CHAPTER I: MISSION AND ORGANIZATION

Evolution of the Mission

The Space and Missile Systems Center traces its ancestry back to the Western Development Division (WDD) of the Air Research and Development Command (ARDC). WDD was activated in Inglewood, California, on 1 July 1954 by ARDC's General Order 42. It was redesignated the Air Force Ballistic Missile Division (AFBMD) on 1 June 1957. The organization's original mission was to develop strategic missiles for the Air Force, but ARDC added the responsibility for developing the first military satellite system on 17 October 1955. A separate unit[1] of Air Materiel Command shared office facilities with WDD and AFBMD and performed contracting and procurement functions for the missile and space development programs until 1 April 1961.

Members of the Weapon System 117L program gather at the Western Development Division in 1956, soon after the first Air Force satellite program was transferred from Wright Air Development Center.

The responsibilities for both strategic missiles and space remained with AFBMD and its successors through the decades that followed, but the Department of Defense continued to modify and add to its assignment of the space mission. On 7 February 1958, the Eisenhower administration activated the Advanced Research Projects Agency (ARPA) and placed it in charge of all military space programs during their research and development phases. After an intense year and a half of reorganizing and initiating space programs, ARPA lost its dominant role when Secretary of Defense Neil McElroy divided responsibilities for developing military space systems among the three services on 18 September 1959. The Army was to develop communication satellites; the Navy, navigation satellites; and the Air Force (in effect, AFBMD), reconnaissance and

[1] See names and dates of organizations and commanders in Appendix A.

surveillance satellites. Only the Air Force, however, was to develop and launch military space boosters.

Secretary of Defense Neil McElroy at the headquarters of the Air Force Ballistic Missile Division in 1959. Left to right: Secretary McElroy, Major General Ben I. Funk (commander of Ballistic Missiles Center), Major General Osmond J. Ritland (commander of AFBMD), and Brigadier General Charles H. Terhune, Jr. (vice commander of AFBMD) (U.S. Air Force Photograph)

This arrangement continued until 6 March 1961, when Secretary of Defense Robert McNamara gave the Air Force a near monopoly on development of all military space systems, ending the role of the Army and the Navy except under exceptional circumstances. Some important exceptions to this developmental near monopoly occurred during the next 50 years. For example, the development of reconnaissance satellites and related systems soon came under the authority of the National Reconnaissance Office (NRO), and the Navy sponsored the development of the first successful space-based navigation system. However, the Air Force continued to exercise a predominant responsibility for military space efforts.[2]

Evolution of the Organization

By 1961, therefore, AFBMD had two parallel missions to perform, but it was not necessarily clear that the two missions belonged together. Over the next several decades, in fact, the missile and space functions were separated and rejoined repeatedly, causing several major reorganizations and redesignations. Because of the increasing importance of space systems, the space and missile functions were first separated on 1 April 1961, when AFBMD was inactivated and replaced by the Ballistic Systems Division (BSD) and

[2] That predominance was recognized by DOD's Commission to Assess U.S. National Security Space Management and Organization in its report published on 11 January 2001. It was translated into policy when Secretary of Defense Donald Rumsfeld, acting on the Commission's recommendations, assigned to the Air Force the "responsibility for planning, programming, and acquisition of space systems" in his assessment of the Commission's report provided to Congress on 8 May 2001.

the Space Systems Division (SSD).[3] On 1 July 1967, the space and missile functions were reconsolidated in the interest of economy, and BSD and SSD were merged to form the Space and Missile Systems Organization (SAMSO). Space and missile functions were separated a second time on 1 October 1979, when SAMSO was divided into the Space Division and the Ballistic Missile Office. Those two organizations were redesignated Space Systems Division (SSD) and Ballistic Systems Division (BSD) on 15 March 1989.

By the early 1990s, missile programs were being cut back because the cold war had ended, and a final series of redesignations and realignments brought the space and missile functions together for a third time. On 5 May 1990, BSD was redesignated the Ballistic Missile Organization (BMO) and realigned under SSD. On 1 July 1992, SSD was redesignated the Space and Missile Systems Center (SMC), the name it bears today. Finally, on 2 September 1993, BMO was inactivated and absorbed by SMC, recreating the situation that had existed in the 1950s and again in the 1970s, when a single organization was responsible for both space and missile programs.

The Space Commission of 2000

During the years 2000-2001, changes in SMC's relationship to its higher headquarters underwent profound changes. Supporters of more highly centralized military space functions had been gaining strength within Congress, and they inserted

General Lester L. Lyles, commander of Air Force Materiel Command, hands SMC's flag to Lieutenant General Roger G. DeKok, vice commander of Air Force Space Command, during ceremonies observing SMC's transfer to a new major command. Lieutenant General Brian A. Arnold, commander of SMC, stands at right. Both Lyles and DeKok were former commanders of SMC. (U.S. Air Force Photograph)

[3] An umbrella organization, called the Deputy Commander for Aerospace Systems, was also created when the space and missile functions were separated, but it was soon inactivated on 10 October 1962.

language in the National Defense Authorization Act for FY 2000 calling for a commission to assess the management and organization of space activities that supported national security. When constituted, the Commission to Assess United States National Security Space Management and Organization included prestigious space experts drawn from DOD and Congress, and its report, published on 11 January 2001, carried great weight.[4] The Commission emphasized the importance of the Air Force's management of space programs by recommending that the Secretary of Defense formally designate the Air Force as the executive agent for space within the Department of Defense. Among other managerial changes, the Commission proposed consolidating the Air Force's management of space efforts by realigning SMC from Air Force Materiel Command (AFMC) to Air Force Space Command (AFSPC), thus bringing the developers and operators of military space systems together under one major command. During a ceremony at Fort MacArthur on 1 October 2001, SMC's flag passed from the hands of AFMC's commander to the hands of AFSPC's commander, thus beginning in fact as well as in symbol a significant change in the management of military space programs, a change intended to better integrate space efforts with other defense efforts.

The Program Executive Officer for Space

Another significant change in the management of Air Force space programs also resulted from the recommendations of the Space Commission. Until 1986, space and other acquisition efforts managed by the Air Force had reported on the status of their programs through the organizational chain of command. On 30 June 1986, however, the President's Blue Ribbon Commission on Defense Management, known as the Packard Commission, recommended that managers of individual programs report to Program Executive Officers (PEOs), who would report to Service Acquisition Executives in the service secretariats. The Air Force began to implement this recommendation in 1987, designating acquisition programs with large budgets as executive programs and leaving the other programs to the oversight of product division commanders. The new system created few changes in practice because product division commanders were usually designated as PEOs for the executive programs managed by their organizations. However, in 1989 the President asked for another review of the defense procurement process. The review was known as the Defense Management Review, and it endorsed the recommendations of the Packard Commission but proposed that product division commanders not be allowed to serve as PEOs. The Air Force implemented this proposal in January 1990, appointing new PEOs for major areas of acquisition, including space. Eventually, all of the PEOs were reassigned to the area of Washington, D.C., to improve communications with acquisition executives in the Pentagon. The PEO for Space was reassigned to Washington effective 1 September 1990.

When the Space Commission issued its report on 11 January 2001, it recommended that the PEO for Space be transferred from the Pentagon back to SMC in order to consolidate SMC's space research, development, and acquisition responsibilities under Air Force Space Command. The Air Force PEO for Space was physically

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[4] Not the least cause of the Commission's influence was the fact that the incoming Bush administration's Secretary of Defense, Donald Rumsfeld, had chaired the Commission during most of its term.

reassigned to SMC in June 2001 during the transition to the Commission's recommendations. On 19 February 2002, Secretary of the Air Force James G. Roche officially assigned the responsibilities of the PEO for Space to SMC's commander, directing that all acquisition programs at SMC were to be considered PEO programs. In matters of acquisition, the PEO for Space reported at first to the Under Secretary of the Air Force but, after 25 August 2010, to the Assistant Secretary of the Air Force for Acquisition. The Air Force modified the PEO's responsibilities on 16 March 2011, when a separate PEO for Space Launch was appointed within the office of the Assistant Secretary for Acquisition.

The Attempt to Reorganize into Wings, Groups, and Squadrons

SMC, like other product centers, underwent an unsuccessful experiment in internal organization during 2006-2010 that attempted to make its major acquisition programs more closely resemble the traditional organization of the operational Air Force in wings, groups, and squadrons. The reorganization took place at the direction of the Secretary of the Air Force even though the newly constituted organizations did not meet the normal criteria, such as numbers of personnel, for wings, groups, and squadrons. AFMC, to which all other Air Force acquisition centers reported, transformed its system program offices (SPOs) into wings, groups, and squadrons during 2005. On 1 August 2006, Air Force Special Order GD-012 activated six wings, 21 groups, and 12 squadrons assigned to SMC, and the new establishments adopted the traditional command structure as well as lineage and honors with approved unit emblems.[5]

By 2009, however, the Air Force was becoming concerned about the increasing number of its units in the face of declining manpower, and the Air Force Chief of Staff issued guidelines for the minimum numbers of personnel required for wings, groups, and squadrons. SMC's acquisition organizations, like those under AFMC, did not meet those manpower standards. On 4 May 2009, Air Force Secretary Michael Donley and Chief of Staff General Norton Schwarz issued an Acquisition Improvement Plan which emphasized the establishment of clear lines of authority and accountability in all acquisition programs. Product centers like SMC were to be streamlined into directorates, divisions, and branches during 2010 to achieve those clearer lines of authority and accountability by eliminating lower levels of command. Consequently, Air Force Special Order GD-002 inactivated SMC's acquisition wings, groups, and squadrons effective 10 November 2010. The 61st ABG would now be the only group-level organization under SMC, as it had been before 2006.[6]

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[5] The reorganization in 2006 created seven new wings under SMC: the 61st Air Base Wing, the Launch and Range Systems Wing, the Global Positioning Systems Wing, the Space-Based Infrared Systems Wing, the Military Satellite Communications Systems Wing, the Space Superiority Systems Wing, and the Space Development and Test Wing. It also created three new independent groups, reporting directly to HQ SMC rather than to one of its wings: the Defense Meteorological Satellite Program Systems Group, the Satellite Control and Network Systems Group, and the Space Logistics Group.

[6] During 2006-2010, base support for SMC at Los Angeles AFB was provided by a wing-level organization, the 61st ABW, but it was inactivated on 30 July 2010. The 61st ABG was redesignated the 61st Mission Support Group during 2006-2010.

Official emblems of wings and groups reporting directly to HQ SMC during 2006-2010

The Aerospace Corporation

SMC and its predecessors have been supported over the years by private sector organizations that have provided systems engineering for its programs and technical direction to its contractors. The first such organization was the Ramo-Wooldridge Corporation, chosen in 1954 to provide systems engineering and technical direction for WDD's missile programs. By 1958, that function was being performed by a subsidiary of Ramo-Wooldridge called Space Technology Laboratories (STL). STL built space systems under contract as well as advising the government, thus creating the potential for a conflict of interest, and that potential increased in 1958 when Ramo-Wooldridge merged with Thompson Products to form Thompson-Ramo-Wooldridge (TRW).

Congress expressed reservations about the propriety of a profit-making entity serving an agency of the government so closely and exclusively, and Air Force Secretary James H. Douglas chartered a committee, known as the Millikan Committee, to recommend a solution. In January 1960, the committee recommended the creation of a new, not-for-profit corporation to replace STL in providing technical assistance and advice to the Air Force. The new company drew heavily from STL's staff in forming up, and it was formally incorporated on 3 June 1960 as The Aerospace Corporation. Its creation was publicly announced at a news conference on 25 June 1960. At that time, plans called for TRW to continue providing systems engineering for existing missile programs and for Aerospace to provide systems engineering for all space programs and for future missile programs. As it turned out, Aerospace focused primarily on space, although it did perform some work in the missile field, but TRW remained the primary source of systems engineering for missile programs for many years. The Aerospace Corporation remained the Federally Funded Research Corporation providing technical support to SMC's space acquisition programs from the time of its creation in 1960.

The public announcement of the creation of the Aerospace Corporation on 25 June 1960. L-R: Trevor Gardner (trustee), Charles Lauritsen (vice chairman of the board), Roswell Gilpatrick (chairman of the board), Joseph Charyk (Air Force undersecretary), and Lt Gen Bernard Schriever (commander of AFSC)

Field Units

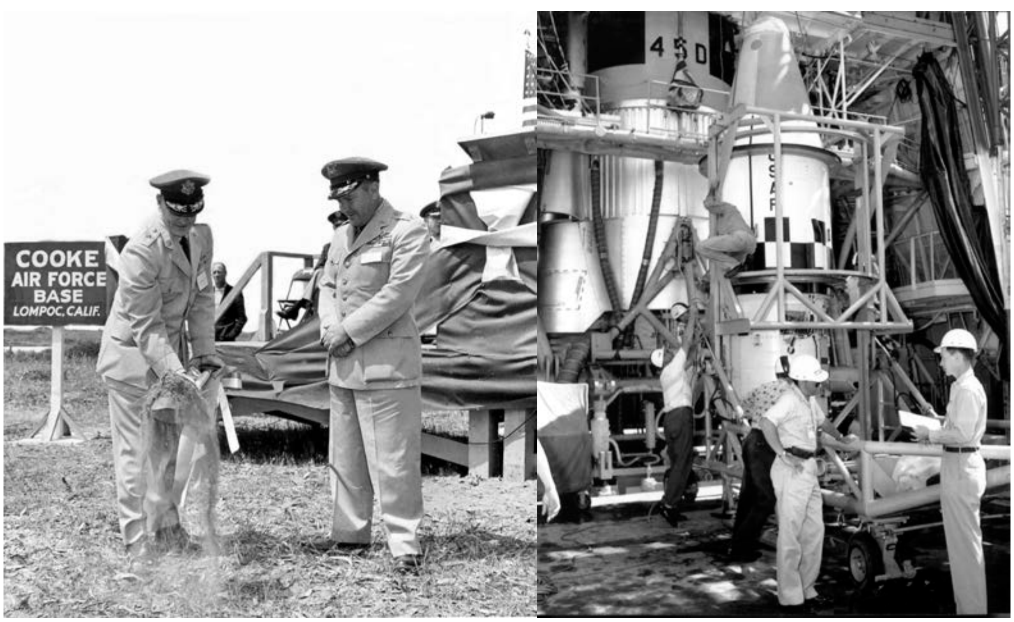
Changes in the organizational structure of SMC and its predecessors were paralleled by changes in field units. Through those field units, its predecessors were involved not only in the development and acquisition of space systems but in space operations as well. Beginning in the 1950s, SMC's predecessors provided or acquired units that controlled military satellites in orbit, conducted satellite launches as well as R&D missile launches, and operated the ranges that supported those launches.[7] The

[7] The ranges themselves—that is, the facilities as opposed to the organizations that conducted launches—were controlled during the 1950s and 1960s by organizations that did not report to AFBMD. The ranges reported directly to Air Force Systems Command and were designated the Air Force Missile Test Center at Cape Canaveral and the Air Force Space Test Center at Vandenberg AFB. From 1964 to 1970, both ranges—known then as the Eastern Test Range and the Western Test Range—were overseen by the National Range Division, which reported directly to Air Force Systems Command. In 1970, the Space and Missile Test Center (SAMTEC) was set up under SAMSO to oversee both the launching organizations and the ranges as explained above.

satellite control function was originally performed by the 6594th Test Group, created by AFBMD in 1959, and later by the Air Force Satellite Control Facility, which replaced the Test Group in 1965.

During the 1960s, launches were performed by the 6595th Aerospace Test Wing at Vandenberg Air Force Base (AFB) and by the 6555th Aerospace Test Wing at Cape Canaveral Air Force Station (AFS). In 1970, the 6555th became a group and was realigned under the 6595th, and the 6595th was realigned under a new field unit, the Space and Missile Test Center (SAMTEC). SAMTEC was responsible for overseeing launches at both Vandenberg and the Cape and for operating the Western Test Range that supported launches out of Vandenberg. In 1977, it also acquired responsibility for running the Eastern Test Range that supported launches at the Cape. In 1979, SAMTEC was redesignated the Space and Missile Test Organization (SAMTO) and was restructured with two major field units of its own, the Eastern Space and Missile Center (ESMC) and the Western Space and Missile Center (WSMC). ESMC and WSMC conducted launches and operated the ranges on the east and west coasts respectively.

SMC's responsibility for space operations began to change on 1 September 1982, when Air Force Space Command was activated to serve specifically as an operational command for military space systems. In the years that followed, Space Command gradually took over the operational functions previously performed by SMC's field units



Left: Brigadier General Osmond Ritland, then vice commander of WDD, breaks ground at Cooke AFB on 8 May 1957 for the construction of space and missile facilities on the west coast. Cooke was soon renamed Vandenberg AFB. Right: Officers of AFBMD's 6555th ATW discuss their final inspection of the Agena spacecraft (in cradle) for the launch of MIDAS 2 on Atlas 45D (in background) on 24 May 1960.

and, in the process, it absorbed most of the units themselves. The Air Force Satellite Control Facility was inactivated on 1 October 1987, and most of its personnel and functions were taken over by wing-level units assigned to Air Force Space Command.[8] HQ SAMTO was inactivated on 1 October 1989. A year later, the Eastern and Western Space and Missile Centers were reassigned to Space Command, and the transfer of launch operations to Space Command began.[9]

While SMC's predecessors lost field units involved in operations, they temporarily gained units involved in research. In October 1982, the Air Force Space Technology Center (AFSTC) was activated at Kirtland AFB and assigned to Space Division. At the same time, three pre-existing laboratories were assigned to the AFSTC—the Air Force Weapons Laboratory, the Air Force Geophysics Laboratory, and the Air Force Rocket Propulsion Laboratory (later redesignated the Air Force Astronautics Laboratory). Creation of the AFSTC centralized Air Force space technology efforts and reoriented them to better serve the needs of the program offices at Space Division. In December 1990, the AFSTC was redesignated the Phillips Laboratory, and the three laboratories formerly assigned to it were folded into it to form a single super laboratory. In January 1993, Kirtland AFB, where the Phillips Laboratory was located, was transferred to SMC, and the 377th Air Base Wing, the host wing at Kirtland, was assigned to SMC as well.

Nevertheless, SMC's subordinate units and their missions were stripped away again during the late 1990s. Phillips Laboratory became part of AFMC's newly created, centralized Air Force Research Laboratory on 8 April 1997. The 377th ABW was reassigned to the Air Armament Center at Eglin AFB, Florida, on 1 October 1998 to centralize air armament issues within the Air Force.

However, some geographically separated SMC organizations matured into major acquisition or support activities. Certain space and missile programs managed at Kirtland AFB were closely tied SMC's central mission and were not reassigned. In general, they provided test and evaluation, launch of experimental payloads, and on-orbit operations from the Space Shuttle. These programs were placed under SMC's Detachment 12 in 2001. It became an acquisition wing during 2006-2010 and, afterward, an acquisition directorate, the Space Development and Test Directorate. SMC's Detachment 11 at Peterson AFB, responsible for logistics management of space programs, became the Logistics Support Squadron, the Logistics Support Group during 2006-2010, and the Space Logistics Directorate after the inactivation of wings and groups. The ICBM program office at Hill AFB continued to report for program management and execution to SMC's commander as the PEO for space, but organizationally it remained with AFMC even after SMC came under AFSPC in 2001, and it became part of AFMC's new Air Force Nuclear Weapons Center in 2008.

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[8] AFSPC's operational unit in charge of satellite control at Falcon (later renamed Schriever) AFB was the 2nd Space Wing during 1985-1992 and the 50th Space Wing after that. However, experimental as well as R&D payloads were controlled at Onizuka AFS during 1987-1993 by a unit of Space Division (later Space Systems Division, then SMC) called the Consolidated Space Test Center (CSTC).

[9] Launch operations were transferred incrementally. The Delta II and Atlas E launch operations were transferred first, followed by the Atlas II, Titan II, and Titan IV launch operations.

CHAPTER II: FACILITIES

Headquarters

When WDD was established on 1 July 1954, it set up temporary headquarters in a former parochial school and parish church at 401-409 East Manchester Boulevard in Inglewood, California. The old schoolhouse was only a stopgap solution, however, and early in 1955, WDD moved into buildings on Arbor Vitae Street in southwest Los Angeles, near Los Angeles International Airport. These offices housed not only Air Force and civil service personnel, but also personnel working for the Ramo-Wooldridge Corporation, which provided technical support for WDD's missile programs.

These buildings, formerly St. John's Catholic Church and School, housed WDD in the first six months after its creation. The Ramo-Wooldridge Corporation leased the buildings, which were no longer occupied, to use as office space. The largest building, at left, was the church, the building in the center was the rectory, and the building at right was the school administration building. WDD removed several prefabricated classroom buildings to provide parking space. (U.S. Air Force photograph)

In 1955, Ramo-Wooldridge purchased 40 acres on the southeast corner of Aviation and El Segundo Boulevards in El Segundo. The site was three miles from the Arbor Vitae complex but was the closest site available. Beginning in the middle of 1956, a complex of seven buildings was constructed on the site to provide offices and laboratories for Ramo-Wooldridge's operations. That complex, known as the Research and Development (R&D) Center, was completed in the fall of 1958, and employees of the corporation's subsidiary Space Technology Laboratories moved into it.[5]

The Arbor Vitae Complex and the R&D Center provided much more room than the old schoolhouse, but they did not provide enough. By the late 1950s, the missile program had expanded, and WDD's successor, the Air Force Ballistic Missile Division (AFBMD), had become involved in space programs as well. The manpower associated

[5] The Ramo-Wooldridge Corporation's Guided Missile Research Division was renamed Space Technology Laboratories in 1957, just before it moved into the R&D Center. As noted in the previous section, Ramo-Wooldridge became Thompson-Ramo-Wooldridge (TRW) in 1958.

with these growing programs left the Arbor Vitae complex and the R&D Center extremely congested, and AFBMD had to find additional facilities for its staff and their activities. Trailers were rented and parked at the Arbor Vitae complex and the R&D Center, and additional buildings were rented in southwest Los Angeles, Inglewood, Hawthorne, Lawndale, and Torrance.

