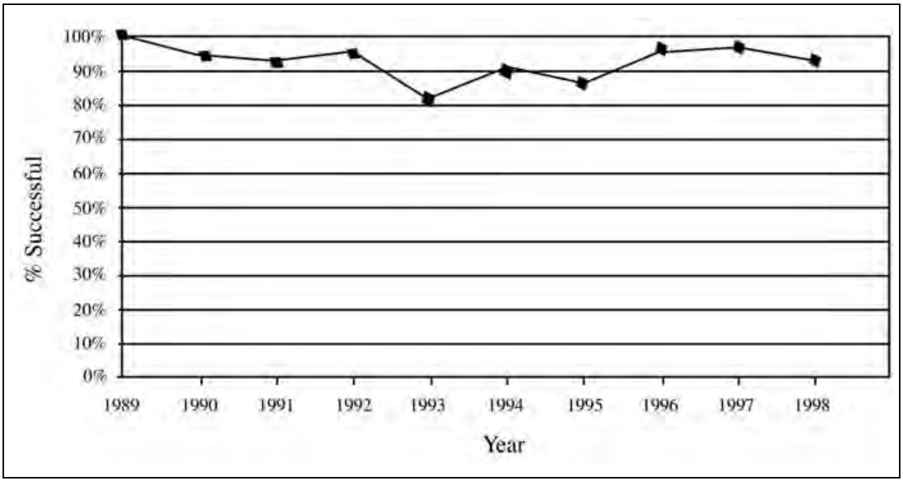

Figure 2–9. Expendable Launch Vehicle Success Rate.

[32] "Space Transportation Operations," *National Aeronautics and Space Administration Fiscal Year 1991 Budget Estimates*, pp. SF 2–11.

1989

In 1989, there were 13 U.S. ELV launches on known launch vehicles: 8 Deltas, 4 Titans, and 1 Atlas. All were successful. One was a NASA scientific spacecraft and one a commercial launch. The remaining launches were DOD satellites.

1990

In 1990, there were 21 U.S. ELV launches: 11 Deltas, 5 Titans, 3 Atlases, 1 Scout, and 1 Pegasus. One Titan launch failed. The launches included one joint NASA–Germany space science satellite, and two joint NASA–DOD environmental research satellites. The remaining satellites were either DOD satellites or commercial communications satellites.

1991

Twelve satellites launched on ELVs in 1991: 5 Deltas, 2 Titans, 4 Atlases, 1 Scout, and 1 Pegasus. One was a NASA launch of a meteorological satellite. The remaining satellites were either DOD or commercial spacecraft. One Atlas launch failed.

1992

Twenty-one satellites launched on American ELVs in 1992: 11 Deltas, 3 Titans, 5 Atlases, and 2 Scouts. Four payloads were science missions. The others were DOD or commercial payloads. One Atlas launch failed. In addition, a joint U.S.–French scientific spacecraft launched on a European Ariane ELV from the Kourou launch complex in French Guiana.

1993

Eighteen satellites launched on American ELVs in 1993: 7 on Deltas, 6 Atlases, 2 Titans, 2 Pegasus, and 1 Scout. One launch was a Department of Energy science payload, two were NASA earth science payloads, and the rest were DOD or commercial payloads. Both Titan launches failed.

1994

In 1994, 20 spacecraft launched on American ELVs: 3 Deltas, 5 Titans, 7 Atlases, 1 Taurus, 1 Scout, and 3 Pegasus. One was a NASA meteorological satellite, one a space science satellite, and the remainder either DOD or commercial satellites. There was one Pegasus launch failure and one Pegasus that inserted its payload into a lower-than-specified orbit.

1995

In 1995, 23 spacecraft were launched on American ELVs—3 were Deltas, 4 Titans, 12 Atlases, 2 Pegasus, 1 Athena, and 1 Conestoga. Payloads included one NASA meteorological satellite, one Canadian remote sensing satellite, two NASA science satellites, and the remainder DOD or commercial satellites. The Athena I, Conestoga, and one of the Pegasus XL launches failed.

1996

There were 26 ELV launches in 1996: 10 Deltas, 7 Atlases, 4 Titans, and 5 Pegasus launches. There were eight science payloads including one joint Italian–Dutch telescope. The rest were DOD or commercial satellites. One Pegasus XL launch failed.

1997

In 1997, 30 spacecraft were launched on ELVs: 11 Deltas, 8 Atlases, 5 Titans, 5 Pegasus, and 1 Athena. These included three Earth science payloads and two space science missions. The remainders were DOD or commercial satellites. One Delta launch failed.

1998

There were 31 ELV launches in 1998: 13 Deltas, 6 Atlases, 3 Titans, 1 Athena, 2 Taurus, and 6 Pegasus. These included five space science payloads and one meteorological payload. The rest were DOD or commercial satellites. One Titan and one Delta, the first Delta III, failed.

Expendable Launch Vehicle Characteristics

The following sections describe each family of U.S. ELVs used from 1989 through 1998. It should be noted that the figures cited in the Launch Characteristics tables are approximations and may not be accurate for all vehicles within a particular model of launch vehicle. Many factors influence detailed specifications. Each payload is different, and the payload size as well as its ultimate orbit will determine the launch vehicle configuration, including the number of stages and strap-on motors, the size of the selected fairing, and the nature of the attach fittings. Variations in payloads also determine the amount of propellant, the burn rate, thrust levels, and other parameters. Source material, although dependable, does not always state under what conditions a particular value is true. For instance, a value for thrust can indicate nominal, maximum, or average force and can exist during liftoff at sea level or in a vacuum. Different payloads and different orbits can also determine performance parameters. The maximum payload for a launch vehicle to low-Earth orbit may be different for a launch from Cape Canaveral, Florida, than for a launch from Vandenberg Air Force Base, California. There are also variations in what is considered low-Earth orbit. The *Aeronautics and Space Report of the President* and the Federal Communications Commission use a 185-kilometer (100-nautical-mile) orbit; other sources range from 144 kilometers to 196 kilometers (78 nautical miles to 106 nautical miles) or consider low-Earth orbit to be the orbit flown by the Space Shuttle.[33]

Measurements are stated in the original units used in the source material. Some measurements will appear as English units and some as metric units. The conversion to the other unit of measure follows in parentheses.

This chapter uses the following abbreviations for propellants: LH_2 = liquid hydrogen, LOX = liquid oxygen, N_2H_2 - = hydrazine, N_2O_4 = nitrogen tetroxide, RJ-1 = liquid hydrocarbon, and RP-1 = kerosene.

Athena Launch Vehicle

The Athena launch vehicle was a privately funded solid-propellant launch vehicle developed by Lockheed Martin beginning in 1993 to carry small to medium payloads into low-Earth, geostationary transfer, and interplanetary orbits. It was initially called the Lockheed Launch Vehicle (LLV) and then the Lockheed Martin Launch Vehicle (LMLV) after Lockheed merged with Martin Marietta in 1994. The core launch vehicle was called LMLV-1, later renamed Athena I. A larger version, the LMLV-2, was renamed Athena II.

Both vehicle models used a 92-inch (234-centimeter)-diameter fairing, and both used solid motors and a small liquid injection stage called the orbit adjust module as its top stage. The top stage contained the altitude control and avionics subsystems. The Athena I and Athena II both had a Castor 120 first stage, a commercial motor made by Thiokol derived from the Peacekeeper intercontinental ballistic missile first-stage motor and modified for space launch use. The Athena II's second stage was another Castor 120. The second and third stages of the Athena I were the same as the third and fourth stages of the Athena II: a Pratt & Whitney Orbus 21D motor and an orbit adjust module powered by four Primex MR-107 engines using hydrazine fuel. The orbit assist module was available with four or six propellant tanks, depending on mission requirements. Figure 2–10 shows the Athena I and Athena II configurations.

The first Athena I launch took place on August 15, 1995. This launch failed when the thrust vector control system failed. The first successful launch was on August 23, 1997, from Vandenberg Air Force Base. Its payload, the Lewis satellite, failed shortly after launch. Later launches of Athena I were planned to take place from the Kodiak Launch Complex in Alaska.

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[33] "Glossary," NASA Life Sciences Data Archive, *http://lsda.jsc.nasa.gov/kids/L&W/glossary.htm* (accessed February 9, 2005). Also "Genesis: Search for Origins," Jet Propulsion Laboratory, *http://www.genesismission.org/glossary.html* (accessed February 9, 2005).

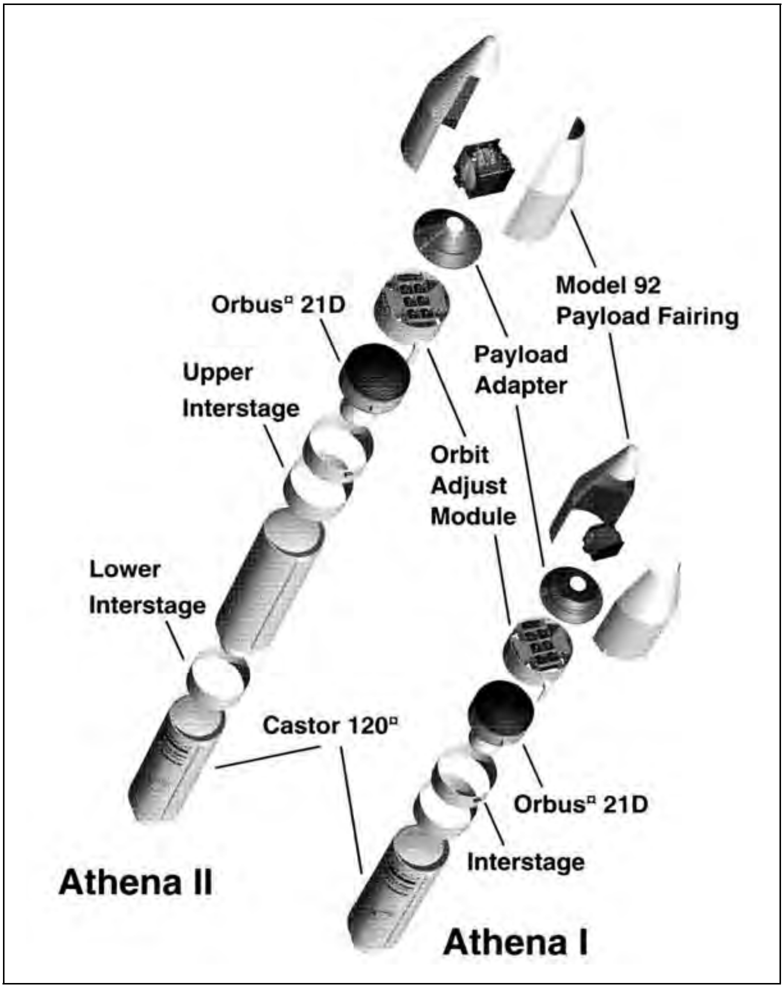

Figure 2–10. Athena I and Athena II. (Lockheed Martin)

Athena II successfully launched NASA's Lunar Prospector into orbit from Cape Canaveral Air Station on January 7, 1998. The Athena II's third stage enabled it to launch larger payloads. Table 2–59 lists Athena launches. Tables 2–60 and 2–61 list Athena I and Athena II characteristics.

The Atlas Family

The Atlas rocket was America's first intercontinental ballistic missile (ICBM). The Air Force used the missile only briefly as an ICBM, however, and made its surplus rockets available for use as space launch vehicles in the 1980s after adding an upper stage allowing the modified rockets to place various types of payloads into low-Earth orbit.

The surplus rockets were used quickly in their new role, and only a few Atlas E and Atlas G Centaur launch vehicles remained in the surplus inventory by the end of the 1980s. NASA used these remaining rockets and then started using new Atlas I, II, IIA, and IIAS launchers.

The production of Atlas rockets was government-initiated through the production of the Atlas G Centaur. The commercial sector took over launch services in June 1987. The first commercial launch took place in July 1990 with the first Atlas I rocket.[34]

The Convair Division of General Dynamics built Atlas rockets at the beginning of the program. Martin Marietta acquired Convair's launch vehicle division in 1994 and took over Atlas production until Martin Marietta merged with Lockheed in 1996 to form Lockheed Martin, the current Atlas producer. All Atlas models, except the Atlas E, used the liquid-fueled Centaur as their upper stage to provide added thrust. This upper stage, developed by General Dynamics for NASA, had been used since the 1960s. The Atlas E used solid-fueled apogee kick motors to supply extra power.

The Atlas I was the first Atlas product using a new naming convention, initiated when Lockheed began using the Atlas for commercial launches in the late 1980s. Rather than use the old letter designation for its rockets (Atlas E, F, and G, for example), Lockheed began using Roman numerals. A letter after the Roman numeral designated different variations in each family, such as Atlas IIA and Atlas IIAS, in which "S" indicated a strap-on motor.

The Atlas has been a dependable launch vehicle with only a few launch failures. Table 2–62 lists all Atlas launches between 1989 and 1998.

Atlas Characteristics

The Atlas launch vehicle system consisted of the Atlas booster (composed of a booster and a sustainer section), the Centaur upper stage, the payload fairing, and an interstage adapter located between the booster/sustainer stage and the Centaur stage. The launch vehicle was typically called a "one-and-a-half"-stage vehicle. The booster stage engines flanked the smaller sustainer engine and did not carry any propellant. The sustainer section contained propellant tanks for both the booster and sustainer burns. All engines ignited at liftoff, and the two smaller vernier engines on the Atlas E and G and Atlas I models ignited seconds later.[35] This differed from later rockets in which the stages fired sequentially.

[34] "Atlas," Lockheed Martin Space Systems Company, *http://www.lockheedmartin.com/wms/findpage.do?dsp=fec&ci=14917&5c=400* (accessed July 18, 2006).
[35] The "I" in Atlas I refers to the Roman numeral "one," not the letter "I."

Atlas E

Atlas E was first used as a launcher in 1960. The last Atlas E launch took place on March 24, 1995, when it launched a military weather satellite into orbit. All Atlas E launches during this period took place from Vandenberg Air Force Base in California. The Atlas E was the only Atlas launch vehicle during this period not using a Centaur upper stage. It obtained additional boosting power from its apogee kick motor (AKM). Dimensions stated in Table 2–63 are approximate because more than one AKM model was used and fairings varied in length.

Atlas G Centaur

The Atlas G Centaur, used primarily to launch communications satellites, was an improved version of the earlier Atlas Centaur launch vehicle. It was 81 inches (2.06 meters) longer than its predecessor to allow greater fuel capacity and had increased booster thrust of 7,500 pounds (33.36 kilonewtons), leading to a total liftoff thrust of 438,877 pounds (1,950 kilonewtons).[36]

The Atlas G Centaur was first used in 1984 with an Intelsat satellite. The final Atlas G Centaur launch took place on September 25, 1989, with the launch of Fltsatcom-8. This launch marked the last NASA-managed ELV launch. From then on, NASA purchased launch services from a series of contractors. Table 2–64 shows Atlas G Centaur characteristics.

Atlas I

The Atlas I was the first of a new family of launch vehicles that could boost payloads into low-Earth orbit, geosynchronous-Earth orbit, and on interplanetary trajectories. The launch vehicle was very similar to the Atlas G Centaur, and it included two boosters, a sustainer, two vernier single-start engines, and a Centaur upper stage. An interstage adapter separated the Atlas stage from the Centaur. The vehicle had two new payload fairings, incorporated significant improvements in the guidance and control systems, and replaced analog flight control components with digital units interconnected with a digital data bus. Figure 2–11 shows an Atlas I. Table 2–65 lists Atlas I characteristics.

The first Atlas I flight took place on July 25, 1990, with the launch of the Combined Release and Radiation Effects Satellite (CRRES), a joint NASA-U.S. Air Force project. The final Atlas I launch took place on April 25, 1997, with the launch of GOES-10 into geosynchronous orbit. Although launch parameters varied slightly depending on launch date, launch time, and payload weight, Table 2–66 presents a typical launch sequence for a geosynchronous mission.

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[36] "Atlas," GlobalSecurity.org, *http://www.globalsecurity.org/space/systems/atlas.htm (accessed* January 26, 2005).

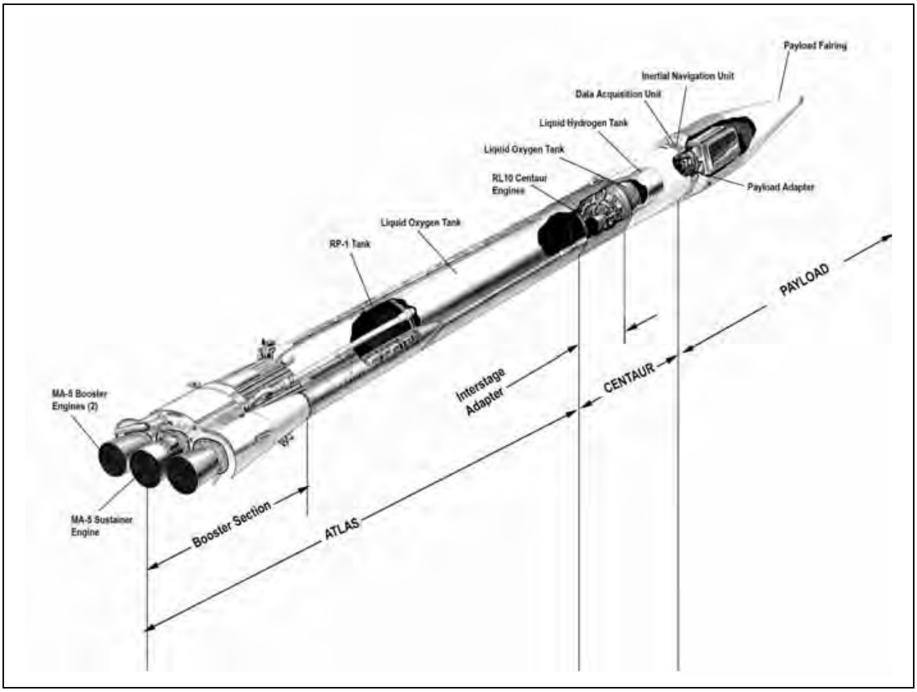

Figure 2–11. Atlas I Components.

General Dynamics produced eleven Atlas I ELVs before the program shifted to Atlas II production. Three Atlas I launches failed to propel their payloads into orbit.

Atlas II Series

The Atlas II series consisted of the Atlas II, the Atlas IIA, and the Atlas IIAS models. Development of the first of these vehicles began in June 1988. They were originally developed to launch the Air Force Defense Satellite Communications System satellites, part of the Air Force Medium Launch Vehicle II program.

The Atlas II launch vehicles were an improved version of the Atlas-Centaur rockets. They provided higher performance by using engines with greater thrust and longer fuel tanks for both the Atlas and Centaur stages. This resulted in increased payload capability. The Atlas II replaced the MA-5 propulsion system used in the Atlas I with the improved MA-5A system. The Atlas II also replaced the vernier engines of Atlas I and earlier Atlas vehicles with a hydrazine roll control system located on the Atlas II interstage that had lower-cost electronics and an improved flight computer.

The Atlas II had a longer booster than the Atlas I for greater fuel stage-one capacity and used upgraded MA-5A engines, improved structures, and a new stabilization system. It also featured a lengthened Centaur upper stage that held more fuel and thus had better upper-stage performance.[37] The Atlas II was the only Atlas to use two R-4D attitude control thrusters for attitude and orbit adjustments.

The first Atlas II flew December 7, 1991, launching Eutelsat II F3. The last Atlas II launch took place March 16, 1998, with the launch of USA 138 (UHF-8), a communications satellite for DOD that replaced the old FLTSATCOM satellites.

With Atlas II, the manufacturers changed the terminology referring to the number of stages although the configuration remained essentially the same as earlier vehicles. The vehicle was then referred to as having "two-and-a-half" stages. These stages consisted of the booster, sustainer, interstage, and Centaur upper stage.

A total of 10 Atlas II launches took place; all were successful. Table 2–67 lists Atlas II characteristics.

The Atlas IIA was the commercial version of the Atlas II. It incorporated higher performance RL10 engines and optional extendible nozzles that provided added thrust to the Centaur upper stage. The first Atlas IIA flight took place on June 8, 1992, with the launch of Intelsat-K. Through the end of 1998, 15 Atlas IIA launches took place; all were successful. Table 2–68 lists Atlas IIA characteristics.

The Atlas IIAS was similar to the earlier Atlas IIA launch vehicle except that this model used four additional strap-on Castor IVA solid rocket boosters (SRB), which provided an average thrust of 433.7 kilonewtons (97,500 pounds) each. These SRBs fired two at a time. The first pair fired at liftoff. The second pair fired during flight after the first pair had burned out, approximately 54 seconds after liftoff. Both pairs were jettisoned soon after each pair burned out. The structure of the first stage was stronger to accommodate the SRBs. Table 2–69 lists Atlas IIAS characteristics. Figure 2–12 shows the Atlas IIAS configuration for the launch of the Solar and Heliospheric Observatory (SOHO) on December 2, 1995.

The first Atlas IIAS launched Telstar 401 on December 15, 1993. Through the end of 1998, 14 Atlas IIAS launches had taken place; all were successful.

[37] "The Evolution of Commercial Launch Vehicles," *Fourth Quarter 2001 Quarterly Launch Report*, *http://ast.faa.gov/files/pdf/q42001.pdf* (accessed January 17, 2005).

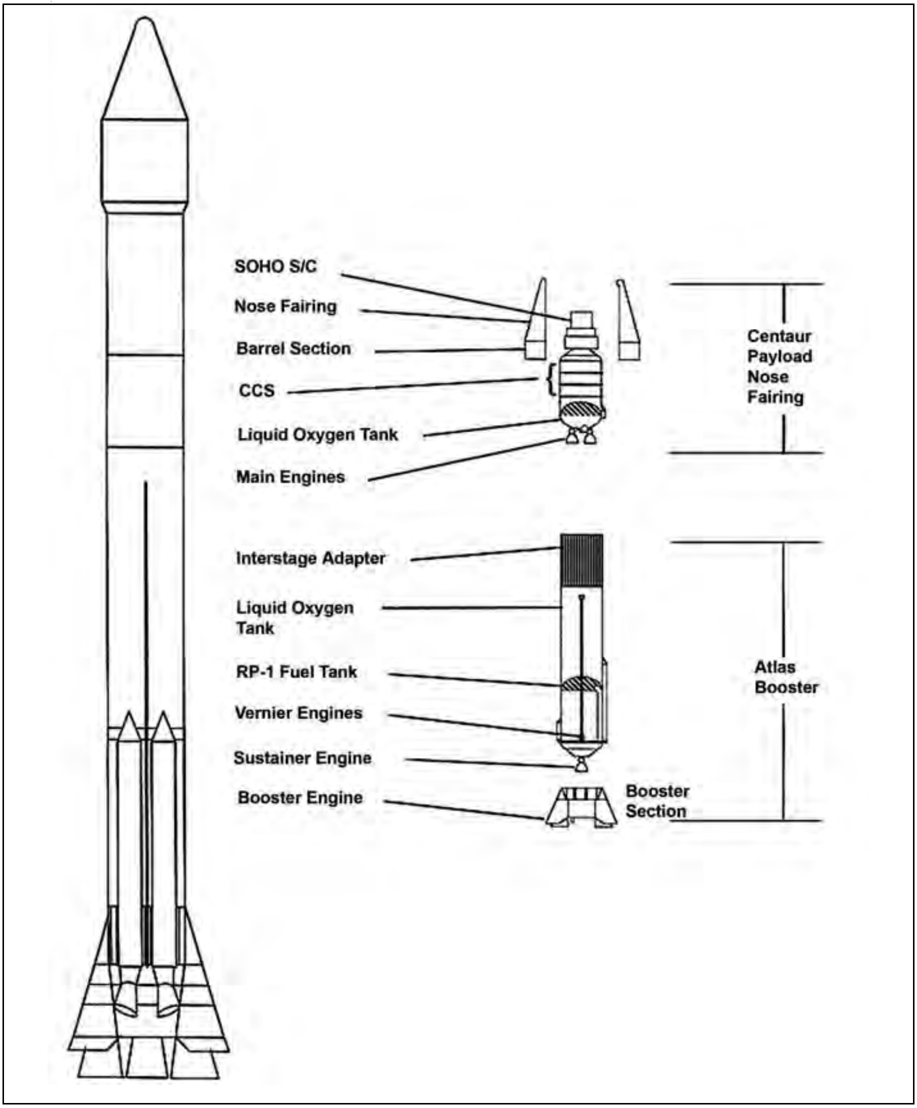

Figure 2–12. Atlas IIAS Launch Vehicle–SOHO Configuration, December 2, 1995. (NASA)

Conestoga Launch Vehicle

The Conestoga was a solid-propellant commercial launch vehicle that attempted to launch the Multiple Experiment Transporter to Earth Orbit and Return (METEOR 1) payload originally known as COMET for Commercial Experiment Transporter into low-Earth orbit in 1995. The privately funded launcher was designed to answer a need by the civilian and military community for a vehicle to launch small size orbital and suborbital payloads (500 pounds to 5,000 pounds) into low-Earth orbit. In 1982, Space Systems Inc. (SSI), managed by Mercury astronaut Donald “Deke” Slayton, successfully launched a single-stage, solid-fueled rocket as a test, ejecting its payload as planned.[38] The rocket was based on an Aerojet M56-A1, the second stage of a Minuteman ICBM. The company was the first to obtain a commercial launch license, in 1985 receiving Department of Transportation mission approval. In 1986, SSI signed the industry's first agreement to use a U.S. Government launch range, Wallops Flight Facility on the Eastern Shore of Virginia, as a commercial launch site.[39]

In November 1990, EER Systems purchased SSI, integrating it into EER's Space Systems Group. In 1991, NASA selected EER to provide Conestoga launch services for its METEOR satellite, a microgravity carrier program. METEOR was to be a recoverable payload, designed for on-orbit microgravity experiments that advanced commercial applications of materials processing and medical research.[40]

The Conestoga launch vehicle had a modular design, which provided a wide range of configurations for various purposes. It's Thiokol booster stage rockets consisted of one core Castor IVB surrounded by a combination of two to six more strap-on Castor IVA or IVB solid rocket motors. A Star 37, 48, or 63 upper stage motor sat immediately above the core booster motor. Four strap-on motors ignited at launch; they were followed by two more, and finally the central Castor. A cold gas reaction control system, located within the payload attach fitting, controlled pitch, yaw, and roll during fourth stage coast, burn, and payload separation. The hydrazine maneuvering and attitude control system sat above the Star motor upper stage and provided velocity augmentation and control of pitch, yaw, and roll. The avionics power, electronics, and guidance equipment were within the payload attach fitting. An aerodynamic payload fairing available in several sizes covered all components from the payload down to and including the Star motor. Varying the number of strap-on motors and selecting the appropriate upper stage extended the Conestoga's performance range from 500 pounds to 5,000 pounds to low-Earth orbit.[41]

METEOR was originally planned as a three-mission project with the first launch initially scheduled for September 1992. However, late delivery of the solid rocket motors delayed completion of the launch vehicle. Management difficulties with the Center for Space Transportation and Applied Research (CSTAR) at the University of Tennessee (the commercial center that had proposed the mission and which provided oversight), as well as rising costs forced NASA to reduce the project to a single mission. Agency review of the

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[38] Deke Slayton was one of the original Mercury astronauts but was relieved of his assignment and did not fly because of a heart condition. After he was cleared to resume full flight status in 1972, he made his first spaceflight as Apollo docking module pilot of the Apollo-Soyuz Test Project mission, July 15–24, 1975.

[39] Isakowitz and Samella, *International Reference Guide to Space Launch Systems,* 2nd ed., p. 220.

[40] U.S. Department of Transportation, Federal Aviation Administration, "Special Report: U.S. Small Launch Vehicles," *Commercial Space Transportation Quarterly Launch Report, 1st Quarter 1996*, *http://ast.faa.gov/files/pdf/sr_96_1q.pdf* (accessed November 2, 2005).

[41] M. Daniels and B. Saaverdra, "The Conestoga Launch Vehicle—A Modular Approach to Meeting User Requirements," AIAA-94-0893, 15th American Institute of Aeronautics and Astronauts International Communications Satellite Systems Conference, February 27–March 3, 1994.

project continued into 1994 as NASA Administrator Goldin announced that NASA would refuse to continue funding the project. There also was the question of liability if the reentry module landed outside the sparsely populated Great Salt Lake desert in Utah. Congress, however, released the needed funds on condition that the contractors agreed to waive NASA's legal liability. NASA also insisted that CSTAR depart from the program. After further discussion with the three contractors providing elements of the vehicle, NASA signed a sole source, fixed-price contract with EER Systems.[42]

After further delays, launch finally took place on October 23, 1995. It was the first orbital flight from Wallops Flight Facility in 10 years.[43] After a promising liftoff, the rocket went off course when its first stage steering mechanism ran out of hydraulic fluid and became inoperable. Forty-six seconds after liftoff, 23 kilometers off Virginia's coast at an altitude of 10 kilometers, the Conestoga broke apart. The destruction resulted in the loss of the METEOR and the 14 microgravity experiments on board. EER Systems left the launch business and abandoned the project. See Table 2–70 for characteristics of the Conestoga 1620, the model that carried the METEOR.

The Delta Family

NASA has used the Delta launch vehicle since 1960 and has regularly upgraded the vehicle as the need for payload capacity grew. The vehicle has a high success rate. In the decade from 1989–1998, 82 Delta launches took place with only two failures. Table 2–71 lists all Delta launches.

The 2900 series was planned as the last Delta series. However, because the Space Shuttle was not yet ready to become an operational space launcher and NASA needed a vehicle with heavier payload capacity, the Delta 3000 series was developed in the late 1970s and early 1980s for payloads that were too heavy for Delta 2000s but did not require the Atlas-Centaur. Because the 3000 series was considered an interim vehicle for medium-weight payloads, NASA not did finance its development and production but instead bought completed vehicles for its civilian and commercial launches from McDonnell Douglas, which obtained private financing for the series. Table 2–72 lists Delta 3920 characteristics.

Delta production formally ended at the end of 1984 when its production line at Huntington Beach, California, closed. But when the *Challenger* explosion brought out the need for launch alternatives, NASA decided to resume using ELVs and reactivated the Delta production line. At the same time, President Ronald Reagan announced that the Space Shuttle would stop carrying commercial payloads.

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[42] Andrew Butrica, "The Commercial Launch Industry, Technological Change, and Government-Industry Relations," *http://www.hq.nasa.gov/office/pao/History/x-33/butr02.htm* (accessed November 3, 2005).
[43] "Conestoga," GlobalSecurity.org, *http://www.globalsecurity.org/space/systems/conestoga.htm* (accessed November 3, 2005).

The commercial Delta era began in January 1987 when the U.S. Air Force announced its selection of McDonnell Douglas to produce seven Deltas IIs to launch its NAVSTAR Global Positioning System (GPS) satellites, originally manifested for the Space Shuttle. The initial contract expanded to 20 vehicles in 1988 when the Air Force exercised two contract options. In the interim, the remaining stock of older Deltas was modified for three missions: the Delta 4925 combined the earlier MB-3 engine with enhanced Castor IVA strap-on motors to launch the BSB-R1 and Insat 1-D satellites, and the Delta 5925 used Castors with the RS-27 engine to launch the Cosmic Background Explorer for NASA. On July 1, 1988, the Air Force officially received custody of Launch Complex 17, located at Cape Canaveral Air Force Station, Florida, from NASA and took over East Coast launch operations, ending 28 years of Delta launches managed by NASA.[44]

McDonnell Douglas built on its successful Delta 3920/PAM-D model to produce the Delta II. The first Delta II, the 6925, flew on February 14, 1989, launching the first of nine Air Force GPS satellites into orbit 20,200 kilometers (10,900 nautical miles) above Earth. NASA first contracted commercially for the Delta II in December 1990 for launch of its Geotail, Wind, and Polar science satellites, which launched in 1992, 1994, and 1996, respectively. NASA was the first U.S. government agency to procure commercial launch services.[45]

The first stage of the Delta 6925 was an 85.6-foot (26-meter)-long Extra Extended Long Tank powered by an RS-27 engine and augmented by nine Castor IVA strap-on motors. The second stage used an Aerojet AJ10-118K engine that delivered approximately 9,645 pounds (42.4 kilonewtons) of thrust. The third stage payload assist module (PAM)-D, equipped with a Thiokol Star 48B solid rocket motor, delivered approximately 15,100 pounds (67 kilonewtons) of thrust and made the vehicle suitable for geosynchronous and Earth-escape missions. Table 2–73 lists Delta II 6925 characteristics.

The versatile Delta II could be configured as a two-stage or three-stage vehicle and could launch with three or four strap-on motors as well as with the more common nine strap-ons. Both two-stage and three-stage Deltas could support 9.5-foot (2.9-meter) and 10-foot (3.05 meter)-diameter fairings. When nine strap-ons were used, six were ignited at launch and the remaining three ignited in flight. The 9.5-foot fairing was primarily designed for the three-stage Delta.[46] The 10-foot (3.05-meter) fairing was lighter than the one it replaced and was also available in a longer version for taller payloads. Typically, two-stage Deltas launched satellites to low-Earth orbit, while three-stage Delta IIs delivered payloads to geosynchronous transfer orbit or were used for deep-space missions.

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[44] "Delta Launch Complex Transferred to Air Force," *NASA News* Release 88-99, July 15, 1988. (NASA History Office Folder 010241).

[45] "Review notes from Charles Gunn September 1, 2005.

[46] "Boeing Delta II Medium Launch Vehicle," Delta II Backgrounder, *http://www.boeing.com/defensespace/space/delta/delta2/contour/mission_info/backgrounders/delta_2_backgrounder.htm* (accessed January 31, 2005).

Also, the Delta II could launch one or more payloads on the same launch vehicle by using a variety of payload attachments. Figure 2–13 shows the Delta II with nine strap-ons.

Several other Delta IIs were developed that eventually replaced the 6925: the 7326, 7420, 7425, the 7920, and the most powerful, the 7925. All Deltas in the 7000 series were equipped with an improved engine designated the RS-27A that boosted engine performance. Also, more power and longer Hercules (later Alliant Techsystems) graphite epoxy motors (GEMs) replaced the Thiokol Castor IVA solid rocket motors. Each GEM was 42.5 feet (13 meters) long and provided 446 kilonewtons (100,300 pounds) of thrust at liftoff (see Table 2–74 and Figure 2–14).[47] The 7925 first flew in November 1990 to launch a NAVSTAR GPS satellite. Other Delta missions launched satellites to Mars, toward asteroids and comets, and were used for Earth-observation and astronomy missions. Figure 2–15 compares the Delta 3920, Delta II 6925, and Delta II 7925.

In 1995, McDonnell Douglas began Delta III development to fulfill growing customer needs for a higher capacity commercial launch service.[48] With a payload delivery capacity to geosynchronous transfer orbit of 3,810 kilograms (8,400 pounds), the Delta III effectively doubled the performance of the Delta II. The first Delta III launch took place in 1998, but a successful launch did not occur until August 2000. Table 2–75 lists the sequence of events for a typical Delta launch to geosynchronous orbit.

Pegasus Booster

The Pegasus was the first all-new U.S. space launch vehicle since the 1970s and the only air-launched space booster vehicle attempted in the United States in approximately 30 years when the U.S. Navy attempted the unsuccessful Project Pilot. Considered the operational successor to the long-lived Scout launch vehicle in the small-payload, solid-propellant-motor category, the Pegasus was developed jointly by Orbital Sciences Corporation and Hercules Aerospace Company (later Alliant Techsystems of ATK Thiokol Propulsion Company).[49] Hercules was responsible for the design and production of the new solid rocket motors and the payload fairings. Orbital was responsible for the remaining mechanical and avionics systems, ground and flight software, the carrier aircraft interface, mission and vehicle integration, overall systems engineering, and program management. The development cost of more than $50 million was split evenly between the two partners.[50]

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[47] Mark Cleary, "Delta II Overview," in *Delta Space Operations at the Cape, 1993–2001*, *https://www.patrick.af.mil/heritage/DELTA%20II%20Overview.htm*, (accessed January 31, 2005).

[48] Boeing acquired the launch organization from McDonnell Douglas in 1997 and transferred production of the Delta to its facilities.

[49] Matt Bille, Pat Johnson, Robyn Kane, and Erika R. Lishock, "History and Development of U.S. Small Launch Vehicles," in *To Reach the High Frontier, A History of U.S. Launch Vehicles*, Roger D. Launius and Dennis R. Jenkins, ed. (Lexington, KY: The University Press of Kentucky, 2002), p. 214.

[50] Isakowitz et al., *International Reference Guide to Space Launch Systems,* 3rd ed., p. 279.

