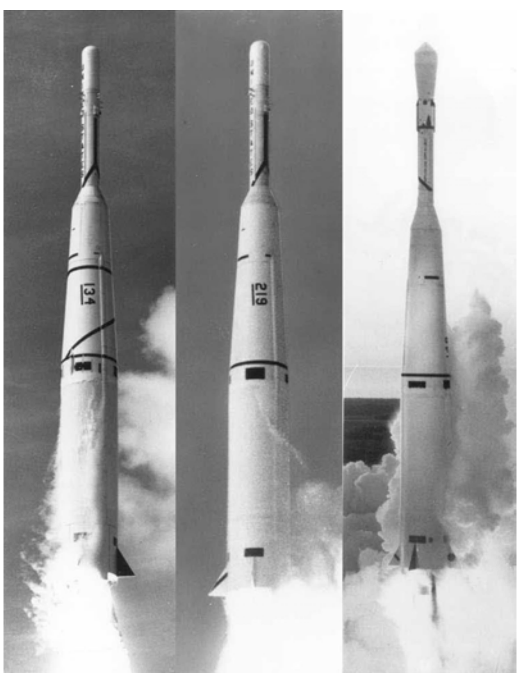
CHAPTER IV: LAUNCH VEHICLES

Thor and Atlas Derivatives

The earliest launch vehicles used by the Air Force were Thor and Atlas missiles modified by the Air Force Ballistic Missile Division and Space Systems Division to serve as space boosters. Indeed, the Air Force achieved its first partial success in space with a lunar probe that was launched by a Thor missile with a Vanguard second stage, a configuration called the Thor Able, on 11 October 1958.[6] Its first satellite was Project SCORE, an Atlas B developmental missile containing a communications repeater in one of its side equipment pods. AFBMD launched the entire missile (minus the spent half stage) into orbit on 18 December 1958. Thor and Atlas missiles with only minor modifications continued to be used as space boosters for a long time, especially for military and civilian weather satellites. The last Thor launch occurred on 15 July 1980, and the last launch of a modified Atlas missile occurred on 24 March 1995, with both boosters carrying military weather satellites. As time went by, Thor and Atlas vehicles were improved and standardized, and families of Standard Launch Vehicles were created. The Thor gave rise to the series known as Standard Launch Vehicle 2, and the Atlas gave birth to the several varieties of Standard Launch Vehicle 3. Upper stages such as the Agena, the Burner II, and the Stage Vehicle System were developed for use with these vehicles. Together with their associated upper stages, Thor and Atlas launch vehicles constituted the backbone of the American space program.



At left are three early launches of Thor Able vehicles. Left to right: Explorer 6, launched 7 August 1959; Pioneer 5, launched 11 March 1960; Tiros 1,launched 1 April 1960. At right is Atlas 10B, the launch vehicle and satellite vehicle for Project SCORE, awaiting launch on 18 December 1958.

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[6] AFBMD launched three lunar probes in 1958 using Thor Able vehicles, only one of which was considered a partial success. See the section entitled Pioneer Lunar Probes in Chapter VII of this history.

Top: Agena A spacecraft 1056 for Discoverer XIV is being integrated with Thor 237 before launch on 18 August 1960. Bottom left: The first Thor Agena launch vehicle sits on the pad at Vandenberg AFB before launching Discoverer I on 28 February 1959. Bottom right: The first Atlas Agena combination rises from the pad at Cape Canaveral in an unsuccessful attempt to launch MIDAS I on 26 February 1960.

The launch vehicles developed by the Air Force Ballistic Missile Division and its successors were used not only by the Air Force, but also by the National Aeronautics and Space Administration (NASA), created in 1958. Civilian programs began using boosters based on the Thor missile immediately, and in 1959, NASA began developing the Delta upper stage for it from the second stage of the Thor Able—the first step in developing the highly successful Delta launch vehicle. NASA started using the Atlas vehicle in 1959, and its first manned space program, Project Mercury, relied on the Atlas for its orbital flights. Project Gemini, the agency's next manned program, employed Titan II boosters developed and procured by Space Systems Division. The Gemini Target Vehicle, an

Agena upper stage, was also developed by Space Systems Division (SSD). The Agena was later modified by NASA and employed extensively by both agencies. The Centaur upper stage, the most powerful upper stage in the national inventory, was born as an Air Force program before being transferred to NASA in 1960. It is noteworthy that much of this cooperation in developing and using launch vehicles was the result of a carefully considered series of written agreements, initiated in 1959 and expanded during the early 1960s, which made up a National Launch Vehicle Program.