In April 1961, AFBMD was divided into Ballistic Systems Division (BSD) and Space Systems Division (SSD). BSD moved to Norton AFB in San Bernardino, California, between July and September 1962. Employees of TRW who performed systems engineering for missile programs went there as well. Meanwhile, in December 1960, the Air Force purchased the R&D Center from TRW to serve as a home for The Aerospace Corporation, which had been created in June 1960 and was now supporting Air Force space programs. As a result of these changes, SSD now occupied the Arbor Vitae complex, and Aerospace occupied the R&D Center. The departure of BSD and TRW relieved pressure on the facilities, and there was now enough office space for SSD and Aerospace.

Douglas Aircraft's El Segundo Division displays its products during an open house on 14 November 1954. Area B of Los Angeles AFB now occupies the area pictured here. The aircraft paint booth in the background was modified to create Building 219, the People Center. The airplanes shown are (left to right) AD-5 Skyraider, AD-6 Skyraider, A4D Skyhawk, A3D Skywarrior, F4D Skyray, F3D Skyknight, and A2D Skyshark. (Photograph courtesy of The Boeing Company)

While the office space problem had been solved, another problem remained: the fact that the Arbor Vitae complex and the R&D Center were three miles apart. It was obviously more efficient to consolidate SSD and Aerospace in one place, and during 1961-1962, a plan was devised to bring that about. The plan involved the acquisition of two pieces of real estate adjoining the R&D Center. One, a 50-acre parcel at the northwest corner of Aviation and El Segundo Boulevards, was part of the Douglas

Aircraft Corporation's El Segundo aircraft plant. The fifty acres in question were owned by the Navy, although they had been used by Douglas during and after World War II as part of its aircraft manufacturing facilities. This 50-acre site was transferred to the Air Force's ownership in October 1962.

The other site involved in the consolidation plan was a 31-acre parcel owned by the Utah Construction and Mining Company at the southwest corner of the same intersection. The Aerospace Corporation acquired that site in November 1962 and built its new headquarters there between February 1963 and April 1964. As Aerospace personnel moved into their new headquarters, Air Force people moved into the R&D Center and the Navy's portion of the former Douglas Aircraft facility. By April 1964, this process was complete. The Air Force[6] designated the property at the intersection of Aviation and El Segundo Boulevards as Los Angeles Air Force Station (AFS) on 1 April 1964. The R&D Center became Area A of Los Angeles AFS, and the former portion of the Douglas Aircraft plant became Area B.[7]

Building 105 in Area A of Los Angeles AFB, as it appeared during the 1960s and early 1970s. Command Section offices were on the sixth floor. The Thor Agena launch vehicle in front of the building, a local landmark for many years, was toppled by a gust of wind on 25 March 1975. (U.S. Air Force photograph)

The headquarters of SSD and its successors have occupied Los Angeles AFS

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[6] Air Force Special Order GA-31 dated 30 April 1964 confirmed that Air Force Plant Number 82 (the property's former designation since coming under Air Force ownership) had been redesignated Los Angeles AFS effective 1 April 1964.

[7] For about twenty years, Los Angeles AFB also owned an annex called the Lawndale Facility on Aviation Boulevard. The facility had one building, a former Army missile plant, which was renovated in 1986 and used as office space by personnel working in ballistic missile defense programs. It was traded to developers in 2004 as part of the land-for-buildings transaction called the SAMS Project (see below).

since 1964. The station was redesignated Los Angeles Air Force Base (AFB) on 15 September 1987. For several decades, the organization responsible for development and production of ICBMs (BSD and its successors) remained in San Bernardino. This geographical separation continued even during the SAMSO era, when the missile and space functions belonged to the same organization. However, the situation finally changed because of the drawdown of missile programs following the end of the cold war. The old BSD-BMO headquarters in San Bernardino closed on 30 September 1995, and the few remaining personnel moved to Los Angeles AFB.

SMC's facilities at Los Angeles AFB underwent profound changes during 2004-2006 when the Air Force traded Area A to developers in exchange for the construction of new office facilities in Area B. The innovative concept for financing the construction was worked out by an assessment team which documented the failures of the existing base facilities to meet fire and seismic safety standards and obtained the support and concurrence of the Air Force's assistant secretary for installations.[8] Led by California's House and Senate delegations, Congress passed enabling legislation in the Defense Authorization Act for 2001 allowing the Air Force to trade land for the cost of construction on the remaining portion of the base. The value of the land did not cover all of the costs, however, and the city governments of Hawthorne and El Segundo as well as Los Angeles County, motivated by the value of SMC's activities for the local economy, approved property tax remissions to make up the difference in cost to the developer.

The ceremonial transfer of the WDD Memorial Rock from Area A to new base facilities on 22 April 2006 Center: Lt Gen Michael A. Hamel, SMC's commander (Photograph courtesy SMC Public Affairs Office)

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[8] SMC's commander, Lt Gen Roger DeKok, appointed an Integrated Product Team in 1997 to determine the best option for modernizing the base. Chaired by the commander of the 61st ABG, Col Dieter Barnes, the IPT developed and proposed a concept for paying for improved facilities by trading land for buildings. The concept was finally approved by Nelson Gibbs, Assistant Secretary of the Air Force for Installations. The developers were a consortium of three real estate corporations known as the SAMS Venture, LLC. See Interview, Robert Mulcahy (SMC/HO) with Col Barnes (AFHRA/CC), 8 May 2003.

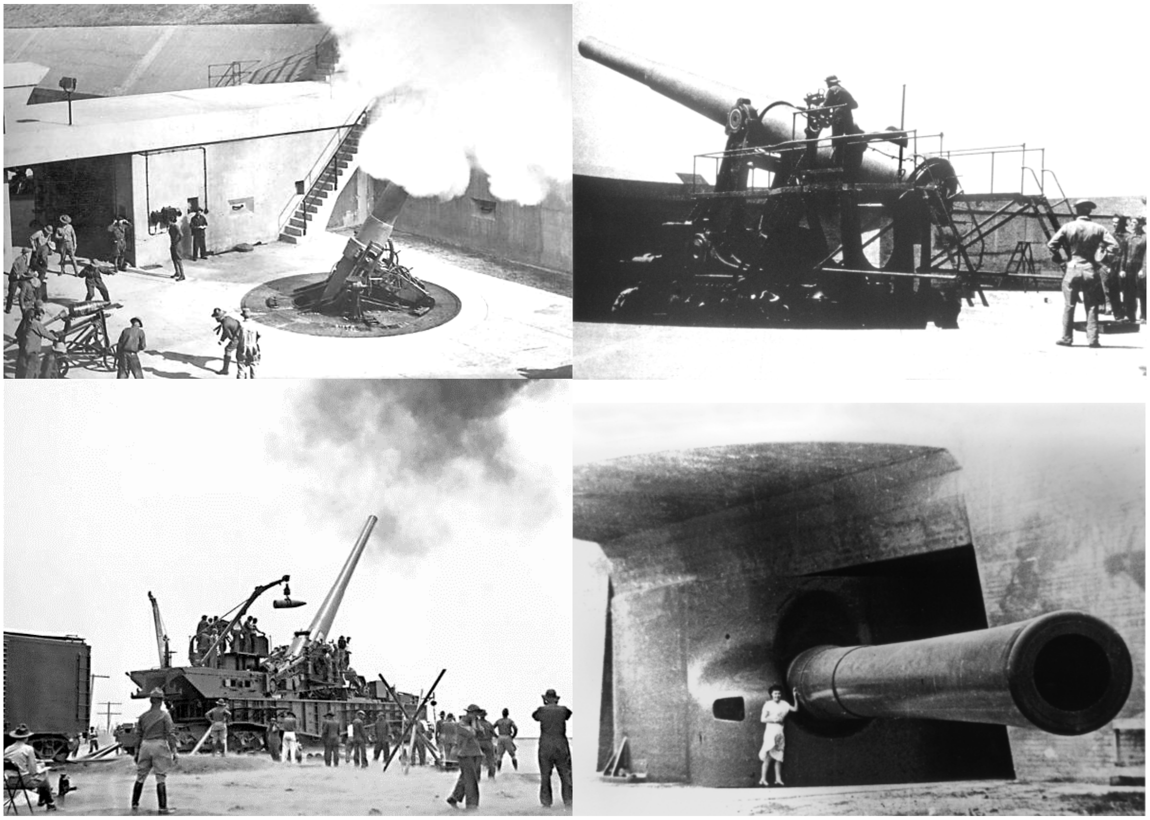
The development was known at first as the SAMS (Systems Acquisition Management Support) Project. The new office facilities were constructed during 2004-2005 on Area B of Los Angeles AFB, which afterward comprised the entire base. The groundbreaking for the first SAMS building occurred on 18 May 2004, and SMC signed the facility acceptance for the buildings on 10 January 2006. A ceremony involving marching military formations and the transfer of the WDD Memorial Rock to the courtyard of the new facilities on 22 April 2006 marked the official date for moving SMC's headquarters. During a dedication ceremony two days later, the new facilities were renamed the Schriever Support Complex.

Fort MacArthur

Fort MacArthur is a former Army installation acquired by the Air Force in 1982. It is 96 acres in size and is located in the community of San Pedro, about 13 miles south of the main base. The Fort now serves as a housing area for military personnel who work at Los Angeles AFB, but it had a long and proud history as an Army installation before it was acquired by the Air Force. We will briefly discuss that early history and then focus on the acquisition of the Fort by the Air Force and the construction of housing for Air Force personnel.

The area occupied by Fort MacArthur has been a government reservation since at least the mid-19th century. When ships of that era discharged cargo on the shore of San Pedro Bay, a tract of land was used primarily for traffic at the boat landing. This tract was defined and protected in 1846 by the last Mexican governor of California, Pio Pico, who confirmed the private ownership of Rancho de los Palos Verdes but required the owners to leave free "500 varas square" (44.25 acres) at the port of San Pedro. After the United States government acquired California from Mexico, it continued to recognize the 500 varas square as a government reservation, and in 1888, President Grover Cleveland declared the area a military reservation. In 1914, the reservation became Fort MacArthur, named in honor of Lieutenant General Arthur MacArthur, a military leader in the Spanish-American war, a governor of the Philippines, and the father of future General of the Army Douglas MacArthur. At that time, the Fort comprised three parcels of land: the original 500 varas square, later known as the Middle Reservation; an area on Point Fermin, later known as the Upper Reservation; and a small plot on Terminal Point. The Middle Reservation would later be expanded to take in much of the area along the bluffs to the south, and the Fort would also acquire other property, including a parcel fronting on Cabrillo Beach, known as the Lower Reservation, and parcels at White Point and Point Vicente.

Fort MacArthur was established to provide a home for coastal artillery batteries that the government had decided to build at San Pedro. In 1917, the Army completed construction of four batteries of 14-inch disappearing carriage rifles and two batteries of 12-inch mortars on Point Fermin. By 1919, it had constructed housing and headquarters buildings on the Middle Reservation in the Mission Revival and California Craftsman architectural styles. In 1917, the fort was garrisoned by the 1st Coast Artillery Company, Fort MacArthur, and, by 1918, by the 2nd and 3rd Companies of the Coast Defenses of Los Angeles. During World War I, the fort guarded the harbor and served as a training and staging area for Army units departing for the European theater. Over 4,000 soldiers at one time were stationed at the fort before the end of the war.



Major types of armament emplaced at Fort MacArthur: 12- inch mortar (upper left); 14- inch disappearing carriage rifle (upper right); 14- inch railway gun (lower left); and 16- inch rifle (lower right). (Photographs courtesy of Fort MacArthur Museum)

During World War II, the fort maintained its defenses, trained artillerymen for service overseas, and processed soldiers entering and leaving military service. None of the large guns was fired at enemy targets, but a small gun shelled a suspected enemy submarine in the first month of the war. The armament was modernized again in 1943 when two 16-inch rifles were emplaced at White Point near the Upper Reservation. All of the major armament was inactivated and most of it sold for scrap between 1943 and 1948.

Fort MacArthur's mission changed radically after the war. In 1948, it became a major training center for Army reservists. Reserve units from all of southern California reported to the fort for supervision and training. In 1954, the fort became an antiaircraft missile site when a Nike Ajax missile battery (Nike Site LA-43) was emplaced on the Upper Reservation. Fifteen other Nike sites were built in remote locations around southern California, all controlled by the 47th Artillery Brigade headquartered at Fort MacArthur until 1969, and later by the 19th Air Defense Artillery Group. During 1958-1963, the Nike Ajax missiles were replaced by the more powerful Nike Hercules missiles, capable of carrying nuclear warheads.

By 1974, the NIKE sites had become obsolete and were shut down, causing the Army to reduce its presence at Fort MacArthur. The Army retained the Middle Reservation as an administrative center for support of active and reserve Army and National Guard units in southern California. However, it disposed of all other land attached to the fort, which included the Lower Reservation, the Hospital Area, the Upper

Reservation, White Point, and Point Vicente. In 1975, Fort MacArthur became a sub-post of Fort Ord and was manned by an Army support detachment.

Left: A Nike Ajax missile, probably at Redstone Arsenal, Alabama, in the 1960s. It was 32 feet long and flew at Mach 2.3 to a range of 30.7 miles and an altitude of 60,000 feet. It carried three conventional warheads detonated by ground command. Fort MacArthur had about 20 Nike Ajax missiles from 1956 to 1963. Right: A Nike Hercules missile at White Sands, New Mexico, probably in the 1960s. The missile was 40 feet long. It flew at Mach 3.65 to a range of 96.3 miles and an altitude of 100,000 feet. It carried one conventional or nuclear warhead detonated by ground command. Fort MacArthur had 12 Nike Hercules missiles from 1963 to 1974. (Photographs courtesy of Redstone Arsenal Historical Information)

In 1978, the Army announced that it would transfer its support units from Fort MacArthur to the Los Alamitos Armed Forces Reserve Center and would declare the remaining land excess. At that point, SAMSO was looking for a site to build housing for its military personnel, many of whom could not afford to buy or even rent housing in the very expensive Los Angeles market. SAMSO saw Fort MacArthur as the solution to its problem, and it asked the Air Staff to place a hold on the land. In September 1979, the Department of Defense approved the transfer of Fort MacArthur from Army to Air Force jurisdiction. After some initial delays, Congress appropriated funds for construction of military housing at the Fort, and 370 townhouses were built there between November 1981 and December 1985. Existing homes at the Fort were also renovated. Fort MacArthur was officially transferred from Army to Air Force control on 1 October 1982, and Air Force families began moving into the first of the newly built townhouses.

While the construction of townhouses at Fort MacArthur alleviated the housing problem for Air Force personnel in Los Angeles, it did not completely solve it, and even before construction was finished, Space Division began looking for a place where it could build additional military housing units. After a great deal of negotiation and compromise with the City of Los Angeles, which had its own plans for using excessed military property, the Air Force received title to former Army land on White Point, where it completed housing developments known as Pacific Heights and Pacific Crest in 1989 as well as a final housing development known as Pacific Heights II in 2000.

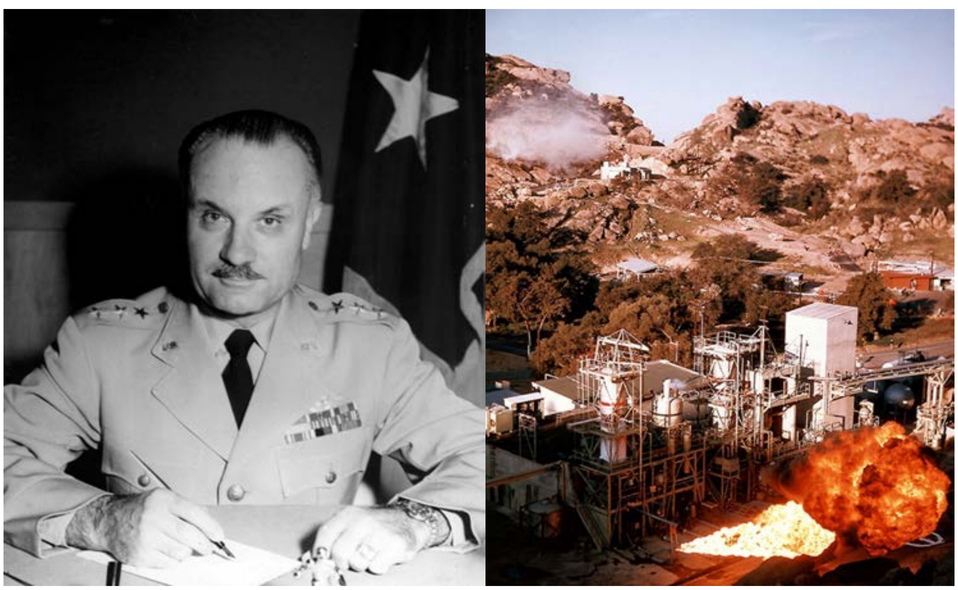
Regardless of its availability, the management of base housing underwent radical changes during 2005-2007 because of policy changes at HQ USAF. The Air Force's wider privatization initiative was a response to a presidential directive aimed at the elimination of inadequate military housing. The Air Force began to transfer the management of its existing housing units to private-sector project owners in return for maintenance, renovation, and operation. After signing leases, military families were to pay rent based on the housing allowance of the military member. The land for military housing for Los Angeles AFB, Peterson AFB, and Schriever AFB was leased to Tierra Vista Communities LLC for a 50-year term starting on 20 September 2007, and the housing areas were henceforth to be known as Tierra Vista Communities.

CHAPTER III: BALLISTIC MISSILES

The Air Force ballistic missile program had its origins in studies and projects initiated by the Army Air Corps immediately after World War II. These efforts aimed at mating the German V-2 ballistic missile and the atomic bomb, a union that carried the potential for a revolution in strategic warfare. Technical problems held the program back at first, but the situation was changed drastically by the so-called "thermonuclear breakthrough" of the early 1950's. This breakthrough made it possible to manufacture high-yield nuclear weapons that were small enough and light enough to be carried as warheads aboard ballistic missiles.

Atlas, Thor, and Titan I

Faced with growing evidence of the Soviet Union's development of thermo-nuclear weapons and ballistic missile technology in 1953, the Air Force Secretariat's architect for research and development, Trevor Gardner, chartered the Strategic Missiles Evaluation ("Teapot") Committee, chaired by Professor John von Neumann, to diagnose the slow pace of America's strategic missile programs. The Committee recommended in 1954 that Project Atlas, the only American ICBM then under development, be reoriented and accelerated. On 21 June 1954, Lieutenant General Donald L. Putt, the Air Staff's Deputy Chief of Staff for Research and Development, directed that Air Research and Development Command (ARDC) establish a field office on the west coast commanded by a general officer with authority over the entire Atlas program, which would have the highest Air Force priority.



Above left: Lieutenant General Donald L. Putt, HQ USAF Deputy Chief of Staff for R&D. On the Air Staff and later as commander of ARDC, he was one of General Schriever's most important allies and influenced early Air Force space and missile programs. Above right: Atlas engine test at Rocketdyne's Santa Susana engine test facility in 1956. Rocketdyne developed the engines for the Atlas. (U.S. Air Force photographs)

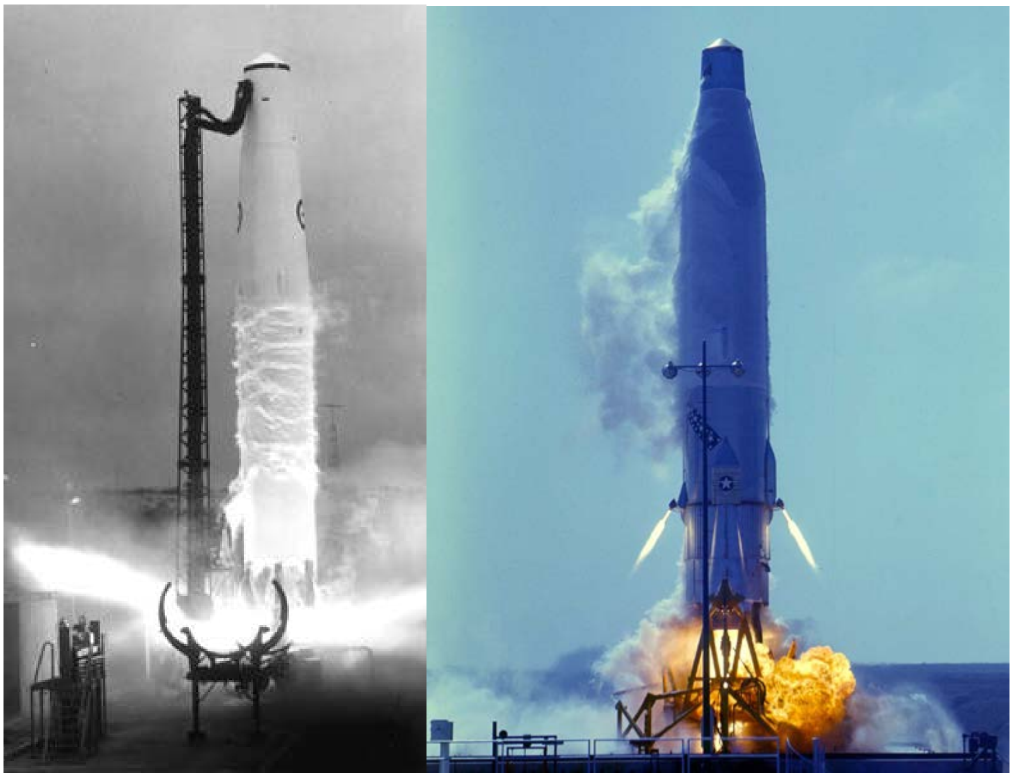
ARDC established the Western Development Division to manage Atlas, sending Brigadier General Bernard A. Schriever to Los Angeles to set up and command the new organization in August 1954. At first, the Division was responsible for developing only the Atlas, which was being designed and manufactured by the Consolidated Vultee Aircraft Corporation (Convair). It was an intercontinental ballistic missile with liquid-fuel engines and a stage-and-a-half configuration. Within a year, the Division also became responsible for developing an alternate missile called the Titan. A more advanced, two-stage missile to be built by the Martin Company, the Titan was a hedge against failure or delay in the Atlas program. By the end of 1955, the Division was also developing an intermediate range ballistic missile, the Thor, under contract to Douglas Aircraft Company. Finally, it was charged with achieving initial operational capability for the three missile systems. That meant deploying them, a massive undertaking in itself. In barely 18 months, the mission of the Division had undergone an enormous expansion.