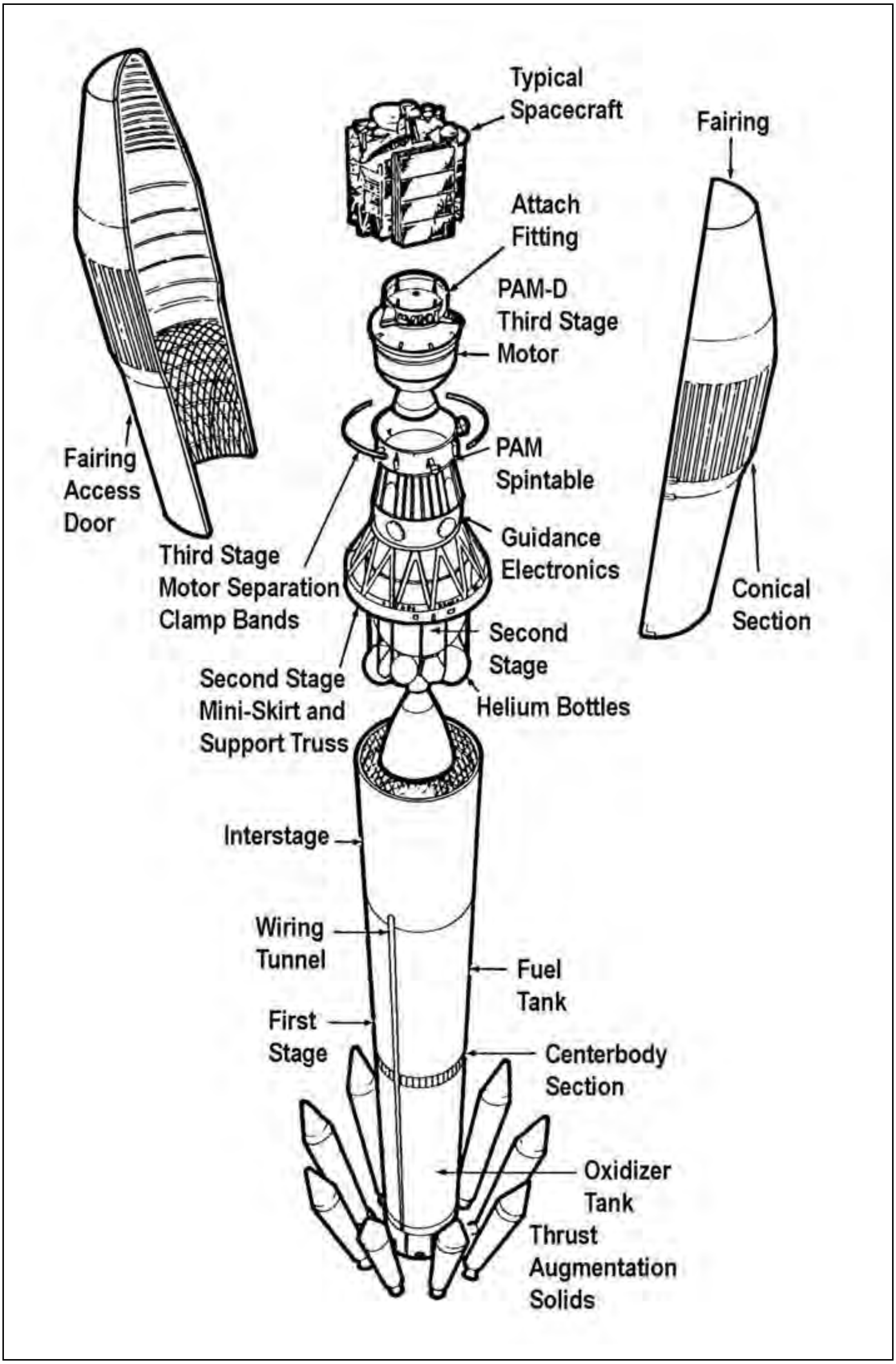

Figure 2–13. Delta II Components. (The Boeing Company)

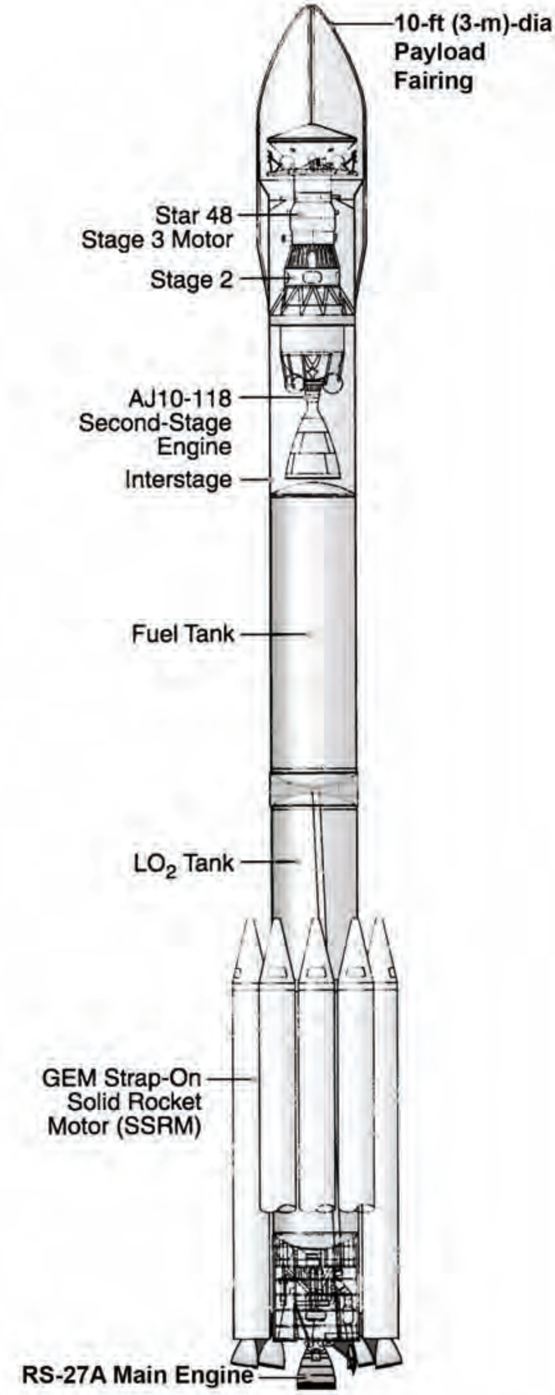

Figure 2–14. Delta II 7925. (The Boeing Company)

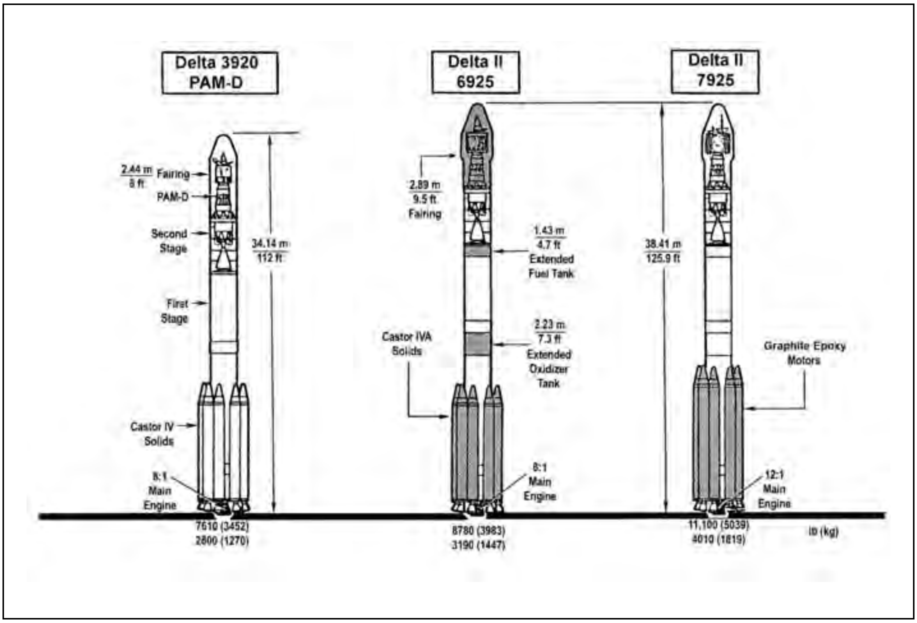

Figure 2–15. Delta 3920/PAM-D, Delta II 6925, and Delta II 7925. (The Boeing Company)

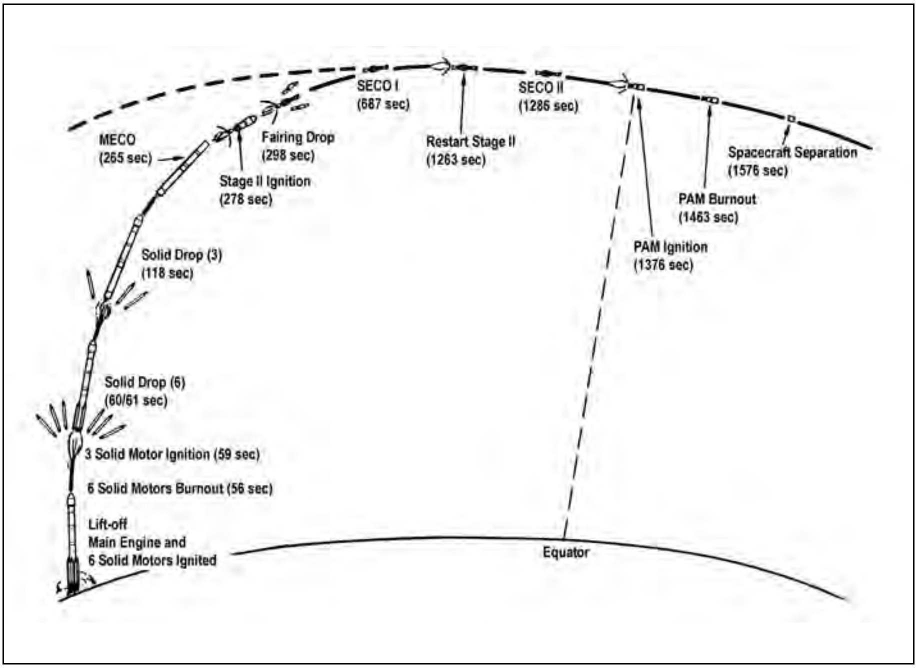

Figure 2–16. Delta II Mission and Launch Sequence Profile for a Typical Geosynchronous Mission. (The Boeing Company)

Orbital established the Pegasus program in 1987. In 1988, the Defense Advanced Research Projects Agency awarded a contract to Orbital for one firm and five options for the rocket. In July 1990, NASA and Orbital Sciences signed an agreement in support of Orbital's commercial launch vehicle programs. This agreement allowed Orbital to enter into sub-agreements with NASA installations in which NASA would provide access to its launch support property and services on a cost-reimbursable basis.[51] In 1991, Goddard Space Flight Center selected the Pegasus to supply Small Expendable Launch Vehicle Services for its Small Explorer program, and on June 4, the Pegasus was chosen for up to 40 more launches under the Air Force Small Launch Vehicle program.[52] The Ballistic Missile Defense Organization awarded another launch contract to Orbital in July 1992. In 1994, NASA selected Orbital for its Ultralight launcher, and Spain selected the Pegasus in October 1994 to launch Minisat 01, the first West European orbital launch.[53] There have been two Pegasus models: the Standard Pegasus, which first flew on April 5, 1990, and the Pegasus XL, which was conceived in 1991 and first flew on June 27, 1994.

The first Pegasus booster rocket was launched on April 5, 1990, from Edwards Air Force Base, California, from underneath NASA's B-52 airplane in a mission originating at Dryden Flight Research Center.[54] Other launches through 1998 took place from the Canary Islands in Spain and Wallops Flight Facility, Virginia, as well as from Edwards and Vandenberg Air Force Bases, both in California, and Cape Canaveral, Florida. The B-52 launched the Pegasus until 1995, when a modified Lockheed L-1011 aircraft, the Orbital "Stargazer," replaced it. The Pegasus XL, an upgraded Pegasus that was longer, heavier, and able to boost larger payloads than the standard Pegasus, used only the L-1011 aircraft. The Pegasus's best-known achievement was its launch of the ORBCOMM communications satellites. Between 1997 and 1999, five Pegasus launches sent 32 satellites into orbit, forming the world's first private, low-Earth orbit communications network.[55] See Table 2–76 for the Pegasus flight history.

Unlike ground-launched rockets, the Pegasus was launched at an altitude of more than 40,000 feet (12,192 meters) from beneath a flying aircraft at an initial speed of Mach 0.8. This air launch offered several advantages. First, because the rocket did not require a launch pad, just a runway from which the aircraft could take off and land, it could be launched from almost anywhere around the world. Second, the booster derived a slight gain in performance (one percent to two percent) from the speed of the carrier aircraft. Third, its trajectory was flatter

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[51] "NASA, Orbital Sciences Corporation Sign Agreement," *NASA News* Release 90-92, July 3, 1990, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1990/90-092.txt* (accessed February 2, 2005).

[52] "Milestones," Orbital, *http://www.orbital.com/About/Milestones/90_99/* (accessed February 2, 2005). Also *Aeronautics and Space Report of the President, Fiscal Year 1991 Activities* (Washington, DC: National Aeronautics and Space Administration, 1992), p. 70; Bille et al., *To Reach the High Frontier, A History of U.S. Launch Vehicles,* p. 216.

[53] Andrew Wilson, ed., *Jane's/Interavia Space Directory, 1999–2000* (Alexandria, VA: 2000), Jane's Information Group (2000), p. 237.

[54] This B-52 was the same aircraft used for the X-15 test flights in the 1960s.

[55] Bille et al., in *To Reach the High Frontier, A History of U.S. Launch Vehicles*, p. 216.

than the trajectory for ground-launched vehicles, so less power was dissipated in achieving the correct attitude for injection into orbit. Fourth, because the carrier aircraft served the same function as the first stage of a ground-launched vehicle, the rocket itself needed to carry less propellant.[56] Fifth, the fact that the launch took place above 75 percent of Earth's atmosphere reduced the energy needed to reach orbit. Finally, its air launch reduced the amount of stress the launch vehicle faced when compared with ground-launched vehicles.[57] Figure 2–17 shows a Pegasus mated to its B-52 mothership.

Figure 2–17. Pegasus Mounted Under B-52 Wing. (NASA-DFRC Photo No. EC91-348-3)

A 22-foot (6.7-meter) delta wing mounted on top of Stage 1 provided extra lift. There were three solid rocket motors in its three stages; a payload fairing; an avionics assembly; a lifting wing; an aft skirt assembly, including three movable control fins; and a payload interface system. It also could be equipped with a liquid-propellant fourth stage, the hydrazine auxiliary propulsion system (HAPS), to boost the payload into a higher orbit. The vehicle's blunt payload fairing blended into a cylindrical fuselage and ended in a flared exhaust nozzle. The wing was made of graphite composite structure, and 94 percent of the structural weight of the original model Pegasus was also graphite composite. Three control fins electromechanically actuated provided pitch, roll, and yaw control while the vehicle was still in Earth's atmosphere. When the vehicle reached the upper atmosphere, small rockets mounted in the base of each fin helped control the vehicle. Figure 2–18 shows the Pegasus vehicle.

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[56] "Pegasus Launch Vehicle," Space & Missile Systems Center (AFMC), Department of the Air Force, *http://www.te.plk.af.mil/factsheet/pegfact.html* (accessed February 8, 2005).

[57] Matt Bille et al. in *To Reach the High Frontier, A History of U.S. Launch Vehicles*, p. 215.

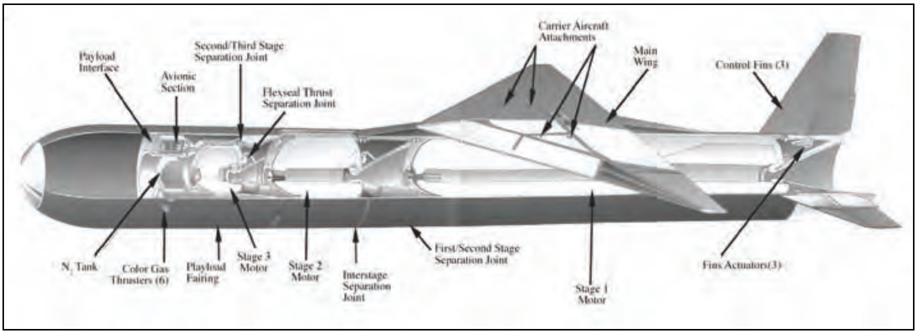

Figure 2–18. Pegasus Vehicle. (Orbital Sciences Corp.)

The standard payload fairing consisted of two graphite composite halves with a nosecap bonded to one of the halves and a separation system. The fairing separated when sequentially actuating pyrotechnic devices released the right and left halves of the fairing from a closed position and moved the halves away from either side of the payload. Pegasus could accommodate multiple payloads on the same mission. The standard fairing had a 1.17-meter (3.8-foot) diameter and was 2.13-meters (7-feet) long. If the optional HAPS was used, the fairing was 1.76-meters or 1.79-meters (5.8-feet or 5.9-feet) long. Table 2–77 lists Standard Pegasus characteristics, and Table 2–78 lists Pegasus XL characteristics.

The typical launch sequence begins with release of the Pegasus from the carrier aircraft at an altitude of approximately 11,900 meters (39,000 feet) and a speed of Mach 0.80. Approximately 5 seconds after its drop from the aircraft, when Pegasus had cleared the aircraft, Stage 1 is ignited. The vehicle quickly accelerates to supersonic speed while beginning a pull-up maneuver. Maximum dynamic pressure is experienced about 25 seconds after ignition. At approximately 20 to 25 seconds, a maneuver begins to depress the trajectory, and the vehicle's angle of attack quickly approaches zero.

Stage 1 burnout occurs at approximately 77 seconds, and Stage 2 ignition follows quickly. The payload fairing is jettisoned during Stage 2 burn as quickly as fairing dynamic pressure and payload aerodynamic heating limitations allow, about 110,000 meters (361,000 feet) and 112 seconds after drop from the aircraft. Stage 2 burnout occurs at approximately 168 seconds and is followed by a long coast, during which the payload and Stage 3 achieves orbital altitude. Stage 3 then provides the additional velocity needed to circularize the orbit. Stage 3 burnout typically occurs approximately 10 minutes after launch and 2,200 kilometers (1,200 nautical miles) downrange of the launch point.[58] Figure 2–19 shows the Pegasus XL mission profile.

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[58] *Pegasus User's Guide*, Release 5.0, August 2000 (Orbital Sciences Corporation, 2000), p. 2-1, *http://www.orbital.com/NewsInfo/Publications/peg-user-guide.pdf* (accessed February 4, 2005).

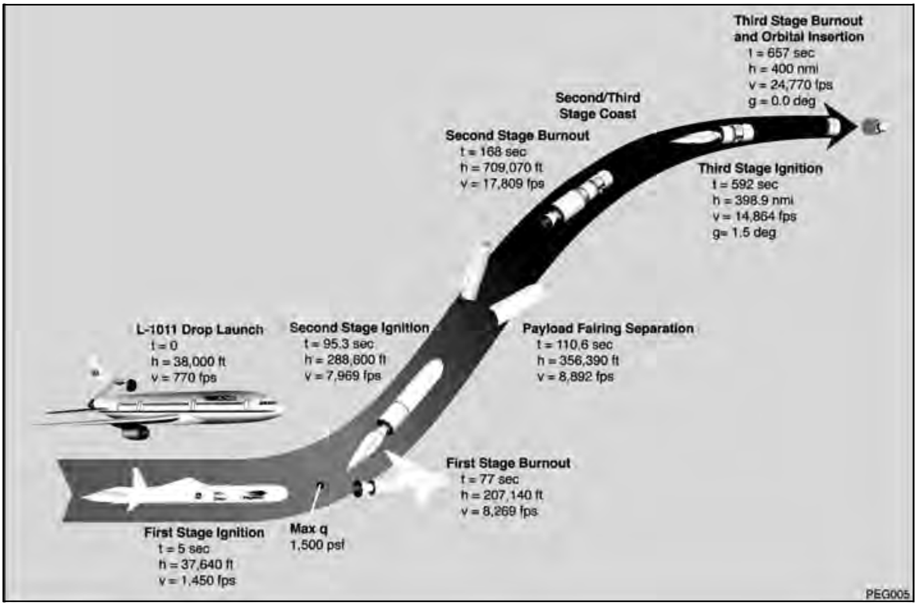

Figure 2–19. Pegasus XL Mission Profile to 741 km (400 nmi) Circular, Polar Orbit with a 227 kg (501 lb) Payload. (Orbital Sciences Corp.)

Scout Launch Vehicle

The standard Scout launch vehicle was a solid propellant, four-stage booster system.[59] It was the world's first all-solid-propellant launch vehicle and one of NASA's most reliable launch vehicles. The Scout was the smallest of the basic NASA launch vehicles. It was used for orbit, probe, and reentry Earth missions. Unlike most of NASA's larger ELVs, the Scout was assembled and the payload integrated and checked-out in the horizontal position. The Scout's first-stage motor was based on an earlier version of the Navy's Polaris missile motor. It's second-stage motor was developed from the Army's Sergeant surface-to-surface missile. The third-stage and fourth-stage motors were adapted by Langley Research Center from the Navy's Vanguard missile.[60] The Scout G1 was the last Scout model. See Table 2–79 for a list of its characteristics.

Since the first Scout launch in 1960, 118 Scout launches had taken place during almost 34 years of service. In the period 1989–1998, six missions successfully launched from Scout ELVs, all from Vandenberg Air Force Base (see Table 2–80). In addition to one NASA payload, Scout also

[59] Scout was an acronym for Solid Controlled Orbital Utility Test.
[60] "Scout Launch Vehicle To Retire After 34 Years of Service," *NASA News* Release 94-72, May 6, 1994, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1994/94-072.txt* (accessed March 22, 2005). Also "Scout–Launch Vehicle," *http://www.vought.com/heritage/special/html/sscout8.html* (accessed November 4, 2005).

launched DOD payloads. The last Scout launched a military satellite on May 9, 1994. The air-launched Pegasus rocket was considered the operational replacement for the Scout.

Langley Research Center managed the Scout project from its beginning in 1958 until January 1, 1991, when management of the Scout moved to Goddard Space Flight Center. Since 1958, LTV had manufactured the NASA-developed Scout rocket under a series of government contracts that procured flight vehicles in support of NASA science missions. In December 1988, NASA and LTV signed an agreement granting the company exclusive rights to produce and market the Scout commercially. This agreement also enabled LTV to obtain access to and use of Scout launch support facilities at Wallops Flight Facility and at Vandenberg Air Force Base.

Taurus Launch Vehicle

The ground-launched Taurus, developed by Orbital Sciences Corporation, was created by adding the three stages of a Pegasus booster (without the wing and fins) atop a Peacekeeper or Castor 120 first-stage solid-propellant motor referred to as "Stage 0." An aluminum skin and stringer construction interstage extended from the forward skirt of the Castor 120 Stage 0 motor to the aft end of the Stage 1 motor. The lower part of the interstage remained with Stage 0, and the upper part of the interstage flew with the next stage. A field joint between the two sections allowed the Taurus upper stage stack to be mated to the Castor 120 Stage 0 (see Table 2–81 and Figure 2–20).

The Defense Advanced Research Programs Agency (DARPA) contracted with Orbital Sciences in 1989 to build the Taurus rapid response launch vehicle using the Pegasus as a baseline.[61] It was designed for easy transport and as a quick-reaction launch vehicle that could be launched from minimally prepared locations in just a few days.[62] The first Taurus launch took place on March 13, 1994 for a DOD mission. The commercial Taurus, developed after the successful demonstration of the military "ARPA" Taurus, used the Castor 120 first stage rather than the Peacekeeper missile, a slightly larger Orion 50S-G second stage, and a larger fairing.[63] For geosynchronous transfer orbit or deep space missions, the third stage could be replaced by a spin-stabilized Thiokol Star 37 perigee kick motor.

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[61] Wilson, ed., *Jane's/Interavia Space Directory*, p. 240.

[62] "Taurus," *http://space.skyrocket.de/doc_lau/taurus.htm* (accessed February 9, 2005).

[63] "ARPA" Taurus was another name for the military Taurus configuration that used the Peacekeeper first stage. Isakowitz et al., *International Reference Guide to Space Launch Systems*, 3rd ed., p. 437.

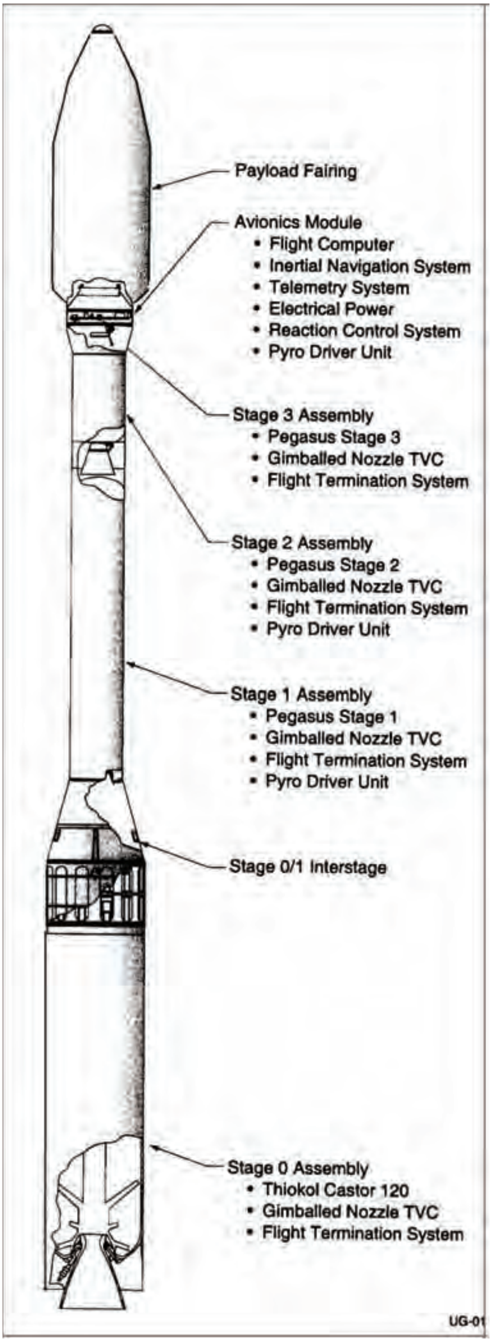

Figure 2–20. Taurus Launch Vehicle Configuration. (Orbital Sciences Corp.)

The Taurus successfully used payload fairings of 63 inches (160 centimeters) and 92 inches (234 centimeters) diameter to encapsulate the payload. Vermont Composites manufactured the 63-inch fairing, while R-Cubed Composites manufactured the 92-inch fairing. Both were bisector shells constructed of graphite/epoxy facesheets with an aluminum honeycomb core. With the addition of a structural adapter, either fairing could accommodate multiple payloads.

From 1994 through 1998, three Taurus launches took place, all from Vandenberg Air Force Base and with multiple payloads (see Table 2–82).

The Titan Family

From the earliest days of the space program, the U.S. Air Force was the primary user of the Titan, first as an intercontinental ballistic missile and later as a space launch vehicle. With its several configurations and enhanced versions, the Titan launched a wide range of military and civilian spacecraft. For a while in the mid-1980s, DOD prepared to launch its payloads exclusively from the Space Shuttle, and it seemed as if the Titan was reaching the end of its useful life. But some felt that a backup vehicle was needed, and in 1985, the Air Force placed an order with Martin Marietta for 10 launch vehicles called the complementary expendable launch vehicle (CELV) or Titan 34D-7, named for its seven-segment solid motor designed for the earlier, unsuccessful Titan IIIM. To be compatible with Shuttle payload capacity, the Titan payload fairing was increased to 5.1 meters (16.7 feet) in diameter. The 34D-7 included a Centaur upper stage and launched exclusively from Cape Canaveral. After the *Challenger* accident and the removal of DOD payloads from the Space Shuttle, the 34D-7 program grew from 10 to 41 vehicles with a mix of upper stages. The vehicles were renamed the Titan IV, and they would eventually be launched from both West and East Coast launch pads.

The Titan IV was the Nation's largest and most powerful ELV. It provided primary access to space for the heaviest and most important DOD and civil payloads. The first Titan IVA launch occurred successfully on June 14, 1989. Eventually, 22 Titan IVAs were launched, the last in August 1998. Figure 2–21 shows the first stage of the Titan IV ELV used to send NASA's Cassini spacecraft to Saturn.

Even before the first Titan IVA launch, the Air Force began looking for ways to upgrade the Titan. In October 1987, the Air Force awarded Hercules Aerospace a contract for upgraded solid rocket boosters that would have a new propellant formulation, new graphite-composite cases, and hydraulically gimbaled nozzles to replace the system used since the first Titan IIIC. The upgraded Titan motors had three segments rather than seven for greater reliability. This upgrade not only increased payload capability by 25 percent but also used fewer components, resulting in a more reliable Stage 0 booster. This model used a more efficient programmable aerospace ground equipment system to control the vehicle before launch and an improved guidance and control system, based on more accurate and lighter ring gyroscopes, manufactured by Honeywell. Mechanical and electrical interfaces to the payload were also standardized, and the design of the core vehicle could be fitted with various kits to adapt to specific payloads. Production processes were redeveloped to use a "factory-to-launch" approach. The goal was to deliver problem-free hardware requiring a minimal amount of launch site assembly and reserving the launch site for final stacking, checkout, countdown, and launch.

Development of the new motors took longer than expected, however, partly because of an explosion during the first test firing. The first flight of the new Titan IV with its new motors, now designated Titan IVB, did not occur until February 23, 1997. The new Titan IV stood 61 meters (200 feet) tall and had a lift capability of 21,680 kilograms (47,796 pounds) to low-Earth orbit and 5,760 kilograms (12,700 pounds) to geosynchronous orbit. Lockheed Martin provided overall program management, system integration, and payload integration for the program. It also built the first and second stages and the Centaur upper stage.[64]

The Air Force found a use, too, for old Titan II ICBMs. As the technology for nuclear deterrence changed, the Air Force began in July 1982 to deactivate its Titan II missiles, removing its last ICBM from its silo in Arkansas on June 23, 1987. In January 1986, the Air Force decided to begin converting some of its deactivated Titan II ICBMs for use as medium-lift space launch vehicles. From its fleet of 54 deactivated Titan IIs, the Air Force selected Martin Marietta to modify 14 for space launches from Vandenberg Air Force Base into polar orbit. Modification entailed replacing the core vehicle's warhead interface with a space payload interface and a 3-meter (9.8-foot) payload fairing and upgrading the electronics, avionics, and guidance systems using Titan III technology. An attitude control system was added for stabilization during the coast phase after second-stage shutdown and before payload separation.[65] Used for launches into polar orbit, the space launch complex at Vandenberg Air Force Base was also modified. The resulting Titan II space launch vehicle was a two-stage, liquid-fueled booster designed to provide a small-to-medium weight class capability. It could lift approximately 4,200 pounds (1,905 kilograms) into polar low-Earth circular orbit.[66] The first launch of a Titan II 23G space launch vehicle took place on September 5, 1988, from Vandenberg Air Force Base when it sent a classified payload into low-Earth orbit.

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[64] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 3rd ed., p. 470. Also "Titan," Lockheed Martin, *http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=15525&rsbci=13181&fti=0&ti=0&sc=400* (accessed December 14, 2004).

[65] Art Falconer, "Epic Proportion: The Titan Launch Vehicle," *Crosslink* (Aerospace Corporation, Winter 2002/2003): 35 (NASA History Office Folder 16680). Also Isakowitz et al., *International Reference Guide to Space Launch Systems,* 3rd ed., p. 470.

[66] "Titan II Space Launch Vehicle," Lockheed Martin (NASA History Office Folder 16680).

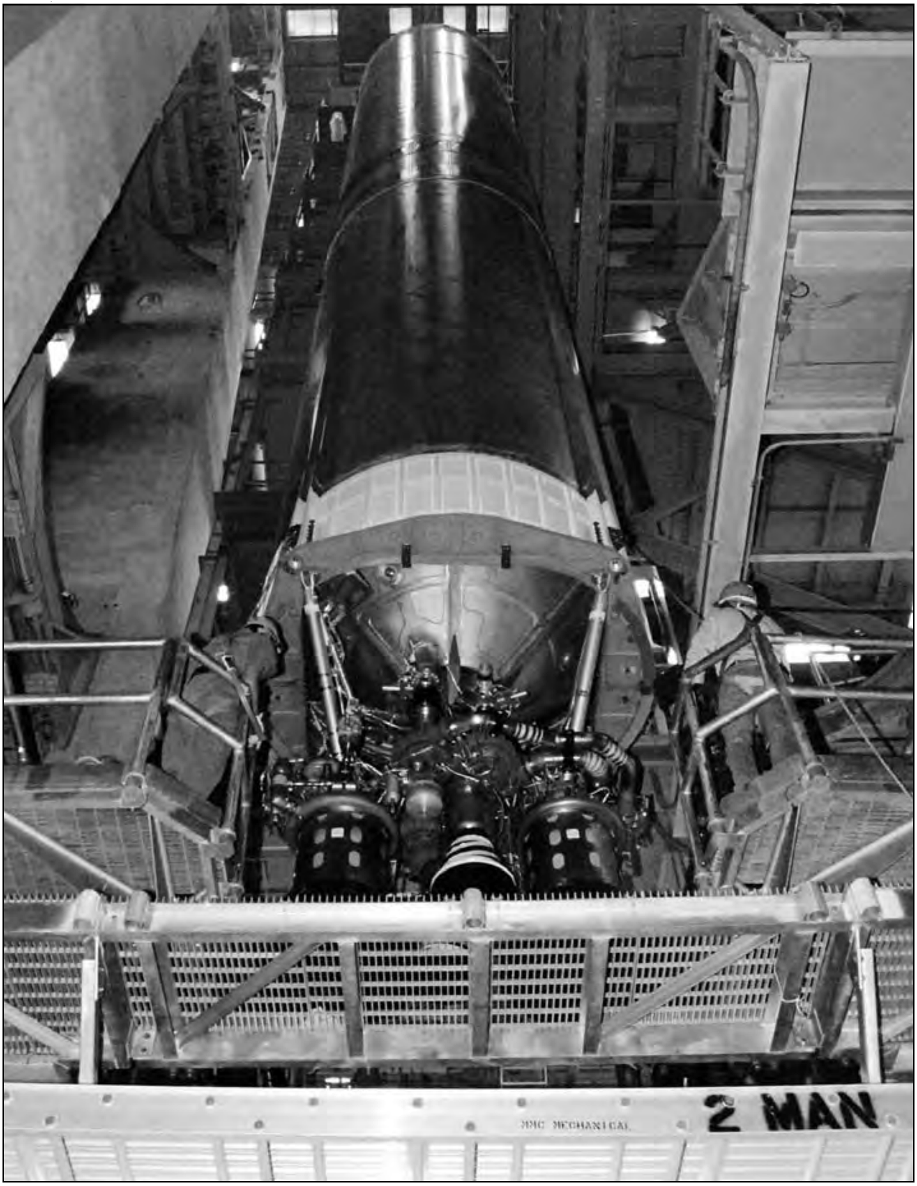

Figure 2–21. The first stage of the Titan IV ELV that sent NASA's Cassini Spacecraft to Saturn and its moon. Titan is Llowered into a high bay in the Vertical Integration Building at Cape Canaveral Air Station to begin stacking operations, April 14, 1997. (NASA Photo No. KSC-97PC-640)

During 1989–1998, the Titan launched only a few civilian spacecraft. All but one were converted Titan ICBMs; the final nonmilitary Titan payload during this decade launched NASA's Cassini spacecraft to Saturn on a new Titan IVB Centaur. Table 2–83 lists all Titan launches during this period. Table 2–84 lists Titan II characteristics.

The Space Shuttle

By 1989, regular Space Shuttle flights had resumed, and 66 Shuttle flights took place in the decade from 1989–1998. Because NASA policy dictated that the Space Shuttle could be used for launches only when a human presence was required or when an ELV was not appropriate to deploy a payload, more on-board science missions took place and the Shuttle deployed fewer payloads than in the years before the *Challenger* accident. Among the Shuttle payloads were some of the most important space science projects, including the Hubble Space Telescope, the Galileo spacecraft, and the Gamma Ray Observatory.

A new orbiter, the *Endeavour*, joined the fleet of *Discovery*, *Columbia*, and *Atlantis* and began flight operations on May 7, 1992, when it blasted off on the STS-49 Intelsat VI repair mission. Table 2–85 lists all Space Shuttle missions from 1989 to 1998

In 1995, the Space Shuttle program demonstrated a new capability. In preparation for construction of the International Space Station, the crews of the Space Shuttle carried out a series of docking missions with the Russian Space Station *Mir*. U.S. astronauts lived aboard *Mir*, sometimes for several months at a time, while they acclimated themselves to living and working in space. At the end of the decade, the first Space Station mission took place when STS-88 sent materials for construction of the Station.

In November 1995, in an effort to reduce costs and increase efficiency, NASA announced its intention to pursue a non-competitive contract with the United Space Alliance (USA) that would consolidate contracts for Space Shuttle processing and operations in a single contract. USA was a joint venture between Rockwell International and Lockheed Martin Corporation. Together, these two companies held 69 percent of the dollar value of all Shuttle-related prime contracts. The consolidation virtually ensured that NASA would negotiate with the new company.[67] In April 1996, NASA signed two agreements designating USA the prime contractor for Shuttle processing work performed by Lockheed at Kennedy Space Center and Shuttle operations work performed by Rockwell at Johnson Space Center.

In September 1996, NASA entered into a contract with USA as the prime contractor for Space Shuttle and International Space Station activities to ensure that all NASA missions were successfully accomplished according to the applicable flight definition and requirements, schedule, and implementation plan. The original six-year contract ran from October 1996 through September 2002 and consisted of two phases for consolidating the existing prime contracts. During the first phase, USA assumed overall responsibility for the fleet of orbiters. During the second phase, which began in September 1997, the contracts for Kennedy Space Center base operations, the waste collection system, flight software, flight equipment, and solid rocket boosters were

[67] "NASA To Pursue Non-Competitive Shuttle Contract With U.S. Alliance," *NASA News* Release 95-205, November 7, 1995, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1995/95-205.txt* (accessed April 17, 2005).

consolidated in the USA contract. As of early 2000, the remaining prime contracts—external tanks, Space Shuttle main engines, and reusable solid rocket motors—remained to be consolidated.[68]

Space Shuttle Characteristics

The Space Shuttle that NASA flew in the decade beginning in 1998 consisted of four primary elements: an orbiter spacecraft, two SRBs, an external tank to house fuel and an oxidizer, and three Space Shuttle main engines (SSMEs). Rockwell International built the orbiters. Rockwell's Rocketdyne Division built the main engines.[69]

Thiokol Corporation produced the SRB motors/ Martin Marietta Corporation built the external tank. Johnson Space Center directed the orbiter and integration contracts, while Marshall Space Flight Center managed the solid rocket booster, external tank, and Space Shuttle main engine contracts.[70] Rockwell also was the contractor for Space Shuttle operations at Johnson Space Center that included maintenance and operation of Space Shuttle facilities, flight preparation, and sustained engineering support. Lockheed Martin was responsible for Shuttle processing at Kennedy Space Center.