Left: The first Atlas Centaur combination rises briefly from the launch complex at Cape Canaveral on 8 May 1962. The Centaur exploded 55 seconds later.
Below: The first Centaur upper stage is unloaded after air transport to Cape Canaveral on 25 October 1961.

Left: A Titan II launch vehicle developed by Space Systems Division from the Titan II missile launches a manned Gemini capsule from Cape Canaveral. The Gemini missions took place during 1965-1966. Because they launched astronauts, these Titan IIs had to be "man-rated," meaning that they had to be made as safe as possible by adding redundant systems wherever that could be accomplished, by thoroughly inspecting for errors, and by giving the manufacturers incentives to build launch vehicles that were free of defects. After they were in orbit, the manned Gemini capsules accomplished rendezvous and docking with unmanned Agena Target Vehicles, also developed by Space Systems Division, perfecting techniques that would be used later in the Apollo program.

Titan III

Thor and Atlas boosters were complemented by the Titan III, a powerful booster capable of launching large, heavy payloads. Development of the Titan III was initiated in late 1961, and the first research and development vehicle was flown on 1 September 1964. This vehicle, a Titan IIIA, consisted of a modified Titan II core topped by an upper stage called the Transtage. A new configuration, the Titan IIIC, was successfully launched from Cape Canaveral on 18 June 1965. The IIIC used two strap-on solid rocket motors that generated around one million pounds of thrust each. From 1965 through 1989, Titan III vehicles performed well in a wide variety of missions and configurations. The family expanded to include the Titan IIIB Agena D, the Titan IIID, and the Titan IIIE Centaur, which was used by NASA for space projects such as the Viking missions to Mars. The final variety of Titan III, the Titan III (34)D, was used during the 1980s as a backup and alternative to the manned Space Shuttle. The last 34D was launched on 4 September 1989.

Left: A Titan IIIC launches seven satellites for the Initial Defense Communications Satellite Program and one experimental satellite on 16 June 1966. Right: A Titan 34D rises from the pad at Cape Canaveral.

Space Transportation System

During the 1970s, NASA developed a Space Transportation System employing a manned, reusable Space Shuttle to replace most expendable launch vehicles. In addition to monitoring the development of the Shuttle to ensure that it would satisfy DOD's requirements, SAMSO contributed several important elements to allow DOD to make full use of the system. It developed and almost completed a launch and landing site at Vandenberg AFB to allow the Shuttle to be launched into polar orbits. It also developed the Inertial Upper Stage (IUS), an upper stage for large Shuttle payloads requiring higher orbits. The IUS was adapted for use with the Titan III and, later, the Titan IV expendable system as well. Although it had a troubled and costly developmental period, the IUS came to be considered an accurate and reliable launch system.

Left: The Space Shuttle's test orbiter ***Enterprise*** *is used for a fit check at SLC-6, the almost completed STS launch facility at Vandenberg AFB, in November 1984.*
Right: IUS-1 enters thermal vacuum testing at Boeing's Seattle facility in May 1982. It launched NASA's TDRSS-A satellite from the Space Shuttle on 4 April 1983.

On 28 January 1986, a Space Shuttle exploded during launch, killing the crew of the orbiter *Challenger*. NASA was forced to suspend all Shuttle launches while it investigated the cause of the explosion and assessed its implications. Military payloads as well as civilian payloads scheduled for the Shuttle had to obtain launches on expendable boosters or wait. Shuttle flights did not resume until 29 September 1988. The disaster had further implications for SSD. Development of the Shuttle facilities at Vandenberg ended after the disaster because of deficiencies in the design of the launch pad and because of national policy changes in favor of returning to expendable launch vehicles for national security missions.

Although eventually the Air Force was able to shift some of its most critical payloads to Titan vehicles, the Titan program happened to be suffering from launch failures of its own when the *Challenger* disaster occurred. After consecutive launches of Titan 34Ds failed on 28 August 1985 and 18 April 1986, further launches were suspended while the causes were investigated. They resumed on 26 October 1987, restoring the only available alternative to the Space Shuttle for large payloads.