The three people most directly responsible for the success of the early Air Force Strategic missile programs: Trevor Gardner (Assistant Secretary of the Air Force for Research and Development), then-Major General Bernard A. Schriever (commander of the Western Development Division), and Dr. Simon Ramo (CEO of the Ramo-Wooldridge Corporation). (U.S. Air Force photograph)

To develop operational missile systems as soon as possible, the Division replaced the conventional pattern of sequential development with concurrent development. Within the framework of a single overall plan, tasks related to development, production, testing, and initial operational capability proceeded simultaneously. Although the concept of concurrency was not new, the Division applied it on a scale never before used in military development programs.

The development of ballistic missile systems slowed in 1956-1957, when the Eisenhower administration made large cuts in defense spending to balance the budget.

However, on 4 October 1957, the Soviet Union used an ICBM to launch the first man-made satellite. Sputnik's impact was dramatic. The United States' missile program was given renewed impetus, restrictions were lifted, previous program priorities were reinstated, and funding was vastly increased.



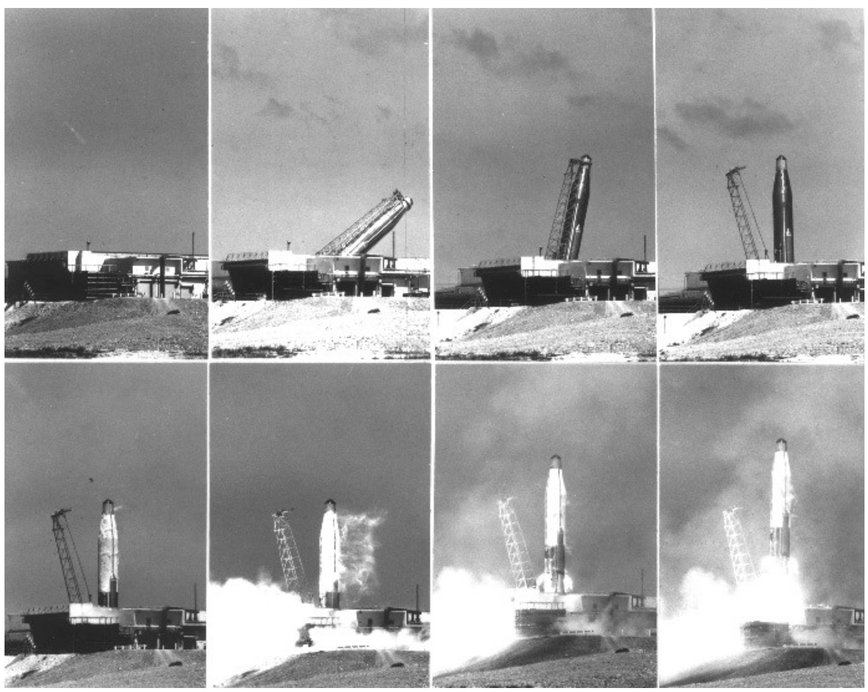
Left: "Lion's Roar," the first launch of a Thor IRBM by an RAF crew, takes place at Vandenberg AFB on 16 April 1959; Right: the first SAC launch of an Atlas missile (Atlas 12D) takes place at Vandenberg AFB on 9 September 1959. SAC then declared the Atlas weapon system operational.

On 20 September 1957, even before Sputnik, the Air Force Ballistic Missile Division successfully launched a Thor missile from Cape Canaveral, Florida. On 17 December, the Division carried out the first successful Atlas launch, also from Cape Canaveral. Following these successes, the Air Force missile program progressed rapidly. Deployment of the Thor was completed in 1960 at four 15-missile Royal Air Force squadrons in England. By the end of 1962, 132 Atlas launchers had been turned over to squadrons of the Strategic Air Command (SAC) by Ballistic Systems Division's Site Activation Task Forces (SATAFs). The Titan I made its first successful operational flight in 1960, and the SATAFs turned over all 54 Titan I launchers to SAC during 1962. By the end of 1962, therefore, all three first-generation missiles were in place and ready for operation.

Titan II and Minuteman

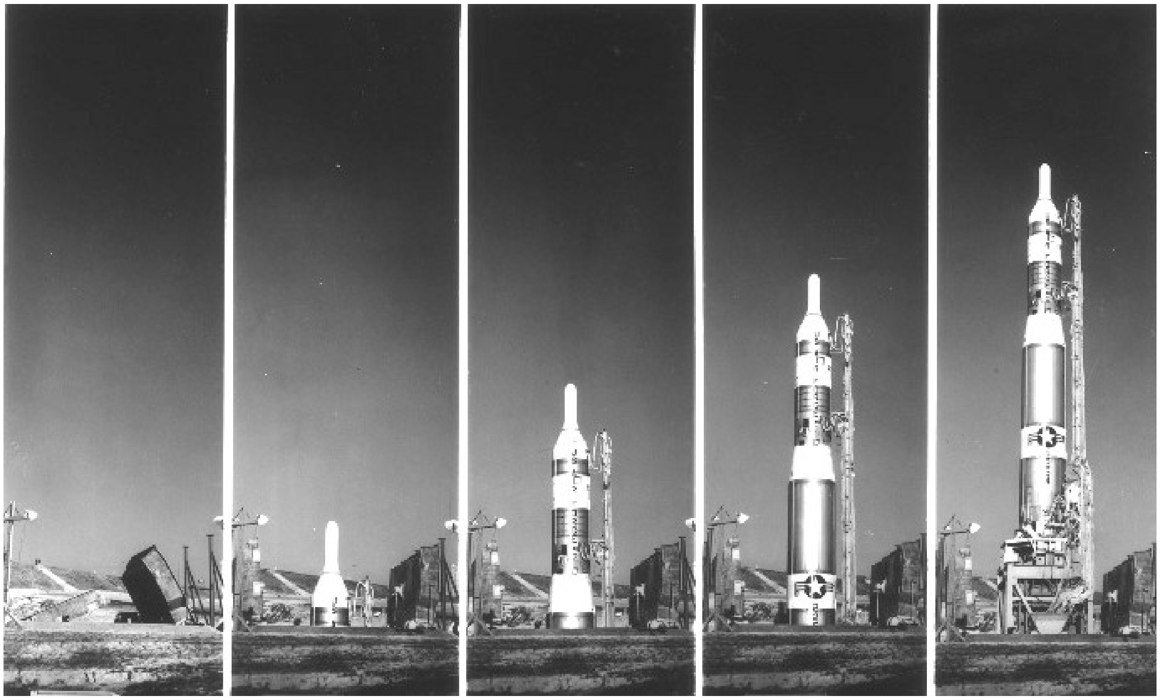
In the late 1950's, the Ballistic Missile Division began developing two second-generation missiles, the Titan II and the Minuteman. Like the original Titan I, Titan II

Titan I missile J-7 begins the first successful flight test of an operational Titan I ICBM on 10 August 1960 at the Atlantic Missile Range.



Atlas missile 25-D rises to a vertical position and begins a test flight on 22 April 1960. Atlas Ds—the first Atlas missiles to become operational—were stored in unprotected, above-ground, horizontal launchers. Later models of the Atlas were better protected. Atlas Es were stored in semi-hardened horizontal launchers, and Atlas Fs were stored in hardened vertical silos.

was a two-stage, liquid fuel missile. Unlike its predecessor, however, it used storable propellants and an all-inertial guidance system, and it could be launched from hardened underground silos. These improvements gave the Titan II quicker reaction time, greater survivability, and improved performance. The first Titan II unit achieved operational status in June 1963 and the last in December of the same year.



A Titan I missile emerges from its silo at Vandenberg's Operational System Test Facility in 1960. The Titan I was stored and fueled in a hardened underground silo, but an elevator had to lift it out of the silo before it could be launched. The entire launch sequence took about 15 minutes. Ultimately, the Titan I was deployed in 54 such silo-lift launchers divided among seven operational sites. All became operational in 1962, and all were inactivated in 1965.

The Minuteman was the first American intercontinental ballistic missile to use solid rather than liquid fuel. It possessed all the virtues of the Titan II, and its use of solid fuel gave it two additional advantages: greater simplicity and economy. The first Minuteman flight test missile was launched on 1 February 1961, and the first two flights of Minuteman missiles was turned over to the Strategic Air Command on 11 December 1962. By the end of 1965, Minuteman missiles had been deployed at four bases in the north central United States, and the older, less efficient, and less economical Atlas and Titan I missiles had been retired from the active inventory. The Minuteman, along with the Titan II, became the mainstay of the nation's strategic missile force. Together with SAC's manned bombers and the Navy's Polaris/Poseidon missile-launching submarines, these missiles formed the triad of strategic deterrent forces that were maintained on day-to-day alert to counter any nuclear attack on the United States or its allies.

Just as the Atlas and the Titan I had been replaced by the Titan II and the Minuteman, the original Minuteman was itself replaced by the more advanced Minuteman II and Minuteman III. The Minuteman II incorporated a new, larger second stage, improved guidance, greater range and payload capacity, and greater resistance to the effects of nuclear blasts. The Minuteman III, for its part, possessed an improved third stage, employed more penetration aids to counter anti-ballistic missile defense systems, and was equipped with up to three independently targetable warheads. By the end of 1975, 450 Minuteman IIs and 550 Minuteman IIIs were in place and ready for operation at six bases in the north central United States.

A Titan II ICBM undergoes a test launch from an underground silo. Unlike Titan I missiles, which had to be raised to the surface before launch, the Titan II's liquid rocket engines were ignited while it was still in the silo. Therefore the silo had to be constructed with flame and exhaust ducts as shown in this photograph.

Other portions of the ballistic missile force were becoming obsolete. The Air Force issued direction to deactivate Titan II missiles on 30 April 1982. The 55 operational missiles were removed from their silos during 1982-1987 and placed into storage for possible conversion to space launch vehicles.

Peacekeeper and Small ICBM

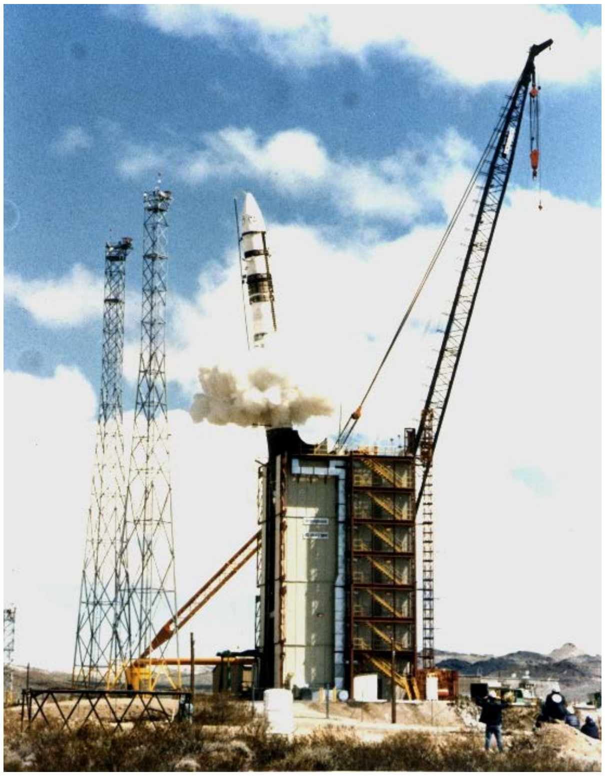
Under the terms of the 1972 Strategic Arms Limitation Agreement with the Soviet Union, this country was barred from increasing the number of strategic missiles in its operational inventory. If it wished to maintain its strategic position *vis a vis* the Soviet Union, therefore, it had to do so by improving the quality of its missiles rather than by increasing the quantity. With this objective in view, an advanced development program was started in late 1973 to define the technology and design concepts for a new strategic missile called Missile X. A great deal of effort was devoted to studying alternate basing concepts for this missile, including air-mobile and ground mobile concepts.

Missile X was renamed the Peacekeeper by President Reagan on 22 November 1982. It was a four-stage ICBM capable of precisely delivering 10 reentry vehicles to different targets more than 6,000 miles away. It successfully carried out its first flight test on 17 June 1983, when a Peacekeeper that had been cold-launched from a canister at Vandenberg AFB reached its target in the Kwajalein Missile Range. In April 1983, the President accepted the recommendation of the Scowcroft Commission that the

A Peacekeeper missile is launched from its silo. Unlike the Minuteman, which was launched by igniting the stage 1 motor while the missile was still in the silo, the Peacekeeper was ejected from its silo by hot gas, and its stage 1 motor was ignited when it was about 100 feet above the ground. (Photograph courtesy Air Force Space Command Public Affairs Office)

Peacekeeper be temporarily based in existing Minuteman silos. The first ten missiles went on alert between 17 October and 22 December 1986, and the basing program achieved full operational capability when the fiftieth missile entered its silo on 20 December 1988. DOD accepted a concept for a permanent basing mode in 1986. It involved placing 50 Peacekeeper missiles on 25 trains, which would be kept in protected shelters scattered throughout the country. When war threatened, the trains would be released to travel over the commercial rail network until their missiles had to be launched. The program entered full-scale development in May 1988. By the early 1990s, however, the Cold War was winding down, and the Soviet threat was diminishing. In a dramatic speech delivered in 27 September 1991, President Bush announced a wide-ranging plan to unilaterally reduce the American nuclear arsenal and eliminate several categories of weapons. As part of the plan, he announced the cancellation of the Peacekeeper Rail Garrison program.

The Scowcroft Commission had also recommended the development of a new, lightweight missile carrying only one reentry vehicle. President Reagan authorized full-scale development of the Small ICBM (SICBM) in December 1986. SICBMs would be housed in mobile launchers based at widespread locations. When hostilities threatened, the launchers would drive out onto the roadways and scatter across the country. The program narrowly escaped termination in 1988 because of reduced funding. It achieved its first totally successful flight test on 18 April 1991, when a SICBM that had been cold-launched from a canister at Vandenberg AFB reached its target in the Kwajalein Test Range. Nevertheless, President Bush canceled the SICBM program in January 1992 because strategic tensions seemed to have decreased after the end of the Cold War.

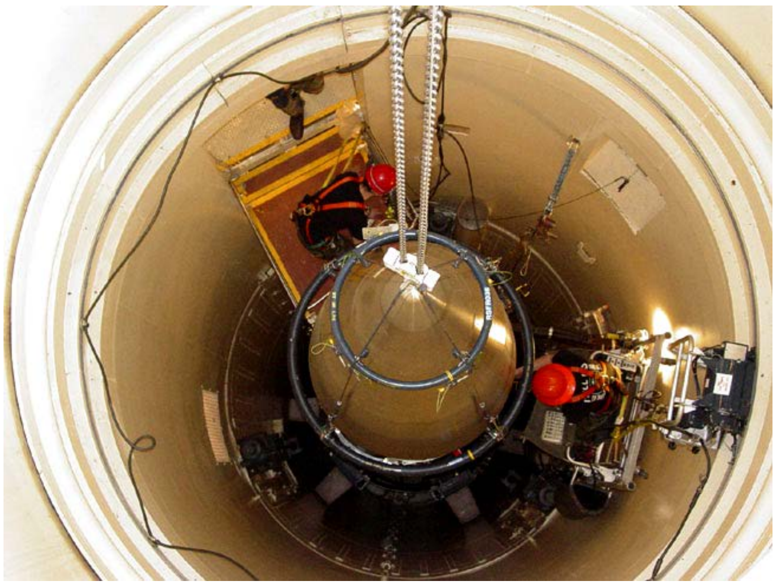


A simulated Small ICBM being ejected from its launch canister in the Canister Assembly Launch Test Program (CALTP). Like the Peacekeeper, the Small ICBM was to be "cold launched." The missile was to be ejected from a canister, and its stage 1 motor was to be ignited after the missile was in mid-air. The CALTP program tested the launch eject system and the effects of a cold launch on stage 1 of the missile.

Effect of ICBM Reduction Agreements

The Strategic Arms Reduction Treaty of 1991 (START I) and the START II treaty of 1993 progressively reduced the number of warheads that the United States and Russia could maintain and eliminated missiles with multiple warheads. These provisions required the United States to reduce the number of Minuteman missiles, permanently reconfigure the remaining missiles to launch only one warhead each, and scrap its Peacekeeper missiles. All of the Peacekeeper missiles were taken off alert and removed from their silos during 2002-2005, and some of their reentry vehicles were designated for use on the remaining Minuteman III missiles. The last Peacekeeper was removed from its silo at F.E. Warren AFB on 14 September 2005. The last Minuteman II missiles were dismantled and stored for use as launch vehicles in 1996, and 150 Minuteman III missile sites were destroyed during 1999-2001. By 2002, the entire Minuteman force consisted of only 500 Minuteman III missiles at three deployment sites (Warren AFB, Malmstrom AFB, and Minot AFB). To maintain them, SMC's ICBM Program Office at Ogden Air Logistics Center conducted major Minuteman life extension programs which replaced guidance systems, solid rocket motors, and power systems on the missiles as well as improving communications, command, and control equipment in the launch facilities.

Although START II was never ratified by the United States, subsequent diplomatic agreements limited the number of warheads in the American and Russian arsenals even further. In June 2002, the United States unilaterally withdrew from the Anti-Ballistic Missile Treaty of 1972 in order to develop a National Missile Defense System. In response, Russia announced that it would no longer be bound by the START II agreements. Nevertheless, a new Strategic Offensive Reductions Treaty (SORT)—also called the Treaty of Moscow—was signed by both countries in Moscow in May 2002. It limited deployed warheads to about half of the previous totals by 2012, a goal achieved by the U.S. in 2007, partly by inactivating another 50 Minuteman IIIs. That brought the total number of deployed land-based ICBMs in the United States to 450 Minuteman IIIs. The two countries signed a new strategic arms reduction treaty known as New START in April 2010, and it took effect after ratification a year later. Under its terms, deployed warheads as well as launchers were to be reduced even further by 2021, the year in which the treaty expired but could be extended. Although total numbers of nuclear-equipped launchers of all kinds were limited to 700 on each side, it was not yet clear by 2014 exactly how the reductions would affect the number of Minuteman IIIs.



An Air Force Space Command crew removes the nose section of a Minuteman III missile in a silo at Malmstrom AFB, Montana, early in 2003. Portions of the missile were to undergo flight testing in a launch from Vandenberg AFB as part of Air Force Space Command's continuing evaluation program for the remaining inventory of ICBMs. (Photograph courtesy Air Force Space Command News Service)

CHAPTER IV: LAUNCH VEHICLES

The world's first rocket launches to reach the edge of space were carried out by Germany in 1944 using V-2 missiles, at least half a dozen of which passed beyond the theoretical boundary between the atmosphere and space.[6] At the conclusion of World War II, the U.S. Army gathered up most of the remaining V-2 missiles and engineers in Germany and shipped them to Fort Bliss, Texas. There they were prepared for experimental launches from White Sands Proving Ground in Project Hermes during 1946-1952, some with various experimental upper stages. The Army also selected and integrated scientific experiments into each V-2 launched from White Sands. In 1947, an experiment from the Naval Research Laboratory took the first photographs of earth from space at an altitude of 100 miles. The Jet Propulsion Laboratory added a WAC Corporal research rocket to the V-2 in 1948, creating a configuration called Bumper, the world's first large rocket to successfully use an upper stage. On 24 February 1949, Bumper 5 reached an altitude of 244 miles, near the maximum altitude at which the International Space Station now orbits, although the upper stage did not attain enough velocity to go into orbit.

The first successful U.S. orbital launches—following the Soviet Union's successful volley of Sputniks on 4 October and 3 November 1957—were carried out by the Army Ballistic Missile Agency (ABMA) and the Naval Research Laboratory (NRL). Unfortunately, they followed the highly publicized failure of the first attempted launch of a Vanguard satellite on 6 December 1957. On 31 January, the ABMA successfully launched the first U.S. satellite, Explorer I, carrying cosmic ray and micro-meteor detectors. On 17 March 1958, on its third orbital attempt, the NRL successfully launched the second U.S. satellite, Vanguard I, carrying additional sensors to provide data on the orbital environment. Indeed, ABMA and NRL carried out the first 10 U.S. orbital launch attempts, though only four were unqualified successes.

They were followed later in 1958 by four unsuccessful attempts to reach the vicinity of the moon and a successful attempt by the ABMA on 4 March 1959 which passed beyond the moon and went into solar orbit. The first three of these lunar attempts in the Pioneer series of deep space missions were the first Air Force space missions and the first to use the Thor IRBM as a space launcher. (For a short description of the Air Force launches in the Pioneer lunar series, see Chapter VII later in this history.)

Thor, Atlas, and Titan II Derivatives

The first 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 (Pioneer 1) with a lunar probe launched on 11 October 1958 by a Thor missile with a Vanguard second stage, a configuration called the Thor Able. The first Air Force satellite was Project SCORE, an Atlas B developmental missile containing communications equipment provided by the Army's Signal Research and Development Laboratory in one of its side equipment pods. AFBMD launched the entire missile (minus the spent half stage) into orbit on 18 December 1958. (See Chapter VII later in this history.)

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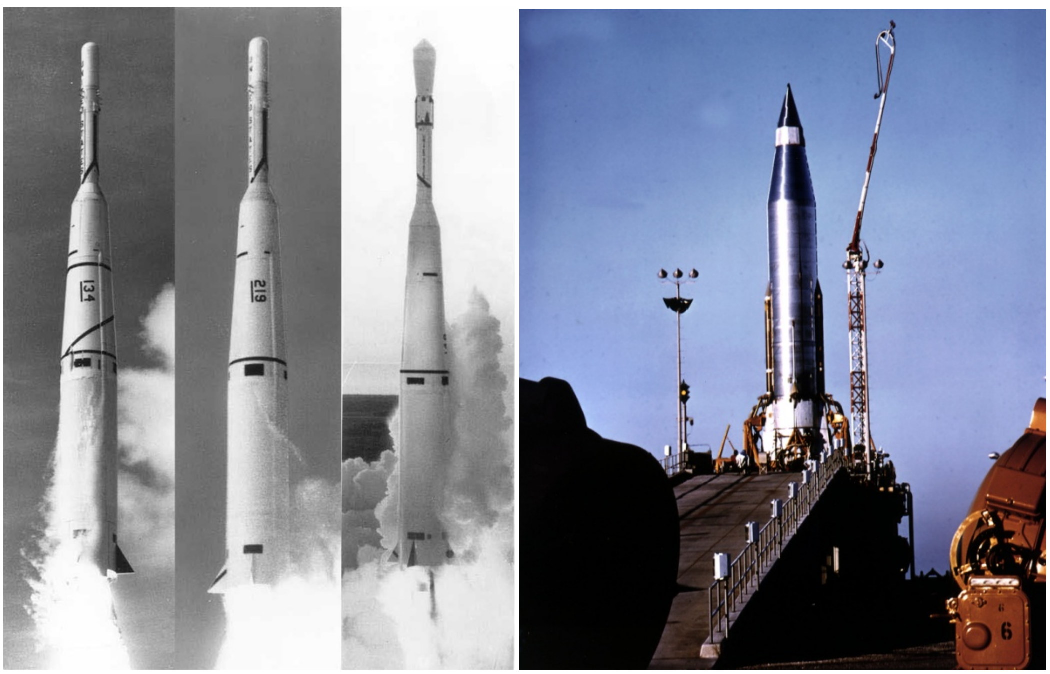
[6] The theoretical boundary of space used most often is the Karman Line, an altitude of 100 kilometers (62 miles) from the earth's surface.