External Tank

The external tank held the liquid hydrogen fuel and liquid oxygen oxidizer in separate pressurized tanks and supplied them under pressure to the three main engines in the orbiter during liftoff and ascent. The main engines consumed approximately 64,000 gallons (242,266 liters) of fuel each minute. When the main engines were shut down, the external tank was jettisoned into Earth's atmosphere where it broke up and fell into a remote ocean area. The external tank was not recovered. When loaded with fuel, the external tank was the largest and heaviest element of the Space Shuttle. Built from aluminum, it also acted as the backbone for the orbiter and solid rocket boosters. The external tank was composed of three major components: the forward liquid oxygen tank, an unpressurized intertank containing most of the electrical components, and the aft liquid hydrogen tank. Characteristics of the external tank are shown in Table 2–86. Figure 2–22 shows a cutaway drawing.

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[68] NASA Office of Inspector General, *Audit Report: Space Flight Operations Contract Phase II–Cost-Benefit Analysis*, IG-00-015, National Aeronautics and Space Administration (March 14, 2000), pp. 1–2.

[69] In December 1996, Boeing purchased the Space and Defense divisions of Rockwell International and renamed them Boeing North American. Rocketdyne had been part of Rockwell when the SSME contract was awarded. It was bought by Boeing in December 1996 when Boeing bought Rockwell. Rocketdyne became the Rocketdyne Division of Boeing North American.

[70] Detailed descriptions of all Space Shuttle components can be found in the *NSTS 1988 News Reference Manual*, September 1988, at *http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/stsref-toc.html#srb-recovery* (accessed February 25, 2005) and in the *Shuttle Crew Operations Manual*, SFOC-FL0884, Rev. B, CPN-3, January 13, 2003. See also a summary in Judy Rumerman, compiler, *NASA Historical Data Book, 1979–1988, Volume V* (Washington, DC: National Aeronautics and Space Administration Special Publication 4012, 1999), pp. 33–47 and pp. 123–147. Also available at *http://history.nasa.gov/SP-4012/vol5/cover5.html*.

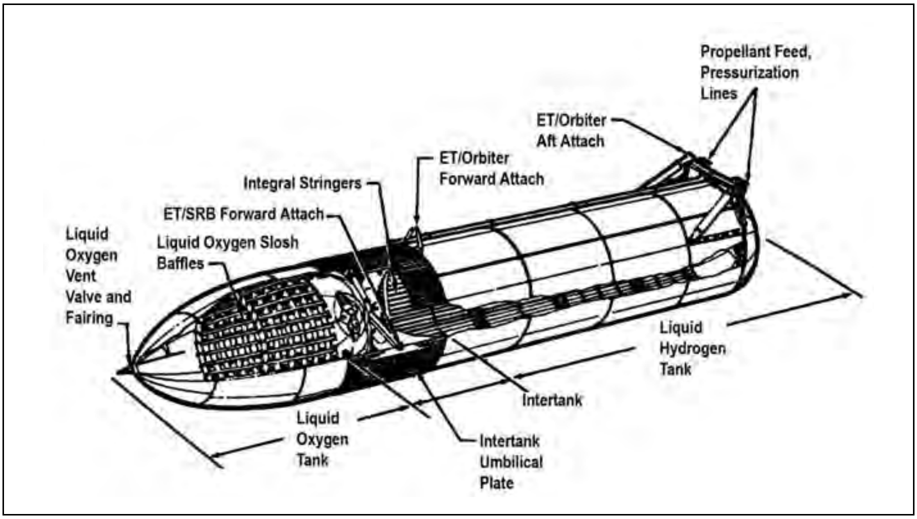

Figure 2–22. Drawing of Space Shuttle External Tank. (NASA)

Solid Rocket Booster

The solid rocket boosters were the largest solid-propellant motors ever flown and the first designed for refurbishment and reuse. The two boosters provided the main thrust to lift the Space Shuttle up off the launch pad to an altitude of about 150,000 feet (45.7 kilometers) or 24 nautical miles. The two solid rocket boosters carried the entire weight of the external tank and orbiter and transmitted the weight load through their structure to the mobile launcher platform. The solid rocket boosters were ignited after the thrust levels of the three main engines were verified. During flight, the solid rocket booster nozzles swiveled up to 6 degrees, redirecting the thrust and steering the Shuttle toward orbit. Seventy-five seconds after booster separation, SRB apogee occurred at an altitude of approximately 220,000 feet (67 kilometers) or 35 nautical miles. Impact in the Atlantic Ocean occurred approximately 122 nautical miles (226 kilometers) downrange. Table 2–87 lists solid rocket booster characteristics. Figure 2–23 shows an exploded view.

Space Shuttle Main Engine

The three Space Shuttle main engines were clustered at the tail end of the orbiter. These high-performance liquid-propellant engines were the world's first reusable rocket engines with each designed to operate for 7.5 hours over a lifespan of 55 starts. They operated with variable thrust levels in a staged combustion cycle. The engines burned liquid hydrogen as the propellant fuel and liquid oxygen as the oxidizer in a 6:1 ratio. The propellant was carried in separate tanks in the external tank and supplied to the main engines under pressure. The main engines could be throttled over a range of 65 percent to

109 percent of their rated power level in 1 percent increments. A value of 100 percent thrust corresponded to a thrust level of 375,000 pounds (1,668 kilonewtons) at sea level and 470,000 pounds (2,091.7 kilonewtons) in a vacuum. A thrust value of 104 percent (called full power) was typically used at launch, although each engine could be throttled to its maximum of 109 percent if necessary. (This power level has never been used on a Shuttle flight). All three engines received the same throttle command at the same time, normally from the orbiter general-purpose computers, although manual control of engine throttling was possible during certain contingency situations.

Firing of the three main engines began 6.6 seconds before launch. The three engines were fired at intervals of 120 milliseconds. If all three engines failed to reach at least 90 percent thrust over the next 3 seconds, a main engine cutoff command was issued automatically, followed by cutoff of all three engines. If launch proceeded normally, the engines were throttled back about 26 seconds after launch to protect the Shuttle from aerodynamic stress and excessive heating. The engines returned to full power about 60 seconds after launch and typically continued at full power for about 8.5 minutes until shortly before the Shuttle entered orbit. At about 7 minutes, 40 seconds after launch, the engines were throttled down so the vehicle and crew were not subject to forces more than 3g. The main engines operated in parallel with the solid rocket boosters during the initial ascent. After the boosters separated, the main engines continued to operate. During ascent, each engine could be gimbaled plus or minus 10.5 degrees around the yaw and pitch axes to help steer the Shuttle.[71]

The Shuttle's main engines were upgraded twice during this decade. The Block 1 SSMEs first flew on STS-70 on July 13, 1995. These engines used a new high-pressure liquid oxidizer turbopump that increased safety margins and the reliability of the Shuttle's main engines. In 1998, the Block IIA SSMEs were first used on STS-95. These upgrades increased safety and reliability and simplified manufacturing and maintenance.[72] The design had a larger nozzle throat that resulted in decreased operating pressure and temperature. To achieve the same performance as the earlier engines, the Block IIA engines typically operated at 104.5 percent thrust at launch. Figure 2–24 shows the SSME components. Table 2–88 lists SSME characteristics.

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[71] David Darling, "Space Shuttle," *The Encyclopedia of Astrobiology, Astronomy, and Spaceflight*, *http://www.daviddarling.info/encyclopedia/S/Space_Shuttle.html* (accessed February 28, 2005).

[72] Susie Unkeless, Jack Vautin, Boeing Rocketdyne, telephone conversation, February 28, 2005. Also "STS-95 Space Shuttle Mission Chronology," *http://www-pao.ksc.nasa.gov/kscpao/chron/sts-95.htm* (accessed February 28, 2005).

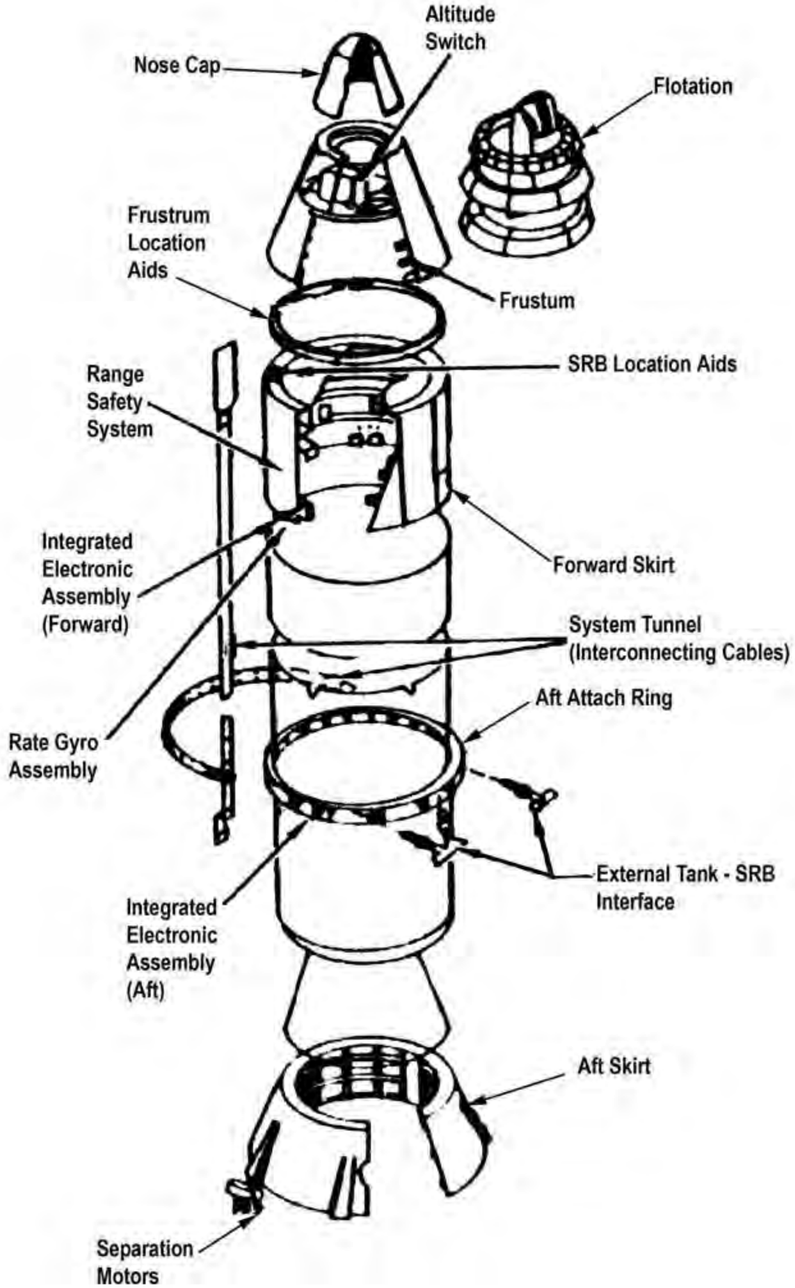

Figure 2–23. Exploded View of Space Shuttle Solid Rocket Booster.

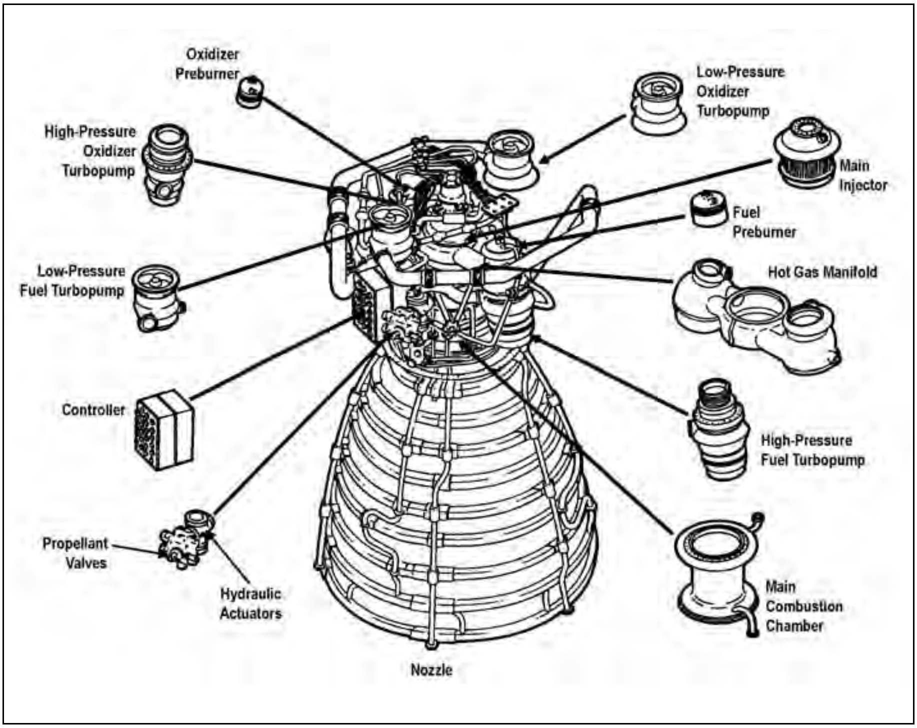

Figure 2–24. Space Shuttle Main Engine Components. (Rocketdyne)

Two orbital maneuvering system engines, mounted on either side of the upper aft orbiter fuselage, provided thrust for major orbital changes. For more precise motions in orbit, 44 small rocket engines, clustered on the Shuttle's nose and on either side of the tail, were used. Together, they were known as the reaction control system and helped Shuttle astronauts retrieve, launch, and repair satellites in orbit.

Launch and Operations

All Space Shuttle missions launched from Kennedy Space Center. The majority also landed there although, during this decade, about 39 percent landed at Edwards Air Force Base in California. See the individual Shuttle mission tables in chapter 3 for specific launch and landing information.

All satellites released from a Space Shuttle initially entered low-Earth orbit. Some remained in that orbit throughout their working lives. Many spacecraft, however, operated in geosynchronous orbit, approximately 35,790 kilometers (19,325 nautical miles or 22,300 miles) above Earth and aligned with the equator, with a speed in orbit that matched the speed of Earth's surface below. Spacecraft reached this altitude by firing an upper stage, an attached propulsion unit such as an IUS or PAM, after deployment from the Shuttle orbiter. Interplanetary explorers launched from the Space Shuttle also used an IUS. They left low-Earth orbit on trajectories that sent them out into our solar system and beyond.

Upper Stages

Upper stages were used to boost ELV and Shuttle payloads from a low-Earth orbit to geostationary transfer orbit, geosynchronous orbit, or into an interplanetary trajectory. During 1989 to 1998, NASA used three types of upper stages: the PAM, the Centaur Upper Stage, and the IUS.

Payload Assist Module

The PAM was designed to boost satellites deployed in low-Earth orbit into a higher operational orbit. Different types of PAMs were used depending on the weight of the satellite it needed to boost. A special PAM, known as PAM-D, was adapted for use with Delta launch vehicles. The PAM-DII was designed to boost Shuttle payloads into an elliptical transfer orbit after a satellite was deployed from the Shuttle's cargo bay. A specially designed PAM-S was used on the Ulysses mission for the first time in combination with an IUS to propel the spacecraft toward Jupiter. The PAM's expendable stage consisted of a spin-stabilized, solid-fueled rocket motor; a payload attach fitting to mate with the satellite; and timing, sequencing, power, and control assemblies.[73] The first launch of the PAM as the top stage of a Delta took place in 1980. The PAM made its debut flight from the Space Shuttle in 1982. Figure 2–25 shows the Ulysses spacecraft with the PAM and IUS.

Centaur Upper Stage

The Centaur was a powerful, liquid-propellant rocket—this country's first high-energy, upper-stage launch vehicle. It was developed under the direction of Lewis Research Center in the 1960s and assembled by General Dynamics. It used a liquid hydrogen-liquid oxygen propellant combination in two restartable Pratt & Whitney RL10 engines that produced more thrust for each pound of propellant burned per second than rockets using only kerosene-based hydrocarbon fuels (see Figure 2–26). The rocket was first developed to be used with the Atlas ELV, and in the decade from 1989–1998, was used on almost all Atlas launches. In the 1970s, the Centaur had been combined with the Titan III to launch larger spacecraft. Later, NASA had planned to use the Centaur to boost Shuttle payloads into higher orbits. But with the increased emphasis on safety following the *Challenger* accident, NASA determined that even with modifications, it was too dangerous to carry a liquid-propellant rocket inside a crewed spacecraft. In June 1986, the Shuttle/Centaur program was cancelled, eliminating the Centaur for use on the Shuttle.

[73] "Space Transportation System Payloads: Payload Assist Module," *http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/carriers.html* (accessed March 17, 2005).

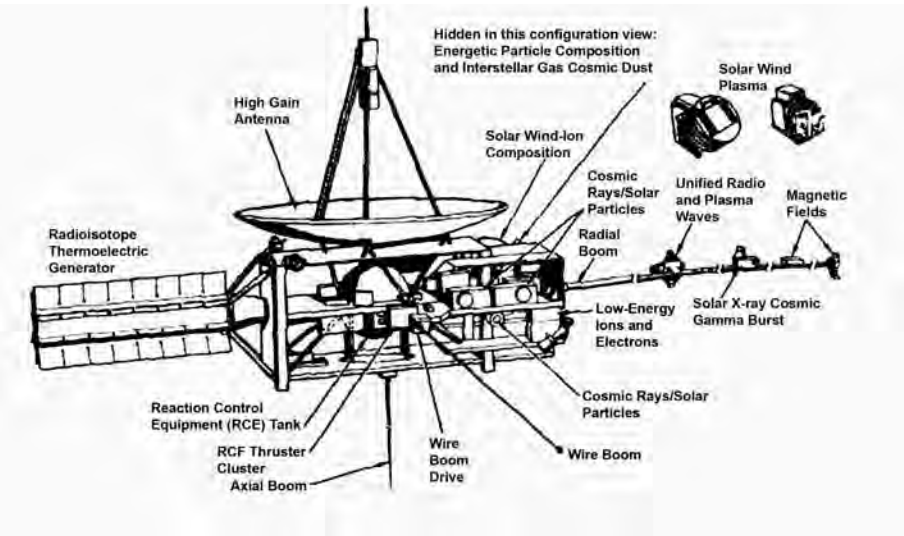

Figure 2–25. Ulysses Sits atop the Payload Assist Module-S and IUS Combination in the Vertical Processing Facility at Kennedy Space Center. (NASA/JPL-Caltech)

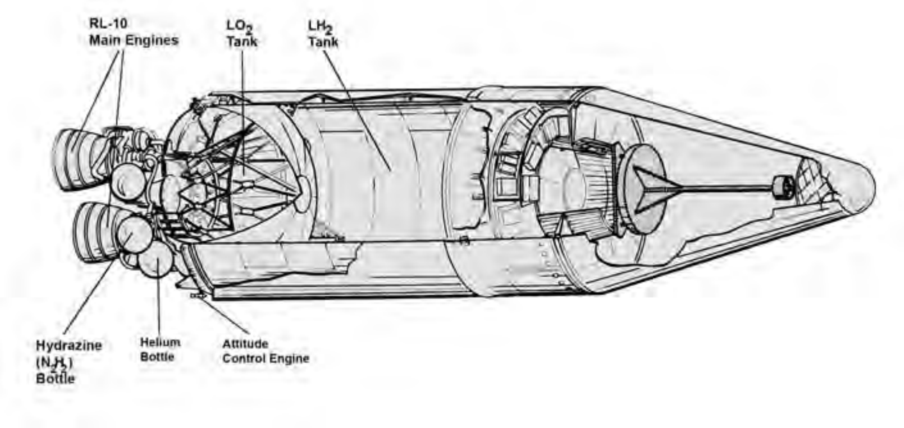

Figure 2–26. Pratt & Whitney RL10 Engine used on the Centaur Upper Stage. (Pratt & Whitney)

In the wake of the *Challenger* accident, the country's space program returned to using ELVs for all missions suitable for those launchers, and attention focused on improving the Centaur for use as an ELV upper stage. As General Dynamics began developing new Atlas launch vehicles in the late 1980s, it also improved the Centaur as its "engineers dusted off NASA studies for Centaur improvements never implemented . . . ." A pressure-fed system replaced its boost pumps, reducing complexity and cost, and its avionics system was upgraded. Designers developed a new 14-foot (4.3-meter)-diameter metal nose fairing to accommodate larger payloads. A computer-controlled pressurization system with redundant sensors was adopted, making the system more versatile and reliable.[74] This updated Centaur was first used on July 25, 1990, for the Atlas I launch of the Combined Release and Radiation Effects Satellite. See Figure 2–27 for a diagram of the Atlas-Centaur upper stage.

The Centaur G model, originally developed for launching Shuttle payloads, was updated for use on the Titan IV. Martin Marietta delivered the first Titan IV Centaur in December 1990. It had a bare metal tank, like that of the Atlas Centaur. However, the upper fuel tank was stretched to 5 meters (16.4 feet) in diameter. Most Titan IV Centaurs were used for classified DOD payloads. However, one model launched the Cassini/Huygens probe for NASA on an interplanetary trajectory in October 1997. Characteristics of the Titan Centaur are given in Table 2–89.

Inertial Upper Stage

The two-stage, solid-fueled IUS delivered a satellite to a high-stage operational orbit or to an escape trajectory for an interplanetary mission from low-Earth orbit. It extended the reach of the Space Shuttle and was also used with the Titan launch vehicle, particularly the Titan 34D and Titan IV. The IUS had two solid rocket motors, an aft skirt, an interstage, and an equipment support section where the avionics were located. It could lift 5,000 pounds (2,268 kilograms) from low-Earth to geosynchronous orbit. Figure 2–28 shows an IUS being attached to the Magellan spacecraft, which launched from STS-30 in 1989.

In a typical Titan IV-IUS launch into geosynchronous orbit, the IUS separated from the Titan's second-stage booster approximately 9 minutes after launch. Then, for the next 6 hours, 54 minutes, the IUS autonomously performed all functions to place the payload into its proper orbit. The first IUS rocket burn, which placed the payload into geosynchronous transfer orbit, occurred a little more than 1 hour into the IUS booster flight. The IUS second solid rocket motor ignited about 6.5 hours into the flight, followed by a coast phase, and then separation of the payload from the IUS after placing it into geosynchronous orbit.

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[74] Virginia P. Dawson and Mark D. Bowles, *Taming Liquid Hydrogen: The Centaur Upper Stage Rocket, 1958-2002* (Washington, DC: National Aeronautics and Space Administration Special Publication-2004-4230, 2004), pp. 242–243.

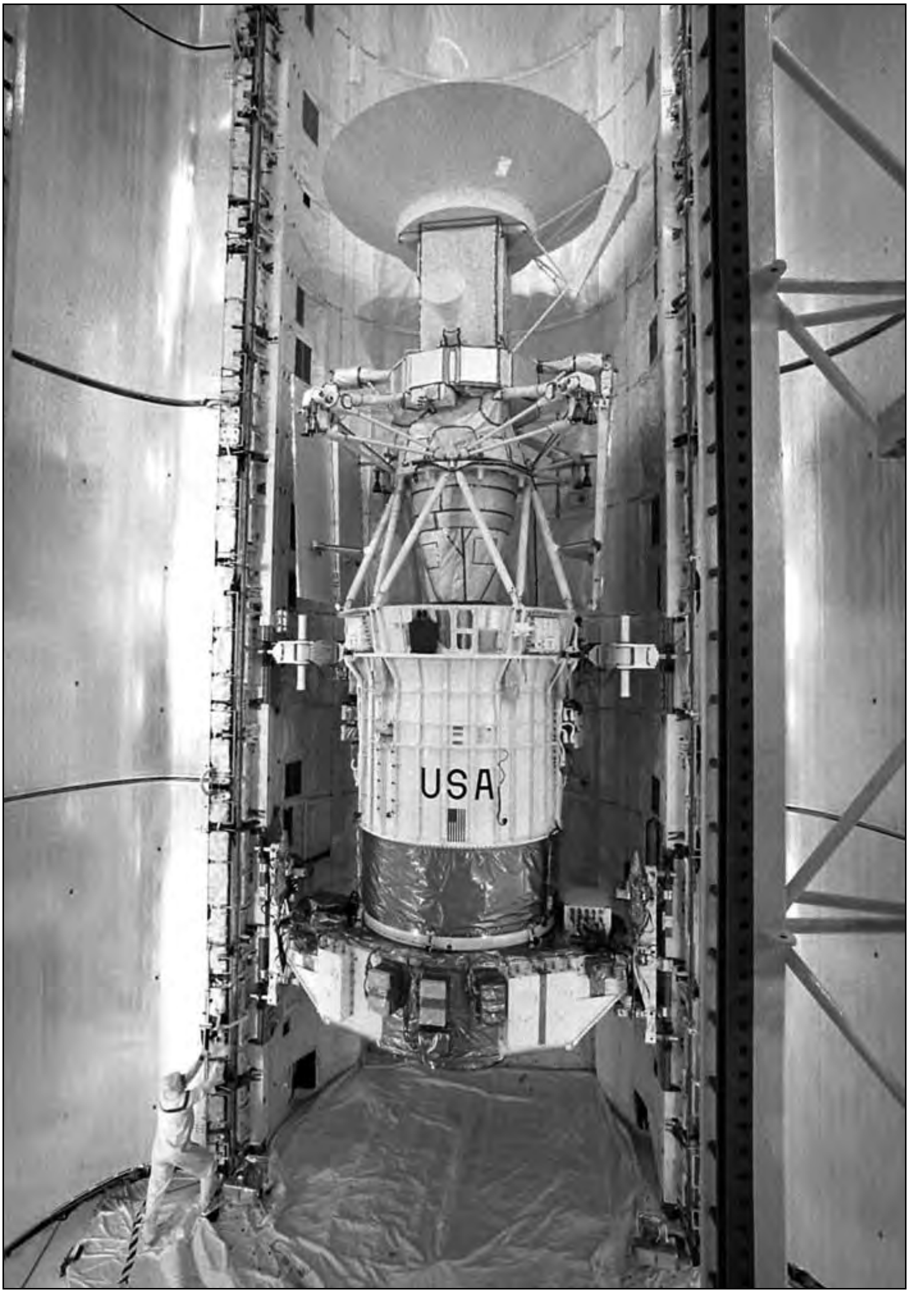

Figure 2–27. Atlas-Centaur Upper Stage. (NASA-GRC Photo No. C-1998-02814)

In a typical Shuttle-IUS launch to geosynchronous orbit, after reaching low-Earth orbit, the Shuttle opened its payload doors and the IUS tilted outward, extending the IUS and its payload into space. After satellite and IUS checkout, the Shuttle astronauts ejected the IUS and its cargo from the orbiter. The IUS onboard computers then directed a series of maneuvers and fired the first-stage motor for approximately 140 seconds to propel the IUS and spacecraft toward the desired geosynchronous position. After a coast period of several hours, the second-stage motor ignited and burned for approximately 100 seconds, injecting the IUS into a final circularized orbit. The IUS then separated from the satellite and moved to a position where it neither collided with nor contaminated the satellite.[75] Table 2–90 lists IUS characteristics. Table 2–91 lists missions using an IUS.

Advanced Programs and Projects

Advanced Programs conducted studies and selected development efforts to support potential new programs, system improvements, and expanded capabilities for space transportation systems. The objectives were to increase reliability, cost effectiveness, and capability of spaceflight systems; continue enhancing crew safety for the Space Shuttle and Space Station; implement flight and ground systems improvements to substantially reduce the cost of spaceflight operations; and pursue technology developments to meet future human spaceflight requirements. Development efforts focused on advanced transportation, advanced operations, and satellite servicing. The two program elements were advanced operations and advanced space systems.

Tethered Satellite System

The Tethered Satellite System (TSS) program was a cooperative effort between the government of Italy and NASA. The TSS program was to enable science to be performed in the upper atmosphere and ionosphere from a satellite connected to the Space Shuttle by means of a tether up to 100-kilometers (62-miles) long. The effect of the tether passing through space also was expected to generate an electric current that could be conducted to the orbiter.

The first attempt at performing the TSS experiment took place on STS-46, launched on July 31, 1992. Due to problems with the deployment mechanism, the *Atlantis* crew could deploy the tethered satellite only 256 meters (840 feet) instead of the goal of 20 kilometers (12.4 miles).

[75] "Inertial Upper Stage: IUS Team," Boeing, *http://www.boeing.com/defense-space/space/ius/ius_team.htm* (accessed March 18, 2005).

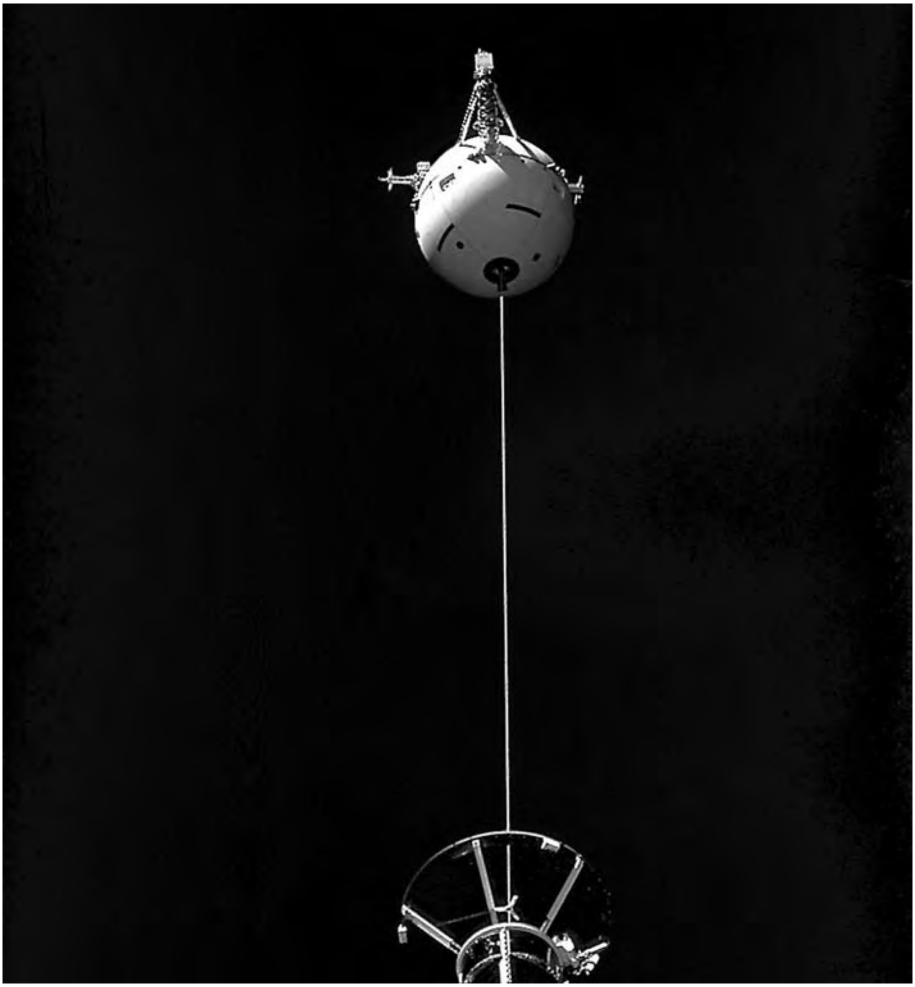

Figure 2–28. The Magellan Spacecraft with its attached Inertial Upper Stage (IUS) Booster is in the Orbiter Atlantis *Payload Bay prior to closure of the doors at T-3 days to launch. Launch of Magellan and STS-30 took place on May 4, 1989. (KSC Photo No. 89PC-0469)*

A second attempt to deploy a tethered satellite from the Shuttle was made on STS-75, launched February 22, 1996. This second attempt also failed to satisfy all the mission objectives. Although the tether unreeled smoothly for almost its full length of 13 miles (21 kilometers), the 0.1-inch (0.25-centimeter)-diameter tether broke about three-fourths of a mile before reaching full length, and the Italian satellite drifted away. There was a low-power current of 3,500 volts and 500 milliamps generated by the unreeling tether in Earth's magnetic field, which satisfied the test's scientific objective.[76]

[76] David M. Harland, *The Story of the Space Shuttle* (Chichester, UK: Springer, Praxis Publishing, 2004), pp. 123, 137. Also Dennis R. Jenkins, *Space Shuttle: The History of the National Space Transportation System, The First 100 Missions* (Cape Canaveral, FL: Dennis R. Jenkins, 1996), p. 309.

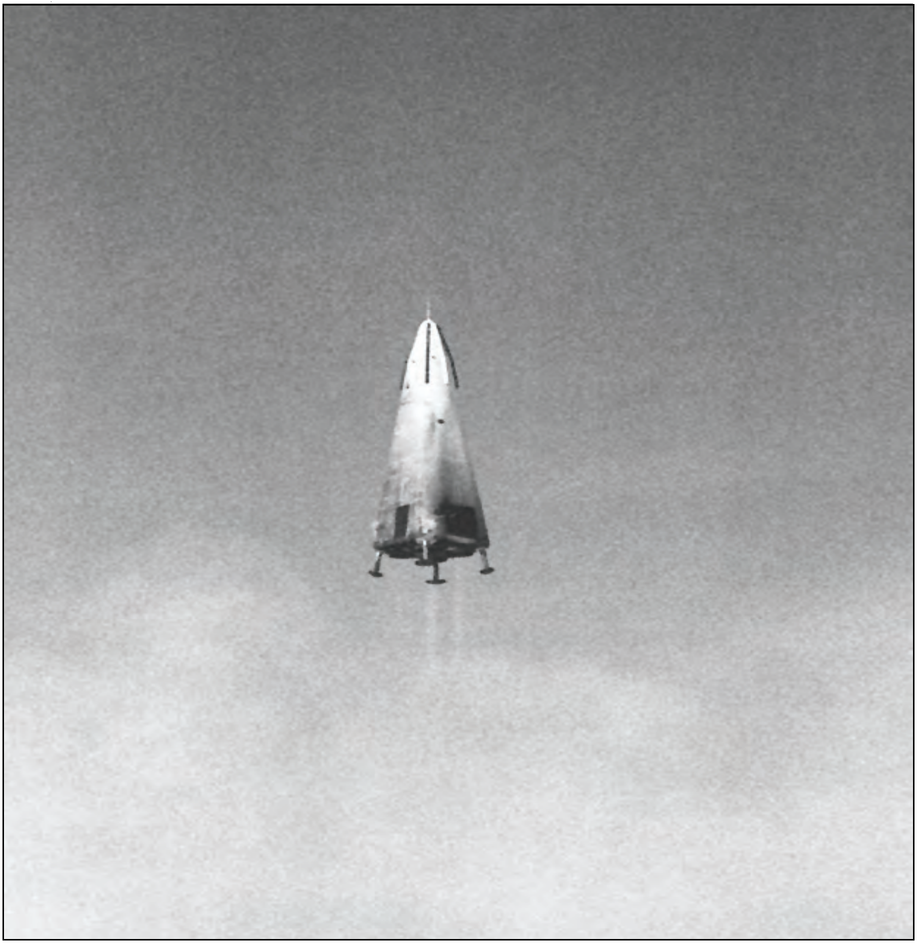

Figure 2–29. First Test Flight of the Delta Clipper-Experimental Advanced (DC-XA), May 18, 1996. (NASA-MSFC Photo No. MSFC-9607854)

A series of less complex tethered experiments took place in 1993 and 1994 from Delta II launch vehicles. They were designed to complement to the TSS deployer when retrieval of the tether was not required. The Small Expendable Deployer System (SEDS-1) was the first of three tether experiments managed by NASA's Office of Space Systems Development Flight Demonstration Program. These experiments were more successful than the Shuttle-based attempts.

On March 29, 1993, about 63 minutes after launch, the first SEDS diagnostic payload was ejected from the Delta by springs. The tether was deployed at an altitude of 720 kilometers (447 miles) above Earth and pointing toward Earth. The tether unreeled smoothly for its full 20-kilometer (12.4-mile) length, and sensors recorded its damping motion for 14 minutes. Then the tether was cut and its 30-kilogram (66-pound) cargo floated away, ending the experiment. A second successful experiment took place from a Delta on June 26, 1993. Called the Plasma

Motor Generator, this experiment assessed the ability of a space tether to generate an electric current. The tether generated about 0.3 amp of current as it moved through Earth's magnetic field.[77] A third experiment took place on March 11, 1994, when the SEDS-2 payload unreeled to its maximum length of 19.8 kilometers (12.3 miles) in 1 hour and 48 minutes. Unlike SEDS-1, when the tether was severed, the tether on this mission remained attached to the Delta rocket, and the payload at the end of the tether transmitted for 10 hours until its battery died.[78]

Shuttle-C

Shuttle-C (cargo) was a concept for a large, uncrewed launch vehicle with a cargo canister in place of the orbiter that would make maximum use of existing Space Shuttle systems. This proposed cargo-carrying launch vehicle would be able to lift approximately 100,000 pounds to 170,000 pounds (45,300 kilograms to 77,000 kilograms) to low-Earth orbit, two to three times the capability of the Shuttle's orbiter. It could reduce by 50 percent the number of launches and length of assembly time for Space Station components. It could also carry scientific spacecraft into orbit. The vehicle would use the same type of external tank, solid rocket boosters, and main engines as the crewed Space Shuttle. Although the U.S. House Subcommittee on VA-HUD-Independent Agencies authorized $1.1 billion on a heavy-lift space cargo vehicle in FY 1991, the vehicle never moved past the study stage and was replaced by the National Launch System, another short-lived initiative.

Advanced Launch System

The Advanced Launch System (ALS) was a joint NASA-DOD program of the late 1980s that was a product of the Strategic Defense Initiative (SDI) "Star Wars" ballistic missile defense system. The program was to define concepts and develop technology for a family of uncrewed launch vehicles that would reduce the cost of putting payloads into orbit. Initially, it was projected that new heavy-lift launchers would be needed to deploy payloads of 10,000 pounds to 200,000 pounds (4,500 kilograms to 90,700 kilograms) to low-Earth orbit for the space-based elements of the SDI program. Three basic booster concepts were proposed. The least costly vehicle would use a hydrogen core and from 6 to 12 solid rocket boosters. A more costly vehicle used a liquid core and from one to six strap-on liquid rocket engines. The most expensive and most advanced ALS alternative, and the least likely because of technological uncertainty, was a winged, fully reusable booster.[79] NASA managed development of the advanced liquid cryogenic propulsion system and the advanced development program.