Titan IV

The *Challenger* disaster gave added weight to the argument for having a variety of expendable launchers available so that failures in one type would not again affect so many payloads. Space Division had already begun the development of a larger, more capable Titan booster known as the Titan IV in 1985. Launched for the first time on 14 June 1989, the Titan IV could be used with either an IUS or a newly developed version of the Centaur upper stage. It was capable of placing 10,000 pounds into geosynchronous orbit using the Centaur. The Titan IV's performance would be considerably enhanced by upgraded solid rocket motors. Their development was delayed when the first qualification motor exploded during a test firing on 1 April 1991, but they successfully completed the final test firing on 12 September 1993. Vehicles without the upgraded motors were known as Titan IVAs, and those with the new motors were called Titan IVBs. For some smaller payloads, Space Division began converting the obsolete Titan II ballistic missiles that had been removed from their silos during 1982-1987.[7] They could place about 4,200 pounds into low-earth, polar orbit, and the first was launched on 5 September 1988.

Left: A Titan II launches the first DMSP Block 5D-3 satellite on 12 December 1999. Center: A Titan IVA on the launch complex at Cape Canaveral before launching the second Milstar satellite on 6 November 1995. Right: A Titan IVB launches a satellite for DOD in 1999. (Photographs courtesy of Lockheed Martin Corporation)

Delta II, Atlas II, and Atlas III

During the suspension of Shuttle flights, Space Division began procuring two new medium launch vehicles—the Delta II and the Atlas II. Development and production of the Delta II, an improved version of the Delta launch vehicle, began in January 1987. It was procured primarily to launch the constellation of 24 operational Global Positioning System (GPS) satellites, and it launched the initial operational constellation without a single failure.[8] The Delta II was developed in two consecutive configurations. The first of these launched the first nine GPS satellites from 14 February 1989 to 1 October 1990, while the second, more powerful version launched the later, heavier GPS satellites from 26 November 1990 to 10 March 1994, completing the constellation. During this entire

[7] A total of 55 Titan II missiles were removed, but only 14 were finally converted to space launch vehicles.

[8] See note 30 below under Navigation Systems in Chapter V.

period, a Delta II successfully launched a GPS satellite about every two months, an accomplishment rarely equaled.[9] Delta IIs also launched other payloads, both military and commercial. On 12 August 1991, and again on 9 April 1993, SMC awarded contracts to Boeing for additional Delta II launch vehicles to replenish the GPS constellation, and they continued to launch replacement GPS satellites, suffering only one failure by early 2003.

Development and production of the Atlas II, an improved version of the Atlas/Centaur launch vehicle, began in June 1988. The Atlas II would be able to launch somewhat heavier payloads in the medium-weight class, and DOD intended it for Defense Satellite Communications System (DSCS) satellites as well as some experimental satellites. It was also used in many commercial launches. Lockheed Martin, the developer, launched the first commercial payload to use an Atlas II on 7 December 1991, and it launched the Air Force's first DSCS III satellite on 11 February 1992. In 1995, SMC began using a modification of the Atlas II known as the Atlas IIA, which employed a more powerful Centaur upper stage, and Lockheed Martin soon developed a further modification, the Atlas IIAS, which employed four strap-on solid rocket motors. The first military payload to use the Atlas IIAS was launched on 6 December 2000. By early 2003, about 15 military payloads, including four DSCS III satellites, had been launched on the Atlas II, IIA, and IIAS without any failures. In 1999, SMC used the existing Atlas contract to procure launches of a new Atlas vehicle, the Atlas III, that used a single-stage main propulsion unit called the RD-180. The RD-180 was designed and manufactured by a Russian contractor, NPO Energomash. One of the features that made the engine versatile for space launches was that it could be throttled on command to higher or lower thrust while in flight.

Left: The first Delta II launches the first GPS Block II satellite on 14 February 1989. Center: An Atlas IIA launches a DSCS III satellite on 20 January 2000. Right: An Atlas IIAS launches a satellite for the NRO on 7 December 2000. (Photographs at center and right courtesy of Lockheed Martin Corporation)

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[9] However, the Thor Agena had successfully launched a series of 24 Corona satellites in 20 months during April 1964 – December 1965 and a series of 23 in 41 months during June 1967 – November 1970. The Titan IIIB Agena may have carried out 29 successful launches during June 1967 – October 1971.