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. 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 early backbone of the American space program. 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.



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. (U.S. Air Force photographs)

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 Air Force's Thor Able launcher—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 "man-rated" by Space Systems Division to launch maneuverable capsules carrying astronauts. The Gemini Target Vehicles, which were modified Agena upper stages, were also developed by Space Systems Division (SSD) and launched on Atlas vehicles. The Agena was later modified further by NASA and employed extensively by both agencies. The Centaur upper stage, for long 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.

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. (U.S. Air Force photographs)


Later, Space Division also converted obsolete Titan II missiles that were removed from their silos during 1982-1987.[7] They could place about 4,200 pounds into low-earth,

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

polar orbit, and they were employed primarily for meteorological and some experimental payloads. The first was launched on 5 September 1988. The last launched a satellite for the Defense Meteorological Satellite Program on 18 October 2003.

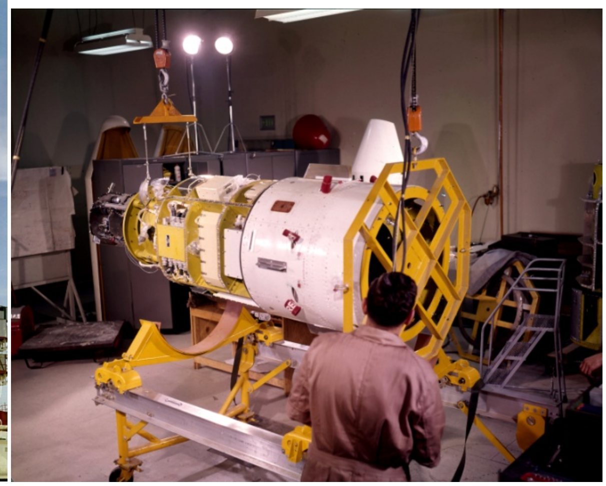
Left: The first Atlas Centaur combination rises briefly from the launch complex at Cape Canaveral on 8 May 1962. The Centaur exploded 55 seconds later. Below: The first Centaur upper stage is unloaded after air transport to Cape Canaveral on 25 October 1961. (U.S. Air Force photographs)

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. (NASA photograph)

Scout

Not all early launch vehicles were derived from missiles, however. The Scout (Standard Launch Vehicle 1) was a 3-, 4-, or 5-stage all-solid-rocket launcher used to place small payloads of 80-200 pounds into low earth orbits. It was the result of a merger of requirements and procurements by NASA and the Air Force. The Air Force Scout program originated in 1956 as a much more ambitious proposal by WDD's parent command, Air Research and Development Command (ARDC), to develop a family of progressively more powerful launchers which could ultimately send payloads on lunar and interplanetary missions. However, DoD's Assistant Secretary for R&D scaled back the program until it became a development plan for a small research vehicle in 1958.[8]

Left: A Blue Scout I (XRM-89) with a HETS payload sits on the pad at Cape Canaveral before its successful launch on 7 January 1961.
Below: The HETS payload carrier being prepared for launch on a Blue Scout. (U.S. Air Force photographs)



NASA's program,[9] which was the first to use the name Scout, originated at Langley Aeronautical Laboratory (then part of the National Advisory Committee for Aeronautics) in 1957 as a proposal for a basic launcher for low-altitude research payloads. In May 1958, the Air Staff proposed that the military and civilian programs be partially combined, and on 14 October 1958 the two agencies signed a memorandum of understanding to do so. NASA proceeded to develop the Scout, and AFBMD, using a different contractor, developed its own modifications into several configurations known collectively as Blue Scout.[10] AFBMD and SSD launched military payloads on the Blue Scout during 1960-1965, but their successors used NASA's Scout configurations until 1994.[11]

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[8] Although it was never approved, the proposal was the first Air Force attempt to create a space launch system not based on a ballistic missile. The concept was named the Ballistic Weapons and Development Supporting System (BALWARDS) in 1957, then the Ballistic Research and Test System (BRATS), and in 1958 the Hypersonic Environment Test System (HETS). The latter two designations were also known as WS 609A. By 1961, HETS had become only a payload carrier called the Hyper Environmental Test System for experiments on Blue Scout launch vehicles.

[9] NASA did not officially exist until 1 October 1958, at which time it absorbed the programs and laboratories of the National Advisory Committee for Aeronautics (NACA).

[10] The various configurations of launchers known as Blue Scout were known separately as Blue Scout 1 (XRM-89), Blue Scout 2 (XRM-90), and Blue Scout Junior (XRM-91).

[11] The Defense Systems Applications Program Block 1 (aka Program 35 and, later, DMSP Block 1) satellites were launched during 1962-1963 on NASA's Scout vehicles from the Point Arguello launch site.

Titan III

SSD also began the development of a new launch vehicle based on the Titan II missile with strap-on large solid rocket motors in late 1961. The primary requirements for the program at the time were providing a backup launcher for NASA’s lunar program and providing a launcher for the Air Force’s manned space glider known as Dyna-Soar. The launch vehicle program was soon named the Titan III, and its first research and development (R&D) launch occurred in September 1964. The R&D configuration, called the Titan IIIA, consisted of a modified Titan II core topped by an upper stage called the Transtage. This configuration augmented with solid motors was named the Titan IIIC, and it was first launched in June 1965. The IIIC used two strap-on solid rocket motors that generated around one million pounds of thrust each. It became a versatile work horse during the 1960s, 1970s, and 1980s for many high-priority DoD payloads, including nuclear surveillance satellites, missile surveillance satellites, and military communications satellites. Indeed, the entire family of Titan III vehicles performed well in a wide variety of missions and configurations from 1965 through 1989. The family

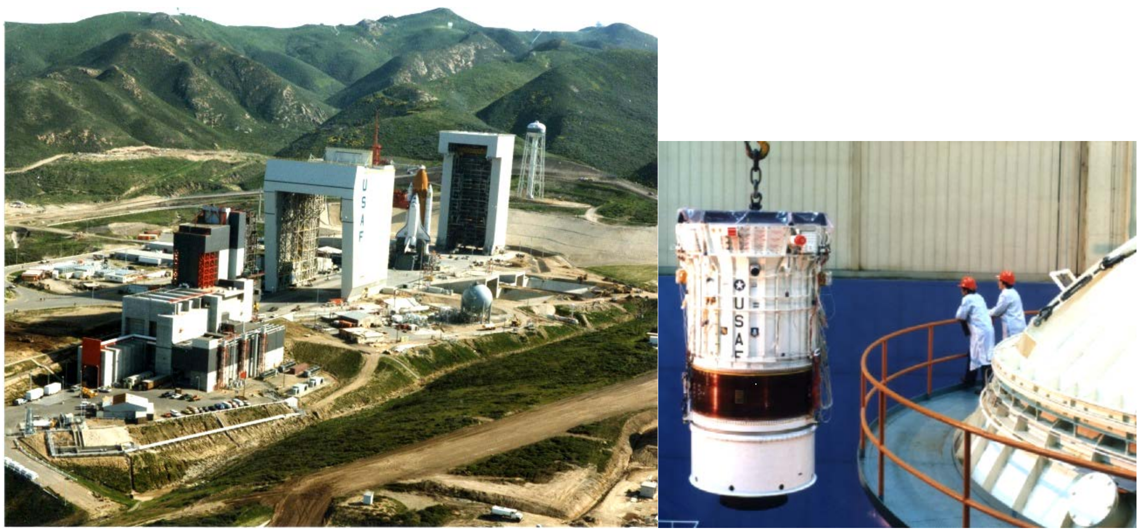
Left: A Titan IIIC launches seven satellites for the Initial Defense Communications Satellite Program and one experimental satellite on 16 June 1966. Right: A Titan 34D rises from the pad at Cape Canaveral. (U.S. Air Force photographs)

expanded to include the Titan IIIB Agena D, the Titan IIID, and the Titan IIIE Centaur. The IIIE 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 in 1989.

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 also 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 systems as well. Although it had a troubled and costly developmental period, the IUS came to be considered an accurate and reliable launch system.

Although DoD's use of the Space Shuttle did not reach the projected frequency for a variety of reasons, most missions of the Space Shuttle carried secondary, experimental payloads manifested by SMC's Space Test Program (STP). Nevertheless, 10 missions in particular were dedicated to major military payloads. Eight of those were classified, although one was subsequently declassified. The unclassified DoD missions



*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. (U.S. Air Force photograph)*
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. (Boeing Company photograph)

included the launch of two Defense Satellite Communications System Block III (DSCS III) satellites (using one IUS) on 3 October 1985, several large STP payloads on 28 April 1991, and a Defense Support Program (DSP) missile detection satellite on 24 November 1991.[12]

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 SMC's predecessor Space Systems Division.

[12] For a discussion of DoD Space Shuttle missions, see Dwayne Day, "A Lighter Shade of Black: The (Non) Mystery of STS-51J," The Space Review, 4 January 2010 (http://www.thespacereview.com/article/1536/1).

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 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.

During the later 1990s, NASA dedicated most Space Shuttle missions to the construction and supply of the International Space Station. However, the Department of Defense had shifted most of its missions during the later 1980s to expendable launch vehicles developed by SMC and its predecessors. NASA launched the last Space Shuttle mission on 8 July 2011.

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 was 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 called Titan IVAs, and those with the new motors, Titan IVBs.

Left: A Titan II 23G 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 Lockheed Martin Corporation)

In December 1996, SMC selected two proposals for a new procurement of launch vehicles known collectively as the Evolved Expendable Launch Vehicle (EELV) program. Neither proposal was based on the Titan, nor were the EELV development contracts that were awarded in October 1998. Since the heavy-lift versions of the EELV would launch the class of payloads that had been launched by Titans, the Titan program ended when the last of the existing Titan IVBs was launched. That launch occurred on 19 October 2005, successfully placing a spacecraft from the National Reconnaissance Office into orbit from Vandenberg AFB. It concluded one of the longest, most critical, and most successful chapters in the history of American space launch programs. For 45 years, Titans of many configurations had served as strategic weapons and as access to space for the nation's most important national security payloads.

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 (GPS Block II) without a single failure.[13] The Delta II was developed for GPS in two consecutive configurations. The first of those (6925) launched the first nine GPS Block II satellites from 14 February 1989 to 1 October 1990, while the second, more powerful version (7925) launched later, heavier Block II satellites (IIA, IIR, and IIR-M) from 26 November 1990 to 10 March 1994. During this entire period, a Delta II successfully launched a GPS satellite about every two months, an accomplishment rarely equaled.[14] 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 until 2009, suffering only one failure on 17 January 1997.

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 its first Air Force payload, a 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 the time of the last launch in 2004, about 15 military payloads, including four DSCS III satellites, had been launched on the Atlas II, IIA, and IIAS without any failures. In 1999,

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[13] See the description of GPS II under Navigation Systems in Chapter V.

[14] 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.

SMC used the existing Atlas contract to procure a few 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 versatile feature of the RD-180 was that it could be throttled on command to higher or lower thrust while in flight, the first such capability for a U.S. launcher.

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 Lockheed Martin Corporation)

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.[15] 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. The policy change undoubtedly contributed to the fact that by 2013 Air Force launches were experiencing the longest unbroken string of successes 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

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

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 proposed to develop a new launcher using existing technology. Nevertheless, the Secretary of Defense canceled it for reasons of cost later that year.

In the National Defense Authorization Act for 1994, Congress directed DoD to develop a plan for the modernization of space launch capabilities. In response, the Air Force initiated the Space Launch Modernization Plan, also known as the Moorman Study,[16] which identified options and costs for doing so. President Clinton signed a National Space Transportation Policy on 5 August 1994 which appeared to be based on those options. Among other provisions, it assigned responsibility for expendable launch vehicles to DoD and directed DoD to develop improved versions of existing vehicles. The final result was SMC's Evolved Expendable Launch Vehicle (EELV) program 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.[17] 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 Delta IV. The Delta IV vehicles shared a first-stage common booster core (CBC) and a cryogenic second stage.[18] The throttleable 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.[19] Heavier versions added one to five strap-on solid-rocket auxiliary motors. Designs for the heavy version of the Atlas V also used three CBCs joined together in a line, but in 2006, both the Air Force and Lockheed Martin decided that the existing market for heavy EELV launchers was not large enough to make two competing heavy launchers economical, and the Atlas V heavy

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[16] Named for the study's chairman, retired General Thomas S. Moorman, Jr., formerly commander of Air Force Space Command and Air Force Vice Chief of Staff.

[17] 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 considered at the time one of the Air Force's standard bearers in streamlined acquisition reform.

[18] 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.

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

was never produced.

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-

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 (Photograph courtesy International Launch Services). 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 courtesy The Boeing Company.)

2006. By the year 2000, however, agreements provided for launching the Atlas V only from the east coast but the Delta IV from both coasts. Unfortunately, the expected commercial market for EELV launch services failed to materialize because of increased foreign competition and economic problems in the satellite industry. Both EELV contractors announced their intention to withdraw from the launch market unless the government could cover their fixed costs. Using a strategy approved by the Secretary of the Air Force on 21 March 2005, SMC awarded contracts to both contractors in 2006 to maintain the launch infrastructure and launch services. In December 2006, Boeing and Lockheed Martin set up a jointly owned but separate corporation, United Launch Alliance (ULA), to provide launch services for both types of EELVs.

The Delta IV successfully passed several important operational milestones within its first few years. The first launch of the Delta IV placed a commercial satellite into a nominal orbit from Cape Canaveral on 20 November 2002. The first military 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, the first EELV launch of any kind from the west coast, took place on 27 June

2006.[20] The first operational launch of the Delta IV Heavy, an important milestone for assured access to space, successfully placed the last satellite in the Defense Support Program (DSP-23) into orbit from Cape Canaveral on 10 November 2007.

The Atlas V also passed its first operational milestones within the same period. The first launch of the Atlas V placed a commercial satellite into the correct orbit on 21 August 2002. Its first Air Force mission, which took place on 8 March 2007, successfully launched six experimental satellites for SMC's Space Test Program from Cape Canaveral. Its first launch from the west coast placed a classified payload into orbit from Vandenberg AFB on 13 March 2008.

The first Delta IV launch from the west coast on 27 June 2006 satisfied the final remaining operational requirement for the EELV program, and the commander of Air Force Space Command formally declared full operational capability (FOC) for the system on 12 December 2006. By the last quarter of 2013, the EELV program had accumulated an unprecedented string of 64 successful launches.[21]

Smaller Launch Vehicles

Although the EELV program replaced launch vehicles in the medium and heavy class, smaller launch vehicles were in use long before the EELV, and some continued to be used for lighter payloads, including sounding and ballistic missions and lighter military payloads in low earth orbits. Besides the Scout vehicle (see above), SMC and its predecessors employed several other types of small launchers. One of the earliest was the Pegasus, a winged, air-launched, three-stage, solid propellant vehicle developed by Orbital Sciences Corporation as the first privately developed launcher.[22] It was capable of placing payloads weighing less than a thousand pounds into low earth orbit. First launched in 1990, by the end of 2013 it had carried out 42 launches, all but three or four of which were successful. It was used often by SMC's Space Test Program and for other experimental missions by government agencies as well as for smaller commercial payloads.

Some small launchers were managed by SMC's Rocket Systems Launch Program (RSLP). RSLP traced its roots to the Advanced Ballistic Reentry Systems (ABRES) program, which was established on 14 May 1963 as a DoD joint-service program managed by Ballistic Systems Division to develop and test experimental reentry vehicles for strategic missiles using surplus missiles.[23] Those missiles were also used for space

[20] It was also 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. It had been modified later for the Space Shuttle and now had been modified again for the Delta IV. For information about the Manned Orbiting Laboratory (MOL) program, see Chapter VII, Other Programs, later in this history.

[21] This approximate number included 40 for Atlas V and 24 for Delta IV. It also included both commercial and government launches. However, each type of EELV suffered one partial failure. The CBCs on the first Delta IV Heavy cut off prematurely in 2004, and the Centaur upper stage on an Atlas V cut off prematurely in 2007.

[22] The Pegasus was launched from an aircraft at an altitude of about 40,000 feet. Its first launches used a B-52 as a carrier aircraft, and later launches used an L-1011.

[23] The experimental RVs were launched on surplus or inactivated Atlas missiles from Vandenberg AFB during 1963-1974, and subscale models were launched on Athena missiles from Green River, Utah, during 1964-1973. The ABRES program also used Minuteman missiles to test RVs during the 1970s. In January

launches after a memorandum issued by the Secretary of Defense on 21 August 1972. By the mid 1990s, the mission of providing space launches for DoD on a cost-reimbursable basis using surplus missiles was the primary mission of the program known by then as the Rocket Systems Launch Program (RSLP), which supported a diversity of missions including reentry testing, ballistic missile defense, guidance and navigation testing, and small space payloads.

RSLP stored and managed stages from inactivated Minuteman and Peacekeeper missiles. In some cases, it used the stages as targets for antiballistic missile programs. For space launches, it reused the stages primarily in small launch vehicles called the Minotaur and Taurus, both of which were built by Orbital Sciences Corporation.

The Minotaur was a four- or five-stage, ground-launched, solid propellant vehicle used in several different configurations, the smallest of which were based on Minuteman stages, and the most powerful of which were based on Peacekeeper stages. It was first launched in 2000, and, by the end of 2013, it had carried out 25 launches, all of which were successful. The Minotaur was often used by SMC's Space Test Program (STP) for experimental payloads.[24] The Taurus was a four-stage, ground-launched, solid propellant vehicle using stages from the Pegasus launcher (minus wings) on top of the first stage of

Top left: L-1011 launcher aircraft with Pegasus launch vehicle underneath; Top right: Minotaur I launch vehicle on pad at Wallops Flight Facility in preparation for launch of the ORS-1 satellite on 29 June 2011; Bottom left: First launch of Taurus launch vehicle on 13 March 1994 with DARPASAT and STEP Mission 0 (Photographs courtesy Orbital Sciences Corp.)

1982, ABRES became part of a broader program called Advanced Strategic Missile Systems (ASMS), the reentry part of which was known as the Reentry Systems Launch Program (RSLP) and managed surplus missile launch assets for all three services.

[24] The most recent of these was the Operationally Responsive Space (ORS-3) mission of 19 November 2013, which successfully launched STP's standard interface unit with 28 small "cubesats" from NASA's facility on Wallops Island.

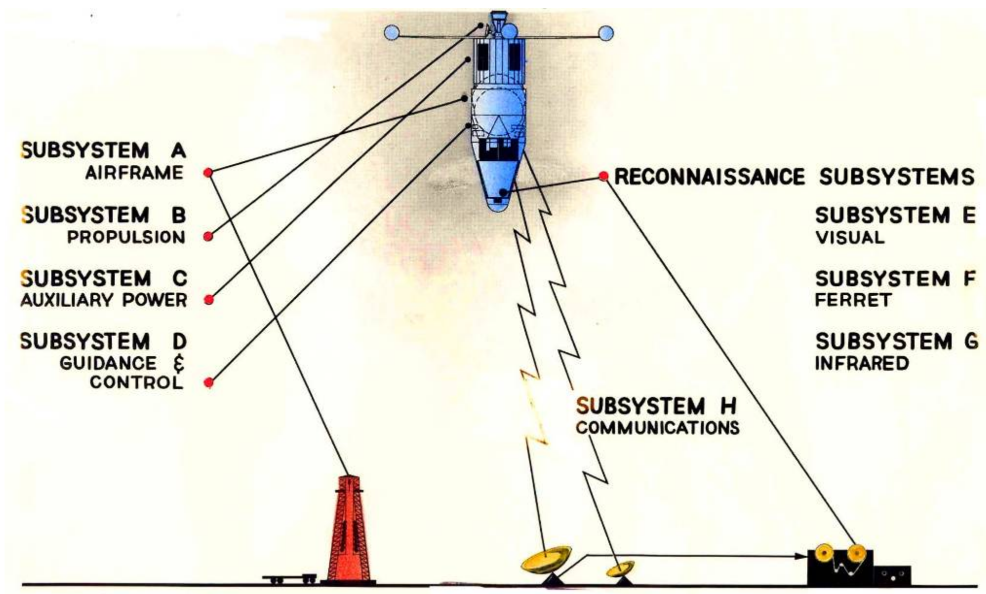
a Peacekeeper missile. The Defense Advanced Research Projects Agency (DARPA) began to develop the Taurus in 1989, and it was first launched in 1994. By 2013, it had been used for a variety of military and civil payloads, attempting nine launches and failing three times.

The Next Generation of Launch Vehicles

Although ULA was at first the only supplier for Air Force launches in the EELV class after 2006, other companies were soon attempting to break into the market. They included Space Exploration Technologies, Orbital Sciences Corporation, and Alliant Techsystems, each of which was developing space launch capabilities which might reintroduce competition in contracting for launch services for heavier payloads. The Air Force, NASA, and the National Reconnaissance Office in particular wished to take advantage of competitive new launch capabilities. In October 2010, the three agencies agreed to collaborate on efforts to satisfy launch requirements, and, in March 2011, they signed a memorandum of understanding which set out their shared plans for future acquisitions of launch vehicles in the EELV class. A major part of those plans involved a coordinated strategy for certifying the qualifications of new launch vehicles developed by companies who might bid on contracts for launch services. The three agencies signed an agreement which established criteria for certifying potential launch vehicles on 12 October 2011. The overall intent of the agreement, called the New Entrant Launch Vehicle Certification, was to allow emerging commercial launch providers to compete for future government missions.