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[77] Joel W. Powell, "Satellite Tethers Unwind," *Spaceflight*, 36 (March 1994): 97–99.

[78] "Jonathan's Space Report," no. 188 (March 14, 1994*), http://www.planet4589.org/space/jsr/back/news.188* (accessed March 21, 2005).

[79] Mark Cleary, "Future Space Operations: The Space Transportation Architecture Study and Advanced Launch System (ALS) Studies," *Military Space Operations, 1971–1992*, 45th Space Wing History Office, *https://www.patrick.af.mil/heritage/Cape/Cape4/cape4-2.htm* (accessed March 24, 2005).

However, by late 1989, the Cold War was waning, and the SDI initiative was greatly reduced in scope. In October 1989, funding cutbacks shifted emphasis to lightweight weapons, which reduced payload requirements dramatically. On December 7, 1989, the Secretary of the Air Force directed the ALS program office to terminate design efforts "as soon as possible" and suspend any new spending. The three ALS contractors, Boeing, General Dynamics, and a Martin Marietta-McDonnell Douglas team, were directed to transfer ALS technology to the existing fleet of ELVs, which all stood to benefit from technologies developed for the ALS program.[80] In January 1990, the program was downscaled to focus on propulsion technologies, particularly the Space Transportation Main Engine, although little funding was provided to pay for the project at the time.

National Launch System

One of the recommendations in the December 1990 report of the Advisory Committee on the Future of the U.S. Space Program, headed by Norman Augustine, was that the U.S. Space Program end reliance on the Shuttle. It stated that the Administration should provide funds for a "firm program for development of an evolutionary, unmanned but man-rateable, heavy-lift launch vehicle" that "should reach operational capability in time to support all but the initial phase of the Space Station deployment."[81] On January 2, 1991, Vice President Daniel Quayle directed NASA and the DOD to jointly develop a plan for a new space launch system. On April 16, 1991, the Vice President and the National Space Council directed the two organizations to "pursue the development of a new space launch system with the objective of achieving significant improvements in reliability, responsiveness, and operational efficiency."[82] This plan would meet civil and military space needs and actively consider commercial space requirements; costs would be shared equally by NASA and the Defense Department.[83]

The ensuing program, the National Launch System, sometimes called the New Launch System, replaced and combined elements of the previous Advanced Launch System and NASA's Shuttle-C programs. As stated by NASA, program goals were to: 1) develop a modular launch system with a medium-lift to heavy-lift capability, 2) facilitate evolutionary changes as requirements evolved into the 21st century, 3) use existing components from the Shuttle and ELVs to expedite initial capability and reduce development costs,

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[80] Cleary, *Military Space Operations*," *https://www.patrick.af.mil/heritage/Cape/Cape4/cape4-2.htm*. Also, Department of Defense and National Aeronautics and Space Administration *National Space Launch Program Report to Congress,* (March 14, 1989), p. 20.

[81] Advisory Committee on the Future of the U.S. Space Program, "Report of the Advisory Committee on the Future of the U.S. Space Program," December 17, 1990, *http://www.hq.nasa.gov/office/pao/History/augustine/racfup1.htm* (accessed March 15, 2005).

[82] *Aeronautics and Space Report of the President, Fiscal Year 1992 Activities*, p. 18.

[83] David N. Spires and Rick W. Sturdevant, "Epilogue: 'To the Very Limit of Our Ability,'" in Launius and Jenkins, *To Reach the High Frontier*, p. 488.

and 4) develop a system that, while being uncrewed initially, could be "man-rated" in the future.[84] The proposed heavy-lift space cargo vehicle would support the logistics requirements of Space Station *Freedom*. Evolution of vehicles that could support the Nation's return to the Moon and mission to Mars was also envisioned.[85] NASA's Office of Space Systems Development managed the program.

In August 1991, NASA awarded study contracts for the NLS, each valued at $500,000, to Lockheed Missiles and Space, McDonnell Douglas, and TRW Inc. The NASA FY 1992 budget request for the NLS increased the estimate from $23.9 million for the ALS and Shuttle-C to $175 million for NASA's share of the funding. It was anticipated that activities in FY 1992 would focus on beginning development of the Space Transportation Main Engine (STME) prototype, conducting definition and design studies of vehicle components and elements, and assessing requirements and design options for supporting launch facilities.[86]

Initially, the system comprised three different-sized launch vehicles with varying payload capacities to low-Earth orbit. They would be derived from a common core element consisting of the Space Shuttle external tank and a new STME. In 1992, NASA eliminated the largest rocket from the original three when a study determined that the needed modular family of vehicles should span the medium launch vehicle class up to a booster capable of supporting the Space Station's resupply missions. One of the proposed vehicles would be able to deliver 50,000 pounds (22,680 kilograms) to low-Earth orbit; the second, smaller vehicle, could deliver 20,000 pounds (9,000 kilograms).

The program continued into 1992, although funding for FY 1993 was reduced by $137 million consistent with a first launch in 2002. The remaining $28 million was earmarked to support development of the STME. However, in early 1993, the program was terminated, and no funding was included in the FY 1994 budget.

Reusable Launch Vehicles

Developing an RLV, either to supplement or replace the Space Shuttle, received a great deal of attention and significant resources during the decade beginning in 1989. The National Aerospace Plane (the X-30), a program supported strongly by President Ronald Reagan, had been initiated in 1982 as a DARPA project. Planned as a new reusable, air-breathing, single-stage-to-orbit

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[84] "New Launch System," NASA Fact Sheet, National Aeronautics and Space Administration, Marshall Space Flight Center, August 29, 1991 (NASA History Office Folder 010274). Also, "National Launch System–NLS," FAS Space Policy Project, Military Space Programs, *http://www.fas.org/spp/military/program/launch/nls.htm* (accessed March 24, 2005).

[85] "NASA Awards Study Contracts for National Launch System," *NASA News* Release C91-gg, August 16, 1991 (NASA History Office Folder 010274).

[86] "New Launch System," *National Aeronautics and Space Administration FY 1992 Budget Estimate*, pp. RD 2-18–2-19.

hypersonic vehicle, the X-30 became a joint NASA-DARPA program in 1985. Although the project produced some important technological advances, it became too costly in a time of competing priorities, and the program was cancelled in 1994 while still in the technology development phase.

NASA Administrator Goldin joined NASA in April 1992, a time when the Shuttle and other NASA programs were under attack from Congress for their high costs. Taking advantage of the change in presidential administrations in 1993, and also to put his mark on the Agency, Goldin initiated the "Access to Space" study to identify alternative, less expensive approaches to gain access to space that would also increase safety for flight crews. Released in January 1994, the study report was followed later that year by the first executive policy specifically recommending development of an RLV. On August 5, 1994, President William Clinton issued the National Space Transportation Policy making NASA "the lead agency for technology development and demonstration of next generation reusable space transportation systems," while the DOD was given responsibility for improving ELVs.[87] The policy statement led directly to the formation of NASA's RLV Technology program.

NASA's RLV Technology program was a partnership among NASA, the U.S. Air Force, and private industry to develop a new generation of single-stage-to-orbit launch vehicles. The program consisted of the Delta Clipper-Experimental Advanced (DC-XA), X-34, X-33, and related long-term technology development efforts. RLV program managers committed themselves to developing new operations and component technologies, as well as producing an industry-Government relationship that would change the space launch industry worldwide.

DC-X

The Delta Clipper-Experimental (DC-X) program, initiated by the Ballistic Missile Defense Organization (BMDO) in 1990, supported NASA's RLV program. It successfully tested an experimental suborbital launch vehicle in a series of flight tests beginning in 1993. The early RLV efforts were conducted by the U.S. Air Force Phillips Laboratory at Kirtland Air Force Base, New Mexico, under the auspices of the BMDO Single Stage Rocket Technology program. This program's charter was to demonstrate the practicality, reliability, operability, and cost efficiency of a fully reusable rapid turnaround single-stage rocket, with the ultimate goal of aircraft-like operations of RLVs. The program focused on using existing technologies and systems to demonstrate the feasibility of building RLVs for suborbital and orbital flight that could fly into space, return to the launch site, and be serviced and ready for the next mission within three days.

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[87] The White House, Office of Science and Technology Policy, Presidential Decision Directive, National Science and Technology Council-4, *National Space Transportation Policy*, August 5, 1994, *http://www.au.af.mil/au/awc/awcgate/nstc4.htm* (accessed March 20, 2005).

A design and risk reduction competition awarded McDonnell Douglas a $60 million contract in August 1991 to build the DC-X. The DC-X design emphasized simplified ground and flight operations and vehicle maintenance, rapid turnaround, and operational characteristics also relevant to future orbital vehicles. Table 2–92 lists its characteristics.

The flight test program took place in mid-1993. It started with low-altitude hover flights gradually increasing in altitude and duration and eventually leading to suborbital flights to approximately 18,000 feet (5,486 meters). The DC-X flew a total of eight test flights in 1993, 1994, and 1995; the 1995 flights supported NASA's RLV program. The test flight on June 27, 1994, experienced an on-board fire and successfully demonstrated the vehicle's autoland capabilities. On the July 7, 1995, flight, following a successful flight that demonstrated the vehicle's ability to turn itself around and reverse direction, the aeroshell cracked during landing, damaging the vehicle and ending the tests. At the conclusion of this test, the DC-X was officially turned over to NASA. The vehicle was returned to McDonnell Douglas for conversion into the DC-XA.[88]

The DC-XA was a modified DC-X with technology intended for use in the X-33 or X-34 RLVs being developed by NASA and industry partners. The DC-XA had a lightweight graphite-epoxy liquid hydrogen tank and an advanced graphite/aluminum honeycomb intertank built by McDonnell Douglas; an aluminum-lithium liquid oxygen tank built by Energia; and an improved reaction control system from Aerojet. These improvements reduced dry vehicle mass by 620 kilograms (1,367 pounds). NASA and the DOD operated the DC-XA under NASA's RLV program. The flight vehicle was tested at White Sands, New Mexico, during the summer of 1996. It demonstrated a short 26-hour turnaround time between its second and third flights, a record for any rocket.

The DC-XA flew until it was destroyed. During its fourth demonstration flight on July 31, 1996, a landing strut failed to extend, causing the unbalanced vehicle to tip over on the landing pad. The liquid oxygen tank exploded and there were indications of secondary explosions in the liquid hydrogen tank. The ensuing fire damaged large sections of the vehicle. An investigation board later determined that an unconnected helium pressurant line supplying hydraulic pressure to extend the landing strut caused the explosion. The program ended due to lack of funding to build a new vehicle. All flight tests are listed in Table 2–93.

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[88] "DC-X Fact Sheet," BMDOLINK, *http://www.hq.nasa.gov/office/pao/History/x-33/dcx-facts.htm* (accessed March 22, 2005).

Figure 2–30. The X-34 Testbed Demonstrator being delivered to Dryden Flight Research Center, April 16, 1999. (NASA-DFRC Photo No. EC99-44976-31)

X-34

The X-34 program was to bridge the gap between the earlier subsonic DC-XA vehicle and the larger and higher performance X-33 demonstrator. It was structured originally as a cooperative agreement between NASA and Orbital Sciences Corporation signed in March 1995. The government team included Marshall Space Flight Center, responsible for the main propulsion system, including the Fastrac engine; Langley Research Center, responsible for wind tunnel testing and analysis; Ames Research Center, responsible for the thermal protection system; Dryden Flight Research Center; Holloman Air Force Base; White Sands Test Facility; and White Sands Missile Range, responsible for testing and flight support operations.

The proposed winged, reusable, single-stage vehicle, propelled by a kerosene/liquid oxygen engine, was expected to demonstrate key technologies. These included 1) composite primary and secondary airframe structures; 2) cryogenic insulation and propulsion system elements; 3) advanced thermal protection systems and materials; 4) low-cost avionics, including differential Global Positioning and inertial navigation systems; and 5) key operations technologies such as integrated vehicle health-monitoring and automated checkout systems. It was expected to significantly reduce mission costs for sending 1,000-pound to 2,000-pound (454-kilogram to 907-kilogram) payloads into low-Earth orbit. The vehicle would be air-dropped from beneath Orbital's L-1011 aircraft, reach speeds of Mach 8, and fly at altitudes of approximately 50 miles (80 kilometers). The vehicle would also demonstrate the ability to conduct subsonic flights through rain or fog and autonomous landings in crosswinds of up to 20 knots (23 miles per hour or 37 kilometers per hour). Characteristics of the technology demonstrator are listed in Table 2–94.

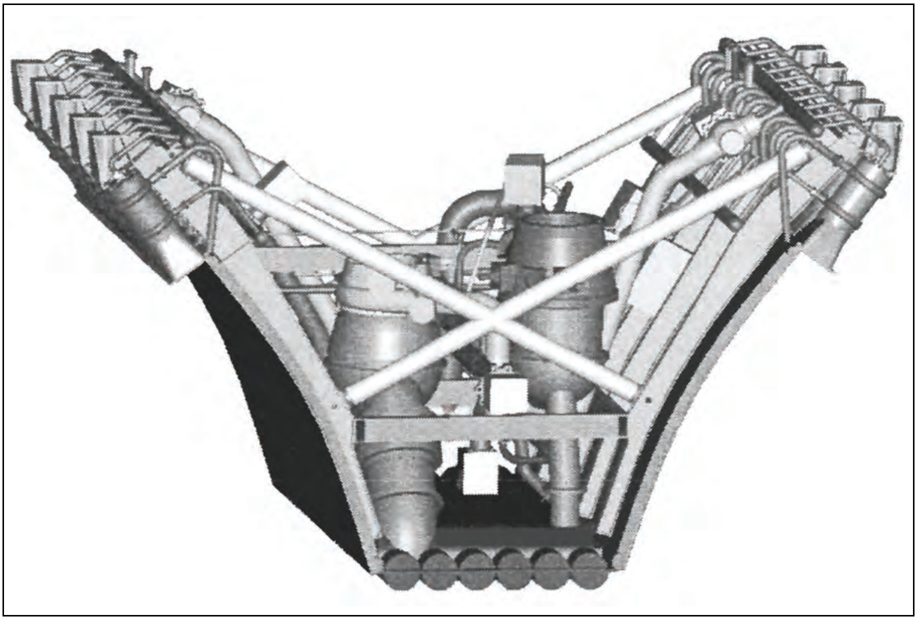

Figure 2–31. Aerospike Engine. (NASA-MSFC)

Originally, the X-34 was to progress rapidly through hardware design, flight tests planned for late 1997, and a launch expected by mid-1998. Orbital, however, withdrew from the cooperative agreement in less than a year partly because of changes in the projected profitability of the venture. NASA subsequently structured a new NASA Research Announcement in March 1996 focusing on the technology demonstration flight tests rather than on the commercial potential of the vehicle. NASA awarded the restructured fixed-price contract to Orbital in June 1996. This 30-month contract had a value of approximately $49.5 million. It included two powered test flights scheduled to begin in late 1998. NASA would spend an additional $10 million in direct support of the X-34. The contract had an option for up to 25 additional test flights after the initial contract period ended.[89]

In August 1997, a critical series of tests on the Fastrac engine were successfully completed at Marshall Space Flight Center. The Fastrac engine, only the second U.S.-made engine developed in the last 25 years, was to be the primary propulsion system for the X-34 demonstration vehicle when it began its flight tests.[90] The following May, a government-Orbital review was held final-

[89] "NASA Finalizes X-34 Contract With Orbital Sciences Corp.," NASA Marshall Space Flight Center News Releases, Release 96-161, August 30, 1996, *http://www.msfc.nasa.gov/news/news/releases/1996/96-161.html* (accessed March 23, 2005).

izing the design of the vehicle. This allowed the program to proceed with fabrication and manufacturing of systems such as structures; guidance; navigation and control; avionics; thermal protection; and main propulsion systems.[91]

To reduce program risk, NASA decided in January 1998 to modify its contract with Orbital to provide for a second flight vehicle. The modification also would allow for additional unpowered tests and more flexibility in demonstrating various technologies. The change increased the contract value by $7.7 million to purchase long lead-time hardware. NASA committed $2 million more for wind tunnel testing, additional testing and analysis, and a second leading-edge thermal protection system. An $8.5 million option called for purchase of shorter lead-time hardware, while a $1.8 million option was added for assembly.

In July 1998, the program passed a critical milestone as the first wing assembly completed qualification tests and was shipped to Orbital Sciences and mated to the X-34 test vehicle under construction. It was ultimately to fly aboard one of the two flight vehicles under construction at Orbital.

At the end of 1998, NASA exercised its option with Orbital for 25 additional test flights during a 12-month period beginning immediately after completion of the initial contract. Flights were to take place at the U.S. Army's White Sands Missile Range in New Mexico. The option was valued at more than $10 million, with government organizations performing an additional $4.7 million in work.[92]

The first of three planned X-34 technology demonstrators "rolled-out" on April 30, 1999, at Dryden Flight Research Center. The vehicle took its first test flight locked underneath the L-1011 carrier aircraft in June 1999. In August 1999, an $11 million contract for the Fastrac engine was awarded to Summa Technology. Assembly and preflight tests continued through 2000. However, in 2001, NASA decided not to add funds to the X-34 program from money dedicated to the Agency's Space Launch Initiative because the government determined that "the benefits to be derived from continuing the X-34 program did not justify the cost." This action coincided with the end of NASA's contract with Orbital Sciences Corporation. At the project's end, NASA had spent $205 million on the X-34 since its inception in 1996.

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[90] "X-34 Fastrac Engine Passes Critical Tests," *NASA News* Release 97-232, August 14, 1997, *http://www.msfc.nasa.gov/news/news/releases/1997/97-232.html* (accessed March 23, 2005).

[91] "X-34 Systems Design Freeze Completed," *NASA News* Release 97-107, May 22, 1997, *http://www.qadas.com/qadas/nasa/nasa-hm/0872.html* (accessed March 25, 2005).

[92] "NASA Exercises X-34 Contract Option for 25 Test Flights," Marshall Space Flight Center News Releases, Release 98-251, December 18, 1998, *http://www.msfc.nasa.gov/news/news/releases/1998/98-251.html* (accessed March 23, 2005).

X-33

The X-33 program, the third RLV program, was to demonstrate a half-scale, single-stage-to-orbit vehicle that could go from launch to orbit without using multiple stages like ELVs or dropping rocket motors and fuel tanks like the Space Shuttle. Flying as fast as Mach 15, it was to decrease the per-pound cost of putting payloads into space from $10,000 to $1,000, while at the same time dramatically increasing launch vehicle safety and reliability. Ultimately, the goal of the full-size vehicle, named the "VentureStar," was to resupply the Space Station more quickly and cheaply than the Space Shuttle.

The program was a high-risk venture with unproven technologies that challenged its developers. In particular, the design required development of linear aerospike rocket engines, which had never been used in flight and had been rejected by Space Shuttle developers 25 years earlier. The program required the development of a wingless "lifting body" airframe that could keep the vehicle flying smoothly during launch and return to Earth. The program also required composite fuel tanks that could withstand the pressures of a space launch while filled with pressurized liquid hydrogen at a temperature of -423°F (-253°C).[93]

NASA initiated this NASA-industry partnership through a Cooperative Agreement Notice for Phase I concept definition and design of a technology demonstrator vehicle, the X-33, issued in January 1995. In March, NASA signed cooperative agreements with three companies—Lockheed Advanced Development Company (the Skunk Works), McDonnell Douglas Aerospace, and Rockwell International Corporation—to design the vehicle. The agreement called for NASA to work with each of these companies over the next 15 months on vehicle concept definition and design. The government would provide approximately $7 million to each of the companies, and each company was expected to match the investment.

Each company produced a design concept: all the vehicles would take off vertically, but only the McDonnell Douglas concept would land vertically. The others landed horizontally like an airplane.

At the beginning of April 1996, NASA issued another Cooperative Agreement Notice for Phase II of the project: the design, fabrication, and flight test of the X-33 demonstrator. It was planned that Phase II of the project would culminate in flight demonstration testing of the X-33 to begin in early 1999. NASA and industry would share costs during this phase. This was the first time a cooperative agreement rather than a conventional contract was used for a program of this size.

After a selection process of only a few months (due to an innovative paperless procurement process), on July 2, 1996, amid much fanfare, Vice President Albert Gore announced that NASA had selected Lockheed Martin

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[93] "NASA's Billion-Dollar Shuttle Replacement May Never Fly," *CNN.com/Space* (September 25, 2000), *http://archives.cnn.com/2000/TECH/space/09/25/troudledspaceship.ap/index.html* (accessed March 24, 2005).

to build the X-33 test vehicle. According to the terms of the agreement, by March 1999, Lockheed Martin would design, build, and conduct the first test flight of the remotely piloted demonstration vehicle and would conduct at least 15 flights by December 1999. Major components would include a more robust metal heat shield in place of the Space Shuttle's tiles and an updated aerospike engine. The X-33 design was based on a lifting body shape that would be launched vertically like a rocket and land horizontally like an airplane. NASA had budgeted $941 million for the effort. Lockheed Martin initially invested $220 million of its own funds in the design. Figure 2–33 shows an artist's concept of the X-33 and VentureStar. Table 2–95 lists X-33 characteristics.

In 1997, the project successfully passed two important milestones. The Critical Design Review (CDR), held in October, ended 51 subsystem and component CDRs that had been held earlier that year. It allowed the program to proceed with fabrication of the remaining components, completion of subsystems, and assembly of the subscale prototype launch vehicle. Earlier in the year, the project had needed to resolve issues regarding aerodynamic stability and control and vehicle weight by modifying the design of the vehicle's canted and vertical fins. The project also planned to reduce weight by using composite materials and densified propellants.[94] In November, NASA completed the environmental impact statement process, which allowed all 15 test flights to proceed from the launch site at Haystack Butte on the eastern part of Edwards Air Force Base, California, and land at Michael Army Air Field, Dugway Proving Ground, Utah, and Malmstrom Air Force Base near Great Falls, Montana.[95]

The next major milestone was completion of flight-testing of the thermal protection system (TPS) materials. The tests took place in June 1998 at Dryden Flight Research Center on its F-15B Aerodynamic Flight Facility aircraft. The plane reached an altitude of 36,000 feet (10,973 kilometers) and a top speed of Mach 1.4 during the tests. The materials in the TPS included metallic Inconel tiles, soft Advanced Flexible Reusable surface insulation tiles, and sealing materials.

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[94] "X-33 Program Successfully Completes Critical Design Review," *NASA News* Release 97-250, October 31, 1997, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1997/97-250.txt* (accessed March 15, 2005).

[95] "NASA Completes X-33 Environmental Impact Statement Process," *NASA News* Release 97-254, November 5, 1997, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1997/97-254.txt* (accessed March 15, 2005).

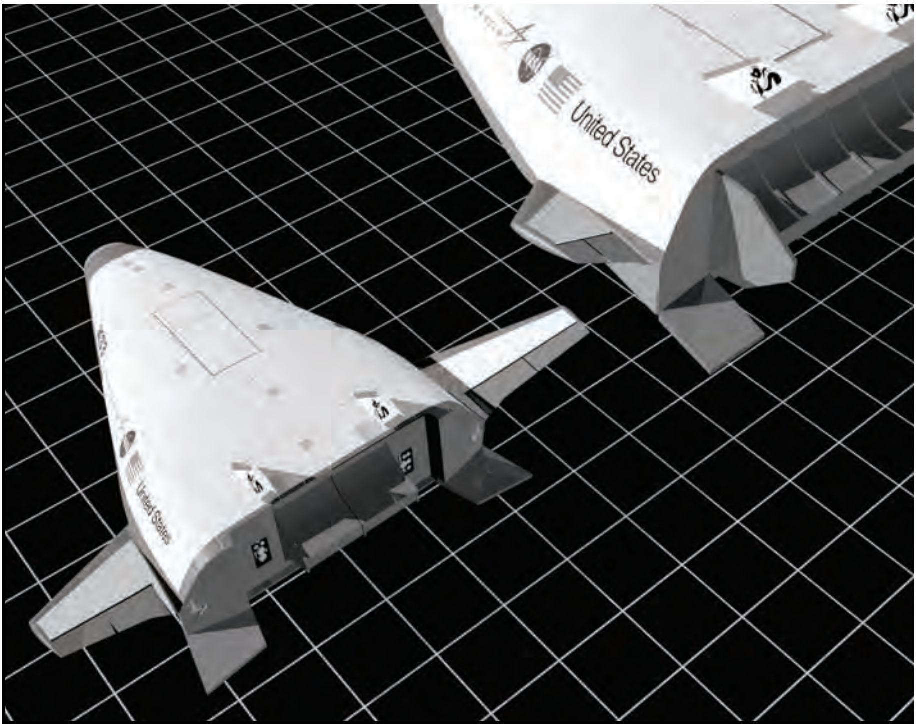

Figure 2–32. Artist's concept showing the relative size of the X-33 (left) and the proposed operational VentureStar. The VentureStar was to be twice the size of the half-scale X-33. (NASA-DFRC Photo No. ED97-43938-1)

Meanwhile, NASA's Office of Inspector General was investigating the program. The first inquiry examined whether NASA's use of a cooperative agreement on the X-33 program was appropriate for the program and "whether the agreement effectively defined roles, responsibilities, and rights of the government and industry partners." A secondary objective was to determine whether NASA implemented and managed the program consistent with congressional guidance. An audit determined that obligated funds for Lockheed Martin had not been recorded in a timely manner, a potential violation of federal law. Consequently, the Inspector General concluded that reports and financial statements "did not accurately reflect the financial status" of the program.[96] The next year, another audit from the Office of Inspector General examined whether the government had adequately addressed the cost of the project and its cost risk and cost estimate. The audit concluded that a better risk analysis "would have alerted NASA decision-makers to the probability of cost overruns" that "put NASA's investment . . . at risk."[97]

[96] Office of Inspector General, National Aeronautics and Space Administration, "Audit Report: X-33 Funding Issues," IG-99-001, November 3, 1998, pp. 1–3, *http://www.hq.nasa.gov/office/oig/hq/ig-99-001es.htm* (accessed March 19, 2005).
[97] Office of Inspector General, National Aeronautics and Space Administration, "Audit Report: X-33 Cost Estimating Processes," IG-99-052, September 24, 1999, pp. i–ii, *http://www.hq.nasa.gov/office/oig/hq/ig-99-052es.htm* (accessed March 15, 2005).

In 1999, the X-33 program experienced a setback when the composite materials used for its liquid hydrogen fuel tank failed during testing. An investigation into the cause of the failure determined that the composite technology was not "mature enough" for such a use. Lockheed Martin proposed replacing the composite tanks with aluminum tanks, which NASA agreed to if Lockheed Martin could obtain Space Launch Initiative funding. However, it was determined that the benefit did not justify the cost, and NASA cancelled the program in 2001 before proceeding to the next phase.[98] NASA investment in the X-33 program totaled $912 million, staying within its 1996 budget projection for the program. Lockheed Martin originally committed to invest $220 million in the X-33 and, during the life of the program, increased that amount to $357 million. In response to the cancellation, Lockheed Martin chose not to continue developing the VentureStar. A criticism of both the X-34 and X-33 programs was that NASA had not developed risk management plans until well after the programs had begun. Table 2–96 lists the chronology for NASA's RLV development.

[98] Leonard David, "NASA Shuts Down X-33, X-34 Programs," *Space.com*, *http://www.space.com/missionlaunches/missions/x33_cancel_010301.html* (accessed March 22, 2005).

Table 2–1. Authorized/Appropriated Budget (FY 1989–FY 1998) (in thousands of dollars)

	1989	1990	1991	1992	1993	1994
R&D[a]	4,191,700	5,366,050	5,600,000	6,413,800	7,089,300	7,509,300
Space Transportation Capability Development[b]	606,600	651,500	763,400	679,800[c]	733,700[d]	751,600[e]
Upper Stages	156,200	—	—	—	—	—
Orbital Maneuvering Vehicle	—	—	45,400,000	—	—	—
Shuttle-C	—	—	40,000,000[f]	—	—	—
SFC&DC[g]	4,364,200	4,614,600	6,319,132	5,157,075	5,086,000	4,878,400
Space Shuttle Production and Operational Capability	1,335,500	1,340,300	1,364,000[h]	1,328,900	1,315,800	1,069,200
Advanced Solid Rocket Motor	51,000	35,000	—	375,000	315,000	150,000[i]
Safety Enhancements	—	75,000	—	—	—	—
Space Transportation (Shuttle) Operations	2,365,400	2,544,900	2,831,400[j]	2,970,600	3,085,200	3,006,500
Expendable Launch Vehicles (Launch Services)	—	169,500	229,200[k]	291,000	207,500	300,300
	1995	**1996**	**1997[l]**	**1998[m]**		
Human Space Flight[n]	5,573,900[o]	5,456,600	5,362,900	5,506,500		
Payload and Utilization Operations[p]	346,200[q]	315,000	271,800	247,400		
Space Shuttle Safety and Performance Upgrades	3,309,000[r]	837,000	636,000	483,400		
Space Shuttle Production and Operational Capability	—	—	—	—		
Space Shuttle Operations	—	2,341,800	2,514,900	2,494,400		
Launch Services	313,700	—	—	—		
Science, Aeronautics and Technology[s]	5,901,200	5,928,900	5,762,100	5,690,000		
Advanced Concepts and Technology/Space Access and Technology	623,000[t]	639,800	711,000	696,600[u]		
Advanced Space Transportation	—	193,000	324,700	—		

Table 2–1. Authorized/Appropriated Budget (FY 1989–FY 1998) (in thousands of dollars) (Continued)

	1995	1996	1997[l]	1998[m]
X-33 Advanced Technology Demonstration Vehicle	—	—	—	333,500
Follow-on to X-33 Focused Technology Demonstration	—	—	—	150,000
Experimental Vehicle Procurement	—	—	—	150,000

[a] Total R&D amounts were stated in the appropriations bills, not in the authorization bills. R&D amounts shown did not equal the amounts shown in subcategories. Amounts for subordinate categories were from authorization bills unless otherwise noted.

[b] Amounts authorized for Space Transportation Capability Development included the Spacelab category, addressed in chapter 3, Human Spaceflight.

[c] Includes $40 million authorized for propulsion technology development and $10 million authorized for launch vehicle design studies, including single-stage-to-orbit vehicles.

[d] Specified $30 million for development of the Space Transportation Main Engine.

[e] Included $21million to develop improvements in existing ELVs (including development of a single-engine version of the Centaur upper stage rocket) and $21.4 million to support development of advanced launch technologies, including single-stage-to-orbit technologies and components.

[f] Required in FY 1991 authorizations bill. Does not appear in programmed amounts in NASA's budget.

[g] Amounts for SFC&DC were stated in appropriations bill, not in authorization bills. Amounts for subordinate categories were from authorization bills unless otherwise noted.

[h] Of such funds, $45 million for FY 1991 was to be used for the Space Shuttle main engine, solid/rocket booster/solid rocket motor, external tank, orbiter, and the Assured Shuttle Availability program.

[i] For termination of program.

[j] Of these funds, $4 million was to be made available for the provision of launch services for eligible satellites in accordance with Section 6 of the Commercial Space Launch Act Amendments of 1988, Public Law 100-657.

[k] Launch Services (ELVs) transferred to Office of Space Science and Applications under the R&D appropriation.

[l] In the FY 1997 and FY 1998 authorization, Congress included NASA's authorization in a bill titled the Omnibus Civilian Science Authorization Act. H.R. 3322 was passed by the House. It was referred to Senate committee but was not acted upon by the Senate.

[m] Authorization bill H.R. 1275 passed by House. Referred to Senate committee but was not acted upon by Senate.

[n] Beginning with the FY 1995 estimate, and computation of FY 1993 programmed amounts, many R&D and SFC&DC amounts that involved human spaceflight moved to a single, new appropriation called Human Space Flight.

[o] Appropriated amount per Conference Committee.

[p] Formerly Space Transportation Capability Development.

[q] Included $40,000,000 to develop improvements in existing ELVs (including the development of a single-engine version of the Centaur upper stage rocket) and $46,000,000 to support development of advanced launch technologies, including single-stage-to-orbit technologies and components as well as other Space Transportation Capability Development/Payload and Utilization Operations budget categories.

[r] Amount included total Space Shuttle category: Production and Operational Capability and Operations.

[s] SAT appropriation used for some launch systems items.

[t] Included $40 million for single-stage-to-orbit technology development program, $13.6 million for University Space Engineering Research Centers, and $12.5 million for Small Spacecraft Technology Initiative.

[u] Called Advanced Space Transportation Technology in H.R. 1275.

Table 2–2. Programmed Budget (FY 1989–FY 1998) (in thousands of dollars)

	1989	**1990**	**1991**	**1992**	**1993[a]**	**1994**	**1995**	**1996**	**1997**	**1998**
R&D/SAT					Human Space Flight[b]					
Space transportation capability Development/payload and utilization operations[c]	674,000	558,142	602,467	739,711	442,300	405,600	320,100[d]	323,000	265,300	205,400
Upper stages	131,600	79,700	82,467	41,200	47,700[e]	6,900	—	—	—	—
Engineering and technical base	160,600	181,600	208,500	210,800	214,200	180,400	165,600	169,700	144,600	102,900
Payload operations & support equipment	60,700	65,461	101,200	130,100	95,200	85,100	44,000[f]	40,600	45,900	46,700
Tethered satellite system	26,400	27,300	21,900	16,400	4,000	7,400	7,400	1,800	—	—
Orbital maneuvering vehicle	73,000	75,681	—	—	—	—	—	—	—	—
Advanced programs	52,700	34,700	35,200	34,700	—	—	—	—	—	—
Advanced projects	—	—	—	—	16,100	7,200	12,200	24,200	34,700	46,700
Advanced space transportation[g]	—	—	—	—	114,600[h]	109,100[i]	162,100	234,000	—	417,100
Advanced concepts and technology	—	—	—	—	464,900	502,400	605,400	—	—	—
Advanced transportation technology[j]	81,400	—	23,900[k]	28,000	10,000[l]	20,000	—[m]	—	—	—
Reusable launch vehicle–systems engineering and analysis	—	—	—	—	—	3,500	3,800	—	—	—
Reusable launch vehicle–technology program	—	—	—	—	—	28,400	75,500	—	—	—
Reusable launch vehicle–initial flight demo program (FDP)	—	—	—	—	—	2,300	49,200	—	—	—

Table 2–2. Programmed Budget (FY 1989–FY 1998) (in thousands of dollars) (Continued)

	1989	1990	1991	1992	1993[a]	1994	1995	1996	1997	1998
X-33 advanced technology demonstrator	—	—	—	—	—	—	—	157,500	262,000	319,300
X-34 technology demonstration program	—	—	—	—	—	—	—	30,000	20,500	26,700
Transportation technology support	—	—	—	—	—	54,900	33,600	29,500[n]	34,400	62,100
SFC&DC/HSF										
Shuttle production and operational capability/safety and performance upgrades[o]	1,121,600	1,194,949	1,313,945	1,296,400	1,131,000	1,009,700	710,000	658,400	496,000	568,400
Orbiter	159,000	148,300	186,300	158,800	—	—	—	—	—	—
Orbiter improvements	—	—	—	—	235,000	204,300	194,800	271,400	159,900	232,500
Systems integration	34,500	15,000	10,700	7,200	—	—	—	—	—	—
Extended duration orbiter	20,000	23,700	25,000	10,700	—	—	—	—	—	—
Structural spares	20,300	22,900	66,000	57,600	—	—	—	—	—	—
Orbiter spares	48,000	28,200	26,800	13,800	—	—	—	—	—	—
Flight operations upgrades	—	—	—	—	121,100	109,900	54,300	73,400	66,000	40,300
Launch site equipment	104,100	105,700	101,200	93,100	80,100[p]	81,700	50,200	24,200	58,600	115,400
Mission operations and support capability[q]	153,500	177,349	136,045	148,100	—	—	—	—	—	—
Space Shuttle main engine upgrades	—	—	—	—	320,300	355,500	318,900	234,100	196,000	170,100
Solid rocket booster[r]	121,000	72,500	50,400	34,900	—	—	—	—	—	—
Solid rocket booster improvements	—	—	—	—	1,400	23,500	39,100	7,200	800	1,200
External tank	7,000	2,700	—	—	—	—	—	—	—	—

Table 2–2. Programmed Budget (FY 1989–FY 1998) (in thousands of dollars) (Continued)

	1989	1990	1991	1992	1993[a]	1994	1995	1996	1997	1998
Super lightweight tank	—	—	—	—	—	50,800	41,200	30,700	6,000	700
Construction of facilities[s]	—	—	—	—	178,100	34,300	12,300	17,400	—	8,200
Advanced solid rocket motor	51,000	160,400	309,100	315,000	195,000	149,700[t]	—	—	—	—
Assured Shuttle availability[u]	—	—	—	104,600	—	—	—	—	—	—
Space transportation operations/ Space Shuttle operations[v]	2,612,700	2,632,400	2,752,400	3,029,300	2,857,200	2,549,000	2,444,300	2,485,400	—	2,344,400
Mission support[w]	230,900	252,600	275,000	295,900	361,000[x]	316,000	287,700	358,900	46,200	814,700
Integration	285,000	303,200	317,900	315,400	200,000	199,000	169,500	142,500	—	—
Support	182,500	194,900	194,300	196,600	—	—	—	—	—	—
Orbiter	314,100	397,800	414,500	430,700	477,000	387,900	358,700	378,500	—	507,900
Space Shuttle main engine	403,200	438,200	402,400	322,100	239,900	189,200	163,300	185,000	208,300	173,400
Solid rocket booster	704,100	458,600	577,400	542,000	172,000	158,200	163,000	153,300	151,200	152,200
Redesigned solid rocket motor	—	—	—	—	409,400	396,400	370,700[y]	395,700	412,800	360,200
External tank	295,000	344,600	378,100	354,100	300,200	252,200	305,000	327,500	352,500	336,000
Launch and landing operations	534,600	541,000	595,200	642,900	697,100[z]	650,100	621,400	544,000	801,400	—[aa]
Launch operations	481,600	484,000	539,200	578,600	—	—	—	—	—	—
Payload and launch support	53,000	57,000	56,000	64,300	—	—	—	—	—	—
Expendable launch vehicles and services	66,500	139,700	229,200[ab]	155,800	180,801	84,600	255,600	245,300	240,600[ac] 84,700[ad]	212,900[ae] 27,600[af] 39,400[ag]
Small class	13,900	11,900	14,100	32,600	25,272[ah]	10,400	—	—	—	—
Medium class	45,000	75,400	97,300	58,100	61,451[ai]	43,000	—	—	—	—

Table 2–2. Programmed Budget (FY 1989–FY 1998) (in thousands of dollars) (Continued)

	1989	1990	1991	1992	1993[a]	1994	1995	1996	1997	1998
Intermediate class	6,300	49,600	108,100	45,000	41,100[aj]	43,000	—	—	—	—
Large class	1,300	2,800	9,700	20,100	5,278[ak]	—	—	—	—	—
Launch services mission support	—	—	—	—	—	37,100	—	—	—	—

[a] Beginning with the FY 1995 estimate, and computation of FY 1993 programmed amounts, all R&D and SFC&DC amounts that involved human spaceflight moved to a single, new appropriation called Human Space Flight.
[b] HSF appropriation except where noted otherwise.
[c] Budget for Space Transportation Capability Development includes Spacelab category. This is addressed with budget information in chapter 3, Human Spaceflight.
[d] Became Payload and Utilization Operations under HSF appropriations category.
[e] SAT appropriation, Office of Space Science.
[f] Renamed Payload Processing and Support.
[g] SAT appropriation within budget category Advanced Concepts and Technology. Items include Advanced Transportation Technology, Technology Assessment and Development, Advanced Technology Maturation, In-Space Transportation, and Single Engine Centaur.
[h] SAT appropriation.
[i] Part of Office of Space Access and Technology.
[j] Called Advanced Launch Systems in FY 1989 and FY 1990. Called Advanced Launch Technology in FY 1995 budget estimate. Advanced Transportation Technology includes: advanced launch system–-civil needs, advanced launched system-–propulsion, Shuttle-C studies (funding provided within Advanced Programs under Advanced Transportation line item), and heavy-lift vehicle studies.
[k] Called New Launch System beginning in FY 1993.
[l] SAT appropriation.
[m] Advanced Space Transportation Technology was also supported by $15 million in FY 1996 and $12 million in FY 1997, funded within the Engineering and Technical Base program of the Office of Space Flight.
[n] Renamed Advanced Space Transportation Program.
[o] Changed to Safety and Performance Upgrades in FY 1993.
[p] Included Launch Site Equipment upgrades (HSF appropriation) from FY 1993.
[q] Called Mission Support Capability beginning with FY 1992 estimate.
[r] Included safety upgrades and improvements to solid rocket booster and redesigned solid rocket motor.
[s] Construction of Facilities funding for Space Shuttle projects was provided to refurbish, modify, replace, and restore facilities at Office of Space Flight Centers to improve performance, address environmental concerns of the older facilities, and to ensure their readiness to support Space Shuttle Operations.
[t] Termination funding.
[u] Name changed to Safety and Obsolescence Upgrade beginning with FY 1994 budget estimate.
[v] Name changed to “Space Shuttle Operations” beginning in FY 1993.