Launch Broad Area Review

Unfortunately, six closely spaced failures hit American launch programs from August 1998 to May 1999. They included three Air Force Titan IVs and destroyed three important payloads: a satellite from the National Reconnaissance Office, an early warning satellite from SMC's Defense Support Program, and a military communications satellite from SMC's Milstar program.[10] At the direction of both Congress and the president, DOD set up an independent review known as the Launch Broad Area Review (BAR) to study the causes of the failures and recommend remedial measures. The BAR confirmed that the immediate causes were unrelated, but it issued a set of recommendations on 1 November 1999 that broadened SMC's responsibility for each DOD launch from acquisition of the hardware through delivery of the spacecraft on orbit. As a result, SMC's responsibility for hardware and engineering throughout every launch became clear, explicit, and formal. By May 2003, Air Force launches were experiencing one of the longest unbroken strings of successful launches in history.

Evolved Expendable Launch Vehicle

Programs to develop a new generation of launch vehicles got off to a slow start. In 1987, the Air Force and NASA had begun a cooperative program to develop a more efficient family of boosters to replace the Space Transportation System and expendable launch vehicles. The program was known at first as the Advanced Launch System and later as the National Launch System before Congress ceased to fund it. In 1993, the Air Force and SMC tried a new, more frugal approach known as the Spacelifter program, which intended to develop a new launcher using existing technology. Nevertheless, the Secretary of Defense canceled it for reasons of cost later that year.

Efforts to develop a new, more efficient launcher received a badly needed endorsement when President Clinton signed a National Space Transportation Policy on 5 August 1994. Among other provisions, it assigned responsibility for expendable launch vehicles to DOD and directed DOD to develop improved versions of existing vehicles. The response was SMC's Evolved Expendable Launch Vehicle (EELV) program, which proposed to develop a family of launch vehicles for medium to heavy payloads based on existing vehicles or their components and using existing technology. SMC awarded four contracts for the initial phase of the EELV program on 24 August 1995, and it selected two proposals on 20 December 1996.[11] On 16 October 1998, SMC awarded contracts for both concepts covering the final stage of development.

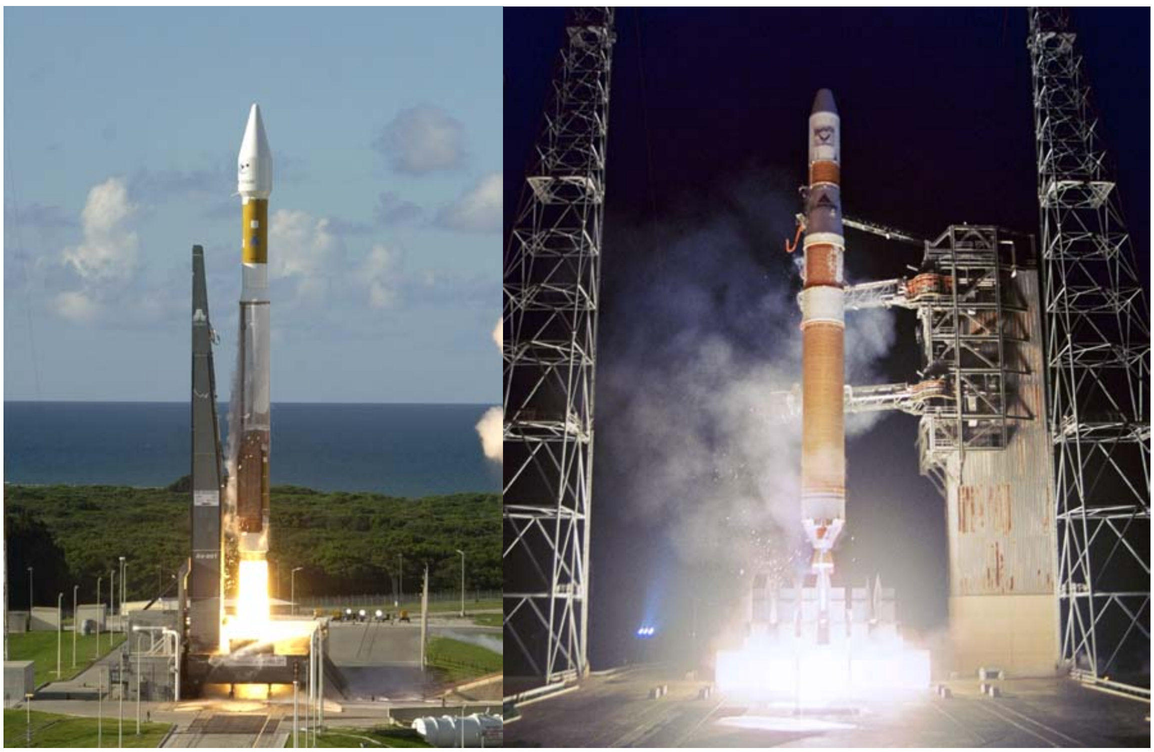
One of the two EELV contracts went to McDonnell Douglas (later acquired by Boeing) for a proposed family of upgraded Delta launchers known collectively as the