CHAPTER V: SATELLITE SYSTEMS

The Air Force was the last U.S. military department to launch a satellite, but it was the first to sponsor engineering and conceptual studies of a satellite with specific military applications and the first to undertake the development of such a spacecraft. Its first effort emerged on 2 May 1946, when Douglas Aircraft Company's Project RAND issued a 250-page report called "Preliminary Design of an Experimental World-Circling Spaceship"[15] to support the claim of the Army Air Forces to the proposed new mission area of space.[16] RAND's report not only examined solutions to engineering problems for orbiting a satellite, it also discussed some of the major mission areas for satellites that were later developed by the Air Force, including reconnaissance, communications, and meteorology. Under contract after 1947 to the newly independent Air Force, and especially beginning in 1950 to the new Air Research and Development Command (ARDC), RAND continued to conduct studies that examined engineering solutions to problems involved in developing satellites with specific military missions. One of the most influential of those efforts was Project Feed Back, which culminated in a report issued on 1 March 1954 proposing the development of a reconnaissance satellite to provide photographic data on Soviet military preparations. Before the report was even issued, ARDC established a very small office at Wright Air Development Center[17] on 24 December 1953 to manage preparations to award design and development contracts for



A concept for WS 117L and its subsystems from a briefing given in 1957

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[15] A scanned copy of the entire report is available on the RAND Corporation's Internet site.

[16] Major General Curtis E. Lemay, then the Air Staff's Deputy Chief of Staff for Research and Development, issued the direction for the RAND report to counterbalance more general feasibility studies by the Navy that were being considered by the War Department's Aeronautical Board.

[17] The most detailed and interesting description of the activities of the early WS 117L project office is the first-person narrative of James S. Coolbaugh, published as "Genesis of the USAF's First Satellite Programme" in *The Journal of the British Interplanetary Society*, vol. 51 (1998), pp. 283-300. According to his narrative, Maj Coolbaugh became the first manager of the project on 24 December 1953.

the satellite, known at first as Project 1115 and soon afterward as the Advanced Reconnaissance System or Weapon System 117L (WS 117L).

The military satellite project was soon added to the mission of the Western Development Division, largely because of the development's intimate association with ballistic missiles, which rapidly acquired a role as space launchers equal to their role as weapons. The commander of Air Research and Development Command transferred responsibility for the program from Wright Air Development Center to WDD on 17 October 1955[18], and satellites grew into an increasingly important part of the activities of the Division's successors.

WS 117L was, in concept, a family of separate subsystems that could carry out different missions, including photographic reconnaissance and missile warning. After evaluating system design studies from Lockheed, RCA, and Martin, WDD awarded the first Air Force space development contract to Lockheed on 29 October 1956. However, by the end of 1959, WS 117L had evolved into at least three separate satellite programs: the Discoverer Program, the Satellite and Missile Observation System (SAMOS),[19] and the Missile Defense Alarm System (MIDAS).[20] Discoverer and SAMOS undertook the photographic reconnaissance mission, and MIDAS undertook the missile-warning mission.[21]

Reconnaissance Systems

The Discoverer program aimed at developing a film-return photographic reconnaissance satellite. The satellite carried a camera that took pictures from space as it passed over the Soviet Union and China. Film from the camera returned from orbit in a capsule. A parachute deployed to slow the descent of the capsule, and C-119J (later, JC-130) aircraft operated by the 6593rd Test Squadron from Hickam AFB, Hawaii, recovered the capsule in mid-air.[22] However, Discoverer's photo reconnaissance mission was not revealed to the public at the time. It was, instead, presented as an experimental program

[18] ARDC transferred oversight of the project office to WDD in a revision to System Requirement No. 5, dated 17 October 1955. However, the project's personnel did not physically complete their move to WDD until 1 April 1956.

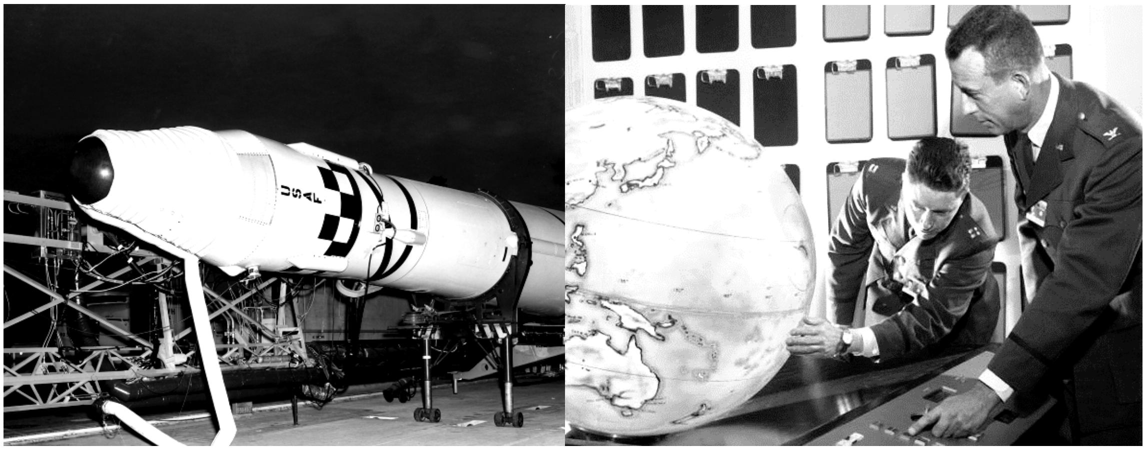
[19] SAMOS may have been made into an acronym after the name had been selected to go with MIDAS.

[20] The newly created Advanced Research Projects Agency (ARPA) was primarily responsible for the division of WS 117L into separate satellite programs. It issued separate directives for these and other military space programs from June 1958 to September 1959. ARPA's purpose was to accelerate near-term achievements in military space, and it succeeded in doing so.

[21] Under the WS 117L program, the visual reconnaissance payloads (which became the Discoverer and SAMOS programs) were known as Subsystem E, and the infrared reconnaissance payload (which became the MIDAS early warning program) was called Subsystem G. The spacecraft, which finally became the Agena combined upper stage and spacecraft, was called Subsystem A for the airframe and Subsystem B for the propulsion elements. Subsystem H for communications led eventually to the early Air Force Satellite Control Network.

[22] Not all capsule recoveries were nominal, however. A few were not recovered successfully in midair and had to be secured by air-dropped divers, rafts, and ships. For first-person accounts of recovery techniques and missions, see Robert Mulcahy, ed., *Corona Star Catchers*, GPO: June 2012.

to develop and test satellite subsystems and explore environmental conditions in space.[23]



Left: The Agena spacecraft for Discoverer 13, mated to its Thor launch vehicle, waits on the pad at Vandenberg AFB before being erected. The covering cooled and protected the spacecraft. Right: Colonel C. Lee Battle, Discoverer program director, and Captain Albert W. Johnson observe the ground track of a Discoverer (Corona) satellite in 1960, taking care not to look at the Soviet Union.

The Discoverer Program carried out 38 public launches and achieved many technological breakthroughs. Discoverer I, launched on 28 February 1959, may have been the world's first polar orbiting satellite.[24] Discoverer II, launched on 13 April 1959, was the first satellite to be stabilized in orbit in all three axes, to be maneuvered on command from the earth, to separate a reentry vehicle on command, and to send its reentry vehicle back to earth.[25] Discoverer XIII, launched on 10 August 1960, ejected a capsule that was subsequently recovered in the water near Hawaii, the first successful recovery of a man-made object ejected from an orbiting satellite. Discoverer XIV, launched on 18 August 1960, ejected a capsule that was recovered in midair northwest of Hawaii by a JC-119 aircraft, the first successful aerial recovery of an object returned from orbit. The capsule from Discoverer XIV was the first to return film from orbit, inaugurating the age of satellite reconnaissance. Satellite reconnaissance filled a crucial need because President Eisenhower had suspended aerial reconnaissance of the Soviet Union just three months earlier after the Soviets had shot down the U-2 spy plane piloted by Francis Gary Powers.

The Discoverer Program ostensibly ended after the launch of Discoverer

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[23] Nevertheless, some Discoverer missions carried experimental payloads instead of or in addition to their normal reconnaissance payloads. Mission 2 carried simulated biological experiments, but its payload was not recovered (at least, not by the U.S.). Mission 3 carried actual biological experiments, but its payload did not attain orbit. Missions 19, 21, 49, 52, 57, 73, 92, and 99 gathered infrared background data for the MIDAS program. Other missions carried geodetic payloads. For short descriptions of all Corona payloads, see Curtis Peebles, <u>The Corona Project</u>, Naval Institute Press, 1997.

[24] The Air Force officially claimed that Discoverer I had reached orbit, but the program's operations officer, Col Frank Buzard, said many years later that tracking stations had not received a verifiable signal. If Discoverer I did not achieve orbit, the distinction of being the first polar-orbiting satellite should go to Discoverer II.

[25] However, the reentered capsule was not recovered by the U.S. The consensus of researchers seems to be that it reentered over or near the island of Spitzbergen, where it may have been found by Russian miners.

XXXVIII on 27 February 1962. In reality, however, it continued in clandestine form until 31 May 1972 (the date of the last film recovery), carrying out 145 launches[26] under the secret code name Corona. At the direction first of President Eisenhower and later of President Kennedy, the direction and management of Corona and other satellite reconnaissance programs passed to a new DOD agency, the National Reconnaissance Office (NRO), when it was created in 1961.[27] Corona's first major accomplishment was to provide photographs of Soviet missile launch complexes. It also identified the Plesetsk Missile Test Range, north of Moscow, and provided information about what missiles were being developed, tested, and deployed. These and other accomplishments came to light when the Corona program was declassified in February 1995.

Left: A recovery crew of the 6593rd Test Squadron (Special) performs a practice midair capsule recovery in a JC-119 aircraft in 1959. Recovery crews flew JC-119s for the first 29 Discoverer missions and JC-130s after that. Right: President Dwight D. Eisenhower holds a news conference on 15 August 1960 to exhibit the capsule from Discoverer 13, recovered from the ocean four days earlier. Behind the president, left to right, are Colonel C. Lee Battle (Discoverer program director), General Curtis E. Lemay (Air Force vice chief of staff), Lieutenant General Bernard A. Schriever (commander of Air Research and Development Command), Dudley C. Sharp (Secretary of the Air Force), Thomas Gates (Secretary of Defense), General Thomas White (Air Force Chief of Staff).

SAMOS, the second program that evolved from WS 117L, aimed at developing a heavier reconnaissance payload that would be launched by an Atlas Agena booster rather than the Thor Agena used to launch Discoverer. The payloads were intended to collect photographic and electromagnetic reconnaissance data. The photographic data would be collected by cameras in the Agena spacecraft, like the Corona payloads. However, the film would be scanned electronically in orbit and transmitted to ground stations. SAMOS

[26] Including the 38 Discoverer launches.

[27] On 31 August 1960, Secretary of the Air Force Dudley C. Sharp created an Office of Missile and Satellite Systems. Reconnaissance programs under that office reported to the secretary of the Air Force through an undersecretary, Joseph V. Charyk. On 6 September 1961, the new Kennedy Administration established the NRO. Its joint directors, the undersecretary of the Air Force and the deputy director of the CIA, reported directly to the deputy secretary of defense for reconnaissance matters.

had three unclassified launches from the west coast: 11 October 1960, 31 January 1961, and 9 September 1961. Only the launch in January 1961 was successful. In 1962, a veil of secrecy was drawn across the SAMOS program, and the Air Force stopped releasing information about it. After several more classified launches, however, it was apparent that the technology required for downloading the imagery was not yet sufficiently advanced, and Air Force undersecretary Joseph V. Charyk canceled further work on the payload.[28]

Although SMC did not directly manage the development of imaging reconnaissance satellites after this, it did manage programs that were linked to them or their products. One of the most important was the Defense Dissemination System (DDS), whose broad outlines were declassified in 1996. The Defense Dissemination Program Office (DDPO) was established at SAMSO in July 1974 to develop a means to securely and rapidly provide reconnaissance imagery in nearly original quality to both strategic and tactical users. The DDPO developed a system consisting of segments for processing, transmitting, and receiving. The system was deployed to four strategic sites during 1976-1978, providing the first electronic dissemination of digital imagery for targeting and strategic threat assessment.

The DDS went through three more generations of increasingly sophisticated improvements for compressing, transmitting, receiving, and reconstructing imagery for military users in the field. One of the third-generation DDS units was deployed to the Persian Gulf to support Operations Desert Shield and Desert Storm. Fourth-generation DDS units were fielded to 70 strategic and tactical users by 1998. However, the DDPO itself ceased to exist as a program office on 1 October 1996,[29] when it was combined with other agencies to create the National Imagery and Mapping Agency (later renamed the National Geospatial-Intelligence Agency).

Infrared Early Warning Systems

The MIDAS program, the third offshoot of WS 117L, focused on developing a satellite with an infrared sensor to detect hostile ICBM launches. It began its life as a separate program when AFBMD placed the infrared portion of WS 117L (Subsystem under a separate contract with Lockheed effective 1 July 1959. The payload consisted of an infrared sensor array and telescope inside a rotating turret mounted in the nose of an Agena spacecraft. Plans which were never carried out called for an operational constellation of eight satellites in polar orbits to constantly monitor launches from the Soviet Union. Unfortunately, the program's first four test satellites launched in 1960 and 1961 ended in a launch failure and early on-orbit failures.

DOD kept the program in a research and development phase rather than approve an operational system in 1962. The MIDAS program was lengthened and renamed Program 461. The next two launches in 1962 also ended in an early on-orbit failure and a

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[28] However, the technology was secretly transferred to NASA, which used it successfully in its Lunar Orbiter imaging lunar satellites. See R. Cargill Hall, "SAMOS to the Moon: The Clandestine Transfer of Reconnaissance Technology Between Federal Agencies," NRO Office of the Historian, October 2001.

[29] As an organization, the DDPO was characterized by unusually high *esprit de corps*. It received a larger number of Air Force Organizational Excellence Awards than any other program office in SMC's history.

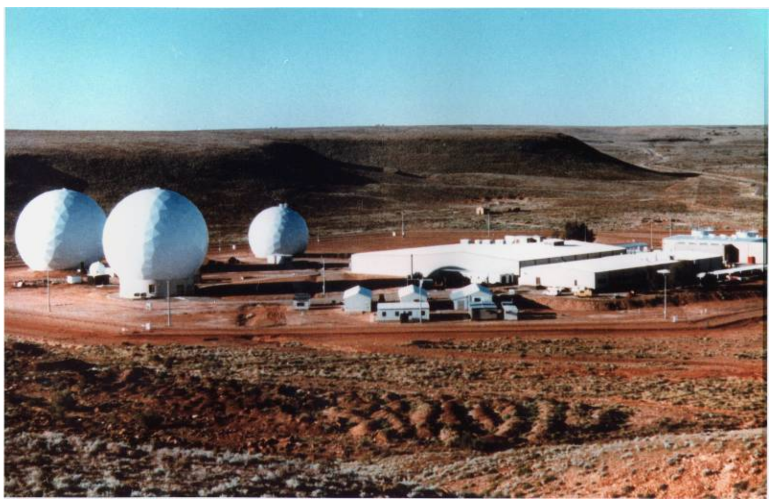
launch failure. Finally, a satellite launched on 9 May 1963 operated long enough to detect 9 missile launches. After another launch failure in 1963, the last Program 461 satellite, launched on 18 July 1963, operated long enough to detect a missile and some Soviet ground tests. Data collection and analysis continued until 1968 under Lockheed's contract for Program 461 to support the next early warning program. Additional launches in 1966, using improved spacecraft and sensors, demonstrated the system's increasing reliability and longevity. Although a launch on 9 June 1966 failed, launches on 19 August and 5 October 1966 placed their spacecraft into highly useful orbits, where their infrared sensors gathered data for a year, reporting on 139 American and Soviet launches. The MIDAS program and its successors were declassified in November 1998.

Left: The Agena spacecraft for MIDAS I waits for installation on Atlas 29D before its unsuccessful launch on 26 February 1960. Right: The payload for an advanced version of MIDAS, known as AFP 461, is covered with the Agena's nose cone before its unsuccessful launch as MIDAS 6 on 17 December 1962.

DOD initiated a new program late in 1963 to develop an improved infrared early warning system, which ultimately became the Defense Support Program. After an early phase known as Program 266, contracts for development of Program 949, the Defense Support Program (DSP), were awarded to TRW for the spacecraft on 6 March 1967 and to Aerojet for the infrared sensor on 1 March 1967. The new concept involved placing the satellites into orbits at geosynchronous altitude (22,237 miles), where only three or four would be necessary for global surveillance. Like MIDAS, the satellites would employ telescopes and IR detectors, but the necessary scanning motion would be accomplished by rotating the entire satellite around its axis in space several times per minute. An evolving network of two, and later three, large ground stations in Australia, Europe, and the continental U.S. controlled the spacecraft and data.

The first DSP satellite was launched on 6 November 1970, using a Titan IIIC launch vehicle. A long series of increasingly larger, more sophisticated, and more reliable satellites followed,[30] all of them except two launched on Titan III or Titan IV vehicles.[31] The 23rd and final DSP satellite was successfully launched on the first operational Delta IV Heavy EELV in November 2007.

Right: The first DSP satellite, known as DSP Flight 1, is shown in testing at the facilities of TRW, the prime contractor. SAMSO's DSP program director, Colonel Frederick S. Porter, Jr., stands at the right of the satellite. It was launched successfully on 6 November 1970 from Cape Canaveral.



Left: The first operational fixed ground station for DSP, known as the Overseas Ground Station (OGS), was located at Woomera Air Station, Australia. It became operational in 1971.

DSP provided a level of early warning that soon became indispensable for both military and civil defense. The spacecraft also carried sensors that performed nuclear surveillance, a mission inherited from the Vela system (following in this chapter). Although designed for strategic uses, DSP proved to be more versatile. During the

[30] DSP satellites launched during 1970-1973 weighed 2,000 pounds, had a design life of 1.25 years, and incorporated 2,000 lead sulfide detectors operating in the short wave infrared range; they could see targets only below the line of the earth's horizon. After undergoing five major upgrades, satellites launched beginning in 1989 weighed 5,250 pounds, had a design life of 3 years, and incorporated 6,000 lead sulfide detectors with an additional set of mercury cadmium telluride detectors operating in the short wave and medium wave infrared range; they could see targets both below and above the line of the earth's horizon. See Major James Rosolanka, "The Defense Support Program (DSP): A Pictorial Chronology, 1970-1998," SBIRS Program Office.

[31] DSP-16 was launched on a Space Shuttle (STS-44) on 24 November 1991.

Persian Gulf War, it provided early warning against tactical missiles as well. By 1997, SMC and Air Force Space Command had exploited that capability by adding central processing facilities and tactical ground stations to provide tactical data from DSP to battlefield commanders more rapidly and efficiently.

During the early 1990s, SMC began to pursue concepts and technologies for follow-on systems to replace DSP. By 1994, the concept for a system to succeed DSP was known as the Space-Based Infrared System (SBIRS) and was identified as a requirement by DoD in a "Space-Based Warning Summer Study" issued in September 1994. SBIRS was to be an integrated system that would support several missions: missile warning, missile defense, battlespace characterization, and technical intelligence.

The SBIRS concept actually included two planned satellite systems, referred to as SBIRS High[32] and SBIRS Low.[33] Both were heirs of infrared technology developed for the Ballistic Missile Defense Program (earlier known as the Strategic Defense Initiative) during 1983-1995. SBIRS High was focused on the detection and tracking of missiles during the earlier phase of their flight, while their motors were generating heat and infrared signatures in short wave lengths. SBIRS Low would add the capability of tracking and reporting other data about missiles during the middle portions of their flight, when their infrared signatures were at longer wave lengths.

To prepare for the development of SBIRS Low, SMC awarded contracts for on-orbit demonstrations to TRW on 2 May 1995 and to Boeing on 2 September 1996. However, oversight of the SBIRS Low program was transferred back to the Missile Defense Agency (MDA) during 2001, where it was renamed the Space Tracking and Surveillance System (STSS). The MDA developed STSS demonstration satellites to test the feasibility of providing midcourse surveillance of ballistic missile launches, and it launched the first two demonstration satellites together on 25 September 2009 using a Delta II vehicle. By the end of 2013, the STSS demonstration satellites were participating in successful missile intercept tests by the MDA.

SMC awarded a ten-year development contract for SBIRS High to Lockheed Martin on 8 November 1996. The SBIRS High program had to be restructured during 2001 and again in 2005 to deal with potential cost and schedule overruns, but its technical progress continued. On 18 December 2001, a consolidated SBIRS Mission Control Station (MCS) at Buckley AFB, Colorado, was declared operational. The MCS provided a central capability for command and control of all operational DSP satellites and other infrared data sources. The completion of this first segment of the ground system upgrade allowed older DSP ground stations to be closed. Afterward, the ground system continued to evolve to support satellites of the SBIRS High system.

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[32] The technological basis for the high-altitude follow-on system to detect missile launches was an earlier program under OSD's Strategic Defense Initiative (SDI) known as the Boost Surveillance and Tracking System (BSTS). It had been transferred to the Air Force in FY 1992 and had gone through several conceptual changes known as the Advanced Warning System (AWS), the Follow-on Early Warning System (FEWS), and the Alert Locate and Report Missiles (ALARM) program.

[33] The technological basis for the low-altitude follow-on system to track missiles in the middle portion of their trajectories had also been an SDI program. It had been known as the Space Surveillance and Tracking System (SSTS) during the mid and late 1980s and as Brilliant Eyes during the early 1990s.