[w] Name of category changed to "mission operations" in FY 1992. Description of function was unchanged.
[x] Called Mission and Crew Operations.
[y] Name changed to Reusable Solid Rocket Motor. Description of activity remained the same.
[z] Not broken down into smaller budget categories. Includes payload and launch support.
[aa] Combined with Mission Support.
[ab] Expendable Launch Vehicles and Services were officially transferred to the Office of Space Science and Applications (OSSA). Actual (appropriated) costs were charged to OSSA in FY 1991.
[ac] Space Science ELVs and launch support.
[ad] Earth Science ELVs and launch support.
[ae] Moved to HSF appropriation.
[af] Space Science launch support.
[ag] Earth Science launch support.
[ah] SAT appropriation.
[ai] SAT appropriation.
[aj] SAT appropriation.
[ak] SAT appropriation.

Table 2–3. Space Transportation Capability Development/Payload and Utilization Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Programmed
1989	631,300/681,000	606,600	674,000
1990	639,000/562,381	651,500	558,142
1991	773,400/602,500	763,400	602,467
1992	879,800/731,456	679,800[a]	739,711
1993	863,700/649,216	733,700[b]	442,300
1994	649,200/412,600	751,600[c]	405,600
1995[d]	356,200/320,100	819,300	320,100
1996	315,600/315,000	315,000	323,000
1997	271,800/275,300	271,800	—[e]
1998	227,400/205,400	247,400	205,400

[a] Included $40,000,000 authorized for propulsion technology development and $10,000,000 authorized for launch vehicle design studies, including single-stage-to-orbit vehicles.

[b] Specified $30,000,000 for development of the Space Transportation Main Engine for use with the Advanced/New Launch System.

[c] Included $21,000,000 to develop improvements in existing ELVs (including development of a single-engine version of the Centaur upper stage rocket) and $21,400,000 to support development of advanced launch technologies, including single-stage-to-orbit technologies and components.

[d] Payload and Utilization Operations budget category (beginning FY 1995) included same subcategories as Space Transportation Capability Development (Spacelab, Tethered Satellite System, Payload Processing and Support, Advanced Projects, and Engineering and Technical Base).

[e] No programmed amount shown.

Table 2–4. Upper Stages Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	146,200/138,800	131,600
1990	88,600/84,600	79,700
1991	91,300/82,200	82,467
1992	108,500/62,256	41,200
1993[a]	56,500/47,700	47,700[b]
1994	51,100/43,600	6,900
1995	31,800/15,200	—
1996	18,300/—[c]	—

[a] Moved to Expendable Launch Vehicle category in FY 1993, which had been relocated to OSSA in FY 1993; was a SAT appropriation.

[b] SAT appropriation, Office of Space Science.

[c] Funding for mission-unique launch services was now included under the budget request for the benefiting program. Funding support for management oversight of the entire Launch Services program rested with the Launch Vehicles Office (LVO), which was now part of the newly formed Office of Space Access and Technology. The LVO aggregated NASA, NOAA, and international cooperative ELV mission requirements. The administration, procurement, and technical oversight of launch services in the small and medium performance classes were managed by Goddard Space Flight Center (Pegasus XL, Med-lite, and Delta II). Intermediate launch services (Atlas I/IIAS) were managed by Lewis Research Center. Upper stages were managed by Marshall Space Flight Center. Kennedy Space Center was delegated responsibility for technical oversight of vehicle assembly and testing at the launch site by Goddard and Lewis and was responsible for spacecraft processing at the launch site.

Table 2–5. Engineering and Technical Base Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	158,900/155,400	160,600
1990	189,800/181,600	181,600
1991	218,500/208,500	208,500
1992	235,200/215,800	210,800
1993	224,200/214,155	214,200
1994	203,400/180,400	180,400
1995	176,400/165,600	165,600
1996	171,700/171,700	169,700
1997	151,500/148,600	144,600
1998	102,900/102,900	102,900

Table 2–6. Payload Operations and Support Equipment[a] Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	67,300/64,700	60,700
1990	81,100/66,700	65,461
1991	122,500/101,500	101,200
1992	144,500/119,100	130,100
1993	153,600/92,100	95,200
1994	95,400/92,100	85,100
1995	62,600/36,300[b]	44,000
1996	30,300/40,600	40,600
1997	42,700/41,700	45,900
1998	51,600/43,900	46,700

[a] Name of category changed to Payload Processing and Support in FY 1995.
[b] Reduction reflected closing of four of the 10 payload processing facilities before the end of the year.

Table 2–7. Advanced Programs Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	45,000/52,700	52,700
1990	48,700/33,600	34,700
1991	53,200/35,200	35,200
1992	53,800/39,300	34,700
1993	57,700/32,897	—
1994	60,700[a]/—	—

[a] Most elements moved to Advanced Space Technology.

Table 2–8. Advanced Projects Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	—[a]	16,100
1994	7,200/—	7,200
1995	15,200/12,200	12,200
1996	12,200/12,200	24,200
1997	15,200/34,700	34,700
1998	58,700/46,700	46,700

[a] Budget category not established at time of budget submission.

Table 2–9. Tethered Satellite System Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	23,800/26,400	26,400
1990	19,900/24,000	27,300
1991	17,900/21,900	21.900
1992	12,600/16,400	16,400
1993	3,400/3,400	4,000
1994	—7,400[a]	7,400
1995	9,700/7,400	7,400
1996	3,800/3,800	1,800

[a] The Tether mission was flown on STS-46 in August 1992. No further Tether missions were manifested when the initial budget estimate was prepared. In 1993, it was determined that a reflight could be readily accomplished and several improvements to enhance the probability of success were recommended. The reflight was manifested for early 1996.

Table 2–10. Orbital Maneuvering Vehicle Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	96,500/73,000	73,000
1990	107,000/76,281	75,681
1991	85,400/—[a]	—

[a] A decision was made to terminate the Orbital Maneuvering Vehicle program in June 1990. Consistent with congressional direction, no FY 1991 funding was provided.

Table 2–11. Advanced Concepts and Technology/Space Access and Technology Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Authorization	Programmed
1993	—[b]	—	464,900
1994	495,300/495,300	—	562,400
1995	608,400/642,400	623,000[c]	605,400
1996	705,600/641,300	639,800	—
1997	725,000/—	711,000	—
1998	—[d]	696,600[e]	—

[a] Funding categories dealing with advanced transportation varied frequently. Included Advanced Space Transportation, Launch Vehicle Support, and other budget categories not relevant to Launch Systems.

[b] Budget category not established at time of budget submission.

[c] $40,000,000 for single-stage-to-orbit technology development program, $13,600,000 for University Space Engineering Research Centers, and $12,500,000 for Small Spacecraft Technology Initiative.

[d] Budget category not shown in budget submission or programmed amount.

[e] Called Advanced Space Transportation Technology in H.R. 1275, "Civilian Space Authorization Act, Fiscal Years 1998 and 1999."

Table 2–12. Advanced Space Transportation Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Authorization	Programmed
1993	—	—	114,600
1994	—[b]/121,900	—	109,100
1995	103,100/162,100	—	162,100
1996	193,000/188,500	193,000	234,000
1997	324,700/336,700	324,700	336,700
1998	396,600/417.100	—	417,100

[a] Categories varied depending on year and active projects. At times they included Advanced Launch Technology, Reusable Launch Vehicles, Transportation Technology Support, New Launch System, Single-Stage Centaur, and other categories.

[b] Budget category not established at time of budget submission.

Table 2–13. Advanced Transportation Technology/New Launch System Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Authorization	Programmed
1989	13,000/81,400[b]	6,500	81,400
1990	5,000/(10,500)[c]	—	—[d]
1991[e]	53,900/23,900[f]	40,000[g]	23,900[h]
1992	175,000[i]/38,000[j]	—	28,000
1993[k]	125,000[l]/10,042[m]	—	10,000[n]
1994	—	—	20,000

[a] Called Advanced Launch System in congressional documents.

[b] Renamed Advanced Launch Systems. This was a joint NASA–DOD program with the objective of defining a new heavy-lift capability based on advanced technology that would reduce the cost of placing payloads in space. NASA had responsibility for the civil requirements not addressed by the joint ALS baseline design. The original FY 1989 budget estimate of $13 million, reflected only the civil requirements. The revised estimate of $81.4 million reflected both a reduced civil requirement of $6.5 million and the propulsion element estimated at $74.9 million.

[c] Funding was deleted in FY 1990 legislation. Total funding for Advanced Launch Systems, including NASA-managed elements, was included in the DOD budget request. NASA's Advanced Launch Systems propulsion advanced development effort was provided through reimbursable funding rather than appropriation transfers.

[d] No programmed amount shown.

[e] Included Advanced Launch Systems, Shuttle-C, Heavy Lift Vehicle Studies.

[f] This revised estimate was consistent with congressional direction. It was accommodated primarily through deferral of the Assured Crew Return Vehicle Phase B study and other program realignments.

[g] Amount specified for Shuttle-C. Other uses for funds not listed.

[h] Called New Launch System beginning in FY 1993.

[i] Increase reflected plans to proceed with the initial stages of a new launch system. Program planning for FY 1992 was not completed when the estimate was prepared. It was thought that the focus of FY 1992 activities would be initiating development of the Space Transportation Main Engine prototype, conducting definition and design studies of vehicle components and elements, and assessing requirements and design options for supporting launch facilities. Technologies and operational approaches that could reduce per-flight costs and increase system robustness would also be pursued.

[j] The budget reduction supported a change to a 2002 first launch schedule. An equal amount was budgeted by DOD.

[k] Called New Launch System beginning in FY 1993.

[l] Funding level (along with an equal amount from DOD) allowed completion of the preliminary design effort for the New Launch System.

[m] The New Launch System (formerly Advanced Transportation Technology) was to be a joint program with the DOD to develop a new family of launch vehicles that would improve national launch capability with reductions in operating costs and improvements in launch system reliability, responsiveness, and mission performance. Initial efforts focused on developing the Space Transportation Main Engine (STME) since this was the common element of all configuration. The reduction in the FY 1993 budget estimate terminated the effort on the NLS while retaining options to develop the STME and/or examine alternative engine technologies.

[n] SAT appropriation.

Table 2–14. Reusable Launch Vehicle–Systems Engineering and Analysis Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]	3,500
1995	—/4,600	3,800
1996	4,700/500	—[b]

[a] Budget category not established at time of budget submission.
[b] No programmed amount shown.

Table 2–15. Reusable Launch Vehicle–Technology Program Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]	28,400
1995	—/76,900	75,500
1996	59,300/49,500	—[b]

[a] Budget category not established at time of budget submission.
[b] No programmed amount shown.

Table 2–16. Reusable Launch Vehicle–Initial Flight Demonstration Program (FDP) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]	2,300
1995	—/47,000	49,200
1996	60,000/109,000	—[b]
1997	266,100/—[c]	—

[a] Budget category not established at time of budget submission.
[b] No programmed amount shown.
[c] No revised budget submission for this category.

Table 2–17. X-33 Advanced Technology Demonstrator Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Authorization
1996	—[b]	157,500
1997	—/246,800	262,000
1998	333,500/318,300	319,300

[a] Part of Reusable Launch Vehicle Program.
[b] Budget category not established at time of budget submission.

Table 2–18. X-34 Technology Demonstration Program Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Programmed
1996	—[b]	30,000
1997	—/36,700	20,500
1998	43,100/26,700	26,700

[a] Part of Reusable Launch Vehicle Program.
[b] Budget category not established at time of budget submission.

Table 2–19. Transportation Technology Support Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]	54,900
1995	—/33,600	33,600
1996	34,000/29,500	29,500[b]
1997	16,600/53,200	34,400
1998	43,100/26,100	62,100

[a] Budget category not established at time of budget submission.
[b] Renamed Advanced Space Transportation Program.

Table 2–20. Space Shuttle Production and Operational Capability/ Safety and Performance Upgrades Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Authorization	Programmed
1989	1,400,500/1,128,200	1,335,500	1,121,600
1990	1,305,300/1,119,500	1,340,300	1,194,949
1991	1,302,000/1,327,800	1,364,000[b]	1,313,945
1992	1,288,900/1,276,400	1,328,900	1,296,400
1993	1,021,800/1,053,016	1,315,800	1,131,000
1994	1,189,600/978,700	1,069,200	1,009,700
1995	903,900/739,800	3,309,000[c]	710,000
1996	837,000/663,400	837,000	658,400
1997	636,000/636,000	636,000	496,000
1998	483,400/553,400	483,400	568,400

[a] Included orbiter improvements, propulsion upgrades (SSME upgrades, SRB improvements, super lightweight tank), flight operations and launch site equipment upgrades, advanced solid rocket motor, and construction of facility budget categories are displayed separately below.
[b] $45 million to be used only for 1) SSME, 2) SRB/SRM, 3) ET, 4), orbiter, and 5) assured Shuttle availability.
[c] Amount for total Space Shuttle budget category, including both Production and Operational Capability and Operations.

Table 2–21. Orbiter (Orbiter Operational Capability) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	181,000/155,800	159,000
1990	157,500/125,900	148,300
1991	113,400/144,900	186,300
1992	143,300/162,100	158,800
1993	196,900/179,516	—[a]

[a] No programmed amount shown.

Table 2–22. Systems Integration (Orbiter Operational Capability) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	17,000/30,500	34,500
1990	9,000/15,400	15,000
1991	11,100/11,400	10,700
1992	19,900/9,100	7,200
1993	26,900/13,400	—[a]
1994	14,400/—[b]	—

[a] No programmed amount shown.
[b] No revised budget submission in this category.

Table 2–23. Orbiter Improvements Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	—[a]	235,000
1994	215,500/127,100	204,300
1995	191,800/194,800	194,800
1996	227,900/258,700	271,400
1997	169,900/169,900	159,900
1998	137,300/232,500	232,500

[a] Budget category not established at time of budget submission.

Table 2–24. Extended Duration Orbiter (Orbiter Operational Capability) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	10,000/20,000	20,000
1990	157,500[a]/125,900	23,700
1991	15,000/25,000	25,000
1992	18,500/10,500	10,700
1993	21,700/22,600	—[b]
1994	67,700[c]/—[d]	—

[a] Funding increase reflected expectations of development of a 28-day extended duration orbiter.
[b] Budget category not established at time of budget submission.
[c] Funding was to cover the payback costs to the prime contractor for use of the cryogenic pallet kit to extend on-orbit stay time capability from the baseline 7 to 10 days to 14 to 16 days. It also was to initiate the required modifications on *Endeavour* and *Atlantis*.
[d] No revised budget request submitted in this category.

Table 2–25. Structural Spares (Orbiter Operational Capability) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	57,300/20,300[a]	20,300
1990	15,200/25,200	22,900
1991	52,400/71,000	66,000
1992	78,300/50,600	57,600
1993	51,000/35,000	—[b]
1994	35,000/—[c]	—

[a] Reduction in funding reflected slower start of structural spares program than expected.
[b] Programmed amount not shown.
[c] No revised budget request submitted.

Table 2–26. Orbiter Spares (Orbiter Operational Capability) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	54,000/55,200	48,000
1990	30,300/27,100	28,200
1991	21,700/23,300	26,800
1992	13,800/13,800	13,800
1993	9,000/9,000	—[a]
1994	—[b]	—

[a] No programmed amount shown.
[b] Activity was concluded in FY 1993.

Table 2–27. Flight Operations Upgrades Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	—[a]	121,000
1994	—/107,700	109,900
1995	110,900/63,900	54,300
1996	89,000/69,400	73,400
1997	69,500/89,000	66,000
1998	51,500/70,600	40,300

[a] Budget category not established at time of budget submission.

Table 2–28. Launch Site Equipment (Launch and Mission Support) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	142,000/109,400	104,100
1990	98,500/89,400	105,700
1991	114,900/110,400	101,200
1992	79,400/85,100	93,100
1993	86,000/69,000	80,100[a]
1994	81,700/68,500	81,700
1995	76,100/40,600	50,200
1996	43,800/21,100	24,200
1997	45,50026,000	58,600
1998	40,800/67,500	115,400

[a] Launch site equipment upgrades.

Table 2–29. Mission Support Capability (Launch and Mission Support) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed[a]
1989	93,500/42,100[b]	—[c]
1990	75,600/—[d]	—

[a] Combined into Mission Operations and Support Capability.
[b] Mission support decreased as program reserves were deleted to comply with the FY 1989 appropriations general reduction.
[c] No programmed amount shown.
[d] Combined with Mission Operations Capability into Mission Operations and Support Capability.

Table 2–30. Mission Operations Capability (Launch and Mission Support) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	108,200/112,700	— [a]
1990	166,900/— [b]	—

[a] Combined into Mission Operations and Support Capability.
[b] Combined with Mission Support Capability into Mission Operations and Support Capability.

Table 2–31. Mission Operations and Support Capability (Launch and Mission Support) Funding History (in thousands of dollars)[a]

Year (Fiscal)	Submission	Programmed
1989	— [b]	153,500
1990	242,500/169,900	177,349
1991	150,600/142,600	136,045
1992	190,700/176,600	148,100
1993	124,700/109,100	— [c]
1994	105,400/— [d]	—

[a] Combined Mission Support Capability and Mission Operations Capability.
[b] Budget category not established at time of budget submission.
[c] No programmed amount shown.
[d] No revised request submitted.

Table 2–32. Space Shuttle Main Engine Upgrades Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	— [a]	320,300 [b]
1994	—/287,900 [c]	355,500
1995	380,500/354,200	318,900
1996	357,200/251,300	234,100
1997	309,500/324,500	196,000
1998	231,200/170,700	170,100

[a] Budget category not established at time of budget submission.
[b] Unclear where this programmed amount originated. Some activities, e.g., the alternate turbopump and the large throat main combustion chamber, were specifically named in the SFC&DC SSME budget line item. However, "other upgrades" were not specified, so it is not clear where the costs for these previously resided since the amount was larger than the entire amount budgeted for SSME under the SFC&DC appropriation.
[c] New budget category under HSF appropriation.

Table 2–33. Solid Rocket Booster (Propulsion Systems) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	105,000/123,700	121,000
1990	106,700/75,300	72,500
1991	82,900/50,400	50,400
1992	48,600/38,200	34,900[a]
1993	43,100/30,200	—[b]

[a] Included SRB safety upgrades.
[b] No programmed amount shown.

Table 2–34. Solid Rocket Booster Improvements Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	43,100/30,200	1,400
1994	52,500[a]/23,200	23,500
1995	51,600/34,400	39,100
1996	69,000/1,400	7,200
1997	2,100/800	800
1998	6,600/3,500	1,200

[a] Included improvements to redesigned solid rocket motor.

Table 2–35. External Tank (Propulsion Systems) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	7,000/7,000	7,000
1990	2,700/2,700[a]	2,700

[a] Closeout of production funding for external tank tooling and equipment to support manufacturing rate capability requirements took place in FY 1990.

Table 2–36. Super Lightweight Tank Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]/49,500	50,800
1995	80,700/39,600	41,200
1996	32,700/44,100	30,700
1997	31,200/17,500	6,000
1998	9,200/1,800	700

[a] Budget category not established at initial time of budget submission.

Table 2–37. Construction of Facilities Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	—[a]	178,100
1994	—/33,500	34,300
1995	12,300/12,300	12,300
1996	17,400/17,400	17,400
1997	8,300/8,300	8,300
1998	6,800/6,800	8,200

[a] Budget category not established at time of budget submission.

Table 2–38. Advanced Solid Rocket Motor (Propulsion Systems) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Programmed
1989	88,000/51,000	51,000	51,000
1990	121,300/125,400	35,000	160,400
1991	309,100/309,100	—[a]	309,100
1992	200,000/315,000[b]	375,000	315,000
1993	—[c]/195,000	315,000	195,000
1994	280,000/179,700	150,000[d]	149,700[e]

[a] Not stated in authorization bill.

[b] Funding for the Advanced Solid Rocket Motor was increased $115 million based on congressional direction. However, the program was terminated.

[c] Due to the tight budget environment, the Advanced Solid Rocket Motor was not included in the initial FY 1993 budget request. Congress reinstated funding in the FY 1993 appropriation at a lower funding level than for the previous year.

[d] For termination of program.

[e] Reflected program termination.

Table 2–39. Assured Shuttle Availability Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1992	122,300/104,600	104,600
1993	138,900/89,500[a]	—
1994	140,200/—	—

[a] Name changed to Safety and Obsolescence Upgrades. Included items that moved to other Safety and Performance Upgrades categories in next fiscal year, e.g., alternative turbopump, large throat main combustion chamber, hardware interface module replace, cable plant upgrades, and multifunction electronic display system.

Table 2–40. Space Transportation (Space Shuttle) Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Programmed
1989	2,405,400/2,390,700	2,365,400	2,612,700
1990	2,732,200/2,636,036	2,544,900	2,632,400
1991	3,118,600/3,019,200	2,831,400[a]	2,752,400
1992	3,023,600/2,943,400	2,970,600	3,029,300
1993	3,115,200/3,015,953	3,085,200	2,857,200
1994	3,006,500/2,570,600	3,006,500	2,549,000
1995	2,420,100/2,415,297	3,309,000[b]	2,444,300
1996	2,394,800/2,485,400	2.341,800	2,485,400
1997	2,514,900/1,514,900	2,514,900	2,464,900
1998	2,369,400/2,494,400	2,494,400	2,344,400

[a] In accordance with the Commercial Space Launch Act Amendments of 1988, less than or equal to $4 million was made available for the provision of launch services for eligible satellites. *Commercial Space Launch Act Amendments of 1988*, 100th Congress., 1st sess., Public Law 100-657 (November 15, 1988).

[b] Amount was for total Space Shuttle costs, including both Shuttle Operations and Production and Operational Capability.

Table 2–41. Mission Support (Flight Operations) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	215,400/230,500	230,900
1990	247,500/253,700	252,600
1991[a]	280,500/276,500	275,000
1992	318,800/260,400	295,900
1993	338,400/329,117	361,000[b]
1994	330,900/322,800	316,000
1995	298,400/253,700	287,700
1996	284,600/358,900	358,900
1997	289,700/289,700	46,200[c]
1998	289,100/94,500	814,700[d]

[a] Name of category changed to Mission Operations.

[b] Called Mission and Crew Operations.

[c] Reflected transfer of flight operations to consolidated United Space Alliance contract from Boeing and Lockheed Martin contracts.

[d] Renamed Mission and Launch Operations. Included costs for Launch and Landing Operations.

Table 2–42. Integration (Flight Operations) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	264,100/268,800	285,000
1990	300,300/314,100	303,200
1991	335,600/319,900	317,900
1992	342,300/315,400	315,400
1993	163,000/146,000	200,000
1994	151,700/211,200	199,000
1995	190,500/168,400	169,500
1996	152,200/142,500	142,500
1997	141,200/141,200	124,700
1998	126,200/107,000	—[a]

[a] Combined with Orbiter budget category.

Table 2–43. Support (Flight Operations) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	180,600/186,400	182,500
1990	224,800/191,000	194,900
1991	199,500/205,100	194,300
1992	251,400/214,500	196,600
1993	239,000/277,000	—[a]
1994	285,200—[b]	—

[a] No programmed amount shown.
[b] No revised budget request submitted.

Table 2–44. Orbiter (Flight Hardware) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	339,400/301,300	314,100
1990	351,800/370,200	397,800
1991	397,800/442,900	414,500
1992	441,700/390,400	430,700
1993	522,700/540,853	477,000
1994	508,900/364,100	387,900
1995	292,800/359,800	358,700
1996	352,700/378,500	378,500
1997	375,400/375,400	367,900
1998	376,700/356,100	507,900[a]

[a] Included both orbiter and integration budget categories.

Table 2–45. Space Shuttle Main Engine (Propulsion Systems) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	511,800/400,500	403,200
1990	496,600/438,200	438,200
1991	430,900/388,300	402,400
1992	374,100/362,200	322,100
1993	314,600/263,200	239,900
1994	245,400/191,800[a]	189,200
1995	144,400/149,200	163,300
1996	145,600/185,000	185,000
1997	172,300/182,300	208,300
1998	184,900/204,600	173,400

[a] Change to HSF appropriation from SFC&DC took place with budget estimate for FY 1995 and revised FY 1994 budget request. Old SFC&DC SSME budget category included both production of SSME and upgrades and safety. New budget category under HSF appropriation was only for shuttle operations and did not include upgrades and safety, which was budgeted separately.

Table 2–46. Solid Rocket Booster (Flight Hardware) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	382,500/516,800	704,100
1990	537,000/487,500	458,600
1991	691,300/572,900	577,400
1992	592,400/541,300	542,000
1993	556,700/559,100	172,000
1994	515,700/156,400[a]	158,200
1995	144,900/162,200	163,000
1996	164,200/153,300	153,300
1997	174,800/150,400	151,200
1998	157,700/135,500	152,200

[a] Reduction reflected creation of new budget category: Redesigned Solid Rocket Motor.

Table 2–47. Redesigned Solid Rocket Motor (Flight Hardware) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1993	—	409,400
1994	—[a]/368,900	396,400
1995	373,100/365,997	370,000
1996	355,400/395,700	395,700
1997	402,900/427,000	412,800
1998	434,600/380,400	360,200

[a] No initial FY 1994 budget request for Redesigned Solid Rocket Motor

Table 2–48. External Tank (Flight Hardware) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	313,300/294,600	295,000
1990	347,700/347,500	344,600
1991	378,100/377,500	378,100
1992	382,900/365,400	354,100
1993	375,900/298,200	300,200
1994	340,000/305,300	252,200
1995	379,600/329,600	305,000
1996	328,000/327,500	327,500
1997	348,700/339,000	352,400
1998	359,700/341,300	336,000

Table 2–49. Launch and Landing Operations Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	514,600/506,800	534,600
1990	492,500/471,500	541,000
1991	606,600/596,200	595,200
1992	694,400/628,300	642,900
1993	639,900/690,800	697,100[a]
1994	696,400/650,100	650,100
1995	596,400/626,400	621,400
1996	612,100/544,000	544,000
1997	609,900/609,900	801,400
1998	605,300/720,200	—[b]

[a] Included launch operations and payload and launch support.
[b] Combined with Mission Support.

Table 2–50. Launch Operations (Launch and Landing Operations) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	456,600/452,800	481,600
1990	492,500/471,500	484,000
1991	546,400/537,500	539,200
1992	629,300/567,500	578,600
1993	581,100/632,000	—
1994	637,500/—[a]	—

[a] No revised estimate submitted for this budget category.

Table 2–51. Payload and Launch Support (Launch and Landing Operations) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	58,000/54,000	53,000
1990	61,100/58,700	57,000
1991	60,200/57,700	56,000
1992	64,800/60,800	64,300
1993	58,800/58,800	—
1994	58,900/—[a]	—

[a] No revised estimate submitted for this category.

Table 2–52. Expendable Launch Vehicles and Services[a] Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Authorization	Programmed
1989	195,500/85,500	—[b]	66,500
1990	169,500/141,836	169,500	139,700
1991	229,200/229,200	229,200	229,200[c]
1992	341,900/195,300	291,000	155,800
1993	217,500/180,801[d]	207,500	180,801
1994	300,300/313,500	300,300	84,600
1995	340,900/95,800	313,700	255,600
1996	74,200/254,300	—[e]	245,300
1997	253,500/240,600	—	240,600: Space Science 84,700: Earth Science
1998	236,300/215,900: Space Science 34,800: Earth Science	—	212,900[f] 27,600: Space Science 39,400: Earth Science

[a] Included funds for upcoming missions in all classes of ELVs.
[b] Not stated in authorization bill.
[c] Expendable Launch Vehicles and Services was officially transferred to the OSSA. Actual (appropriated) costs were charged to OSSA (SAT) in FY 1991.
[d] Included amounts budgeted for upper stages.
[e] Not stated in authorization bill.
[f] Moved to HSF appropriation from SAT.

Table 2–53. Small Class (Expendable Launch Vehicles and Services) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	—[a]	13,900
1990	26,300/12,100	11,900
1991	15,000/14,800	14,100
1992	33,700/33,100	32,600
1993	27,900/25,272	25,272
1994	26,200/16,800[b]	10,400
1995	31,400[c]/4,000	—
1996	10,800/—[d]	—

[a] Budget category not established at time of budget submission.
[b] SAT appropriation from revised budget estimate.
[c] SAT appropriation.
[d] Budget category no longer appeared in budget.

Table 2–54. Medium Class (Expendable Launch Vehicles and Services) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	—[a]	45,000
1990	86,200/76,036	75,400
1991	102,90098,700	97,300
1992	81,500/61,100	58,100
1993	67,300/61,451	61,451[b]
1994	77,500/93,500[c]	43,000
1995	116,200[d]/35,600	—
1996	31,000/—[e]	—

[a] Budget category not established at time of budget submission.
[b] SAT appropriation.
[c] SAT appropriation from revised budget estimate.
[d] SAT appropriation.
[e] No revised estimate submitted for this budget category.

Table 2–55. Intermediate Class (Expendable Launch Vehicles and Services) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	—[a]	6,300
1990	54,900/50,400	49,600
1991	101,100/106,000	108,100
1992	156,500/85,000[b]	45,000[c]
1993	54,800/41,000	41,100
1994	63,200/63,200[d]	43,000
1995	70,200[e]/26,000	—

[a] Budget category not established at time of budget submission.
[b] Funding was decreased partially because the launch of TDRS-7, originally scheduled to take place from an ELV, was assigned to the Shuttle.
[c] SAT appropriation.
[d] SAT appropriation from revised budget estimate.
[e] SAT appropriation.

Table 2–56. Large Class (Expendable Launch Vehicles and Services) Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1989	—[a]	1,300
1990	2,100/3,300	2,800
1991	10,200/9,700	9,700
1992	70,200/16,100[b]	20,100
1993	11,000/5,278	5,278[c]
1994	82,300[d]/86,400[e]	—
1995	91,300[f]/—	—

[a] Budget category not established at time of budget submission.
[b] Funding reduction due to deferral of the Cassini launch to October 1997, thereby reducing the funding requirements for the Titan IV/Centaur vehicle.
[c] SAT appropriation.
[d] Increase in large-class ELV funding requests was for Titan IV vehicle needed to support the Cassini mission, scheduled for an October 1997 launch. These funds also supported the required Centaur upper stage, with both vehicle elements purchased as a package from the U.S. Air Force.
[e] SAT appropriation from revised budget estimate.
[f] SAT appropriation.

Table 2–57. Launch Services Mission Support Funding History (in thousands of dollars)

Year (Fiscal)	Submission	Programmed
1994	—[a]	37,100
1995	—/37,000	—[b]
1996	37,600/—	—

[a] Budget category not established at time of budget submission.
[b] No programmed amount shown.

Table 2–58. Expendable Launch Vehicle Success Rate by Year and Launch Vehicle

Year	Athena	Atlas-G Centaur/E	Atlas I/IIA/ IIAS	Conestoga	Delta	Pegasus	Scout	Taurus	Titan	Total
1989		1/1			8/8				4/4	13/13
1990		2/2	1/1		11/11	1/1	1/1		4/5	20/21
1991		2/2	1/2		5/5	1/1	1/1		2/2	12/13
1992			4/5		11/11		2/2		3/3	20/21
1993		1/1	4/5		7/7	2/2	1/1		1/2	15/18
1994		2/2	5/5		3/3	1/3[a]	1/1	1/1	5/5	18/20
1995	0/1	1/1	11/11	0/1	3/3[b]	1/2			4/4	20/23
1996			7/7		10/10	4/5			4/4	25/26
1997	1/1		8/8		10/11	5/5			5/5	29/30
1998	1/1		6/6		12/13	6/6		2/2	2/3	29/31
Totals	2/3	9/9	47/50	0/1	79/82	21/25	6/6	3/3	34/37	202/215

[a] The Pegasus launch on May 19, 1994 did not reach its intended orbit and was classified in most sources as a "partial failure." It is counted as a failure in this table.

[b] The Delta launch on August 5, 1995 placed the Koreasat spacecraft in a lower than expected orbit. It still allowed the mission to achieve most of its objectives, although it shortened the satellite's useful life. It is counted as a success in this table.

Table 2–59. Athena Launches (1989–1998)

Launch Date	Mission	Vehicle Type	Comment
August 15, 1995	Gemstar 1	Athena I	Failed
August 23, 1997	Lewis	Athena I	Launch successful but spacecraft failed
January 7, 1998	Lunar Prospector	Athena II	Successful lunar mission

Table 2–60. Athena I Characteristics[a]

	Stage 1	Stage 2	Orbit Assist Module	Payload Fairing Envelope	Total
Length	10.7 m (35.2 ft)	3.0 m (10.0 ft)	1.0 m (3.3 ft)	6.1 m (20 ft)	18.9 m (61.9 ft)
Diameter	2.3 m (7.7 ft)	2.3 m (7.7 ft)	2.3 m (7.7 ft)	7.7 ft (2.3 m) outer; 6.75 ft (2.1 m) inner	
Inert mass	4,375 kg (9,650 lb)	1,030 kg (2,280 lb)	360 kg (790 lb)		
Gross mass	53,100 kg (117,100 lb)	10,810 kg (23,840 lb)	596 kg or 715 kg (1,310 lb or 1,570 lb)	535 kg (1,180 lb)	66,300 kg (146,100 lb)
Propulsion	Castor 120 Motor	Orbus 21D motor	Four Primex MR-107		
Propellant	HTPB	HTPB	Hydrazine		
Propellant mass	48,700 kg (107,400 lb)	8,780 kg (21,560 lb)	236 kg or 354 kg (520 lb or 780 lb)		
Avg. thrust	Sea level: 1,450 kN (325,900 lb) Vac.: (1,604 kN (360,500 lb)	187 kN (42,400 lb)	Initially 890 N (200 lb), decreases with time		1,450 kN (325,900 lb) at liftoff
Nominal burn time	83.4 sec	150 sec	1,500 sec (depends on mission)		
Max. payload	545 kg–820 kg (1,200 lb–1,805 lb) to low-Earth orbit depending on launch inclination				
Contractor	Thiokol	Pratt & Whitney	Primex Technologies	Lockheed Martin	Lockheed Martin

[a] Steven Isakowitz, Joseph P. Hopkins, Jr., and Joshua B. Hopkins, *International Reference Guide to Space Launch Systems,* 3rd ed., (Reston, Virginia: American Institute of Aeronautics and Astronautics, 1999), pp. 40–47.