[10] Two of the other launches involved Delta III rockets, and the other involved an Athena rocket. However, the payloads in these launches were commercial.

[11] At first, SMC planned for these two contractors to compete for full scale development, but in 1997, it decided to keep two contractors over the life of the program because their products could be sold to a larger commercial market than originally anticipated and because two available launchers would tend to maintain competition for individual launches. For this and other innovations in acquisition, the EELV program was one of the Air Force's standard bearers in streamlined acquisition reform.

Delta IV. The Delta IV vehicles shared a first-stage common booster core (CBC) and a cryogenic second stage.[12] The first-stage engine, known as the RS-68, burned liquid oxygen and liquid hydrogen. Versions for somewhat heavier payloads added two to four strap-on solid-rocket auxiliary motors. The heavy version used three CBCs joined together in a line.

The other EELV contract went to Lockheed Martin for its proposed family of upgraded Atlas launchers known collectively as the Atlas V. The Atlas V vehicles also shared a first-stage CBC and second stage. The Atlas V's CBC employed the Russian-built RD-180 engine used in the Atlas III commercial launcher. The second stage consisted of a one- or two-engine cryogenic upper stage.[13] Heavier versions added one to five strap-on solid-rocket auxiliary motors. The heavy version of the Atlas V also used three CBCs joined together in a line.



Left: The first launch of the Atlas V EELV places Eutelsat's Hot Bird 6 commercial communications satellite into orbit on 21 August 2002 at Cape Canaveral. Right: The second launch of the Delta IV EELV places a DSCS III satellite into geosynchronous orbit on 10 March 2003 at Cape Canaveral. (Photograph at left courtesy of International Launch Services. Photograph at right courtesy of The Boeing Company.)

SMC awarded contracts on 16 October 1998 that provided launch services for Delta IV and Atlas V missions from both the east and the west coasts during FY 2002-2006. By the year 2000, however, agreements provided for launching the Atlas V from

[12] The second stage of the Delta IV used Pratt & Whitney's restartable RL-10B2 cryogenic liquid oxygen/liquid hydrogen engine, a variation of the RL-10 engine used in the Centaur upper stage.

[13] The upper stage of the Atlas V consisted of a one- or two-engine Centaur employing the RL-10A-4-2 restartable engine.

the east coast only and the Delta IV from both coasts. The first launch of the Atlas V, which took place at Cape Canaveral, placed a European commercial telecommunications satellite into the correct orbit on 21 August 2002. The first DOD payload for the Atlas V was scheduled for launch in 2003. The first launch of the Delta IV took place on 20 November 2002, also from Cape Canaveral, and it too placed a European telecommunications satellite into a nominal orbit. The first DOD payload for the Delta IV was a satellite from SMC's Defense Satellite Communications System III (DSCS III) program, which the launcher placed into a nominal geosynchronous orbit from Cape Canaveral on 11 March 2003. The first launch of a Delta IV from the west coast was scheduled to take place early in 2004. It would be the first launch of any kind from SLC-6, the launch complex which had been built originally in 1969 to launch the Manned Orbiting Laboratory.[14] It had been modified later for the Space Shuttle and now had been modified again for the Delta IV.

[14] For information about the Manned Orbiting Laboratory (MOL) program, see Chapter VII, Other Programs, later in this history.