The space segment of SBIRS High consisted of two kinds of satellites occupying very different orbits. Payloads known as SBIRS HEO flew in highly elliptical orbits and were designed to detect ballistic missiles launched from submarines in the region of the Arctic Ocean as well as certain other targets. HEO payloads, which were equipped with scanning IR sensors, were carried on host satellites from other programs. Payloads known as SBIRS GEO flew on their own satellites in geosynchronous orbit and were designed to carry out strategic missile warning and detection with scanning IR sensors as well as tactical missile warning and detection (and other technical intelligence) in focus areas using staring IR sensors. The satellite's sensors featured greatly improved sensitivity and revisit rates compared to DSP.

Left: SBIRS HEO-1 payload in testing at Northrup Grumman's Azusa facility in 2005
Below: SBIRS GEO-2 payload during encapsulation for launch in March 2013
(Photographs courtesy Lockheed Martin)

The restructured SBIRS program after 2005 called for delivery of two developmental GEO satellites, two HEO payloads, and associated ground systems. Based on the success of the developmental hardware in testing, SMC awarded a follow-on production contract for the third GEO satellite and the third HEO payload to Lockheed Martin in 2009. It exercised options for the fourth GEO satellite and HEO payload in 2011.

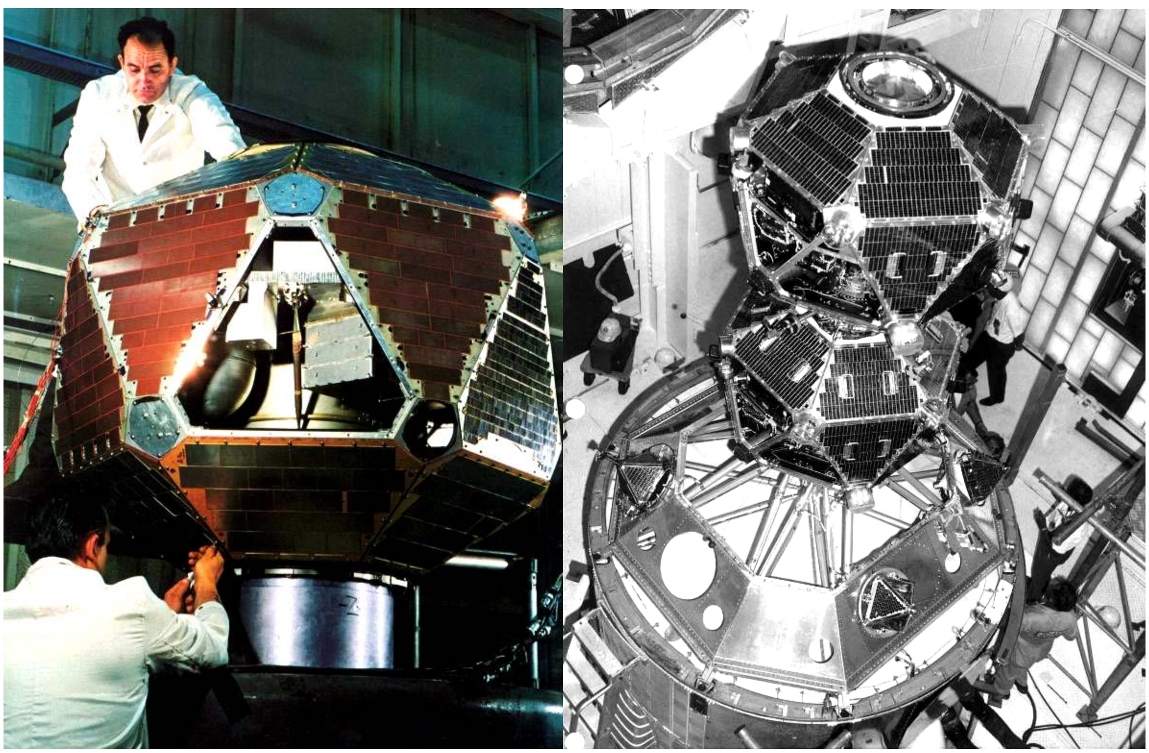
By the end of 2013, operational results after the initial launches of SBIRS HEO and GEO were proving the systems to be highly successful, and the new SBIRS constellations continued to grow. The first two orbiting HEO payloads were operationally certified by US Strategic Command on 5 December 2008 and 7 August 2009. SMC accepted delivery of the HEO-3 payload in July 2013 and approved its shipment for integration with the host spacecraft. The GEO-1 and GEO-2 satellites were launched on 7 May 2011 and 19 March 2013 using Atlas V vehicles. Air Force Space Command accepted both GEO satellites for operations during 2013.

SMC also began to examine alternatives and improvements for the SBIRS system. One possibility that led to orbital testing was called the Commercially Hosted Infrared

Payload (CHIRP). It consisted of a wide-field-of-view staring infrared sensor built by Science Applications International Corporation. The payload was hosted on a commercial geosynchronous communications satellite called SES-2. It was launched on 21 September 2011 and carried out many demonstrations of possible tactical applications for commercially hosted infrared technology. After several extensions of the contract for additional demonstrations, the sensor was decommissioned on 6 December 2013.

Nuclear Surveillance

In addition to reconnaissance and missile warning, SMC and its predecessors have developed satellites to serve a number of other purposes, among which are nuclear surveillance, weather observation, navigation, and communication. The first space system to accomplish nuclear surveillance was called Vela Hotel—later, simply Vela. Representatives of the Air Force Ballistic Missile Division (AFBMD), the Atomic Energy Commission, and NASA met on 15 December 1960 to initiate a joint program to develop a high-altitude satellite system that could detect nuclear explosions. Its primary purpose was to monitor compliance with the Nuclear Test Ban Treaty then being negotiated in Geneva. During 1961-1962, the Atomic Energy Commission developed detectors and flew experimental versions on Space Systems Division's Discoverer satellites.



Left: A Vela satellite in fabrication at TRW's facility. Right: A pair of Vela satellites (Vela 5A and 5B) mounted on their Titan IIIC launch vehicle before installation of the fairing. They were launched successfully on 23 May 1969. (U.S. Air Force photographs)

SSD issued a contract for the spacecraft to Space Technology Laboratories (later part of TRW) on 24 November 1961. The first pair of satellites was launched using an Atlas Agena on 16 October 1963, a few days after the Limited Nuclear Test Ban Treaty went into effect, and two more pairs were launched on 16 July 1964 and 17 July 1965. Six Advanced Vela satellites, containing additional, more sophisticated detectors, were launched in pairs on Titan IIIC vehicles on 28 April 1967, 23 May 1969, and 8 April 1970.

The Vela satellites successfully monitored compliance with the Limited Nuclear Test Ban Treaty of 1963, but also with later treaties such as the Outer Space Treaty of 1967 and the Non-ProliferationTreaty of 1968. They also provided scientific data on natural sources of space radiation for many years.[34] The least successful of the original satellites operated for ten times its design lifetime of six months. The last of the advanced Vela satellites was deliberately turned off on 27 September 1984, over fifteen years after it had been launched. However, their mission continued to be performed by payloads of the Nuclear Detection System hosted on DSP and GPS satellites.

Meteorological Systems

Providing the systems with which to conduct military weather observations from space is presently the mission of the Defense Meteorological Satellite Program (DMSP), which maintains a constellation of at least two operational weather satellites in polar orbits about 450 miles above the earth. DMSP satellites now carry primary sensors that provide images of cloud cover over the earth's surface during both day and night, and they also carry other sensors that provide additional types of data on weather and on the space environment.

The first DMSP satellites[35] were developed by a program office physically located with Space Systems Division but reporting to the National Reconnaissance Office (NRO),[36] which needed analyses of cloud cover over Eurasia to plan its photographic reconnaissance.[37] The program office awarded a development contract for weather satellites employing television cameras to RCA in 1961. DMSP Block I began with five launch attempts on Scout launch vehicles during 1962 and 1963, all but one of which failed.[38] Later Block I launches on Thor Agena and Thor Burner I vehicles were more

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[34] Vela satellites provided data that led to the discovery of the astronomical sources of gamma ray bursts. They also provided data for studies of radiation in the earth’s magnetosphere and studies of atmospheric phenomena such as meteoric fireballs and lightning.

[35] The program was known at first as the Defense System Applications Program (DSAP), which also used the numerical designation Program 35 during 1961-1962 and Program 417 during 1962-1973. In 1973, the program was partially declassified and renamed the Defense Meteorological Satellite Program.

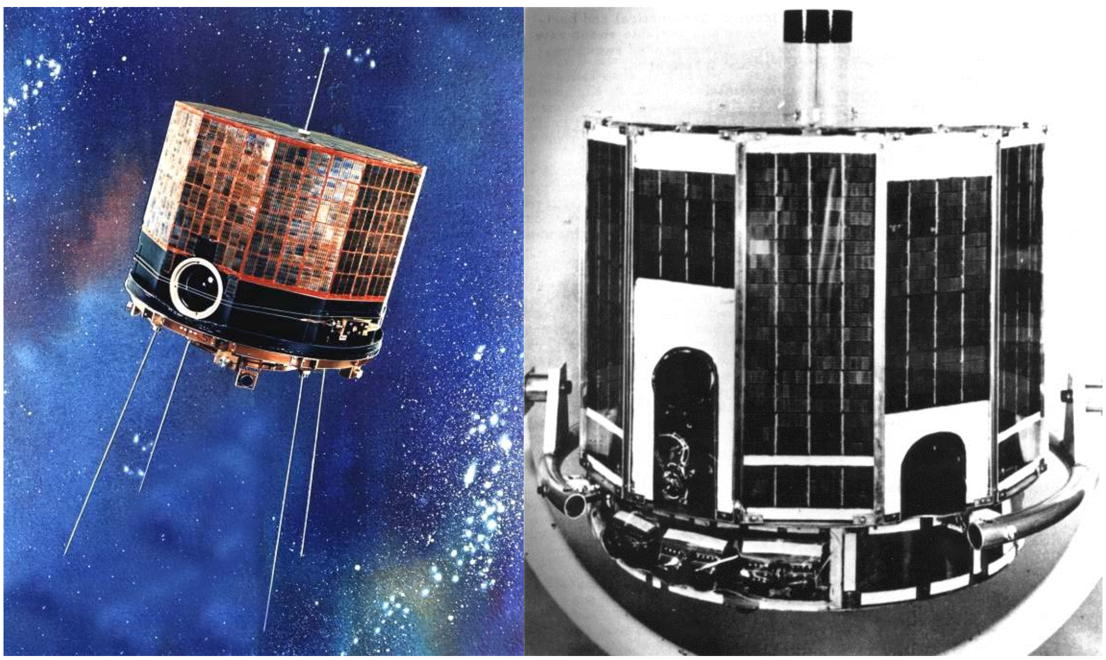
[36] See R. Cargill Hall, A History of the Military Polar Orbiting Meteorological Satellite Program, National Reconnaissance Office, September 2001.

[37] Although NASA was developing a National Operational Meteorological Satellite System, the NRO’s director, Under Secretary of the Air Force Joseph V. Charyk, did not believe it would adequately support the NRO’s missions.

[38] The first launch attempt took place on 23 May 1962, but it failed. The first successful launch was the second attempt on 23 August 1962. Later unsuccessful Scout launches took place on 19 February 1963, 26 April 1963, and 27 September 1963. Successful Thor Agena D launches were carried out on 19 January 1964 and 17 June 1964. Block I launches on Thor Burner I rockets took place on 18 January 1965 (failure) and 18 March 1965 (success). Block II launches on Thor Burner I vehicles were on 9 September 1965 (success), 7 January 1966 (failure), and 30 March 1966 (success). The only Block III satellite was launched successfully on 20 May 1965 using a Thor Burner I launch vehicle.

successful. Two launches in 1964 using Thor Agena vehicles placed two Block I satellites in orbit during each launch and provided enough weather imagery for strategic purposes for the first time. Six launch attempts during 1965 and 1966 employed a new Thor upper stage known as Burner I for DMSP payloads, including two more Block I, three Block II, and one Block III.

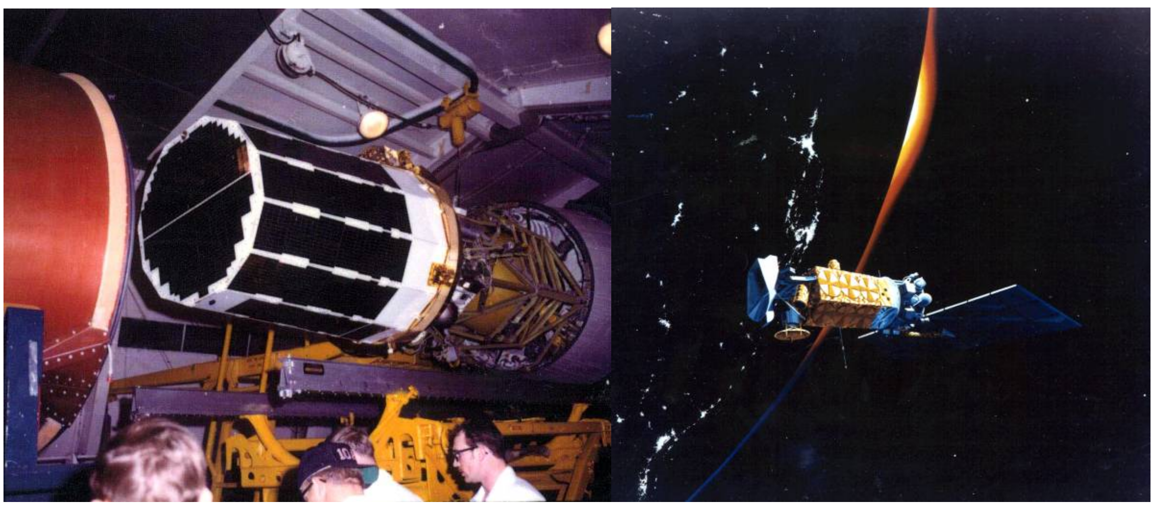
Besides providing weather information for strategic purposes, early DMSP satellites also provided the earliest tactical uses of space-based weather information. A Block I satellite launched on 18 March 1965 secretly provided weather data for North and South Vietnam to a ground station at Tan Son Nhut Air Base in Saigon. This was the world's first use of satellite imagery to support tactical military operations. The Block II satellites were also modified for direct readout of meteorological data so that they could be used for planning tactical air operations in Southeast Asia while continuing to provide weather information for strategic reconnaissance. The single Block III satellite, launched in 1965, was equipped only for tactical uses in Southeast Asia.



Left: An artist's concept for the DMSP Block I satellite, launched 1962-1963. Blocks II and III were similar. Right: DMSP Block IV satellites, launched 1966-1969, included the first major improvements in DMSP sensors.

Wider military uses for weather data led to an important change in the program's reporting structure when, on 1 July 1965, it became a program office under Space Systems Division. Development of more capable and more complex satellites also came to fruition with DMSP Block 4 satellites, seven of which were launched during 1966-1969. Television resolution improved from 3 to 4 nautical miles with Blocks I and II to 0.8 to 3 nautical miles with Block 4, along with many other improvements in the sophistication of secondary sensors. Block 5A satellites introduced the Operational Line Scan (OLS) sensor, which provided images of clouds in both visual and infrared spectra. Television resolution improved to 0.3 nautical miles in daylight. Three Block 5A, five 5B, and three 5C satellites were launched during 1970-1976 on Thor Burner II launch vehicles. Larger and much more sophisticated Block 5D-1 satellites were also developed during the 1970s, but only five were built. This proved to be a mistake in 1980, when the fifth 5D-1 satellite was lost in a launch failure, and the operational 5D-1 satellites in orbit ceased to function prematurely. From August 1980 to December 1982, when the first Block 5D-2 satellite was successfully launched, meteorological data was supplied to DOD entirely by civilian satellites. That mistake was not repeated with Block 5D-2 satellites, nine of which were launched during 1982-1997 on Atlas E and Titan II launch vehicles.

In 1989, Space Systems Division began the procurement of five Block 5D-3 satellites from General Electric (later acquired by Lockheed Martin). The 5D-3 satellites featured advanced spacecraft buses as well as significant enhancements in their suite of sensors, power and communications subsystems, and expected lifetimes.[39] Launches of the fully developed 5D-3 satellites began with F-16 in 2003, using the last Titan II vehicle. Satellite F-17 was launched on a Delta IV vehicle in 2006 and F-18 on an Atlas V in 2009. By early 2014, two more Block 5D-3 satellites were waiting to replenish the constellation.



Left: The payload fairing is being installed over a DMSP Block 5A satellite mated to a Burner II upper stage on a Thor Burner (LV-2F) launch vehicle about 1970-1971. Right: This artist's concept depicts a DMSP Block 5D-3 satellite in an early-morning orbit. The DMSP constellation consists of two operational satellites and two spares in sun-synchronous polar orbits. One of the operational satellites crosses the equator (northward) early in the morning, and the other does so at noon local time.

U.S. civilian weather satellites were operated by the National Oceanic and Atmospheric Administration (NOAA). Proposals to merge the civilian and military meteorological systems had been made from time to time since the early 1970s. On 5 May 1994, President Clinton issued a presidential decision directive ordering the convergence and eventual merger of the two programs into a new national space-based system for environmental monitoring. SMC was responsible for carrying out the major systems acquisitions, including satellites and launch vehicles. However, NOAA was to

[39] In the late 1990s, SMC conducted a separate acquisition of another satellite from RCA using the advanced spacecraft but with a suite of sensors closer to the 5D-2 satellites. It was launched as DMSP F-15 in 1999.

have overall responsibility for operating the new system, which was soon named the National Polar-orbiting Operational Environmental Satellite System (NPOESS). A Tri-Agency Integrated Program Office (IPO) made up of representatives from NOAA, NASA, and DOD would be responsible for carrying out major systems acquisitions, including satellites and launch vehicles. However, NOAA would have overall responsibility for operating the new system, which was soon named the National Polar-orbiting Operational Environmental Satellite System (NPOESS). A major step in convergence occurred in 1998, when the new Satellite Operations Control Center (SOCC) for NPOESS took over control authority of the existing DMSP system.

The merger of the two programs proved to be an unsuccessful experiment. After a phase of competitive development, SMC issued a contract to TRW (acquired by Northrop Grumman) in 2002 to further develop, deploy, and operate NPOESS under the direction of the NPOESS Integrated Program Office (IPO). Unfortunately, the development program suffered a long period of cost increases and schedule delays. Despite restructuring by DoD in 2006, the problems continued. A presidential task force formed to examine the problem in 2009 concluded that the IPO's management structure was fundamentally flawed, and it recommended dividing NPOESS into civilian and military programs once again. NOAA began the development of a follow-on system known as the Joint Polar Satellite System (JPSS), and DoD established the Defense Weather Satellite System (DWSS) in 2010 as the follow-on program for DMSP and the DoD replacement for NPOESS.

Nevertheless, Congress cancelled funding for DWSS for 2012, and the Air Force formally terminated design work on the new system in April 2012. Despite the cancellation, Congress provided funding to begin work on a new development program for a space-based military weather system in its appropriations for 2014. Fortunately, the long projected on-orbit lifetimes of Block 5D-3 satellites along with the two satellites not yet launched allowed a cautious approach to a new DoD weather system. One possibility under consideration was a concept known as disaggregation, which would involve placing various weather sensors on different satellites.

Navigation Systems

The world's first space-based navigation system was called Transit. It was developed by scientists at Johns Hopkins University's Applied Physics Laboratory in 1958. DOD's Advanced Research Projects Agency (ARPA) initiated the development program in September 1958 and assigned it to the Navy a year later. The Air Force Ballistic Missile Division launched the Navy's first Transit satellite on 13 April 1960. The system achieved initial operational capability in 1964 and full operational capability in October 1968. It used three operational satellites to produce signals whose Doppler effects and known positions allowed receivers—primarily ships and submarines—to calculate their positions in two dimensions. Transit established the principle and some of the technology of navigation by satellite and prepared military users to rely on such a system. However, it was too slow and imprecise for rapidly moving, three-dimensional platforms such as aircraft. Transit's signals were turned off deliberately in December 1996 because DOD had decided to rely on a newer, faster, and more accurate system.

All of DOD's navigation and position-finding missions are now performed by the Global Positioning System (GPS). The system consists of 24 operational satellites that broadcast navigation signals to the earth, a control segment that maintains the accuracy of the signals, and user equipment that receives and processes the signals. By processing signals from four satellites, a user set is able to derive the location of each satellite and its distance from each one. From that information, it rapidly derives its own location in three dimensions.

Besides Transit, GPS had two immediate programmatic ancestors: a technology program called Project 621B, initiated by SAMSO and the Aerospace Corporation in October 1963, and a parallel program called Timation, undertaken by the Naval Research Laboratory in 1964. Project 621B envisioned a constellation of 20 satellites in synchronous inclined orbits providing continuous three-dimensional positioning information. The satellites would broadcast ranging signals using pseudorandom noise, a technique later incorporated in GPS. The project conducted feasibility tests at White Sands Missile Range in 1972, inverting the planned future direction of the signals by using aircraft with prototype user equipment that received signals broadcast by transmitters on the ground and in balloons.

Left: The second Transit satellite (Transit 1B) undergoes checkout at Cape Canaveral before launch on 13 April 1960. Right: This artist's concept depicts the second Navigation Technology Satellite (NTS-2) in orbit. NTS-2 was used as part of the GPS Block 1 test constellation.

The NRL's Timation Program envisioned a constellation of 21 to 27 satellites in medium altitude orbits providing three-dimensional positioning information. The satellites broadcast passive ranging signals based on highly stable internal clocks, another technique later incorporated in GPS. Experimental Timation satellites 1 and 2, with clocks using quartz-crystal oscillators, were launched in 1967 and 1969. Timation satellites 3 and 4, renamed Navigation Technology Satellites (NTS) 1 and 2, incorporated atomic clocks and were launched in 1974 and 1977 as part of the Phase 1 GPS program.

In 1973, elements of the two programs were combined into the GPS concept, which employed the signal structure and frequencies of 621B with medium altitude orbits and atomic clocks similar to those used for Timation. Deputy Secretary of Defense William P. Clements authorized the start of a program to "test and evaluate the concepts and costs of an advanced navigation system" on 17 April 1973, and he authorized the start of concept validation for the GPS system on 22 December 1973.[40]

GPS was acquired in the classical three phases: validation, development, and production. During the validation phase, Block I navigation satellites and a prototype control segment were built and deployed, and advanced development models of various types of user equipment were built and tested. During the development phase, additional Block I satellites were launched to maintain the initial satellite constellation, a qualification model Block II satellite was built and tested, and manufacture of additional Block II satellites was initiated.[41] In addition, an operational control segment was activated, and prototype user equipment was developed and tested. During the production phase, a full constellation of 24 Block II and IIA (A for advanced) satellites was deployed. User equipment was also produced and put into operation by issuing it to foot soldiers and installing it in ships, submarines, aircraft, and ground vehicles. The full constellation was completed on 9 March 1994, allowing the system to attain full operational capability in April 1995.