Table 2–61. Athena II Characteristics[a]

	Stage 1	Stage 2	Stage 3	Orbit Assist Module	Payload Fairing Envelope	Total
Length	10.7 m (35.2 ft)	10.7 m (35.2 ft)	3.0 m (10.0 ft)	1.0 m (3.3 ft)	6.1 m (20 ft)	28.2 m (93.2 ft)
Diameter	2.3 m (7.7 ft)	2.3 m (7.7 ft)	2.3 m (7.7 ft)	2.3 m (7.7 ft)	7.7 ft (2.3 m) outer; 6.75 ft (2.1 m) inner	
Inert mass	4,375 kg (9,650 lb)	4,375 kg (9,650 lb)	1,030 kg (2,280 lb)	360 kg (790 lb)		
Gross mass	53,100 kg (117,100 lb)	53,100 kg (117,100 lb)	10,810 kg (23,840 lb)	596 kg or 715 kg (1,310 lb or 1,570 lb)	535 kg (1,180 lb)	120,700 kg (266,100 lb)
Propulsion	Castor 120 Motor	Castor 120 Motor	Orbus 21D motor	Four Primex MR-107		
Propellant	HTPB	HTPB	HTPB	Hydrazine		
Propellant mass	48,700 kg (107,400 lb)	48,700 kg (107,400 lb)	8,780 kg (21,560 lb)	236 kg or 354 kg (520 lb or 780 lb)		
Avg. thrust	Sea level: 1,450 kN (325,900 lb) Vac.: (1,604 kN (360,500 lb)	Sea level: 1,450 kN (325,900 lb) Vac.: (1,604 kN (360,500 lb)	187 kN (42,400 lb)	Initially 890 N (200 lb), decreases with time		1,450 kN (325,900 lb) at liftoff
Nominal burn time	83.4 sec	83.4 sec	150 sec	1,500 sec (depends on mission)		
Max. payload	1,575 kg to 2,065 kg (3,470 lb to 4,520 lb) to low-Earth orbit depending on orbital inclination					
Contractor	Thiokol	Thiokol	Pratt & Whitney	Primex Technologies	Lockheed Martin	Lockheed Martin

[a] Isakowitz, et al., *International Reference Guide to Space Launch Systems,* 3rd ed., pp. 40–47.

Table 2–62. Atlas Launches (1989–1998)

Vehicle Number[a]	Mission	Launch Date (Based on GMT)	Vehicle Type[b]	Comments
AC-68	Fltsatcom F-8	September 25, 1989	Atlas G Centaur	Launched by NASA/ industry team for Navy. Last in NASA inventory of Atlas G Centaur rockets.
S/N 28	USA 56, 57, 58	April 11, 1990	Atlas E	DOD meteorological satellite. Classified mission.
AC-69	Combined Release and Radiation Effects Satellite (CRRES)	July 25, 1990	Atlas I	NASA–DOD mission. First Atlas I launch.
S/N 61	USA 68 (DMSP-10)	December 1, 1990	Atlas E	Defense Meteorological Satellite Program (DMSP) satellite.
AC-70	Yuri 3H (BS 3H)	April 18, 1991	Atlas I	Failed when one of the two Centaur engines did not start.
S/N 50	NOAA-12	May 14, 1991	Atlas E	NOAA weather satellite.
S/N 53	USA 73 (DMSP-11)	November 28, 1991	Atlas E	DOD weather satellite.
AC-102	Eutelsat II F3	December 7, 1991	Atlas II	European communications satellite.
AC-101	USA 78 (DSCS III-06)	February 11, 1992	Atlas II	Defense Satellite Communications Systems (DSCS) III satellite.
AC-72	Galaxy 5	March 14, 1992	Atlas I	Commercial communications satellite.

Table 2–62. Atlas Launches (1989–1998) (Continued)

Vehicle Number[a]	Mission	Launch Date (Based on GMT)	Vehicle Type[b]	Comments
AC-105	Intelsat-K	June 10, 1992	Atlas IIA	International communications satellite. First Atlas IIA launch.
AC-103	USA 82	July 2, 1992	Atlas II	DSCS III satellite.
AC-71	Galaxy 1R	August 22, 1992	Atlas I	Failed when one of the two Centaur engines did not start.
AC-74	UFO 1 (UHF-1)	March 25, 1993	Atlas I	Military communications satellite. Failed to reach operational orbit.
AC-104	USA 93 (DSCS III F8)	July 19, 1993	Atlas II	DSCS III satellite.
S/N 34	NOAA-13	August 9, 1993	Atlas E	NOAA weather satellite.
AC-75	UHF-2	September 3, 1993	Atlas I	U.S. Navy communications satellite.
AC-106	DSCS III	November 28, 1993	Atlas II	Military communications satellite.
AC-108	Telstar 401	December 16, 1993	Atlas IIAS	Communications satellite. First Atlas IIAS launch.
AC-73	GOES-8	April 13, 1994	Atlas I	NOAA weather satellite.
AC-76	UFO 3 (UHF-3)	June 24, 1994	Atlas I	U.S. Navy communications satellite.
AC-107	DBS-2	August 3, 1994	Atlas IIA	Communications satellite.
S/N 20	DMSP F-12	August 29, 1994	Atlas E	DMSP satellite.
AC-111	Intelsat 703	October 6, 1994	Atlas IIAS	International communications satellite.

Table 2–62. Atlas Launches (1989–1998) (Continued)

Vehicle Number[a]	Mission	Launch Date (Based on GMT)	Vehicle Type[b]	Comments
AC-110	Orion 1	November 29, 1994	Atlas IIA	German communications satellite.
S/N 11	NOAA-14	December 30, 1994	Atlas E	NOAA weather satellite.
AC-113	Intelsat 704	January 10, 1995	Atlas IIAS	International communications satellite.
AC-112	UFO-4 (USA 108)	January 29, 1995	Atlas II	U.S. Navy communications satellite.
AC-115	Intelsat 705	March 22, 1995	Atlas IIAS	International communications satellite.
S/N 45	USA 109 (DMSP-F13)	March 24, 1995	Atlas E	DMSP/F13 satellite. Last Atlas E launch.
AC-114	AMSC-1 (MSAT)	April 7, 1995	Atlas IIA	Provide mobile telephone communication.
AC-77	GOES-9	May 23, 1995	Atlas I	NOAA geostationary weather satellite.
AC-116	UHF 6 (USA 111)	May 31, 1995	Atlas II	Navy communications satellite.
AC-118	USA 113 (DSCSIII B5)	July 31, 1995	Atlas IIA	DSCS III satellite.
AC-117	JCSat 3	August 29, 1995	Atlas IIAS	Japanese communications satellite.
AC-119	UFO-6 (USA 114)	October 22, 1995	Atlas II	Military communications satellite.

Table 2–62. Atlas Launches (1989–1998) (Continued)

Vehicle Number[a]	Mission	Launch Date (Based on GMT)	Vehicle Type[b]	Comments
AC-121	Solar and Heliospheric Observatory	December 2, 1995	Atlas IIAS	NASA-European Space Agency space science mission.
AC-120	Galaxy 3-R	December 15, 1995	Atlas IIA	Commercial communications satellite.
AC-126	Palapa C-1	February 1, 1996	Atlas IIAS	Indonesian communications satellite.
AC-122	Inmarsat 3 F1	April 3, 1996	Atlas IIA	International communications satellite.
AC-78	Beppo-SAX	April 30, 1996	Atlas I	Italian Dutch telescope.
AC-125	UFO 7 (USA 127)	July 25, 1996	Atlas II	Military communications satellite.
AC-123	GE-1	September 8, 1996	Atlas IIA	Commercial communications satellite.
AC-124	Hot Bird 2	November 21, 1996	Atlas IIA	European communications satellite.
AC-129	Inmarsat 3 F3	December 18, 1996	Atlas IIA	Communications satellite.
AC-127	JCSat 4	February 17, 1997	Atlas IIAS	Japanese communications satellite.
AC-128	Tempo 2	March 8, 1997	Atlas IIA	Commercial communications satellite.
AC-79	GOES-10	April 25, 1997	Atlas I	NOAA geostationary weather satellite. Last Atlas I launch.
AC-133	Superbird C	July 28, 1997	Atlas IIAS	Japanese communications satellite.

Table 2–62. Atlas Launches (1989–1998) (Continued)

Vehicle Number[a]	Mission	Launch Date (Based on GMT)	Vehicle Type[b]	Comments
AC-146	GE-3	September 4, 1997	Atlas IIAS	Communications satellite.
AC-135	EchoStar 3	October 5, 1997	Atlas IIAS	Communications satellite.
AC-131	USA 133 (Lacrosse 3)/USA 135 (Defense Satellite Communications System 3 and Falcon Gold)	October 25, 1997	Atlas IIA	Military satellite.
AC-149	Galaxy 8i	December 8, 1997	Atlas IIAS	Communications satellite.
AC-109	USA 137 (Capricorn)	January 29, 1998	Atlas IIA	Military satellite.
AC-151	Intelsat 806	February 28, 1998	Atlas IIAS	International communications satellite.
AC-132	USA 138, UHF F8	March 16, 1998	Atlas II	Military communications satellite. Last Atlas II launch.
AC-153	Intelsat 805	June 18, 1998	Atlas IIAS	International communications satellite.
AC-134	Hotbird 5	October 9, 1998	Atlas IIA	Communications satellite.
AC-130	UHF F9	October 20, 1998	Atlas IIA	Military communications satellite.

[a] Atlas Centaur vehicle numbers from Jean-Jacques Serra and Gunter Krebs, "Atlas Centaur, Atlas Centaur Launches," *The Satellite Encyclopedia*, *http://www.tbs-satellite.com/tse/online/lanc_atlas_centaur.html* (accessed January 24, 2005).

[b] "Atlas Launches," International Launch Services Launch Archives, *http://www.ilslaunch.com/launches* (accessed January 25, 2005).

Table 2–63. Atlas E Characteristics[a]

	1-1/2 Stages (Booster and Sustainer)	Star Apogee Kick Motor (AKM)	Fairing	Total
Length	21.3 m (69.8 ft)	0.94 m (3.1 ft)	6.9 m (22.5 ft)	Up to 28.1 m (92.1 ft)
Diameter	3.05 m (10 ft)	0.94 m (3.1 ft)	2.1 m (7 ft)	
Gross mass	121,000 kg (266,759 lb)	47.7 kg (105 lb) (weight of motor)	735 kg (1,620 lb) assembly case after depletion of fuel	121,000 kg (266,759 lb)
Propulsion	MA-3 system consisting of two LR 89-NA-5 boosters, one LR 105-NA-5 sustainer, and two LR 101-NA-7 vernier engines (VE)	TE-M-364-15 motor		
Propellant	LOX-RP-1-1	Solid		
Propellant mass	112,900 kg (248,902 lb)	666 kg (1,468 lb)		
Liftoff thrust	Booster: 1,470 kN (330,000 lb) Sustainer: 267 kN (60,000 lb) Each vernier engine: 3.0 kN (670 lb)	42.4 kN (9,532 lb)[b]		1,743 kN (391,842 lb)
Burn time (average)	Booster: 120 sec, Sustainer: 309 sec	45 sec		
Max. payload	2,090 kg (4,608 lb) to 195-km (105-nmi) orbit from polar launch with dual TE-364-4 engines; 1,500 kg (3,307 lb) to 195-km orbit from polar launch with single TE 374-4 engine			
Contractors	Rocketdyne	Thiokol		General Dynamics
Remarks	Atlas E in this decade was used primarily to launch meteorological satellites into polar or geosynchronous orbit			

[a] Steven J. Isakowitz and Jeff Samella, *International Reference Guide to Space Launch Systems*, 2nd ed., (Washington, DC: American Institute of Aeronautics and Astronautics, 1991), pp. 206–211.

[b] "NOAA-D," Friends and Partners in Space, (downloaded to Friends and Partners from NASA Spacelink), *http://www.friends-partners.org/oldfriends/jgreen/noaa.html* (accessed January 25, 2005).

Table 2–64. Atlas G Centaur Characteristics[a]

	Atlas G Booster and Sustainer	Centaur Stage	Total
Length	22.2 m (72.8 ft)	9.15 m (30 ft)	38.0 m (125 ft) (includes fairing)
Diameter	3.05 m (10 ft)	3.05 m (10 ft)	3.05 m (10 ft)
Gross mass	145,700 kg (321,200 lb)	15,600 kg (34,300 lb)	166,140 kg (366,276 lb)[b] at liftoff (includes fairing)
Propulsion	MA-5 system consisting of two LR-89-NA-7 boosters, one LR-105-NA-7 sustainer, and two vernier engines	Two RL10A-3-3A[c] multiple-start engines and 12 small hydrogen peroxide thrusters	
Propellant	Oxidizer: LOX Fuel: RP-1	Oxidizer: LOX Fuel: LH_2	
Propellant mass	138,300 kg (305,000 lb)	13,900 kg (30,600 lb)	
Liftoff thrust	Booster: 1,680 kN (377,500 lb) Sustainer: 269 kN (60,600 lb) Each vernier engine: 3 kN (670 lb)	146.8 kN (33,000 lb) vacuum	1,950 kN (438,877 lb)
Nominal burn time	Booster: 174 sec, Sustainer: 266 sec	402 sec	
Max. payload	6,100 kg (13,448 lb) to 185 km (100 nmi) orbit; 2,360 kg (5,203 lb) to geosynchronous transfer trajectory[d]		
Contractors	Rocketdyne	Pratt & Whitney	General Dynamics
Remarks	The lower booster and sustainer stage was integrated electronically with the Centaur upper stage		

[a] Isakowitz and Samella, *International Reference Guide to Space Launch Systems*, 2nd ed., pp. 206–210. The Atlas G was almost identical to the Atlas I. Isakowitz does not list Atlas G specifications, and Atlas I specifications are used in this table unless a different reference specific to Atlas G is noted.

[b] Federal Aviation Administration, "The Evolution of Commercial Launch Vehicles," *Fourth Quarter 2001 Launch Report*, *http://ast.faa.gov/files/pdf/q42001.pdf* (accessed January 25, 2005). Also "Atlas G," *Encyclopedia Astronautica*, *http://www.astronautix.com/lvs/atlasg.htm* (accessed January 25, 2005).

[c] According to Pratt & Whitney records, the RL10-3-3A engine was used on the launch of Fltsatcom F-8 on September 25, 1989. A number of earlier Atlas G launches used the RL10-3-3 engine.

[d] *Aeronautics and Space Report of the President, 1988 Activities*, (Washington, DC: National Aeronautics and Space Administration, 1990), p. 184.

Table 2–65. Atlas I Characteristics[a]

	Atlas I First Stage	Centaur Stage	Total
Length	22.2 m (72.8 ft)	9.15 m (30 ft)	Up to 43.9 m (144 ft) with large fairing
Diameter	3.05 m (10 ft)	3.05 m (10 ft)	
Gross mass	145,700 kg (321,200 lb)	15,600 kg (34,000 lb)	164,300 kg (362,200 lb)
Propulsion	MA-5 propulsion system consisting of two LR-89-NA-7 boosters, one LR-105-NA-7 sustainer, and two vernier single-start engines	Two RL10A-3-3A multiple start engines and 12 small hydrogen peroxide thrusters	
Propellant	Oxidizer: LOX Fuel: RP-1	Oxidizer: LOX Fuel: LH_2	
Propellant mass	138,300 kg (305,000 lb)	13,900 kg (30,600 lb)	
Liftoff thrust	Booster: 1,680 kN (377,500 lb) Sustainer: 269 kN (60,600 lb) Each vernier engine: 3 kN (670 lb)	146.8 kN (33,000 lb) vacuum	1,950 kN (438,877 lb)[b]
Nominal burn time	Booster: 174 sec, Sustainer: 266 sec	402 sec	
Max. payload	6,580 kg (14,500 lb) to low-Earth orbit; 2,610 kg (5,754 lb) to geosynchronous transfer orbit; 4,300 kg (9,480 lb) to sun synchronous orbit[c]		
Contractors	Rocketdyne	Pratt & Whitney	General Dynamics
Remarks	An aluminum interstage adapter with a length of 3.96 m (13 ft), diameter of 3.05 m (10 ft), and mass of 477 kg (1,052 lb) supported the Centaur until separation took place.		

[a] Isakowitz and Samella, *International Reference Guide to Space Launch Systems*, 2nd ed., pp. 206–210.
[b] Liftoff thrust refers only to thrust produced by the Atlas stage. Thrust produced by the Centaur upper stage is produced approximately 4 minutes, 40 seconds after liftoff.
[c] *Aeronautics and Space Report of the President, Fiscal Year 1992 Activities* (Washington, DC: National Aeronautics and Space Administration, 1993), p. 94.

Table 2–66. Typical Atlas Launch Events Sequence for a Geosynchronous Mission[a]

Event	Time After Liftoff	Altitude Miles (Km)	Downrange Miles (Km)	Speed (mph/km per hr)
Liftoff	T-0			
Atlas booster engine cutoff	2 min 35 sec	37 (60)	54 (87)	6,527 (10,504)
Jettison Atlas booster engine	2 min 38 sec	38 (61)	59 (95)	6,590 (10,606)
Jettison Centaur insulation panel	3 min 0 sec	50 (80)	70 (113)	6,967 (11,212)
Jettison nose fairing	3 min 36 sec	67 (108)	154 (248)	7,746 (12,466)
Atlas sustainer/ vernier engines cutoff	4 min 27 sec	85 (137)	258 (415)	9,326 (15,009)
Atlas/Centaur separation	4 min 29 sec	86 (138)	266 (428)	9,330 (15,015)
First Centaur main engine start	4 min 40 sec	89 (143)	286 (460)	9,306 (14,977)
Centaur main engine cutoff	9 min 53 sec	94 (151)	1,298 (2,088)	17,953 (28,893)
Second Centaur main engine start	24 min 53 sec	212 (341)	5,366 (8,636)	17,487 (28,143)
Second Centaur main engine cutoff	26 min 29 sec	241 (388)	5,836 (9,392)	22,535 (36,267)
Centaur/payload separation	28 min 44 sec	334 (538)	6,566 (10,567)	22,262 (35,827)

[a] "CRRES Press Kit," Press Kit, July 1990, (from NASA Spacelink), *http://www.flyaria.com/document/html/mission/crres/cr.htm* (accessed July 18, 2006).

Table 2–67. Atlas II Characteristics[a]

	Atlas II Stage	Centaur II Upper Stage	Total
Length	24.9 m (81.7 ft)	9.15 m (30 ft)	47.5 m (156 ft) with large fairing
Diameter	3.05 m (10 ft)	3.05 m (10 ft)	
Gross mass	165,700 kg (365,300 lb)	15,600 kg (34,300 lb)	187,600 kg (413,500 lb)
Propulsion	MA-5A system with one two-chamber RS-27 booster engine and one RS-56SA sustainer engine	Two 10A-3-3A cryogenic multiple start engines	
Propellant	Oxidizer: LOX Fuel: RP-1	Oxidizer: LOX Fuel: LH_2	
Propellant mass	155,900 kg (345,500 lb)	13,900 kg (30,000 lb)	
Avg. thrust	Booster: 1,840 kN (414,000 lb) Sustainer: 269 kN (60,500 lb)	146.8 kN (33,000 lb) (vacuum)	2,110 kN (474,500 lb)
Nominal burn time	Booster: 172 sec, Sustainer: 283 sec	402 sec	
Max. payload	6,580 kg (14,500 lb) to low-Earth orbit from Cape Canaveral; 5,510 kg (12,150 lb) to low-Earth orbit from Vandenberg AFB; 2,810 kg (6,200 lb) to geosynchronous transfer orbit		
Contractors	Rocketdyne	Pratt & Whitney	General Dynamics/ Lockheed
Remarks	The Atlas was integrated with the Centaur vehicle by an interstage adapter weighing 482 kg (1,067 lb) and measuring 3.05 m (10 ft) in diameter and 4 m (13 ft) long		

[a] Isakowitz and Samella, *International Reference Guide to Space Launch Systems,* 2nd ed., pp. 206–210.

Table 2–68. Atlas IIA Characteristics[a]

	Atlas IIA Stage	Centaur IIA Upper Stage	Payload Fairing	Total
Length	24.9 m (81.7 ft) + 4-m (13-ft) interstage	10 m (33 ft)	Large: 12.0 m (39.4 ft); extended: 12.9 m (42.4 ft)	47.4 m with large payload fairing and interstage
Diameter	3.05 m (10 ft)	3.05 m (10 ft)	4.2 m (13.7 ft)	
Inert mass	9,800 kg (21,605 lb) + 545-kg (1,202-lb) interstage	2,200 kg (4,850 lb)		
Gross mass	166,700 kg (367,510 lb) (includes interstage)	18,980 kg (41,844 lb)	Large: 2,085 kg (4,600 lb); extended: 2,255 kg (4,970 lb)	187,500 kg (413,366 lb) with large payload fairing
Propulsion	MA-5A system with one two-chamber RS-27 booster engine and one RS-56SA sustainer engine	Two RL10A-4 cryogenic multiple start engines		
Propellant	Oxidizer: LOX Fuel: RP-1	Oxidizer: LOX Fuel: LH_2		
Propellant mass	156,400 kg (344,800 lb)	16,780 kg (37,000 lb)		
Avg. thrust	Booster: 1,854 kN (416,000 lb) sea level Sustainer: 266 kN (59,800 lb) sea level	185.2 kN (41,635 lb)		2,140 kN (481,200 lb) at liftoff
Nominal burn time	Booster: 165 sec, Sustainer: 274 sec	370 sec		
Max. payload	6,192 kg (13,651 lb)–7,316 kg (16,129 lb) to low-Earth orbit with large fairing depending on launch inclination; 3,066 kg (6,760 lb) to geosynchronous transfer orbit with large fairing			
Contractors	Rocketdyne	Pratt & Whitney		Lockheed Martin
Remarks	The operational Atlas IIA had uprated RL10 engines with optional nozzle extensions for the Centaur stage.			

[a] Isakowitz, et al., *International Reference Guide to Space Launch Systems,* 3rd ed., pp. 54, 68–73. Also, International Launch Services, *Atlas Launch System Mission Planner's Guide, Rev. 7* (December 1998), pp. 1–6, A9, *http://www.ilslaunch.com/missionplanner/pdf/ampg_r7.pdf* (accessed January 27, 2005).

Table 2–69. Atlas IIAS Characteristics[a]

	Atlas IIAS Stage	Centaur IIAS Upper Stage	Payload Fairing	Total
Length	24.9 m (81.7 ft) + 4-m (13-ft) interstage SRB: 13.6 m (44.6 ft)	10 m (33 ft)	Large: 12.0 m (39.4 ft) Extended: 12.9 m (42.4 ft)	47.4 m with large payload fairing
Diameter	3.05 m (10 ft) SRBs: 102-cm (40 in)	3.05 m (10 ft)	4.2 m (13.7 ft)	
Inert mass	9,800 kg (21,605 lb) + 545-kg (1,202-lb) interstage	2,200 kg (4,850 lb)		
Gross mass	166,700 kg (367,510 lb) (includes interstage) SRBs: 11,567 kg (25,500 lb) (each fueled)	18,980 kg (41,850 lb)	Large: 2,085 kg (4,600 lb) Extended: 2,255 kg (4,970 lb)	237,200 kg (522,900 lb)
Propulsion	MA-5A system with one two-chamber RS-27 booster engine, and one RS-56SA sustainer engine augmented with four Castor IVA SRBs	Two 10A-4 cryogenic multiple-start engines		
Propellant	Oxidizer: LOX, Fuel: RP-1	Oxidizer: LOX, Fuel: LH_2		
Propellant mass	156,400 kg (344,800 lb)	16,780 kg (37,800 lb)		
Thrust	Booster: 1,854 kN (416,000 lb) sea level Sustainer: 266 kN (59,800 lb) sea level SRBs: 433.7 kN (97,500 lb) each	185.2 kN (41,635 lb)		3,000 kN (676,200 lb)

Table 2–69. Atlas IIAS Characteristics[a] *(Continued)*

	Atlas IIAS Stage	Centaur IIAS Upper Stage	Payload Fairing	Total
Nominal burn time	Booster: 163 sec Sustainer: 289 sec	370 sec		
Max. payload	6,192 kg (15,900 lb) to 7,360 kg (19,000 lb) to low-Earth orbit depending on launch inclination; 3,719 kg (8,200 lb) to geosynchronous transfer orbit			
Contractors	Rocketdyne Thiokol: SRBs	Pratt & Whitney		Lockheed Martin

[a] Isakowitz, et al., *International Reference Guide to Space Launch Systems*, 3rd ed., pp. 54, 68–73. Also, International Launch Services, *Atlas Launch System Mission Planner's Guide, Rev. 7* (December 1998), pp. 1–6, A–9.

Table 2–70. Conestoga 1620 Characteristics[a]

	Booster Solid Rocket Motor Stage	Upper Stage	Payload Fairing	Total
Length	30 ft (9.12 m)	6.8 ft (2.07 m)	16 ft (4.88 m)	50 ft (15.24 m)
Diameter	3.3 ft (1.0 m)	4.1 ft (1.25 m)	72 in (1.83 m)	
Gross mass	Each: 25,100 lb (11,400 kg)	4,765 lb (2,161 kg)	Varies	192,700 lb (87.407 kg)
Propulsion	Two Castor IVA and four Castor IVB strap-on motors plus one Castor IVB core strap-on motor	Star 48V motor		
Propellant	Hydroxyl-terminated polybutadiene (HTPB)[b]	HTPB		
Propellant mass	Each: 22,300 lb (10,100 kg)	4,430 lb (2,010 kg)		
Thrust	Each: 111,000 lb (493,700 kN)	15,355 lb (68,300 N)		355,600 lb (1,581 kN)
Max. payload	5,000 lb to low-Earth orbit			
Contractors	Thiokol	Thiokol		EER Systems

[a] Isakowitz and Samella, *International Reference Guide to Space Launch Systems*, 2nd ed., pp. 221–224.

[b] This definition of HTPB as hydroxyl-terminated polybutadiene comes from the NASA Kennedy Space Center acronym list at *www.ksc.nasa.gov/facts/acronyms.html*. Other reliable acronym lists, including the NASA Scientific and Technical Information acronym list (*http://www.sti.nasa.gov/acronym/h.html*) define HTPB as hydroxy-terminated polybutadiene.

Table 2–71. Delta Launches (1989–1998)[a]

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
184	NAVSTAR II-1 GPS	February 14, 1989	Delta II/6925	Global Positioning System (GPS). First Delta II launch.
183	SDI Delta Star	March 24, 1989	Delta/3920-8	Last Delta 3920 launch.
185	NAVSTAR II-2 GPS	June 10, 1989	Delta II/6925	Second Block II NAVSTAR GPS satellite.
186	NAVSTAR II-3 GPS	August 18, 1989	Delta II/6925	Third Block II NAVSTAR GPS satellite.
187	BSB-R1	August 27, 1989	Delta/4925-8	Launched for British Satellite Broadcasting. First commercial licensed NASA U.S. space launch.
188	NAVSTAR II-4 GPS	October 21, 1989	Delta II/6925	Fourth Block II NAVSTAR GPS satellite.
189	COBE	November 18, 1989	Delta/5920	Cosmic Background Explorer. Last NASA-owned Delta.
190	NAVSTAR II-5 GPS	December 11, 1989	Delta II/6925	Fifth Block II NAVSTAR GPS satellite.
191	NAVSTAR II-6 GPS	January 24, 1990	Delta II/6925	Sixth Block II NAVSTAR GPS satellite.
192	SDI-LACE/RME (LOSAT)	February 14, 1990	Delta II/6920-8	Part of Strategic Defense Initiative program testing.
193	NAVSTAR II-7 GPS	March 26, 1990	Delta II/6925	Seventh Block II NAVSTAR GPS satellite.
194	Palapa B-2R	April 13, 1990	Delta II/6925-8	Indonesian communications satellite.
195	ROSAT	June 1, 1990	Delta II/6920-10	Röentgen Satellite. Joint German, U.S., and British space science mission.
196	INSAT-1D	June 12, 1990	Delta/4925-8	Indian communications and weather satellite. Last Delta I launch.
197	NAVSTAR II-8 GPS	August 2, 1990	Delta II/6925	Eighth Block II NAVSTAR GPS satellite.
198	BSB-R2 (Thor 1)	August 18, 1990	Delta II/6925	Launched for British Satellite Broadcasting.

Table 2–71. Delta Launches (1989–1998)[a] (Continued)

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
199	NAVSTAR II-9 GPS	October 1, 1990	Delta II/6925	Ninth Block II NAVSTAR GPS satellite.
200	INMARSAT-2 (F1)	October 30, 1990	Delta II/6925	International Maritime Satellite Organization.
201	NAVSTAR II-10 GPS	November 26, 1990	Delta II/7925	First Delta 7925. Tenth Block II NAVSTAR GPS satellite.
202	NATO IV-A	January 8, 1991	Delta II/7925	Military communications satellite.
203	INMARSAT-2 (F2)	March 8, 1991	Delta II/6925	International Maritime Satellite Organization.
204	ASC-2	April 13, 1991	Delta II/7925	Communications satellite.
205	Aurora II	May 29, 1991	Delta II/7925	Communications satellite.
206	NAVSTAR II-11 GPS and LOSAT-X	July 4, 1991	Delta II/7925	Eleventh Block II NAVSTAR GPS satellite and DOD mission.
207	NAVSTAR II-12 GPS	February 23, 1992	Delta II/7925	Twelfth Block II NAVSTAR GPS satellite.
208	NAVSTAR II-13 GPS	April 10, 1992	Delta II/7925	Thirteenth Block II NAVSTAR GPS satellite.
209	Palapa B4	May 14, 1992	Delta II/7925-8	Indonesian communications satellite.
210	EUVE	June 7, 1992	Delta II/6920-10	Extreme Ultraviolet Explorer.
211	NAVSTAR II-14 GPS	July 7, 1992	Delta II/7925	Fourteenth Block II NAVSTAR GPS satellite.
212	1) Geotail, 2) DUVE	July 24, 1992	Delta II/6925	1) Joint NASA-Japanese Institute of Space and Astronomical Science mission; 2) DUVE (Diffuse Ultraviolet Experiment) was attached to the 2nd stage.
213	SATCOM C-4	August 31, 1992	Delta II/7925	Comsat.

Table 2–71. Delta Launches (1989–1998)[a] (Continued)

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
214	NAVSTAR II-15 GPS	September 9, 1992	Delta II/7925	Fifteenth Block II NAVSTAR GPS satellite.
215	DFS 3 Kopernikus	October 12, 1992	Delta II/7925	Communications satellite launched by McDonnell Douglas for Germany.
216	NAVSTAR II-16 GPS	November 22, 1992	Delta II/7925	Sixteenth Block II NAVSTAR GPS satellite.
217	NAVSTAR II-17 GPS	December 18, 1992	Delta II/7925	Seventeenth Block II NAVSTAR GPS satellite.
218	NAVSTAR II-18 GPS	February 3, 1993	Delta II/7925	Eighteenth Block II NAVSTAR GPS satellite.
219	NAVSTAR II-19 GPS and SEDS-1	March 30, 1993	Delta II/7925	Nineteenth Block II NAVSTAR GPS satellite and Small Expendable Deployer System tether experiment.
220	NAVSTAR II-20 GPS	May 13, 1993	Delta II/7925	Twentieth Block II NAVSTAR GPS satellite.
221	NAVSTAR II-21 GPS and PMG	June 26, 1993	Delta II/7925	Twenty-first Block II NAVSTAR GPS satellite and Plasma Motor Generator was tethered to the 2nd stage.
222	NAVSTAR II-22 GPS	August 30, 1993	Delta II/7925	Twenty-second Block II NAVSTAR GPS satellite.
223	NAVSTAR II-23 GPS	October 26, 1993	Delta II/7925	Twenty-third Block II NAVSTAR GPS satellite.
224	NATO IVB	December 8, 1993	Delta II 7925	Military communications satellite. Launched commercially by McDonnell Douglas.
225	Galaxy I-R	February 19, 1994	Delta II/7925-8	Communications satellite launched commercially by McDonnell Douglas.

Table 2–71. Delta Launches (1989–1998)[a] (Continued)

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
226	NAVSTAR II-24 GPS and SEDS-2	March 10, 1994	Delta II/7925	Twenty-fourth Block II NAVSTAR GPS satellite and SED-2 tether experiment.
227	Wind	November 1, 1994	Delta II/7925-10	International Solar Terrestrial Physics/ Global Geospace Science program.
228	Koreasat-1	August 5, 1995	Delta II/7925	Partial failure; booster failed to separate.[b]
229	RADARSAT and SURFSAT	November 4, 1995	Delta II/7920-10	Canadian remote sensing mission and Student Undergraduate Research Fellowship Satellite.
230	RXTE	December 30, 1995	Delta II/7920-10	Rossi X-ray Timing Explorer.
231	Koreasat-2	January 14, 1996	Delta II/7925	Korean communications satellite.
232	NEAR	February 17, 1996	Delta II/7925-8	Near Earth Asteroid Rendezvous.
233	Polar	February 24, 1996	Delta II/7925-10	Space physics satellite.
234	NAVSTAR II-25 GPS	March 28, 1996	Delta II/7925	Twenty-fifth Block II NAVSTAR GPS satellite.
235	Middlecourse Space Experiment (MSX)	April 24, 1996	Delta II/7920-10	USA 118.
236	Galaxy IX	May 24, 1996	Delta II/7925-8	Commercial communications satellite.
237	NAVSTAR II-26 GPS	July 16, 1996	Delta II/7925	Twenty-sixth Block II NAVSTAR GPS satellite.
238	NAVSTAR II-27 GPS	September 12, 1996	Delta II/7925	Twenty-seventh Block II NAVSTAR GPS satellite.
239	Mars Global Surveyor	November 7, 1996	Delta II/7925	Remote sensing mission of Mars.
240	Mars Pathfinder	December 4, 1996	Delta II/7925	Planetary spacecraft with rover.

Table 2–71. Delta Launches (1989–1998)[a] (Continued)

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
241	GPS BIIR-01 (NAVSTAR 2R-1)	January 17, 1997	Delta II/7925	Failed due to split in the casing of one of the solid rocket motors.
242	MS-1 Iridium® (5 satellites)	May 5, 1997	Delta II/7920-10C	Communications satellites.
243	Thor II	May 20, 1997	Delta II/7925	Norwegian communications satellite.
244	MS-2 Iridium® (5 satellites)	July 9, 1997	Delta II/7920-10C	Communications satellites.
245	NAVSTAR GPS-IIR2	July 23, 1997	Delta II/7925	Block IIR NAVSTAR GPS satellite.
246	MS-3 Iridium® (5 satellites)	August 21, 1997	Delta II/7920-10C	Communications satellites.
247	Advanced Composition Explorer (ACE)	August 25, 1997	Delta II/7920-8	Space science mission.
248	MS-4 Iridium® (5 satellites)	September 27, 1997	Delta II/7920-10C	Communications satellites.
249	NAVSTAR II-28 GPS	November 6, 1997	Delta II/7925	Twenty-eighth block II NAVSTAR GPS satellite.
250	MS-5 Iridium® (5 satellites)	November 9, 1997	Delta II/7920-10C	Communications satellites.
251	MS-6 Iridium® (5 satellites)	December 20, 1997	Delta II/7920-10C	Communications satellites.
252	Skynet 4D	January 10, 1998	Delta II/7925	British military communications satellite.
253	Globalstar-1 (4 satellites Space Systems/Loral)	February 14, 1998	Delta II/7420	Communications satellites.

Table 2–71. Delta Launches (1989–1998)[a] (Continued)

Delta Mission No.	Mission	Launch Date (GMT)	Vehicle Type	Comments
254	MS-7 Iridium® (5 satellites)	February 18, 1998	Delta II/7920-10C	Communications satellites.
255	MS-8 Iridium® (5 satellites)	March 30, 1998	Delta II/7920-10C	Communications satellites.
256	Globalstar-2 (4 satellites Space Systems/Loral)	April 24, 1998	Delta II/7420-10C	British military communications satellites.
257	MS-9 Iridium® (5 satellites)	May 17, 1998	Delta II/7920-10C	Communications satellites.
258	Thor III	June 10, 1998	Delta II/7925	European communications satellite.
259	Galaxy X	August 27, 1998	Delta III/8930	Failed. Exploded 80 seconds after liftoff. First Delta III launch.
260	MS-10 Iridium® (5 Satellites)	September 8, 1998	Delta II/7920-10C	Communications satellites.
261	Deep Space 1 and Sedsat	October 24, 1998	Delta II/7326[c]	New Millennium Program and Students for the Exploration and Development of Space Satellite secondary payload.
262	MS-11 Iridium® (5 satellites)	November 6, 1998	Delta II/7920-10C	Communications satellites.
263	BONUM-1	November 22, 1998	Delta II/7925	Russian television satellite.
264	Mars Climate Orbiter	December 11, 1998	Delta II/7425	Interplanetary spacecraft.

[a] "Delta Launch Record," *http://www.boeing.com/defense-space/space/delta/record.htm* (accessed January 31, 2005).

[b] Koreasat-1 was able to achieve orbit. The Delta booster, however, placed the satellite in a lower-than-specified orbit, thus shortening its useful life.

[c] New variant of Delta II that used three solid Alliant GEM-40 strap-ons rather than nine.