GPS supported a wide variety of military operations, including aerial rendezvous and refueling, all-weather air drops, instrument landings, mine laying and mine sweeping, anti-submarine warfare, bombing and shelling, photo mapping, range instrumentation, rescue missions,[42] and satellite navigation. However, GPS was also the focus of a

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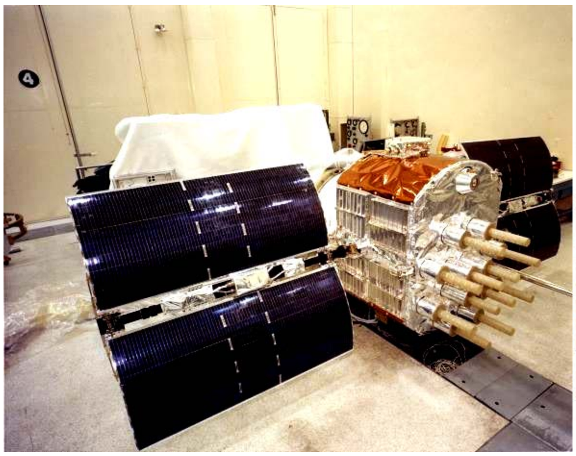
[40] The principal proponent of GPS within the Pentagon was the Director of Defense Research and Engineering, Dr. Malcolm Currie. During 1972-1973, Col Bradford Parkinson, the director of the 621B program, briefed Currie on SAMSO's work in improved satellite-based navigation. Currie sponsored the idea for a new satellite navigation system within DoD, with the understanding that a program should include the best features of the competing concepts. After the memo from Deputy Secretary Clements, Parkinson put together a proposed program based mostly on Program 621B and briefed it to the Defense Systems Acquisition Review Council (DSARC) in August 1973. The DSARC disapproved the program, but Currie assured Parkinson privately that he could win approval by including a better mix of features from the other, rival programs along with Program 621B, and Col Parkinson spent the next several months devising a new proposed program that did so. Much of the work on the conceptual design was done by Parkinson assisted by a dozen Air Force and Aerospace Corporation personnel at the Pentagon over Labor Day weekend in 1973. The improved, more inclusive program was approved by the DSARC in December 1973. See Dr. Parkinson's autobiographical recollections in "The Origins of GPS," GPS World: "Part 1" (1 May 2010) and "Part 2" (1 June 2010). See also the interview with Parkinson by Steven R. Strom on the Aerospace Corporation's Internet site (www.aerospace.org/about-us/history/in-their-own-words/dr-bradford-parkinson/).

[41] Block I, Block II, and Block IIA satellites were built by Rockwell International, which sold its aerospace and defense divisions to Boeing in 1997.

[42] We should take note of a particularly important military application of GPS known as the Combat Survivor Evader Locator (CSEL) system. CSEL was based on an earlier Air Force Space Command procurement called Hook-112 and was designed to enable rescue forces to find, track, and communicate with downed American pilots in hostile territory while making sure they were truly American personnel in need of assistance. It was a technologically sophisticated combination of hand-held radio unit and GPS receiver. Secretary of Defense William J. Perry approved the program in December 1995, and SMC issued a development contract to Rockwell (later absorbed by Boeing) in February 1996. A series of operational

growing civilian market whose users had become far more numerous than military users by the year 2000. Indeed, it was widely used commercially by the time it reached full operational capability, and some commercial applications, such as airline navigation, were both critical and sensitive. At one time, the GPS signal available to civil users contained intentional inaccuracies, a condition known as selective availability, to provide an advantage to authorized military users. At President Clinton's direction, the intentional inaccuracies were set to zero on 1 May 2000, providing significant improvements in the accuracy available to the system's civil users.




Top: A GPS Block I satellite (left) and a GPS Block II satellite (right) undergo acceptance testing at Arnold Engineering Development Center. Bottom left: An artist's concept depicts a GPS Block IIR satellite in orbit. Bottom right: An artist's concept depicts a GPS Block IIF satellite in orbit.


SMC began launching the next block of GPS satellites, known as IIR (R for replacement), in 1997.[43] The following block of GPS satellites, which incorporated

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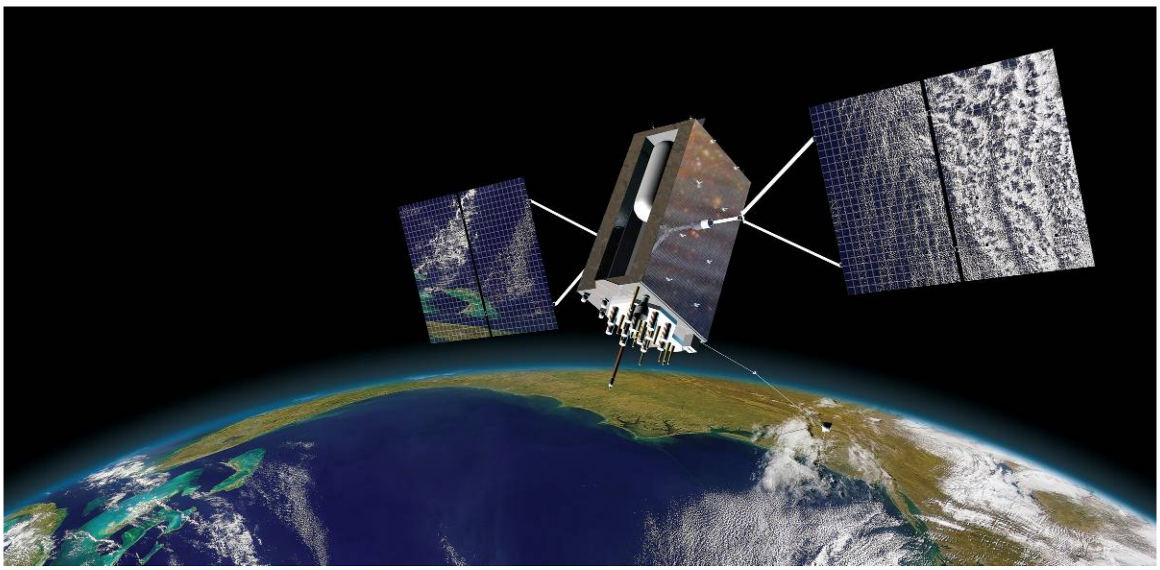
assessments and developmental tests were conducted between 1998 and 2002, and the first limited production units were delivered in late 2002. CSEL entered multiservice operational test and evaluation in June 2003 and was scheduled to begin full-rate production early in 2004.

[43] The launch of the first IIR satellite on 15 January 1997 failed when the Delta launch vehicle exploded. It was the first failure of a Delta II vehicle and only the second launch failure in the history of the GPS program. The first GPS Block IIR satellite to attain orbit and become operational was launched on 23 July 1997.

further improvements, was known as Block IIF (F for follow-on). SMC awarded a contract for the development and production of 33 IIF satellites on 22 April 1996, but it reduced the quantity to 12 in 2000 because the operational lifetimes of GPS satellites were turning out to be longer than expected, and it wished to take advantage of the resulting longer intervals between launches to improve the design of the satellites.[44] Four of the IIF satellites had been launched by early 2014, the first on 27 May 2010 using a Delta IV EELV and the fourth on 15 May 2013 using an Atlas V EELV.

SMC also began the development and initial production of a new and more capable generation of GPS space, control, and user segments known as GPS Block III. It issued competitive system definition and risk reduction contracts to Lockheed Martin and Boeing on 5 January 2004, and it awarded a contract for the first increment of Block III satellites (Block IIIA) to Lockheed Martin on 15 May 2008. The contract provided for development and initial production of two satellites with options for up to 10 additional satellites. By early 2014, the active contract provided for production of six satellites, the first two of which were undergoing integrated testing at Lockheed Martin's facility before delivery.



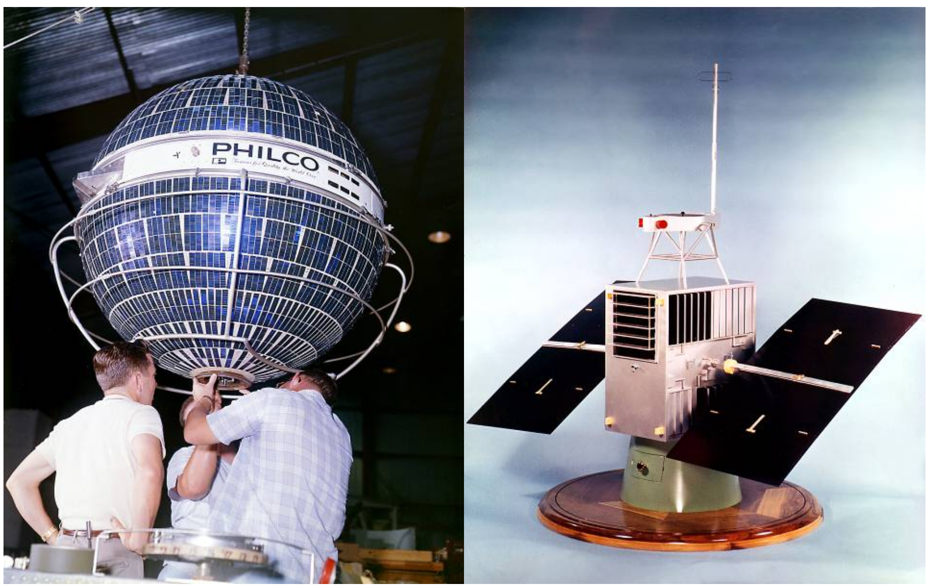
Artist's concept of GPS Block IIIA satellite in orbit (courtesy Lockheed Martin)

The Block III satellites would be larger and heavier than the Block IIF satellites, and they would have major enhancements in capability. They would have a design life of 15 years (rather than 12 for IIF) and offer three times greater navigational accuracy and signal power. A stronger military signal (M-code) would have greater resistance to jamming, and a new fourth civil signal (L1C) would be compatible with signals from the European Space Agency's navigation satellite system known as Galileo.

[44] SMC (then called Space Systems Division) had awarded the contract for Block IIR satellites to General Electric (later part of Lockheed Martin) in 1989. It awarded the contract for Block IIF satellites to Rockwell International (later part of Boeing). See note 41 above.

Communications Systems

The world's first communications satellite—Project SCORE—was launched by the Air Force Ballistic Missile Division, SMC's predecessor, on 18 December 1958. The SCORE payload consisted of commercial communications equipment modified by the Army Signal Corps and installed in an Atlas B missile as a proof-of-concept mission for orbiting communications repeaters. The project was executed under ARPA's direction. AFBMD launched the entire missile, minus the spent half stage, into a low orbit, where it remained for about a month,[45] relaying voice and telegraph messages between ground stations in the United States. Among its first experimental transmissions was President Eisenhower's Christmas message to the world, the first time that a human voice had been transmitted from space. The world's second military[46] communications satellite was Courier 1B, developed by the Army Signal Corps under ARPA's direction. AFBMD successfully launched it on 4 October 1960, using a Thor Able Star launch vehicle. Courier further tested the feasibility of orbiting communications repeaters but did so with a spherical, self-contained satellite that included solar cells and rechargeable batteries. Unfortunately, the spacecraft suffered a command system failure after 17 days in orbit.



Left: Courier 1B satellite in testing, 1960. Right: Model of planned Advent satellite, about 1961.

The first military satellite communications system to be used for operational purposes was known as the Initial Defense Communications Satellite Program (IDCSP). The development program began in 1962, following the cancellation of an earlier, unsuccessful development program called Project Advent.[47] The IDCSP system

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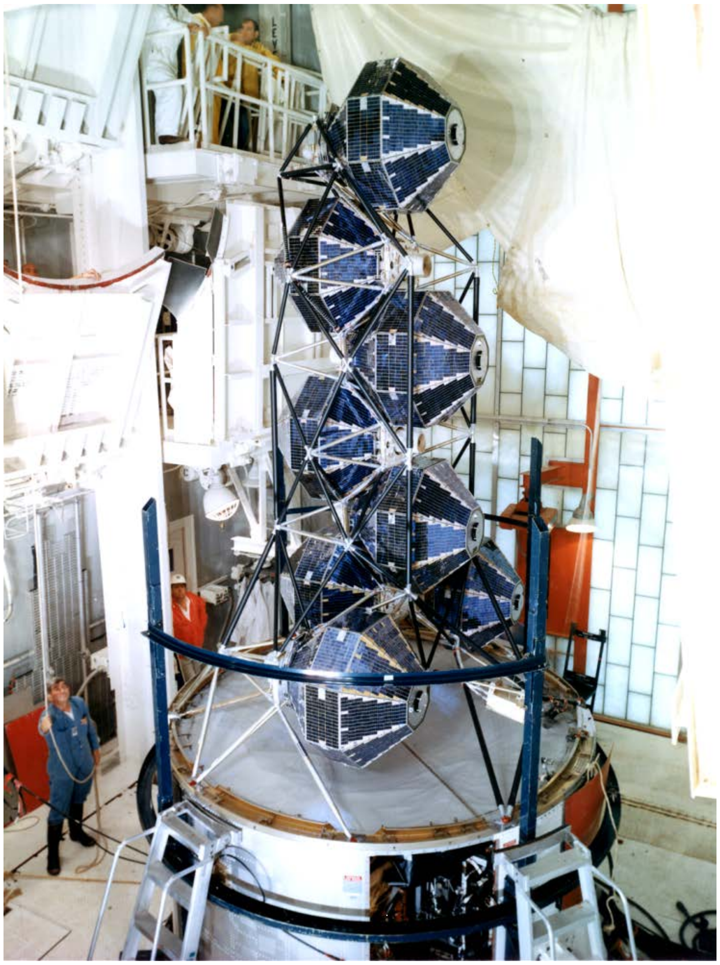
[45] SCORE stopped transmitting when its batteries were exhausted on 31 December 1958. It had no solar cells or other sources of power. It reentered on 21 January 1959.

[46] Echo 1, a metallized balloon that acted as a passive experimental communications satellite, was successfully launched by NASA on 2 August 1960.

[47] Motivated by the necessity of maintaining communications with the Strategic Air Command's large fleet of strategic bombers, ARPA undertook other space-based communications efforts around the same time as Courier. It issued direction to AFBMD on 22 May 1959 to develop a three-part satellite system, with a geosynchronous satellite communications system called Project Decree and two polar satellite

consisted of small, 100-pound satellites launched in clusters. Twenty-six such satellites were placed into orbit in four launches carried out between June 1966 and June 1968.[48] Two fixed and thirty-four mobile ground terminals also became operational in 1968. IDCSP transmitted both voice and photography to support military operations in Southeast Asia. It provided an experimental but usable worldwide military communications system for the Defense Department for ten years until a more sophisticated system could be developed.



Left: The payload fairing is being installed on Titan IIIC-16 at Cape Canaveral. Enclosed in a dispensing mechanism are the last eight satellites of the Initial Defense Communications Satellite Program (IDCSP), successfully launched on 13 June 1968. The IDCSP satellites were small and very simple, with no batteries and no active attitude control system. The dispenser ejected them one at a time into a near-synchronous orbit.

That more sophisticated system was known as the Defense Satellite Communications System, Phase II (DSCS II). The DSCS II satellites were much larger

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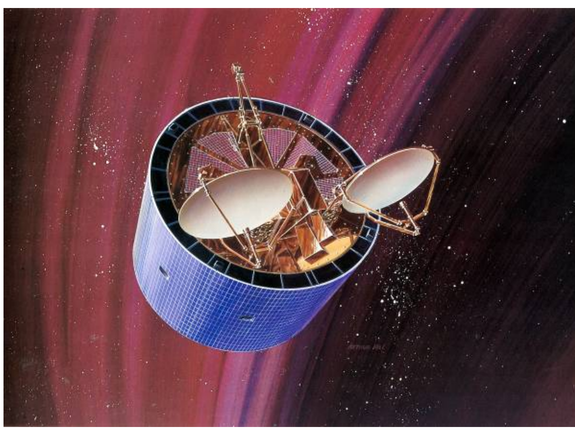
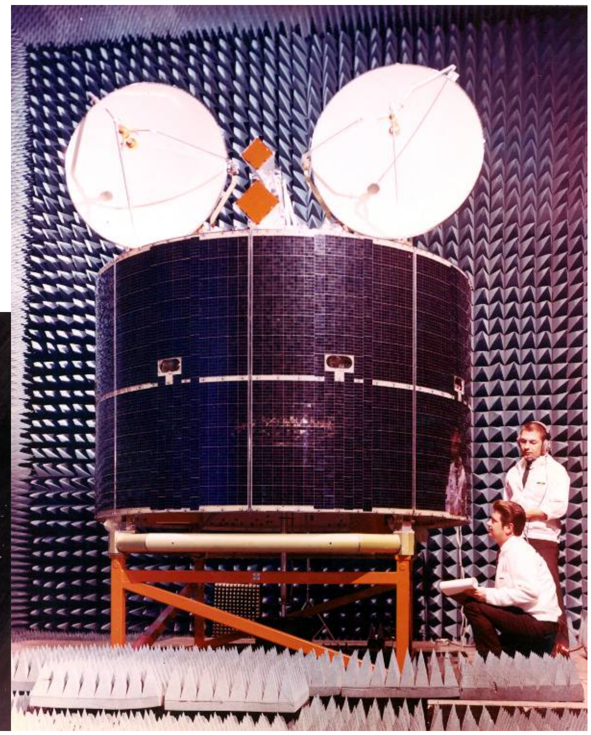
communications systems called Project Steer and Project Tackle. All of these were cancelled and replaced by ARPA on 29 February 1960 by a geosynchronous satellite program called Project Advent, for which the Army was to develop the communications payload and AFBMD was to develop the spacecraft. The entire project was transferred to the Army, then transferred to the Air Force and cancelled by DoD in 1962 because of delays.

48 There were five attempted launches of IDCSP satellites on Titan IIIC launch vehicles during 1966-1968: 16 June 1966, 26 August 1966, 18 January 1967, 1 July 1967, and 13 June 1967. The second launch was unsuccessful because of a structural failure in the Titan. Each launch dispensed from three to eight IDCSP satellites into near-synchronous orbits.

and more sophisticated than the IDCSP satellites, offering increased communications capacity, greater transmission strength, and longer lifetimes. In addition to horn antennas for wide area coverage, they had dish antennas that were steerable by ground command and provided intensified coverage of small areas of the earth's surface. SAMSO awarded a development contract for the DSCS II system to TRW on 3 March 1969, and the first pair of satellites was launched on 2 November 1971. It was the first operational military communications satellite system to occupy a geosynchronous orbit (22,237 miles). Two launch failures delayed completion of the satellite network, but by January 1979, the full constellation of four satellites was in place and in operation. A total of 16 DSCS II satellites was built and launched[49] during the life of the program, with the last launch occurring on 4 September 1989.

Below left: An artist's concept depicts a DSCS II satellite in orbit.
Right: A DSCS II satellite undergoes testing in an anechoic chamber.





In 1973, planning began for the Defense Satellite Communications System, Phase III (DSCS III). DSCS III satellites carried multiple beam antennas to provide flexible coverage and resist jamming, and they offered six active communication channels rather than the four offered by DSCS II. The first DSCS III satellite was successfully launched on 30 October 1982, and a full constellation of five DSCS III satellites was completed on 2 July 1993. Two DSCS IIIs were launched into orbit from a Space Shuttle on 3 October 1985. The constellation was replenished with five launches from 28 November 1993 to 20 October 2000. By early 2003, only two unlaunched DSCS III satellites remained in the inventory. In view of the fact that the DSCS III system would have to support tactical military operations until a follow-on system could be acquired,[50] SMC began an initiative

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[49] DSCS II satellites were launched in pairs using Titan IIIC vehicles through 1979.

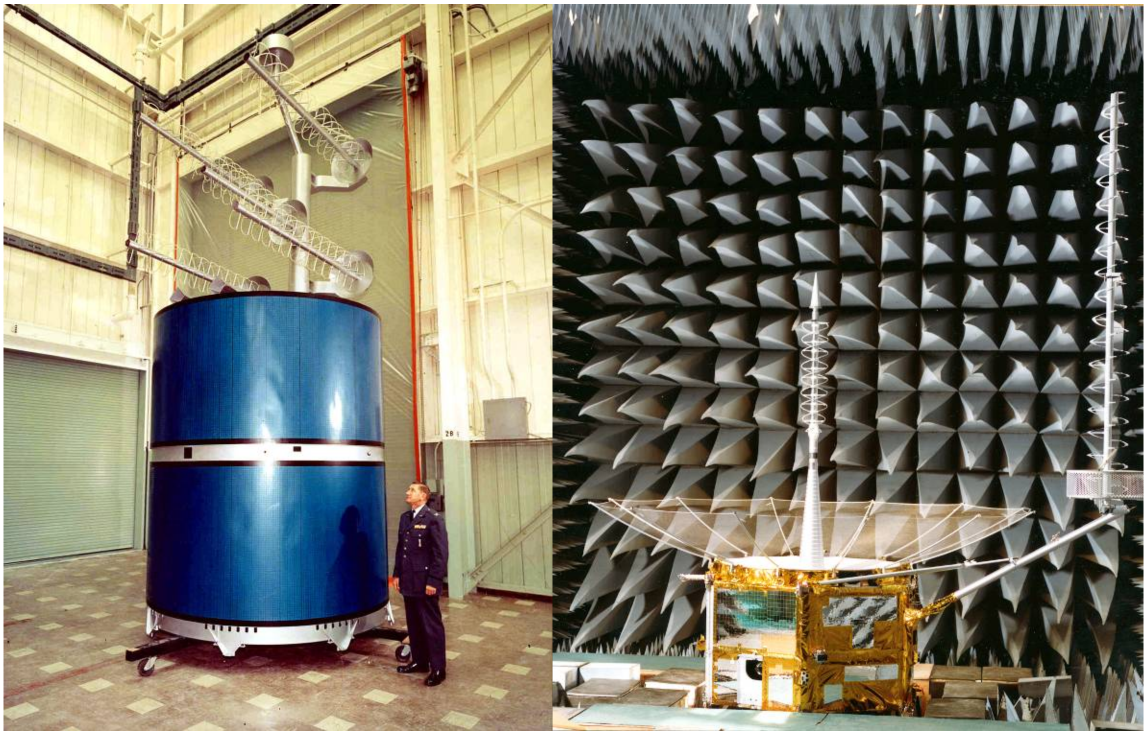
[50] See the Wideband Gapfiller Satellite (WGS) system discussed below.

to improve the tactical utility and extend the lifetime of DSCS III satellites. Known as the Service Life Enhancement Program (SLEP), the initiative added improvements to the last four DSCS III satellites before they were launched. Lockheed Martin was placed under contract to carry out the SLEP modifications on 28 March 1996.