Table 2–72. Delta 3920/PAM-D Characteristics

	Strap-ons (each)[a]	Stage 1	Stage 2	Stage 3 (Payload Assist Module)	Total
Length	9.07 m (30 ft)	22.8 m (75 ft) (includes second stage)	6 m (19.6 ft)	2 m (6.6 ft)	35.5 m (116 ft) including fairing
Diameter	1.02 m (3.3 ft)	2.4 m (8 ft)	2.4 m (8 ft)	1.25 m (4.1 ft)	
Gross mass	10,530 kg (23,215 lb)	85,076 kg (187,560 lb)	6,930 kg (15,331 lb)	1,122 kg (2,474 lb)	
Propulsion	Nine Thiokol Castor IV TX 526-2 strap-on motors	Rocketdyne RS-27 assembly consisting of one RS27 A/B main engine and two LR101-NA-11 vernier engines	Aerojet AJ10-118K engine	Thiokol Star 48 motor	
Propellant	HTPB	Oxidizer: LOX Fuel: RP-1	Aerozine-50 and N_2O_4	HTPB	
Propellant mass	9,373 kg (20,664 lb)	79,380 kg (175,000 lb)	6,004 kg (13,236 lb)	1,909 kg (4,200 lb)	
Avg. Thrust	428 kN (96,218 lb)	1,030 kN (231,553 lb)	44 kN (9,815 lb)	66.6 kN (14,972 lb)	
Nominal burn time	57 sec	224 sec	431 sec	44 sec	
Max. payload	3,045 kg (6,713 lb) to low-Earth orbit; 1,275 kg (2,800 lb) to geosynchronous transfer orbit; 2,135 kg (4,700 lb) to circular sun-synchronous orbit (polar launch)[b]				
Contractors	Thiokol	Rocketdyne	Aerojet	Thiokol	McDonnell Douglas

[a] Jean-Jacques Serra, "Castor," *The Satellite Encyclopedia*, *http://www.tbssatellite.com/tse/online/lanc_castor.html* (accessed April 7, 2005).
[b] *Aeronautics and Space Report of the President, 1989–1990 Activities* (Washington, DC: National Aeronautics and Space Administration, 1991), p. 160.

Table 2–73. Delta II 6925 Characteristics[a]

	Strap-ons (each)	Stage 1	Stage 2	Stage 3 (Payload Assist Module)	Total
Length	11.2 m (36.3 ft)	26.1 m (85.6 ft)	6 m (19.6 ft)	2 m (6.7 ft)	Up to 38.1 m (125 ft) including fairing
Diameter	1.0 m (3.3 ft)	2.44 m (8 ft)	2.44 m (8 ft)	1.25 m (4.1 ft)	
Gross mass	Ground lit: 11,700 kg (25,800 lb) Air lit: 11,900 kg (26,100 lb)	101,700 kg (224,210 lb)	6,997 kg (15,400 lb)	2,141 kg (4,721 lb)	220,000 kg (480,000 lb)
Propulsion	Nine Castor IVA solid rocket motors	Rocketdyne RS-27 assembly consisting of one RS2701A/B main engine and two LR101-NA-11 vernier engines	Aerojet AJ10-118K engine	Thiokol Star 48B motor	
Propellant	HTPB	Oxidizer: LOX Fuel: RP-1	Aerozine-50 and N_2O_4	HTPB	
Propellant mass	10,100 kg (22,300 lb)	96,100 kg (211,900 lb)	6,076 kg (14,400 lb)	2,009 kg (4,430 lb)	
Avg. thrust	427.1 kN (97,700 lb) at sea level 478.3 kN (108,700 lb) vac.	911 kN (204,800 lb) (sea level)	42.4 kN (9,645 lb)	66.4 kN (15,100 lb)	2,620 kN at liftoff (595,000 lb)
Nominal burn time	56.2 sec	265 sec	440 sec	54.8 sec	
Max. payload	5,039 kg (11,100 lb) to low-Earth orbit; 1,819 kg (4,000 lb) to geosynchronous transfer orbit, 3,175 kg (7,000 lb) to sun synchronous orbit[b]				
Contractors	Thiokol	Rocketdyne	Aerojet	Thiokol	McDonnell Douglas

[a] Isakowitz and Samella, *International Reference Guide to Space Launch Systems,* 2nd ed., pp. 234–237.
[b] *Aeronautics and Space Report of the President, Fiscal Year 1992 Activities,* p. 94.

Table 2–74. Delta 7925 Characteristics[a]

	Strap-on Solid Rocket Motors	**Stage 1**	**Stage 2**	**Stage 3 (Payload Assist Module)** [b]	**Total**
Length	13.0 m (42.5 ft)	26.1 (85.6 ft)	6 m (19.6 ft)	2 m (6.7 ft)	38.2 m–38.9 m (125.2 ft–126.5 ft) depending on fairing
Diameter	1.0 m (3.3 ft)	2.4 m (8 ft)	2.4 m (8 ft)	1.25 m (4.1 ft)	
Gross mass	13,080 kg (28,840 lb) each	101,800 kg (224,400 lb)	6,954 kg (15,331 lb)	2,217 kg (4,887 lb)	231,870 kg (511,190 lb)
Propulsion	Nine Hercules GEM 40 solid rocket motors; some configurations used three or four motors	Rocketdyne RS-27 assembly consisting of one RS27A/B main engine and two LR101-NA-11 vernier engines	Aerojet AJ10-118K engine	Thiokol Star 48B motor	
Propellant	HTPB	Oxidizer: LOX Fuel: RP-1	Aerozine-50 and N_2O_4	HTPB	
Propellant mass	11,765 kg (25,940 lb)	96,100 kg (211,900 lb)	6,004 kg (13,236 lb)	2,009 kg (4,430 lb)	
Avg. thrust	Sea level: 446 kN (100,300 lb); air-lit: 516.2 kN (116,100 lb) each	890 kN (200,000 lb) (sea level)	44 kN (9,815 lb)	66.4 kN (14,927 lb)	3,110 kN (699,250 lb) at liftoff
Nominal burn time	63.3 sec	261 sec	431 sec	87.1 sec	
Max. payload	3,895 kg (8,590 lb) to 5,140 kg (11,330 lb) to low-Earth orbit depending on launch inclination; 3,220 kg (7,100 lb) to Sun-synchronous orbit; 1,870 kg (4,120 lb) to geosynchronous transfer orbit				
Contractors	Alliant Techsystems	Rocketdyne	Aerojet	Thiokol	McDonnell Douglas

[a] Isakowitz et al., *International Reference Guide to Space Launch Systems,* 3rd ed., pp. 112, 115–118.
[b] No PAM upper stage was used for low-Earth orbit missions.

Table 2–75. Representative Delta II Mission Profile Events

Event	Mission Elapsed Time (sec)
Main engine and six solid motors ignited, liftoff	0.0
Mach 1	32.4
Maximum dynamic pressure	49.7
Solid motor burnout (6 of 9)	56
Solid motor ignition (3 of 9)	59
Jettison 6 solid motors	60/61
Jettison 3 solid motors	118
Stage 1 main engine cutoff (MECO)	265
Stage 1-2 separation	271.4
Stage 2 ignition	278
Payload fairing jettison	298
Stage 2 engine first cutoff 1 (SECO 1)	687
Stage 2 restart ignition	1263
Second cutoff–Stage 2 (SECO 2)	1286
Stage 2-3 separation	1300
Stage 3/PAM ignition	1376
Stage 3/PAM burnout	1463
Spacecraft separation	1576

Table 2–76. Pegasus Launches (1989–1998)

Launch Date	Vehicle Model	Customer(s)	Payload	Type of Mission
April 5, 1990	Standard	NASA, DOD	PegSat, USA 55 (SECS)	Flight test instrumentation and atmospheric research. Navy experimental satellite.
July 7, 1991	Standard with HAPS	DOD	MicroSat 1, 2, 3, 4, 5, 6, and 7	Tactical communications network. Achieved mission objectives at lower orbit than planned.[a]
February 9, 1993	Standard	1) INPE Brazil	1) SCD-1	1) Data communications.
		2) Orbital Sciences Corp.	2) OXP-1	2) Experimental communications satellite.
April 25, 1993	Standard	1) Department of Energy-sponsored	1) ALEXIS	1) Array of Low Energy X-ray Imaging Sensors. Satellite was damaged at launch, delaying communication with ground by six weeks.
		2) Orbital Sciences Corp.	2) OXP-2[b]	2) Experimental communications satellite.
May 19, 1994	Standard with HAPS	DOD	STEP-2	Technology validation. Satellite placed in lower than expected orbit.
June 27, 1994	XL	DOD	STEP-1	Technology validation. Mission failed.
August 3, 1994	Standard	DOD	APEX	Advanced Photovoltaic and Electronic Experiments. Space physics technology validation.
April 4, 1995	Standard (Hybrid)	1) ORBCOMM	1) FM1 & FM2	1) Communications.
		2) NASA	2) MicroLab 1	2) Atmospheric research.
June 22, 1995	XL	DOD	STEP-3	Technology validation. Mission failed.

Table 2–76. Pegasus Launches (1989–1998) (Continued)

Launch Date	Vehicle Model	Customer(s)	Payload	Type of Mission
March 8, 1996	XL	DOD	REX-2	Radiation experiment. Technology validation.
May 16, 1996	Standard (Hybrid)	U.S. Air Force	MSTI-3	Miniature Sensor Technology Integration. Technology validation.
July 2, 1996	XL	NASA	TOMS-EP	Total Ozone Mapping Spectrometer Earth Probe. Atmospheric research.
August 21, 1996	XL	NASA	FAST	Fast Auroral Snapshot Explorer. Space physics research.
November 4, 1996	XL	NASA	SAC-B HETE-1	Space physics research. Spacecraft did not separate from third stage. Mission failed.[c]
April 21, 1997	XL	INTA Spain	MINISAT 01	Space physics research. Spain's first satellite, also release of funeral ashes.[d]
August 1, 1997	XL	Orbital Sciences Corp./ NASA	OrbView-2 (SeaStar)	Ocean color imaging, Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project.
August 29, 1997	XL	DOD	FORTE	Technology validation.
October 22, 1997	XL	DOD	STEP-4	Technology validation.
December 23, 1997	XL with HAPS	ORBCOMM-1	ORBCOMM 5-12	Eight low-Earth orbit communications satellites.
February 25, 1998	XL	1) NASA, 2) Teledesic	1) SNOE, 2) T1	1) Student Nitric Oxide Explorer. 2) Commercial communications satellite.
April 1, 1998	XL	NASA	TRACE	Transition Region and Coronal Explorer. Solar physics.

Table 2–76. Pegasus Launches (1989–1998) (Continued)

Launch Date	Vehicle Model	Customer(s)	Payload	Type of Mission
August 2, 1998	XL with HAPS	ORBCOMM-2	ORBCOMM 13-20	Eight low-Earth orbit communications satellites.
September 23, 1998	XL with HAPS	ORBCOMM-3	ORBCOMM 21-27	Eight low-Earth orbit communications satellites.
October 22, 1998	Standard (Hybrid)	INPE Brazil	SCD-2	Data communications.
December 5, 1998	XL	NASA	SWAS	Submillimeter Wave Astronomy Satellite. Space physics.

[a] The 356-km by 455-km (192-nmi by 246-nmi) orbit fell short of the planned 720-km (389-nmi) circular orbit because a problem at first stage separation caused a guidance error. Orbital Sciences listed the mission as a “success” and stated that the inclination was on target, allowing mission objectives to be met (*Orbital Sciences Corporation Spacecraft History*, table 2–2, pp. 2–8). The satellites’ customer, the Defense Advanced Research Projects Agency (DARPA), said that the rocket’s guidance system compensated for the low orbit and repositioned the satellites to an elliptical orbit that ensured DARPA’s objectives were met. *Aviation Week & Space Technology*, July 22–July 24, 1991 (NASA History Office Folder 010788). However, other references call it a “failure,” or “partial failure.” (Mark Wade, Astronautix.com, *http://www.astronautix.com/lvs.pegasus.htm* (accessed February 8, 2005)). Also “Launching on Pegasus,” Small Satellites home page, *http://centaur.sstl.co.uk/SSHP/launcher/launch_pegasus.html* (accessed February 8, 2005) and “Pegasus,” *The Satellite Encyclopedia*, *http://tbs-satellite.com/tse/online/lanc_pegasus.html* (accessed February 8, 2005).

[b] This payload is listed on Jonathan’s Space Report, *http://planet4589.org/space/log/launchlog.txt* (accessed February 23, 2005) but does not appear on the Pegasus Mission History list produced by Orbital Sciences: *http://www.orbital.com/SpaceLaunch/Pegasus/pegasus_history.htm* (accessed February 3, 2005). It appears that the payload did not separate from the Pegasus third stage.

[c] SAC-B was unable to deploy its solar arrays because the spacecraft did not separate from the Pegasus third stage due to a battery failure in the Pegasus third stage. HETE remained sealed in the interior of the dual payload support structure. SAC-B solar arrays were deployed via ground commands but were unable to generate enough power to keep the satellite’s batteries charged. Both died due to power failure within days of launch. “SAC-B/HETE Spacecraft No Longer Operational,” *NASA News* Release 96-231, November 7, 1996, *ftp://ftp.hq.nasa.gov/pub/pao/pressrel/1996/96-231.txt* (accessed February 10, 2005); “Partial Launch Vehicle and Spacecraft Re-enter Earth’s Atmosphere,” Goddard Space Flight Center Top Story, April 4, 2002, updated April 7, 2002, *http://www.gsfc.nasa.gov/topstory/20020401hetereenter.html* (accessed February 10, 2005); “SAC-B” Gunter’s Space Page *http;//skyrocket.de/space/doc_sdat/hete.htm* (accessed February 23, 2005) and “HETE 1, 2,” Gunter’s Space Page *http://space/skyrocket.de/doc_sdat/hete.htm* (accessed April 14, 2006).

[d] Among the 24 capsules of funeral ashes taken aloft and put into orbit from this Pegasus were those of the 1960s icon, Timothy Leary, and Gene Roddenberry, creator of “Star Trek.” Marlise Simons, “A Final Turn-On Lifts Timothy Leary Off,” *New York Times*, April 22, 1997, A1.

Table 2–77. Standard Pegasus Characteristics[a]

	Stage 1	**Stage 2**	**Stage 3**	**Total**
Length	8.9 m (29 ft)	2.3 m (7.5 ft)	1.3 m (4.3 ft)	15.2 m[b] (50 ft)
Diameter	1.28 m (4.2 ft) without 6.7-m (22-ft) wingspan	1.28 m (4.2 ft)	0.97 m (3.2 ft)	
Liftoff mass	13,417 kg (29,579 lb)	3,367 kg (7,423 lb)	897 kg (1,978 lb)	
Propulsion	Orion 50S motor	Orion 50 motor	Orion 38 motor	
Propellant	HTPB	HTPB	HTPB	
Propellant mass	12,160 kg (26,808 lb)	3,024 kg (6,667 lb)	771 kg (1,700 lb)	
Nominal burn time[c]	72.4 sec	73.3 sec	68.4	
Thrust (max. vac.)	580.46 kN (130,493 lb)	138.64 kN (31,168 lb)	35.81 kN (8,050 lb)	
Max. payload[d]	380 kg into 185-km orbit; 280 kg into 185-km polar orbit from Vandenberg Air Force Base; 210 kg into sun-synchronous orbit from Vandenberg Air Force Base			
Contractor	Hercules	Hercules	Hercules	Orbital Sciences

[a] All vehicle characteristics are from *NASA SELVS Pegasus Launch System Payload User's Guide*, Release 2.00 (Orbital Sciences Corporation, June 1994), pp. 2–7, unless otherwise indicated.

[b] "Pegasus Launch Vehicle," Space & Missile Systems Center, Department of the Air Force, *http://www.te.plk.af.mil/factsheet/pegfact.html* (accessed February 8, 2005). Included aft skirt assembly, interstage, and fairing.

[c] At 21°C (70°F).

[d] *Aeronautics and Space Report of the President, Fiscal Year 1994 Activities* (Washington, DC: National Aeronautics and Space Administration, 1995), p. 91.

Table 2–78. Pegasus XL Characteristics[a]

	Stage 1	**Stage 2**	**Stage 3**	**Total**
Length	10.3 m (34 ft)	3.1 m (10.2 ft)	1.3 m (4.3 ft)	16.9 m (55.4 ft) including interstage and fairing
Diameter	1.28 m (4.2 ft) without 6.7-m (22-ft) wingspan	1.28 m (4.2 ft)	1 m (3.3 ft)	
Liftoff mass	16,383 kg (36,118 lb)	43,411 kg (95,705 lb)	896 kg (1,975 lb)	23,130 kg (26,742 lb)
Propulsion	Orion 50S XL motor	Orion 50 XL motor	Orion 38 motor	
Propellant	HTPB	HTPB	HTPB	
Propellant mass	15,014 kg (33,100 lb)	3,925 kg (8,653 lb)	770 kg (1,698 lb)	
Nominal burn time[b]	68.6 sec	69.4 sec	68.5 sec	
Thrust (max. vac.)	726 kN (163,211 lb)	196 kN (44,063 lb)	36 kN (8,093 lb)	
Payload capacity[c]	460 kg (1,014 lb) into 185-km orbit; 350 kg (772 lb) into 185-km polar orbit from Vandenberg Air Force Base; 335 kg (739 lb) into sun-synchronous orbit from Vandenberg Air Force Base			
Contractor	Alliant Techsystems	Alliant Techsystems	Alliant Techsystems	Orbital Sciences
Remarks	All XL launches have taken place from the L-1011 “Stargazer” aircraft			

[a] *Pegasus User’s Guide*, Release 5.0, August 2000 (Orbital Sciences Corporation, 2000), pp. 2–4, *http://www.orbital.com/NewsInfo/Publications/peg-user-guide.pdf* (accessed February 4, 2005).

[b] At 21°C (70°F).

[c] *Aeronautics and Space Report of the President, Fiscal Year 1999 Activities* (Washington, DC: National Aeronautics and Space Administration, 2000), p. 97.

Table 2–79. Scout G1 Characteristics[a]

	Stage 1	Stage 2	Stage 3	Stage 4	Total
Length	9.94 m (32.6 ft)	6.56 m (21.5 ft)	3.28 m (10.8 ft)	1.97 m (6.5 ft)	23 m (75 ft) including transition and payload sections
Diameter	1.01 m (3.3 ft) max.	0.79 m (2.6 ft)	0.75 m (2.5 ft)	0.5 m (1.7 m)	
Launch mass	14,255 kg (31,361 lb)	4,424 kg (9,753 lb)	1,395 kg (3,075 lb)	302 kg (665.8 lb)	
Propulsion	Algol IIIA motor	Castor IIA motor	Antares IIIA motor	Altair IIIA motor	
Propellant	Solid	Solid	Solid	Solid	
Propellant mass	12,684 kg (27,965 lb)	3,762 kg (8,294 lb)	1,286 kg (2,835 lb)	275 kg (606.3 lb)	
Avg. thrust	467.1 kN (105,112 lb)	284.3 kN (63,971 lb)	83.1 kN (18,698 lb)	25.4 kN (5713 lb)	
Nominal burn time	56 sec	35 sec	44 sec	29 sec	
Payload capacity	175 kg (386 lb) to a 185-km (100-nmi) orbit				
Prime Contractor	Vought Corp. (LTV Corp.)				

[a] "Scout–Launch Vehicle," Vought Corp., *http://www.vought.com/heritage/special/html/sscout1.html* (accessed February 9, 2005). "Scout Launch Vehicle Program," Langley Research Center Fact Sheet, last updated November 24, 2004, *http://www.nasa.gov/centers/langley/news/factsheets/Scout.html* (accessed February 9, 2005).

Table 2–80. Scout Launches (1989–1998)

Mission No.	Launch Date	Vehicle Type	Customer(s)	Payload	Comment
212C	May 9, 1990	Scout G1	Reimbursable DOD	MACSAT (Multiple Access Comsat)	Two NAVY/DARPA communications satellites
216C	June 29, 1991	Scout G	DOD	REX	Air Force Radiation Experiment
215C	July 3, 1992	Scout G1	NASA	SAMPEX	Solar, Anomalous and Magnetospheric Particle Explorer, first Small Explorer mission
210C	November 21, 1992	Scout G1	Ballistic Missile Defense Organization and U.S. Air Force	MSTI I (Miniature Sensor Technology Integration)	Atmospheric studies
217C	June 25, 1993	Scout G1	U.S. Air Force	RADCAL	Radar Calibration Satellite
218	May 9, 1994	Scout G1	Ballistic Missile Defense Organization and U.S. Air Force	MSTI II	Tracking and Earth observation studies. Last Scout launch

Table 2–81. Taurus 2210 Characteristics[a]

	Stage 0[b]	**Stage 1**	**Stage 2**	**Stage 3**	**Total**
Length	12.8 m (41.9 ft)	8.6 m (28.3 ft)	3.1 m (10.1 ft)	1.3 m (4.4 ft)	27.9 m (91.4 ft) including interstage and fairing
Diameter	2.4 m (7.8 ft)	1.3 m (4.2 ft)	1.3 m (4.2 ft)	1.0 m (3.2 ft)	2.4 m (7.8 ft)
Liftoff mass	53,424, kg (117,800 lb)	13,242 kg (29,200 lb)	3,379 kg (7,450 lb)	875 kg (1,930 lb)	73,000 kg (161,000 lb)[c]
Propulsion	Castor 120 motor	Orion 50S-G motor	Orion 50 motor	Orion 38 motor[d]	
Propellant	HTPB	HTPB	HTPB	HTPB	
Propellant mass	49,024 kg (108,100 lb)	12,154 kg (26,800 lb)	3,027 kg (6,674 lb)	771 kg (1,700 lb)	
Thrust (avg. vac.)	1,615 kN (363,087 lb)	471 kN (106,000 lb)	115 kN (25,910 lb)	13.8 kN (7,155 lb)	
Nominal burn time	82.5 sec	72.4 sec	75.1 sec	68.5 sec	
Payload capacity	1,400 kg (3,086 lb) into 185-km orbit (100-nmi); 1,080 kg (2,381 lb) into 185-km (100-nmi) polar orbit from Vandenberg Air Force Base; 255 kg (562 lb) into geosynchronous transfer orbit; 1,020 kg (2,249 lb) into sun-synchronous orbit from Vandenberg Air Force Base[e]				
Contractor	Thiokol	Alliant Techsystems	Alliant Techsystems	Alliant Techsystems	Orbital Sciences Corp.

[a] *Taurus User's Guide*, Release 3.0 (Orbital Sciences Corporation, September 1999), pp. 2–5, *http://www.orbital.com/NewsInfo/Publications/taurus-user-guide.pdf* (accessed February 9, 2005). Liftoff masses and total length were not available from the *Taurus User's Guide* and were obtained from Isakowitz et al., *International Reference Guide to Space Launch Systems*, 3rd ed., pp. 440–441.

[b] The first stage was known as "Stage 0."

[c] Included interstage and fairing.

[d] This stage could be replaced by a spin-stabilized upper stage using Thiokol's Star 37FM perigee kick motor for insertion into geosynchronous transfer orbit.

[e] *Aeronautics and Space Report of the President, Fiscal Year 1999 Activities*, p. 97.

Table 2–82. Taurus Launches (1989–1998)

Launch Vehicle	Launch Date	Mission	Comments
Taurus ARPA	March 13, 1994	STEP-0 (USA-101), Darpasat (USA-102)	DOD mission
Taurus 2210	February 10, 1998	1) Celestis 2 2) Geosat Follow-on (GFO) 3) ORBCOMM FM-3, FM-4	1) funeral ashes disposal 2) military Earth science 3) communications satellite
Taurus ARPA	October 3, 1998	STEX, ATEX (USA-141)	DOD mission

Table 2–83. Titan Launches (1989–1998)

Titan Launch Vehicle	Launch Date (GMT)	Mission	Comments
34D	May 10, 1989	USA 37	DOD satellite.
IV	June 14, 1989	USA 39	Defense Support Program satellite. IUS booster.
34D	September 4, 1989	USA 43, 44	Defense Satellite Communications System payload.
II	September 6, 1989	USA 45	DOD satellite.
III	January 1, 1990	Skynet 4A/JCSat 2	U.K. defense communications satellite/Japanese communications satellite. First commercial Titan III launch.
III	March 14, 1990	Intelsat 6 F-3	International communications satellite. Second stage reached correct orbit but failed to deploy payload. Satellite separated itself from kick stage and was rescued and reboosted by astronauts on STS-49 mission in May 1992.[a]
IVA	June 8, 1990	USA 59, 60, 61, 62	DOD satellite.
III	June 23, 1990	Intelsat 6 F-4	International communications satellite.
IVA	November 13, 1990	USA 65	DOD satellite. IUS booster.
IVA	March 8, 1991	USA 69	DOD satellite.
IVA	November 8, 1991	USA 72, 74, 76, 77	DOD satellite.
II	April 25, 1992	USA 81	DOD satellite.
III	September 25, 1992	Mars Observer	NASA space science mission launched by refurbished Titan ICBM. Transfer orbit kick stage.
IVA	November 28, 1992	USA 86	DOD satellite.
IVA	August 2, 1993	USA	DOD satellite. Failed. Explosion destroyed vehicle.

Table 2–83. Titan Launches (1989–1998) (Continued)

Titan Launch Vehicle	Launch Date (GMT)	Mission	Comments
II	October 5, 1993	Landsat-6	Earth science mission launched by refurbished Titan ICBM. Failed to achieve orbit due to a ruptured hydrazine manifold that stopped fuel from reaching the satellite's stabilizing engines, preventing its ability to attain a stable orbit.
II	January 25, 1994	Clementine	DOD satellite.
IVA	February 7, 1994	Milstar	Military communications satellite. First Titan IV with Centaur upper stage.
IVA	May 3, 1994	DSP	Defense Support Program satellite. Centaur upper stage.
IVA	August 27, 1994	USA 105	DOD satellite. Centaur upper stage.
IVA	December 22, 1994	USA 107	Defense Support Program satellite. IUS booster.
IVA	May 14, 1995	USA 110	DOD satellite.
IVA	July 10, 1995	USA 112	DOD satellite. Centaur upper stage.
IVA	November 6, 1995	USA 115	Military communications satellite. Centaur upper stage.
IVA	December 5, 1995	USA 116	Military reconnaissance.
IVA	April 24, 1996	USA 118	DOD satellite. Centaur upper stage.
IVA	May 12, 1996	USA 119, 120, 121, 122, 123, 124	DOD satellite.
IVA	July 3, 1996	USA 125	Military reconnaissance.
IVA	December 20, 1996	USA 129	DOD satellite.
IVB	February 23, 1997	USA 130	First Titan IVB launch. DOD satellite. IUS booster.
II	April 4, 1997	USA 131, DMSP F14	DOD satellite.
IVB	October 15, 1997	Cassini/Huygens	NASA space science mission. Centaur upper stage.

Table 2–83. Titan Launches (1989–1998) (Continued)

Titan Launch Vehicle	Launch Date (GMT)	Mission	Comments
IVA	October 24, 1997	USA 133	DOD satellite. Centaur upper stage.
IVA	November 8, 1997	USA 136	DOD satellite. Centaur upper stage.
IVB	May 8, 1998	USA 139	Military reconnaissance. Centaur upper stage.
II	May 13, 1998	NOAA-15	NOAA meteorological satellite.
IVA	August 12, 1998	USA	DOD satellite. Centaur upper stage. Last Titan IVA launch. Failed.

[a] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 3rd ed., p. 453.

Table 2–84. Titan II Characteristics[a]

	Stage 1	**Stage 2**
Length	70 ft (21.3 m)	24 ft (7.3 m)
Diameter	10 ft (3.0 m)	10 ft (3.0 m)
Launch mass	269,000 lb (122,016 kg)	65,000 lb (29,484 kg)
Propulsion	Two LR87-AJ-5	One LR 91-AJ-5
Propellant	Aerozine 50, N_2O_4	Aerozine 50, N_2O_4
Propellant mass	260,000 lb (117,934 kg)	59,000 lb (27,215 kg)
Thrust (vac.)	474,000 lb (2,100 kN)	100,000 lb (450 kN)
Nominal burn time	147 sec	182 sec
Payload capacity	4,200 lb (1,905 kg) to polar low-Earth orbit	
Contractor	Aerojet Techsystems (engines) Lockheed Martin (vehicle refurbishment)	

[a] "Titan II Space Launch Vehicle," Fact Sheet, United States Air Force, *http://www.losangeles.af.mil/SMC/PA/Fact_Sheets/ttn2_fs.htm* (accessed February 14, 2005) and Isakowitz et al., *International Reference Guide to Space Launch Systems,* 3rd ed., pp. 457–458.

Table 2–85. Space Shuttle Flights (1989–1998)

Mission	Date	Orbiter	Payload	Comment
STS-29	March 13–March 18, 1989	*Discovery*	Tracking and Data Relay Satellite (TDRS)-4	NASA communications satellite.
STS-30	May 4–May 8, 1989	*Atlantis*	Magellan	First launch of interplanetary spacecraft. Attached to IUS booster.
STS-28	August 8–August 13, 1989	*Columbia*	DOD payload	
STS-34	October 18–October 23, 1989	*Atlantis*	Galileo	Attached to IUS booster, deployed on trajectory toward Jupiter. Space science mission.
STS-33	November 23–November 26, 1989	*Discovery*	DOD payload	
STS-32	January 9–January 20, 1990	*Columbia*	DOD communications satellite Syncom IV-5	Also retrieved the Long Duration Exposure Facility.
STS-36	February 28–March 4, 1990	*Atlantis*	DOD payload	
STS-31	April 24–April 29, 1990	*Discovery*	Hubble Space Telescope	First "Great Observatory." Space science mission.
STS-41	October 6–October 10, 1990	*Discovery*	European Space Agency-sponsored Ulysses	Attached to IUS and Payload Assist Module S (PAM-S) boosters.
STS-38	November 15–20, November 1990	*Atlantis*	DOD payload	
STS-35	December 2–December 11, 1990	*Columbia*	No deployed payload	Astro-1 Spacelab mission.
STS-37	April 5–April 11, 1991	*Atlantis*	Gamma Ray Observatory	Second "Great Observatory." Space science mission.

Table 2–85. Space Shuttle Flights (1989–1998) (Continued)

Mission	Date	Orbiter	Payload	Comment
STS-39	April 28–May 6, 1991	*Discovery*	Deployed and retrieved Strategic Defense Initiative Organization's Infrared Background Signature Survey experiment, mounted on the Shuttle Pallet Satellite (SPAS)-II platform	First unclassified DOD-dedicated Space Shuttle mission.
STS-40	June 5–June 14, 1991	*Columbia*	No deployed payload	Life sciences mission.
STS-43	August 2–August 11, 1991	*Atlantis*	TDRS-5	NASA communications satellite.
STS-48	September 12–September 18, 1991	*Discovery*	Upper Atmosphere Research Satellite	Earth science mission.
STS-44	November 25–December 1, 1991	*Atlantis*	Defense Support Program Satellite	
STS-42	January 22–January 30, 1992	*Discovery*	No deployed payload	International Microgravity Laboratory (IML)-1.
STS-45	March 24–April 2, 1992	*Atlantis*	No deployed payload	Atmospheric Laboratory for Applications and Science (ATLAS)-1.
STS-49	May 2–May 16, 1992	*Endeavour*	Captured and redeployed Intelsat VI satellite after repair	First flight of *Endeavour*.
STS-50	June 25–July 9, 1992	*Columbia*	No deployed payload	U.S. Microgravity Laboratory (USML)-1.
STS-46	July 31–August 8, 1992	*Atlantis*	European Space Agency European Retrievable Carrier (EURECA)	Also deployed tethered Italian satellite, which did not deploy as planned.

Table 2–85. Space Shuttle Flights (1989–1998) (Continued)

Mission	Date	Orbiter	Payload	Comment
STS-47	September 12–September 20, 1992	*Endeavour*	No deployed payload	Spacelab-J (First Japanese Spacelab).
STS-52	October 22–November 1, 1992	*Columbia*	Laser Geodynamic Satellite II	Joint U.S.-Italy mission. Also U.S. Microgravity Payload (USMP)-1.
STS-53	December 2–December 9, 1992	*Discovery*	DOD payload	Last classified payload.
STS-54	January 13–January 19, 1993	*Endeavour*	TDRS-6	NASA communications satellite.
STS-56	April 8–April 17, 1993	*Discovery*	Deployed and retrieved Shuttle Pointed Autonomous Research Tool for Astronomy (SPARTAN)-201	Also ATLAS-2 science mission.
STS-55	April 26–May 6, 1993	*Columbia*	No deployed payload	German Spacelab D-2.
STS-57	June 21– July 1, 1993	*Endeavour*	Retrieved EURECA	Also commercial SPACEHAB laboratory.
STS-51	September 12–September 22, 1993	*Discovery*	1) Advanced Communications Technology Satellite (ACTS), 2) Orbiting and Retrievable Far and Extreme Ultraviolet Spectrograph (ORFEUS)-SPAS deployed and retrieved	
STS-58	October–18 November 1, 1993	*Columbia*	No deployed payload	Spacelab life sciences mission.
STS-61	December 2–December 13, 1993	*Endeavour*	Hubble Space Telescope retrieved and redeployed	First Hubble servicing mission.

Table 2–85. Space Shuttle Flights (1989–1998) (Continued)

Mission	Date	Orbiter	Payload	Comment
STS-60	February 3–February 11, 1994	*Discovery*	Deployed two payloads from Get Away Special (GAS) canisters	SPACEHAB mission. Wake Shield Facility-1 not deployed as planned.
STS-62	March 9–March 19, 1994	*Columbia*	No deployed payload	1) USMP-2, 2) Office of Aeronautics and Space Technology (OAST)-2 experiments.
STS-59	April 9–April 20, 1994	*Endeavour*	No deployed payload	Space Radar Laboratory (SRL)-1.
STS-65	July 9–July 23, 1994	*Columbia*	No deployed payload	Last *Columbia* mission before scheduled modification and refurbishment. Carried IML-2.
STS-64	September 9–September 20, 1994	*Discovery*	Deployed and retrieved SPARTAN-201	Also LIDAR In-Space Technology Experiment.
STS-68	September 30–October 11, 1994	*Endeavour*	No deployed payload	SRL-2.
STS-66	November 3–November 14, 1994	*Atlantis*	Deployed and retrieved German Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA)-SPAS	Also ATLAS-3 science mission.
STS-63	February 3–February 11, 1995	*Discovery*	Deployed and retrieved SPARTAN-204	Performed approach and fly-around of *Mir*. Also SPACEHAB mission.
STS-67	March 2–March 18, 1995	*Endeavour*	No deployed payload	Astro-2 mission.
STS-71	June 27–July 6, 1995	*Atlantis*	No deployed payload	100th U.S. human spaceflight. Docked with *Mir*.
STS-70	July 13–July 22, 1995	*Discovery*	TDRS-7	NASA communications satellite. Last TDRS deployed.

Table 2–85. Space Shuttle Flights (1989–1998) (Continued)

Mission	Date	Orbiter	Payload	Comment
STS-69	September 7–September 18, 1995	*Endeavour*	Deployed and retrieved SPARTAN 201 and Wake Shield Facility-2	First dual deployment and retrieval.
STS-73	October 20–November 5, 1995	*Columbia*	No deployed payload	USML-2.
STS-74	November 12– November 20, 1995	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-72	January 11–January 20, 1996	*Endeavour*	Deployed and retrieved SPARTAN OAST flyer	Also captured and returned Japanese satellite.
STS-75	February 22–March 7, 1996	*Columbia*	Deployed tethered satellite (3-day duration before tether broke)	USMP-3.
STS-76	March 22–March 30, 1996	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-77	May 19–May 29, 1996	*Endeavour*	Deployed and retrieved SPARTAN-207/Inflatable Antenna Experiment	Commercial SPACEHAB mission.
STS-78	June 20–July 7, 1996	*Columbia*	No deployed payload	Life and Microgravity Spacelab.
STS-79	September 19–September 26, 1996	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-80	November 19–December 7, 1996	*Columbia*	Deployed and retrieved ORFEUS-SPAS and Wake Shield Facility-3	
STS-81	January 12–January 22, 1997	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-82	February 11–February 21, 1997	*Discovery*	Retrieved and redeployed Hubble Space Telescope	Second Hubble servicing mission.
STS-83	April 4–April 8, 1997	*Columbia*	No deployed payload	Microgravity Science Laboratory-1 (MSL-1) postponed.

Table 2–85. Space Shuttle Flights (1989–1998) (Continued)

Mission	Date	Orbiter	Payload	Comment
STS-84	May 15–May 24, 1997	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-94	July 1–July 17, 1997	*Columbia*	No deployed payload	Reflight of MSL-1.
STS-85	August 7– August 19, 1997	*Discovery*	Deployed and retrieved German CRISTA-SPAS-2	
STS-86	September 25– October 6, 1997	*Atlantis*	No deployed payload	Docked with *Mir*.
STS-87	November 19–December 5, 1997	*Columbia*	Deployed and retrieved SPARTAN-201	Also USMP-4 Spacelab.
STS-89	January 22–January 31, 1998	*Endeavour*	No deployed payload	Docked with *Mir*.
STS-90	April 17–May 3, 1998	*Columbia*	No deployed payload	Final scheduled flight of Spacelab. Neurolab mission.
STS-91	June 2–June 12, 1998	*Discovery*	No deployed payload	Docked with *Mir*.
STS-95	October 29–November 7, 1998	*Discovery*	Deployed and retrieved SPARTAN-201	Also SPACEHAB module. Carried Hubble Orbiting Systems Test (HOST) platform. John Glenn flight.
STS-88	December 4–December 15, 1998	*Endeavour*	Satelite de Aplicaciones Cientifico (SAC)-A for Argentina	First Space Station mission.

Table 2–86. External Tank Characteristics[a]

Component	Characteristics
Propellants	LOX/LH_2
Length	153.8 ft (46.9 m)
Diameter	27.6 ft (8.4 m)
Gross liftoff weight	1,655,600 lb (760,947 kg)
Inert weight of lightweight tank	66,000 lb (29,937 kg)
Inert weight of super lightweight tank[b]	58,500 lb (26,535 kg)
Liquid oxygen max. weight	1,361,936 lb (617,764 kg)
Liquid oxygen tank weight (empty)	12,000 lb (5,443 kg)
Liquid oxygen tank volume	19,563 cu ft (553,963 liters)
Liquid oxygen tank length	49.3 ft (15 m)
Liquid oxygen tank diameter	27.6 ft (8.4 m)
Liquid hydrogen max. weight	227,641 lb (103,256 kg)
Liquid hydrogen tank diameter	27.6 ft (8.4 m)
Liquid hydrogen tank length	96.7 ft (29.5 m)
Liquid hydrogen tank volume	53,518 cu ft (1,515,461 liters)
Liquid hydrogen tank weight (empty)	29,000 lb (13,154 kg)
Intertank length	22.5 ft (6.9 m)
Intertank diameter	27.6 ft (8.4 m)
Intertank weight	12,100 lb (5,488 kg)
Prime contractor	Martin Marietta/Lockheed Martin since 1994

[a] "External Tank," *NSTS 1988 News Reference Manual*, September 1988, *http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/et.html* (accessed February 25, 2005).

[b] The super lightweight external tank was first used on STS-91 in June 1998. "Super Lightweight External Tank," Space Shuttle Technology Summary, NASA Marshall Space Flight Center, FS-2003-06-70-MSFC, *http://www.nasa.gov/centers/marshall/pdf/100423main_shuttle_external_tank.pdf* (accessed February 25, 2005).

Table 2–87. Solid Rocket Booster Characteristics[a]

Component	Characteristics
Length	149.16 ft (45.5 m)
Diameter	12.17 ft (3.7 m)
Propellant weight (each solid rocket motor)	1,100,000 lb (500,000 kg)
Inert weight (each SRB)	192,000 lb (89,090 kg)
Thrust at launch	3,300,000 lb (14,679 kN)
Propellant mixture	Ammonium perchlorate oxidizer, aluminum fuel, iron oxide, polymer, epoxy

[a] "Solid Rocket Boosters," *NSTS 1988 News Reference Manual,* September 1988, *http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/srb.html* (accessed February 25, 2005).

Table 2–88. Space Shuttle Main Engine Characteristics[a]

Component	Characteristics
Length	14 ft (4.3 m) at nozzle exit
Diameter	7.5 ft (2.3 m) at nozzle exit
Approx. weight (each)	7,000 lb (3,175 kg)
Number of engines	Three on each orbiter
Range of thrust level	65%–109% of rated power level
Thrust (100%)	Each engine: 375,000 lb (1,668 kN) at sea level, 470,000 lbs (2,091 kN) in vacuum
Thrust (109%)	417,300 lb (1,856 kN) at sea level, 513,250 lb (2,283 kN) in vacuum[a]
Operating life	7.5 hours and 55 starts
Propellant	Fuel: LH_2, Oxidizer: LOX, in a 6:1 ratio
Nominal burn time	522 secb[b]
Prime contractor	Boeing Rocketdyne

[a] "Main Propulsion System," *NSTS 1988 News Reference Manual*, September 1988, *http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts-mps.html* (accessed February 25, 2005).

[b] Boeing Rocketdyne, the engine manufacturer, lists the maximum thrust of each engine in vacuum at 512,950 lb (2,282 kN).

[b] Isakowitz et al., *International Reference Guide to Space Launch Systems*, 3rd ed., p. 407.

Table 2–89. Titan Centaur Upper Stage Characteristics[a]

Component	Characteristics
Length	29.45 ft (9 m)
Diameter	14.2 ft (4.3 m)
Thrust	33,000 lb (15,000 kg)
Propellants	Cryogenic–Liquid Oxygen and Liquid Hydrogen Stage
Propellant weight	46,000 lb (20,865 kg)
Propulsion	Two Pratt & Whitney restartable RL10 engines
Contractor	Lockheed Martin Space Systems

[a] "Titan," Lockheed Martin, *http://www.lockheedmartin.com/wms/findPage.do?dsp=fec&ci=15525&rsbci=0&fti=0&ti=0&sc=400* (accessed March 17, 2005).

Table 2–90. Inertial Upper Stage Characteristics

Component	Characteristics
Length	17 ft (5.18 m)
Diameter	9.25 ft (2.8 m)
Weight	32,500 lb (14,742 kg)
Propulsion	Two solid-fueled United Technologies motors
Propellant weight	First stage: 21,400 lb (9,797 kg) Second stage: 6,000 lb (2,722 kg)
Thrust	First stage: 42,000 lb (188,496 N) Second stage: 18,000 lb (80,784 N)
Contractor	Boeing

Table 2–91. Inertial Upper Stage Launches

Date	Vehicle	Payload
March 13, 1989	STS-29	Tracking and Data Relay Satellite-4
May 4, 1989	STS-30	Magellan
June 14, 1989	Titan IV	Defense Support Program satellite
September 4, 1989	Titan 34D	Defense Satellite Communications System satellite
October 18, 1989	STS-34	Galileo
November 23, 1989	STS-33	DOD payload
October 6, 1990	STS-41	Ulysses
November 13, 1990	Titan IV	Defense Support Program satellite
August 2, 1991	STS-43	Tracking and Data Relay Satellite-5
November 24, 1991	STS-44	Defense Support Program satellite
January 13, 1993	STS-54	Tracking and Data Relay Satellite-6
December 22, 1994	Titan IV	Defense Support Program satellite
July 13, 1995	STS-70	Tracking and Data Relay Satellite-7
February 24, 1997	Titan IV	Defense Support Program satellite

Table 2–92. DC-X Characteristics[a]

Component	Characteristics
Width	13-1/3 ft (4 m) at base, conical shape
Height	40 ft (12.2 m)
Weight (empty)	20,000 lb (9,072 kg)
Weight (with propellants)	41,600 lb (18,870 kg)
Propellants	LOX and LH_2
Propulsion	Four RL10A5 rocket engines
Thrust	13,500 lb each (60,000 N)
Reaction controls	Four 440 lb (1,957 N)-thrust gaseous oxygen, gaseous hydrogen thrusters
Contractor	McDonnell Douglas

[a] "DC-X Fact Sheet," BMDOLink, Delta Clipper-Experimental Fact Sheet, Office of External Affairs, April 1993, *http://www.hq.nasa.gov/office/pao/History/x-33/dcx-facts.htm* (accessed March 22, 2005).

Table 2–93. DC-X and DC-XA Flight Tests[a]

Flight	Launch Date	Duration (sec)	Altitude (m/ft)	Description
DC-X Test Flights				
1	August 18, 1993	59	46/151	Verified flight control systems and vertical landing capabilities
2	September 11, 1993	65.8	92/302	Ascent and landing mode control and ground effects survey
3	September 30, 1993	72.2	370/1,214	180-degree roll; aerostability data
4	June 20, 1994	135.9	870/2,854	Full propellant load; radar altimeter in control loop
5	June 27, 1994	77.9	790/2,592	In-flight abort after gaseous hydrogen explosion; vehicle demonstrated autoland capabilities
6	May 16, 1995	123.6	1,330/4,364	Continued expansion of flight envelope; constant angle of attack
7	June 12, 1995	132	1,740/5,709	First use of reaction control system thrusters; angle of attack from 0 to 70 degrees
8	July 12, 1995	124	2,500/8,202	Final flight of DC-X; demonstrated turnaround maneuver; aeroshell cracked during 14 ft/sec landing
DC-XA Test Flights				
1	May 18, 1996	62	244/801	First flight of DC-XA; aeroshell caught fire during slow landing
2	June 7, 1996	63.6	590/1,936	Maximum structural stresses with 50 percent full LOX tank
3	June 8, 1996	142	3,14010,302	26-hour rapid turnaround demonstration; new altitude and duration record
4	July 31, 1996	140	1,250/4,101	Landing strut 2 failed to extend; vehicle tipped over and LOX tank exploded; vehicle destroyed

[a] "The Delta Clipper Experimental: Flight Testing Archive," *http://www.hq.nasa.gov/office/pao/History/x-33/dcxfile.htm* (Web site created by Kirk Sorensen) (accessed March 22, 2005).

Table 2–94. X-34 Characteristics[a]

Component	Characteristics
Length	58.3 ft (17.8 m)
Wingspan	27.7 ft (8.4 m)
Weight unfueled	18,000 lb (8,165 kg)
Main propulsion	One NASA (Marshall Space Flight Center)-designed Fastrac engine
Propellant	LOX/RP-1
Propellant weight	30,000 lb (13,600 kg)
Thrust	60,000 lb (27,216 kg)
Nominal burn time	154 sec (without throttling)
Maximum speed	Mach 8
Maximum altitude	Approximately 50 miles (80 km)
Prime contractor	Orbital Sciences Corporation

[a] "X-34 Demonstrating Reusable Launch Vehicle Technologies," Historical Fact Sheet, NASA Marshall Space Flight Center, *http://www.nasa.gov/centers/marshall/news/background/facts/x-34.html* (accessed March 22, 2005).

Table 2–95. X-33 Characteristics[a]

Component	Characteristics
Length	69 ft (21 m)
Width	77 ft (23.5 m)
Takeoff weight	285,000 lb (129,274 kg)
Propellant	LH_2/LOX
Fuel weight	210,000 lb (95,254 kg)
Main propulsion	Two J-2S linear aerospike engines
Take-off thrust	410,000 lb (185,973 kg)
Maximum speed	Mach 13+
Contractors	Lockheed Martin (prime) Rocketdyne (engines) Rohr (thermal protection systems) Allied Signal (subsystems) Sverdrup (ground support equipment)

[a] "X-33 Advanced Technology Demonstrator," Historical Fact Sheet, Marshall Space Flight Center, *http://www.nasa.gov/centers/marshall/news/background/facts/x33.html* (accessed March 22, 2005).

Table 2–96. Reusable Launch Vehicle Chronology[a]

Date	Event
1990	Ballistic Missile Defense Organization initiated DC-X program.
August 1991	McDonnell Douglas won a $60 million contract to build the DC-X.
August 18, 1993	Flight tests of DC-X were begun.
January 1994	NASA's Access to Space study released. The study recommended that development of an advanced technology, single-stage-to-orbit, fully reusable rocket launch vehicle become a NASA goal.
February 1994	NASA released a series of NASA Research Announcements to industry for RLV component technology. This program laid the groundwork for technologies to be demonstrated during the X-33 flight program.
May 31, 1994	NASA identified $1 million for the DC-XA test program in addition to $990,000 dollars transferred to the DC-X program earlier in 1994. Enabled acceptance of DC-X vehicle from the Air Force.
June 20, 1994	First flight of DC-X under second phase of program took place.
June 27, 1994	DC-X test demonstrated the vehicle's autoland capabilities.
July 1994	Eighteen cooperative agreements were signed with industry in the areas of structures, thermal protection, and advanced propulsion.
August 5, 1994	President William J. Clinton issued National Space Transportation Policy (NSTC-4) for the RLV Technology program. It called for NASA to formulate an implementation plan by October 5, 1994 for Administration review.
October 31, 1994	NASA's FY 1995 Operating Plan established a new Space Access and Technology Program and funded the RLV program at $93.5 million.
November 7, 1994	The Administration approved the NASA Implementation Plan for the President's National Space Transportation Policy. The plan accelerated the X-33 schedule and called for NASA to select an X-33 technology demonstrator by July 1996.
January 12, 1995	NASA issued two Cooperative Agreement Notices requesting proposals for the development of technology demonstrators for an RLV program.
March 1995	NASA and Orbital Sciences Corporation signed a cooperative agreement for the X-34.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
March 29, 1995	NASA signed three cooperative Phase I agreements to design the X-33, the next generation space booster. Agreements were signed with Lockheed Advanced Development Company (Skunk Works), McDonnell Douglas Aerospace, and Rockwell International Corporation. NASA provided approximately $7 million to each industry partner, with each investing a matching sum.
May 16, 1995	DC-X test flights were begun in support of NASA's RLV program.
July 7, 1995	Last test flight of DC-X took place. The aeroshell cracked during landing. The vehicle was turned over to NASA and sent to McDonnell Douglas for modifications to the DC-XA.
December 15, 1995	NASA issued a draft Cooperative Agreement Notice for the design, fabrication, and flight test of the X-33 advanced technology demonstrator.
March 1996	The President's FY 1997 budget highlighted that the RLV was a science and technology investment. The RLV was cited as a way to significantly cut the cost of reaching space.
March 1996	NASA issued a new NASA Research Announcement for the X-34.
April 1, 1996	NASA issued a Cooperative Agreement Notice for demonstration of single-stage-to-orbit (SSTO) technologies through the design, fabrication, and flight test of an X-33 advanced technology demonstrator.
May 8, 1996	The DC-XA completed a series of ground tests at the U.S. Army White Sands Missile Range in preparation for flight tests.
May 18, 1996	The DC-XA began a new set of test flights.
June 1996	NASA awarded a contract valued at approximately $50 million to Orbital Sciences Corporation for the X-34.
June 14, 1996	A full-scale segment of a graphite-composite wing designed for an RLV was successfully "tested to failure" at Langley Research Center. This was the first structural test of a full-scale component designed and fabricated to validate the use of graphite-composite primary structures for RLVs. The purpose of the test was to determine the maximum load the wing-box could carry as well as to understand how it would fail.
July 2, 1996	Vice President Al Gore announced at the Jet Propulsion Laboratory in Pasadena, California, that Lockheed Martin had been selected to build the X-33 test vehicle, called VentureStar. Lockheed Martin won the competition for the X-33 Phase II contract over contenders McDonnell Douglas and Rockwell International.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
July 31, 1996	A landing strut on the DC-XA failed to extend. The vehicle tipped over and exploded due to an open pressurant line. The vehicle was destroyed.
October 1, 1996	NASA filed Notice of Intent 96-118 with the Federal Register of its intention to prepare an environmental impact statement (EIS) and to conduct scoping meetings for the development and testing of the X-33 vehicle. The EIS addressed environmental issues associated with fabrication, assembly, testing, and preparation of the flight operations and landing sites associated with the X-33 flight vehicle.
November 13, 1996	Gary Payton, NASA's Director of Space Transportation, and T. K. Mattingly, Vice President for Lockheed Martin's RLV Program, held an informal meeting to discuss the program status and answer questions on the X-33, which was undergoing its Preliminary Design Review that week in California to formalize the engineering baseline of the X-33 vehicle before moving on to the detailed design phase.
November 1, 1996	Langley Research Center conducted thermal-mechanical tests toward the development of a durable, lightweight, cryogenic insulation system for possible use on future RLVs.
December 18, 1996	A three-day Preliminary Design Review (PDR) was completed for the X-33 operations segment and ground systems segment. Individual PDRs already had been conducted on the aerospike engine, the hydrogen tank, the structure, and most subsystems.
January 21, 1997	Langley Research Center issued a press release about X-33 wind tunnel testing during Phase I in the 22-Inch Mach 20 Helium Tunnel at Langley.
January 23, 1997	NASA held a public meeting in Idaho Falls, Idaho, to gather public comment on its plan to conduct flight tests of the X-33. The meeting was part of NASA's EIS process in support of the X-33 program. The formal process had begun on October 7, 1996, after NASA published a Notice of Intent 96-118 in the Federal Register. The Idaho Falls meeting was the 12th NASA public meeting to discuss the potential environmental impact of the X-33 test flights. Earlier meetings were held in towns neighboring proposed takeoff and landing sites in Southern California, Utah, Washington, and Montana.
February 20, 1997	A 7.75 percent scale model of the X-33 completed two weeks of wind tunnel tests in the 5.1-meter transonic wind tunnel at the Air Force’s Arnold Engineering Development Center at Arnold Air Force Base, Tullahoma, Tennessee, according to Space Log, March 10 to March 16, 1997.
March 1997	An aluminum and stainless steel model of the X-33 was tested in Langley’s Low-Turbulence Pressure Tunnel.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
March 6, 1997	NASA announced that surveying was underway at Edwards Air Force Base, California, in preparation for the construction of the X-33 launch site. Sverdrup Corporation, the X-33 team's launch facility contractor, was undertaking the surveying of the launch site at Haystack Butte. Construction of the launch pad and facilities was expected to be completed by September 9, 1998. Launch facility activation, which included verification of the launch pad fueling system, was scheduled to be completed by October 1, 1998.
April 10, 1997	NASA announced that an aluminum and stainless steel scale model of the X-33–about 38 cm (15 in) long by 38 cm (15 in) wide–was undergoing extensive wind tunnel testing at Langley’s 16-Foot Transonic Tunnel through mid-April 1997.
April 16, 1997	Continuing wind tunnel testing was carried out at Marshall Space Flight Center to correct an X-33 control deficiency at low supersonic speeds (Mach 1 to Mach 2). Adding canards appeared to be the only viable solution to date.
April 30, 1997	Marshall Space Flight Center announced that, it had conducted hot-fire tests of components for the X-33 linear aerospike engine in its Propulsion Laboratory’s East Test Area. The test apparatus consisted of three hydrogen-cooled thrust cells constructed to represent a section of the X-33 engine, which was to have two banks of 10 side-by-side thrusters. Test results were to be reviewed with Rocketdyne, which built the test thrust cells and was to build the X-33 aerospike engine.
Mid-April–May 1997	Wind tunnel testing of a scale model X-33 in the Langley’s Research Center's Unitary Wind Tunnel at supersonic speeds ranging from Mach 1.5 to Mach 4.5 continued from mid-April to early May. Wind tunnel testing also continued through May at Marshall Space Flight Center.
May 1997	A “tiger team” was working full-time on reducing the dry weight (without fuel) of the X-33 by 5,000 lb (2,268 kg) to 6,000 lb (2,722 kg). The team sorted through more than 400 recommendations of ways to reduce the weight.
May 21, 1997	The “tiger team” working on the X-33 weight problem gave a presentation. Weight reduction recommendations were ranked according to minor, medium, or major cost and schedule impacts. The team indicated that weight could be reduced by about 8,000 lb (3,629 kg) to 11,000 lb (4,990 kg), but the X-33 project costs and schedule would be affected.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
June 1997	Additional wind tunnel testing of X-33 models took place in Langley's Hypersonic Facilities Complex. Also, X-33 wind tunnel testing started in Langley's 14-by-22-Foot Subsonic Tunnel in mid-June.
June 24, 1997	Aerospace Daily reported that "typical development problems" had led to postponement of the first X-33 test flight from March 1999 to July 1999, and slippage of the Critical Design Review (CDR) from September to an unspecified time in the fall. A critical problem behind the postponement was fabrication of the liquid-hydrogen fuel tank. In addition, Aerospace Daily reported that the Lockheed Martin Skunk Works had consolidated X-33 project management at Palmdale, California, and Jerry Rising had been named Vice President for X-33 and RLVs. Rising replaced T.K. Mattingly, who transferred to Lockheed Martin's aeronautical division at corporate headquarters in Bethesda, Maryland.
June 27, 1997	NASA released the draft EIS.
July 1997	In mid-July, wind tunnel testing of X-33 models in Langley's 14-by-22-Foot Subsonic Tunnel was concluded.
July 3, 1997	Aerospace Daily reported on X-33 progress, based on an interview with Lockheed Martin X-33 Vice President Jerry Rising. The Skunk Works was considering use of a colder, denser cryogenic propellant and had dropped plans to add canards for vehicle stability in the low transonic range (Mach 1 and Mach 2) in favor of changes in the tail structure. Weight growth was under attack by a special "tiger team."
August 1997	A critical series of tests on the X-34 Fastrac engine was successfully completed at Marshall Space Flight Center.
August 26, 1997	The Linear Aerospike SR-71 Experiment was mounted on a NASA SR-71 aircraft at Dryden Flight Research Center, Edwards, California, in preparation for the experiment's first flight, then scheduled for September.
August 26, 1997	Aerospace Daily reported that a gas generator adapted for the X-33 aerospike engine from a J-2 Saturn rocket engine had undergone 14 hot-fire tests at Marshall Space Flight Center.
August 28, 1997	Langley Research Center conducted load tests of a full-scale segment of a composite intertank structure for the X-33 program.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
September 11, 1997	Aerospace Daily reported on X-33 progress. Five of eight 100-lb (45.4 kg) liquid hydrogen tank panels had been fabricated by Alliant Techsystems in a Utah plant, and tests of the composite seams were proceeding without any surprises. The liquid oxygen tank had been welded together. Removing the turbo alternator removed a "big hunk" of vehicle weight. Cooling the liquid oxygen and hydrogen propellants to temperatures lower than normal cut overall vehicle weight further and allowed the X-33 to carry additional fuel.
September 18, 1997	A two-day CDR of the X-33 thermal protection system by Rohr at its Chula Vista, California, facility ended
September 24, 1997	The two-day CDR of the X-33 aerospike engine (known also as the XRS-2200 engine) ended. The CDR took place at Rocketdyne's DeSoto campus in Chatsworth, California, where the X-33 engines were being designed.
September 26, 1997	NASA released the Final EIS for the X-33 and named the preferred flight testing launch and landing sites.
October 31, 1997	NASA announced that the X-33 had completed the five-day vehicle CDR successful, a major event in X-33 evolution. With completion of the CDR, NASA gave the Lockheed Martin Skunk Works approval to proceed with the fabrication of all remaining components and the assembly of the flight vehicle. The package of CDR technical information contained roughly 2,750 charts in 11 volumes.
October 31, 1997	The first successful flight of the Linear Aerospike SR-71 Experiment (LASRE) at Dryden Flight Research Center took place.
November 4, 1997	NASA completed its Record of Decision on the X-33 EIS and announced an intention to proceed with the preferred X-33 flight test program as described in the Final EIS issued October 3, 1997.
November 14, 1997	Groundbreaking ceremony took place at the future X-33 launch site on Edwards Air Force Base.
January 1998	NASA decided to modify its contract with Orbital Sciences Corporation to provide for a second X-34 flight vehicle. The modification also allowed for additional unpowered tests and more flexibility in demonstrating various technologies.
January 1, 1998	A faulty control system in the X-33 construction hangar set off water canons intended to fight fires. A crew of about a dozen worked on New Year's Eve to dry out the X-33 construction area. No permanent damage resulted, and work continued as usual.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
January 14, 1998	Construction of the X-33 launch site at Haystack Butte progressed. Sverdrup completed rough grading of the launch site. The new road to the launch site was drivable but, like the site, was still at subgrade level.
January 21, 1998	Sverdrup completed rough grading of the X-33 launch site.
February 11, 1998	The first major X-33 component, the liquid oxygen tank, was delivered to the Palmdale, California, hangar where construction of the vehicle was taking place. An Airbus A300-600ST made the delivery.
February 12, 1998	The ground cold flow test of the LASRE was performed. This test included one normal cold flow and one emergency systems cold flow. The emergency systems cold flow tested the effects of control system power loss during flight. The liquid oxygen tank pressurized normally during the first (normal cold flow) test, validating the repair made to the vent system. The emergency test appeared to have been successful. A data review was scheduled for February 18, 1998.
February 25, 1998	A routine X-33 quarterly review took place at Marshall Space Flight Center. Presentations surveyed current progress.
February 25, 1998	Launch site construction continued to progress as all Edwards Air Force Base infrastructure (roads, power, water, and communications) was extended to the site.
March 4, 1998	A NASA SR-71 completed its first cold flow flight as part of the LASRE at Dryden Flight Research Center, Edwards, California.
March 11–March 12, 1998	The NASA Independent Annual Review of the X-33 program took place. X-33 technical and cost performance was surveyed. A final report detailing findings and conclusions was to be briefed to the NASA Program Management Council on April 15, 1998. The review indicated that Lockheed Martin's Skunk Works had addressed many of the concerns that arose during the September 1997 Independent Annual Review. NASA's Gary Payton and Gene Austin were pleased with the review results.
March 20, 1998	During a project review held at the Rocketdyne facility in Canoga Park, California, Rocketdyne made known certain schedule hazards that had developed with two of their suppliers, Weldmac and CFI. It was reported that, in the worst case, aerospike engine deliveries might slip three to five months. Rocketdyne was looking into their suppliers' difficulties to mitigate risk to the program schedule.
April 8, 1998	With the exception of some fastener shortages, the center thrust structure of the X-33 vehicle was now complete.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
April 19, 1998	The liquid oxygen tank was moved into the main assembly fixture. The move took less than an hour and was completed two days ahead of schedule.
May 18, 1998	NASA's F-15B Aerodynamic Flight Facility fighter aircraft, based at Dryden Flight Research Center, flight-tested thermal protection materials intended for use on the X-33 to determine the durability of the materials, specifically measuring the shear and shock loads to which the materials were exposed. The materials tested included metallic Inconel tiles, soft Advanced Flexible Reusable Surface Isolation tiles, and sealing materials.
June 8, 1998	Aerospace Daily reported that "Lockheed Martin was carrying a 'three-month hazard' on the linear aerospike engine it will need to power the X-33 testbed next summer, but Rocketdyne had developed workarounds and fixes to get the engine back on track," cited Jerry Rising, Lockheed Martin Program Manager.
June 8, 1998	Aerospace Daily reported that leakage into the structure of the subscale aerospike mounted on NASA's SR-71 Blackbird had delayed the first hot-fire test of the engine "a few weeks."
June 8, 1998	Aerospace Daily reported that X-33 Program Manager Jerry Rising and X-34 Program Manager Bob Lindberg threatened to not allow their X vehicles to fly unless Congress passed indemnification legislation protecting them against third-party liability in case of an accident during flight testing.
June 10, 1998	NASA announced that pictures of the X-33 vehicle and launch site, taken every 15 minutes from three digital cameras, would be posted on an Internet site. The images from two cameras would show the vehicle's primary assembly structure, the side-by-side tooling structures for the X-33's upper thermal protection system, and the vehicle's upper internal support structure, while the third camera would focus on the vehicle's launch pad. The vehicle images would not be current, delayed one day.
June 30, 1998	NASA announced completion of the F-15B flight testing of thermal protection materials for the X-33 at Dryden Flight Research Center, Edwards, California. The six flights tested the durability of the materials at hypersonic velocities. The F-15B reached an altitude of 36,000 ft (10,973 M) and a top speed of Mach 1.4. The material samples tested included metallic Inconel tiles, soft Advanced Flexible Reusable Surface Insulation tiles, and sealing materials.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
July 1998	The X-34 program passed a critical milestone as the first wing assembly completed qualification tests and was shipped to Orbital Sciences Corporation and mated to the X-34 test article under construction.
July 6, 1998	Aerospace Daily, in an article titled "Wagons Ho!" reported that the Lockheed Martin Skunk Works had abandoned flying the X-33 back to its launch pad at Edwards Air Force Base in favor of trucking the experimental aircraft overland, "because the Shuttle program won't give up one of its two Boeing 747s for ferry flights."
July 22, 1998	Difficulties with fabricating the X-33 liquid hydrogen tanks continued. As a result, delivery dates for the two tanks slipped from July 31 and September 2 to mid-October and mid-November, respectively. The impact of these delays on vehicle assembly was still being assessed.
July 29, 1998	Aerojet recommended to NASA and Lockheed Martin that they use a thruster configuration that included a nozzle made of columbium to correct for the thermal problems that had caused nozzles to burn through in earlier tests. Using columbium nozzle parts would not increase the X-33's net weight; however, preparing the parts would require a long lead time. To minimize schedule impact, Aerojet proposed delivering the thrusters without nozzles to allow continuation of vehicle assembly and supplying the columbium nozzles at a later date.
August 5, 1998	The X-33 System Architecture Review (SAR) and Optimized Design Review (ODR) were held in Palmdale with representatives from each Skunk Works partner, NASA, and the "Gray Beards" attending. The "Gray Beards" panel of experts was composed mainly of NASA senior personnel led by Del Freeman of Langley Research Center.
August 26, 1998	AlliedSignal delivered the X-33 nose landing gear strut. It was to be modified into the X-33 configuration for a test fit. This same test fit already had been accomplished for the main trunion pivots and the drag link attachments without any problems.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
September 2, 1998	Spence M. (Sam) Armstrong, recently named NASA Associate Administrator for the Office of Aeronautics and Space Transportation Technology (Code R), revealed a reorganization during a staff briefing that would dilute the responsibilities of Gary Payton, who, as Deputy Associate Administrator for Space Transportation Technology, currently headed the X-33, X-34, and advanced space transportation programs, moving him more into the aeronautics half of the Office. Payton would occupy a lower position, Division Director, under the proposed reorganization, which was scheduled to take place on October 1. Payton had championed single-stage-to-orbit vehicles for many years. The change seriously jeopardized the status of the program within the NASA hierarchy.
September 11, 1998	Aerospace Daily reported that the pending reorganization of NASA's Office of Aeronautics and Space Transportation Technology "raised the hackles" of Rep. Dana Rohrabacher of California, a long-time champion of single-stage-to-orbit technology and chairman of the NASA authorization subcommittee. Rohrabacher expressed his concerns in a letter to NASA Administrator Daniel Goldin.
September 23, 1998	A nine-panel thermal protection system array was test-fitted on the bottom of the X-33 during the previous week by a joint team of B.F. Goodrich and Skunk Works technicians. The metallic panels were equipped with the new secondary seal designs. One panel also was removed from the center of the array to prove that any panel could be replaced.
September 27, 1998	Continuing difficulties with fabrication of the two liquid hydrogen tanks were experienced. A cure cycle was lost during the first doubler installation process on tank #2. The tank was removed early from the cure cycle after blowing a bag at the end of a ramp-up point. The combination of the out time and this cure cycle resulted in an unacceptable strength impact to the bond joints. The doublers were removed over the weekend (September 26–27) and could be replaced with existing materials. Loss of the cure cycle delayed fabrication of tank #2 by 30 days. Construction of the vehicle structure and electronics continued.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
October 2, 1998	The X-33 engine testing program began. At 12:13 a.m. Central Time, the first successful aerospike engine-related test took place at Stennis Space Center. The test intended to calibrate the liquid hydrogen and liquid oxygen fuel turbopumps, check facility settings, and verify valve timing to prime the gas generator. The test lasted 2.81 seconds, and no flaws or anomalies were detected. The tested powerpack hardware consisted of the main power-generating and pumping components of the aerospike engine, including the liquid oxygen and liquid hydrogen turbopumps, a gas generator for the turbopump drive, vehicle connect lines, and interconnecting flight ducts. These powerpack tests were critical to the development of the linear aerospike engine because they allowed various performance levels to be tested in parallel with the design and construction of the engine. Full-scale engine tests were scheduled to take place at Stennis Space Center in late 1998.
October 7, 1998	B.F. Goodrich completed the last major testing of the metallic panels for the X-33 thermal protection system at Marshall Space Flight Center.
October 14, 1998	NASA announced the reorganization of NASA's Code R—the Office of Aeronautics and Space Transportation Technology—under Associate Administrator Spence M. Armstrong, to the Office of Aero-Space Technology. In the NASA press release, it was reported that Armstrong stated that "Goldin wanted me to personally be an advocate for the Reusable Launch Vehicle programs to effect a cheaper means of access to space." The press release did not mention Gary Payton's changed role within Code R or on the X-33 program.
October 14, 1998	Boeing presented its estimate to complete engine delivery. Boeing's plan transferred $36 million from the VentureStar RLV to the half-scale X-33 by eliminating the fabrication, assembly, and testing of the RLV power pack. By adding a second engine test stand in Phase III (the program is presently in Phase II), Boeing developed a schedule that would support a first flight of the VentureStar within six months of the Skunk Works schedule. In addition, Boeing declined additional investment in the project. The $36 million transferred from the VentureStar to the X-33 was the same amount as the additional X-33 costs caused by Boeing's delay in delivering the aerospike engine.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
October 21, 1998	The first two upper thermal protection system panels arrived at the hangar from B.F. Goodrich's Riverside plant. They were to be test fitted on the forward-most position of the liquid oxygen tank. Repair patches for liquid hydrogen tank #1 had been completed and shipped, while work continued on the second tank.
October 23, 1998	NASA announced that it and Lockheed Martin would hold a media teleconference on Tuesday, October 27, with program officials Gary Payton, NASA Deputy Associate Administrator for Space Transportation Technology, NASA Headquarters; Gene Austin, NASA X-33 Program Manager; Jerry Rising, Lockheed Martin Skunk Works Vice President for the X-33 and VentureStar; and Cleon Lacefield, Lockheed Martin Skunk Works X-33 Program Manager. A similar teleconference took place the previous October to update the media on the status of the program following the CDR. This teleconference was expected to announce a six-month delay in the X-33 flight tests.
October 27, 1998	In a joint NASA and Lockheed Martin media teleconference, Jerry Rising announced that the first flight of the X-33 would be delayed six months until December 1999 because of late delivery of the aerospike engine in September 1999. This delay in engine delivery would cost an additional $36 million. Lockheed Martin expected Rocketdyne to absorb the additional cost. Lockheed Martin had cut all overtime on the program and planned to cut project personnel to reduce escalating costs.
October 28, 1998	The two leeward #1 composite panels were delivered to the hangar for a fit check on the vehicle. The two leeward #2 panels were to be shipped on November 1 for a fit check. Once the panel fit checks were made, all composite panels would be shipped back to B.F. Goodrich's Riverside plant for completion. Also, a successful cure cycle on liquid hydrogen tank #2 was accomplished October 24–25. As a result, all lobe skins were bonded on both tanks.
November 6, 1998	NASA released the Hawthorne Report, named after the Boston firm, Hawthorne, Krauss, and Associates, LLC.[b] The firm conducted a study titled "Analysis of Potential Alternatives to Reduce NASA's Cost of Human Access to Space." NASA intended to use the Hawthorne Report and the Space Transportation Architecture Study currently under way as guides for planning future space launchers. The Hawthorne report strongly supported the economics of commercial RLVs over continued use of the Space Shuttle. Hawthorne also urged NASA to exercise caution in setting up loan guarantees to support development of commercial RLVs.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
November 11, 1998	The X-33's electronics achieved an important milestone when Sanders shipped two Vehicle Health Monitoring computers to the Skunk Works. Also, the Skunk Works identified a potential winner of the contract to transport the X-33 over land.
November 13, 1998	A test of the aerospike engine power pack took place at 100 percent power over a period of 30 seconds during the week ending November 13. A 250-second test was planned for the following week.
November 18, 1998	Work began on the ballast bulkhead assembly. Faced with a continually slipping schedule at the Sunnyvale plant, subcontractor Alliant and the Lockheed Martin Skunk Works formulated a plan to speed up work. Shift schedules were changed to double manpower.
November 20, 1998	The announcement was made that NASA and Lockheed Martin had terminated the LASRE. The LASRE sought to obtain data on the aerospike engine intended for use on the X-33 and VentureStar by mounting half of a scale-model aerospike engine on the back of an SR-71 aircraft and studying the effects of gas flow. The modified SR-71 carried out seven LASRE test flights. Those flights, however, tested only cold flow gas conditions; all hot flow experiments were now cancelled. Two flights collected aerodynamic data on the combination of the aerospike engine with the SR-71 aircraft. In two other flights, gaseous helium and liquid nitrogen were cycled through the test rig to test its plumbing and, in three more flights, liquid oxygen flowed through the system. The two hot-fire test flights planned to validate computer models of aerospike performance in flight were now cancelled. The LASRE had been repeatedly delayed by hardware and other problems. Cancellation of the LASRE allowed any remaining funds to be used by the Skunk Works to cover X-33 cost overruns.
November 24, 1998	In its December 2, 1998, issue, Aerospace Daily reported that on November 24, 1998, Boeing's Rocketdyne Division completed the first four tests of its XRS-2200 linear aerospike engine at Stennis Space Center. In these tests, the engine's turbomachinery and gas generator were run at full power and then throttled back to 57 percent power.
December 1998	Construction of the X-33 Flight Operations Center was completed a little more than 12 months after groundbreaking. The center was located on the eastern portion of Edwards Air Force Base.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
December 2, 1998	Aerospace Daily reported that NASA's Office of Inspector General, in an audit titled "X-33 Funding Issues" (IG-99-001), found that Marshall Space Flight Center allowed $56 million in year-end obligations for the X-33 to go unrecorded in FYs 1996 and 1997, thereby giving Congress an inaccurate picture of the program's status at the end of those two years. The Inspector General reported that Marshall contract officers had established an arrangement with Lockheed Martin to delay billing for completed X-33 work until the following fiscal year. In FY 1996, that amounted to $22 million, and in FY 1997, to $34 million. The Inspector General maintained that obligations "should be recorded not later than NASA's acceptance of the completed milestone work" and recommended that NASA adjust its financial records to reveal the X-33 program's financial status "fully and accurately," and that NASA review the funding and payment practices used on the X-33 program to ensure that they met the requirements of the Antideficiency Act and internal controls.
December 4, 1998	Senior NASA staff, Boeing representatives, and X-33 project personnel from Boeing, Rocketdyne, and Lockheed Martin attended a meeting at Lockheed Martin's corporate headquarters in Bethesda, Maryland, to discuss development of the X-33 aerospike engine. At the meeting, Boeing proposed to downsize the ground portion of the propulsion demonstration program to use the resulting savings to fund X-33 engine cost overruns. Three teams were formed to evaluate Boeing's proposal and to assess opportunities that NASA Centers might have to mitigate the impact on technology development. The results of these independent team assessments were to be reviewed in mid-January.
December 16, 1998	Construction of the X-33 continued. Both liquid hydrogen tanks completed cures. Two gaseous oxygen tanks and two methane tanks belonging to the auxiliary propellant system were installed on the liquid oxygen tank. The thrust structure was nearly complete. Some clearance issues had emerged during installation of the nose gear support structure. Power pack assembly No. 2 was completed and sent to Stennis Space Center for testing, while power pack assembly No. 1 was still having problems. Construction of the X-33 launch site continued. The four vehicle hold-down posts were installed onto the rotating launch mount. The diesel generator for the site's electrical supply was run for the first time. The Vehicle Positioning System was unpacked and set up for testing. Sanders completed delivery of the Operations Control Center hardware. The X-33 launch site was now complete.

Table 2–96. Reusable Launch Vehicle Chronology[a] (Continued)

Date	Event
December 18, 1998	NASA exercised an option with Orbital Sciences for 25 additional test flights during a 12-month period beginning immediately after completion of the initial contract. The option was valued at more than $10 million, with government organizations performing an additional $4.7 million in work.
March 2001	The X-33 and X-34 programs were cancelled.

[a] Material in this table relating to the X-33 for the years 1996–1998 is drawn largely from Andrew Butrica, "Key X-33 Events," *http://www.hq.nasa.gov/office/pao/History/x-33/1998.htm.* (accessed March 15, 2005).

[b] Hawthorne, Krauss & Associates, LLC, "Analysis of Potential Alternatives to Reduce NASA's Cost of Human Access to Space," September 30, 1998, ftp://ftp.hq.nasa.gov/pub/pao/reports/1998/Hawrep.pdf (accessed May 18, 2005).