Left: An artist's concept depicts a DSCS III satellite in orbit.
Below: A DSCS III satellite is prepared for testing.

DSCS satellites were developed to serve users who transmitted message traffic at medium to high data rates using relatively large ground terminals. However, satellites were also needed to serve users who transmitted at low to medium data rates, using small, mobile or transportable terminals. During the 1960s, experimental satellites were placed into orbit to test technology that might perform this tactical communications mission. Lincoln Experimental Satellites 5 and 6, launched on 1 July 1967 and 26 September 1968, were solid-state, ultra high frequency communication satellites built by Lincoln Laboratory. The 1,600 pound Tactical Communications Satellite, launched on 9 February 1969, operated in both ultra high frequency and super high frequency and tested the feasibility of communications with small, mobile, tactical communications equipment that could be used by ground, naval, and air forces. In July 1970, an initial operational capability for tactical communications was established, using the Tactical Communications Satellite and Lincoln Experimental Satellite 6.

These experimental satellites paved the way for the Fleet Satellite Communications System (FLTSATCOM), the first operational system serving tactical users. The Navy managed the overall program, but SAMSO managed acquisition of the satellites. Development of FLTSATCOM was authorized on 27 September 1971, and five satellites were launched from 9 February 1978 to 6 August 1981. Four achieved orbit and went into operation, but one was damaged during launch and never became operational. Three replenishment satellites were launched from 5 December 1986 to 25 September 1989. Two reached orbit, but one was lost when its booster was hit by lightning.



Left: SAMSO's TACSAT program director poses with TACSAT I in the testing facilities of the prime contractor, Hughes Aircraft Company, about 1969.   SAMSO launched TACSAT using a Titan IIIC on 9 February 1969, and it operated successfully for 46 months. Right: A FLTSATCOM satellite undergoes testing in an anechoic test chamber.

In addition to the long-haul users served by DSCS and the tactical users served by FLTSATCOM, there was a third group of users—the nuclear capable forces—who could be satisfied at the time with low data rates but required high availability, worldwide coverage, and the maximum degree of survivability. The Air Force Satellite Communications System (AFSATCOM) was developed to serve their needs and allow the Air Force to command and control its strategic forces. The space segment of the system relied on transponders (receiver/transmitters) placed on board FLTSATCOM satellites and other DOD spacecraft. The space segment of AFSATCOM became operational on 15 April 1978, and the terminal segment attained initial operational capability on 22 May 1979.

The communications satellites discussed above were all acquired for the U.S. military, but other communications satellites were acquired for the United Kingdom and the North Atlantic Treaty Organization during the 1960s and 1970s. The British Skynet program began in 1966. The first of two Skynet I satellites was placed into orbit on 21 November 1969 and provided the United Kingdom with its first military communications satellite system. The second Skynet satellite was launched from Cape Canaveral on 19 August 1970, but a malfunction in the launch vehicle caused permanent loss of contact with the satellite. In 1970, SAMSO and the United Kingdom began development of a more advanced Skynet II satellite system. The first Skynet II satellite was launched on 18 January 1974, but a malfunction in the launch vehicle again caused the loss of the satellite. The second Skynet II satellite, launched on 22 November 1974, attained orbit successfully and was turned over to the United Kingdom in January 1975.

Development of the NATO satellites began in April 1968, with the initial series of satellites being known as NATO II. One NATO II satellite was placed in orbit on 20 March 1970 and another on 3 February 1971. Both the Skynet and NATO satellites were designed to be compatible and usable with each other and with the Defense Satellite Communications System. Work on a more advanced system, NATO III, began in 1973, and three NATO III satellites were successfully launched between 1976 and 1978. The constellation was replenished in November 1984, when a fourth satellite was successfully launched.

Left: The first NATO III satellite (NATO IIIA) is prepared for testing by two technicians at Philco-Ford Corporation, the prime contractor. SAMSO launched the satellite successfully on a Delta launch vehicle from Cape Canaveral on 22 April 1976.

The next space communications system to be acquired by SMC was Milstar. Milstar I satellites carry a low data rate payload that provides worldwide, survivable, highly jam-resistant communications for the National Command Authority and the tactical and strategic forces.[51] Advanced processing techniques on board the spacecraft as well as satellite-to-satellite cross linking allow Milstar satellites to be relatively independent of ground relay stations and ground distribution networks. Space Division awarded concept validation contracts for the satellite and mission control segment of Milstar I in March 1982 and a development contract to Lockheed on 25 February 1983. The first Milstar I was successfully launched[52] on 7 February 1994, and the second, on 6 November 1995. In October 1993, SMC awarded a contract for development of the Milstar II satellite, which carried both low and medium data rate payloads. The addition of the medium data rate payload greatly increased the ability of tactical forces to communicate within and across theater boundaries. Only four Milstar II satellites were

[51] Unlike DSCS, which operated in the SHF range (superhigh frequency: 3,000-30,000 megaherz), Milstar operated in the EHF range (extremely high frequency: 30,000-300,000 megaherz). EHF had rarely been used for military communications before Milstar. This frequency range provided natural resistance to jamming. EHF also allowed users to employ smaller, highly mobile terminals.

[52] All Milstar satellites have been launched on Titan IV or IVB vehicles.

produced because DOD had decided in 1993 that they were to be replenished by a new, lighter, cheaper series of Advanced EHF satellites. Unfortunately, the first Milstar II satellite went into an unusable orbit on 30 April 1999. The next two Milstar II satellites were successfully launched on 27 February 2001 and 16 January 2002 to complete an on-orbit constellation of four satellites. The sixth and last Milstar satellite was successfully launched on 8 April 2003.

Left: An artist's concept depicts a Milstar II satellite in orbit. Right: The fifth Milstar satellite is enclosed in the payload fairing on top of its Titan IVB launch vehicle. Its successful launch on 15 January 2002 completed the operational constellation of four Milstar satellites. (Images courtesy Lockheed Martin Missiles and Space)

In view of the limited future of the Milstar system, SMC soon began the acquisition of a follow-on EHF[53] military communications system, known as the Advanced EHF system or AEHF. The system was compatible with Milstar elements and incorporated them throughout their useful lifetimes. The completed AEHF constellation would consist of four satellites in geosynchronous orbit. Like Milstar, but greatly enhanced, the AEHF system featured on-board signal processing and satellite crosslinks to eliminate reliance on ground stations for routing data. Data uplinks to the satellites and crosslinks between satellites operated at EHF, and downlinks operated at SHF. Whereas Milstar offered low and medium data rate payloads, AEHF satellites had high data rate payloads as well, providing up to 8.2 Mbps. The AEHF system provided ten times as much data throughput as Milstar for a much larger area of coverage. It enabled a variety of types of communications, including broadcasting, real-time video, data and voice networking, and voice-conferencing. All services used AEHF terminals, which

[53] See note 50 above.

were located on a wide variety of platforms on land, sea, and air.

After competitive system definition efforts ending in 1999, SMC awarded a contract to the team of Lockheed Martin and TRW for the System Development and Demonstration phase of the AEHF system, including production of the first two satellites and the Mission Control Segment. A third satellite was added to the contract in 2006 and a fourth in 2010.[54] In 2009, OSD cancelled a planned follow-on program known as the Transformational Satellite Communications System (TSAT) that would have followed the fourth AEHF satellite, and it directed the Air Force to acquire the fifth and sixth AEHF satellites instead.[55] By 2014, the first three AEHF satellites had been successfully launched on Atlas V vehicles.[56]

Below: Artist's concept of Advanced EHF satellite in orbit (courtesy Lockheed Martin);
Right: Artist's concept of WGS satellite in orbit (courtesy Boeing Company)

In 2000, SMC also led a multi-service program to acquire a new series of communications satellites—known eventually as the Wideband Global SATCOM (WGS)[57] system—to augment DSCS III and finally replace it. However, the capabilities

[54] The gap in production between the third and fourth AEHF satellites caused a shutdown and restart of the production line and resulting cost increases.

[55] For the TSAT program, see below after the discussion of the Wideband Global Satellite Communications (WGS) system.

[56] AEHF-1 was launched on an Atlas V on 14 August 2010. The liquid apogee engine failed to raise the satellite from a transfer orbit to its final geosynchronous orbit, but a mission planning team formed to deal with the anomaly successfully used the satellite's stabilizing thrusters and then the electrical maneuvering thrusters to gradually raise the satellite over the course of about 14 months to its intended orbit, which it reached on 24 October 2011. AEHF-2 was successfully launched on 4 May 2012 and AEHF-3 on 18 September 2013.

[57] WGS was called at first the Wideband Gapfiller Satellite because it would fill the gap between the availability of the existing DSCS III and GBS satellite systems and a planned very advanced system called the Transformational Satellite Communications System (TSAT). The name was changed (but not the abbreviation) in 2007 at the request of HQ USAF. SATCOM is, regrettably, an abbreviation within an abbreviation, and stands for "satellite communications." The TSAT program was cancelled in 2009.

of the WGS system were vastly enhanced in comparison to DSCS. WGS provided not only two-way tactical military communications, but also a two-way Ka-band augmentation of the older one-way, wideband satellite broadcast system called the Global Broadcast Service (GBS).[58] Each WGS satellite could provide up to 3.6 Gbps of data transmission, well over ten times the X-band communications capacity of a DSCS satellite, and 4.875 GHz of instantaneously switchable bandwidth. Block II satellites (starting with WGS-4) provided ultra-high bandwidth and data rates using a radio frequency bypass capability to support airborne intelligence, surveillance and reconnaissance platforms such as unmanned aerial vehicles.

SMC awarded a contract[59] for design and advance procurement of the first three WGS satellites, which constituted Block I, as well as ground-based command and control elements to Boeing Satellite Systems in 2001. It awarded a contract for the next three satellites,[60] constituting Block II, to Boeing in 2006 and a Block II follow-on contract for WGS satellites 7 through 10 in 2010. By 2014, the first six WGS satellites had been successfully launched, the first two on Atlas V vehicles and the next four on Delta IVs.[61]

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[58] The Global Broadcast Service, a joint-service program, became operational about 1999, using its own transponders on the Navy's UHF Follow-on satellites. GBS was a system for extremely rapid, one-way transmission of high-volume data such as weather, intelligence, and imagery from higher echelons to large groups of dispersed users with small, mobile receivers.

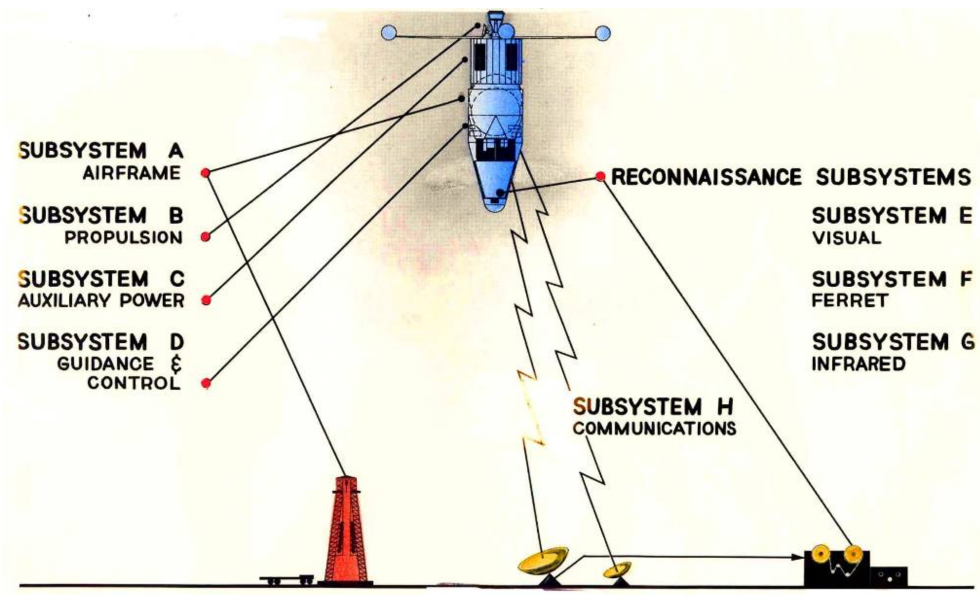
[59] The contract for procurement of WGS Block I was a "near commercial" acquisition, one important feature of which was that little technological development was involved, since most of the components could be obtained commercially.

[60] Australia funded the acquisition of WGS-6 in exchange for allocation of 10 percent of the capacity of the WGS system.

[61] The launch dates in EST were WGS-1: 10 October 2007, WGS-2: 3 April 2009, WGS-3: 5 December 2009, WGS-4: 19 January 2012, WGS-5: 24 May 2013, WGS-6: 7 August 2013.

CHAPTER V: SATELLITE SYSTEMS

The Air Force was the last U.S. military department to launch a satellite, but it was the first to sponsor engineering and conceptual studies of a satellite with specific military applications and the first to undertake the development of such a spacecraft. Its first effort emerged on 2 May 1946, when Douglas Aircraft Company's Project RAND issued a 250-page report called "Preliminary Design of an Experimental World-Circling Spaceship"[15] to support the claim of the Army Air Forces to the proposed new mission area of space.[16] RAND's report not only examined solutions to engineering problems for orbiting a satellite, it also discussed some of the major mission areas for satellites that were later developed by the Air Force, including reconnaissance, communications, and meteorology. Under contract after 1947 to the newly independent Air Force, and especially beginning in 1950 to the new Air Research and Development Command (ARDC), RAND continued to conduct studies that examined engineering solutions to problems involved in developing satellites with specific military missions. One of the most influential of those efforts was Project Feed Back, which culminated in a report issued on 1 March 1954 proposing the development of a reconnaissance satellite to provide photographic data on Soviet military preparations. Before the report was even issued, ARDC established a very small office at Wright Air Development Center[17] on 24 December 1953 to manage preparations to award design and development contracts for



A concept for WS 117L and its subsystems from a briefing given in 1957

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[15] A scanned copy of the entire report is available on the RAND Corporation's Internet site.

[16] Major General Curtis E. Lemay, then the Air Staff's Deputy Chief of Staff for Research and Development, issued the direction for the RAND report to counterbalance more general feasibility studies by the Navy that were being considered by the War Department's Aeronautical Board.

[17] The most detailed and interesting description of the activities of the early WS 117L project office is the first-person narrative of James S. Coolbaugh, published as "Genesis of the USAF's First Satellite Programme" in *The Journal of the British Interplanetary Society*, vol. 51 (1998), pp. 283-300. According to his narrative, Maj Coolbaugh became the first manager of the project on 24 December 1953.

the satellite, known at first as Project 1115 and soon afterward as the Advanced Reconnaissance System or Weapon System 117L (WS 117L).

The military satellite project was soon added to the mission of the Western Development Division, largely because of the development's intimate association with ballistic missiles, which rapidly acquired a role as space launchers equal to their role as weapons. The commander of Air Research and Development Command transferred responsibility for the program from Wright Air Development Center to WDD on 17 October 1955[18], and satellites grew into an increasingly important part of the activities of the Division's successors.

WS 117L was, in concept, a family of separate subsystems that could carry out different missions, including photographic reconnaissance and missile warning. After evaluating system design studies from Lockheed, RCA, and Martin, WDD awarded the first Air Force space development contract to Lockheed on 29 October 1956. However, by the end of 1959, WS 117L had evolved into at least three separate satellite programs: the Discoverer Program, the Satellite and Missile Observation System (SAMOS),[19] and the Missile Defense Alarm System (MIDAS).[20] Discoverer and SAMOS undertook the photographic reconnaissance mission, and MIDAS undertook the missile-warning mission.[21]

Reconnaissance Systems

The Discoverer program aimed at developing a film-return photographic reconnaissance satellite. The satellite carried a camera that took pictures from space as it passed over the Soviet Union and China. Film from the camera returned from orbit in a capsule. A parachute deployed to slow the descent of the capsule, and C-119J (later, JC-130) aircraft operated by the 6593rd Test Squadron from Hickam AFB, Hawaii, recovered the capsule in mid-air.[22] However, Discoverer's photo reconnaissance mission was not revealed to the public at the time. It was, instead, presented as an experimental program to develop and test satellite subsystems and explore environmental conditions in space.[23]

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[18] ARDC transferred oversight of the project office to WDD in a revision to System Requirement No. 5, dated 17 October 1955. However, the project's personnel did not physically complete their move to WDD until 1 April 1956.

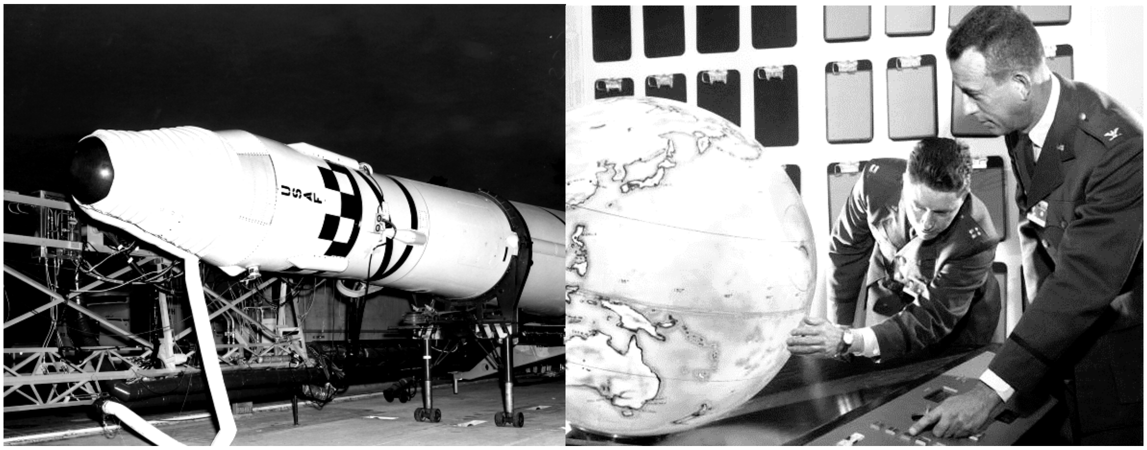
[19] SAMOS may have been made into an acronym after the name had been selected to go with MIDAS.

[20] The newly created Advanced Research Projects Agency (ARPA) was primarily responsible for the division of WS 117L into separate satellite programs. It issued separate directives for these and other military space programs from June 1958 to September 1959. ARPA's purpose was to accelerate near-term achievements in military space, and it succeeded in doing so.

[21] Under the WS 117L program, the visual reconnaissance payloads (which became the Discoverer and SAMOS programs) were known as Subsystem E, and the infrared reconnaissance payload (which became the MIDAS early warning program) was called Subsystem G. The spacecraft, which finally became the Agena combined upper stage and spacecraft, was called Subsystem A for the airframe and Subsystem B for the propulsion elements. Subsystem H for communications led eventually to the early Air Force Satellite Control Network.

[22] Not all capsule recoveries were nominal, however. A few were not recovered successfully in midair and had to be secured by air-dropped divers, rafts, and ships. For first-person accounts of recovery techniques and missions, see Robert Mulcahy, ed., *Corona Star Catchers*, GPO: June 2012.

[23] Nevertheless, some Discoverer missions carried experimental payloads instead of or in addition to their normal reconnaissance payloads. Mission 2 carried simulated biological experiments, but its payload was



Left: The Agena spacecraft for Discoverer 13, mated to its Thor launch vehicle, waits on the pad at Vandenberg AFB before being erected. The covering cooled and protected the spacecraft. Right: Colonel C. Lee Battle, Discoverer program director, and Captain Albert W. Johnson observe the ground track of a Discoverer (Corona) satellite in 1960, taking care not to look at the Soviet Union.

The Discoverer Program carried out 38 public launches and achieved many technological breakthroughs. Discoverer I, launched on 28 February 1959, may have been the world's first polar orbiting satellite.[24] Discoverer II, launched on 13 April 1959, was the first satellite to be stabilized in orbit in all three axes, to be maneuvered on command from the earth, to separate a reentry vehicle on command, and to send its reentry vehicle back to earth.[25] Discoverer XIII, launched on 10 August 1960, ejected a capsule that was subsequently recovered in the water near Hawaii, the first successful recovery of a man-made object ejected from an orbiting satellite. Discoverer XIV, launched on 18 August 1960, ejected a capsule that was recovered in midair northwest of Hawaii by a JC-119 aircraft, the first successful aerial recovery of an object returned from orbit. The capsule from Discoverer XIV was the first to return film from orbit, inaugurating the age of satellite reconnaissance. Satellite reconnaissance filled a crucial need because President Eisenhower had suspended aerial reconnaissance of the Soviet Union just three months earlier after the Soviets had shot down the U-2 spy plane piloted by Francis Gary Powers.

The Discoverer Program ostensibly ended after the launch of Discoverer XXXVIII on 27 February 1962. In reality, however, it continued in clandestine form until 31 May 1972 (the date of the last film recovery), carrying out 145 launches[26] under the secret code name Corona. At the direction first of President Eisenhower and later of

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not recovered (at least, not by the U.S.). Mission 3 carried actual biological experiments, but its payload did not attain orbit. Missions 19, 21, 49, 52, 57, 73, 92, and 99 gathered infrared background data for the MIDAS program. Other missions carried geodetic payloads. For short descriptions of all Corona payloads, see Curtis Peebles, The Corona Project, Naval Institute Press, 1997.

[24] The Air Force officially claimed that Discoverer I had reached orbit, but the program's operations officer, Col Frank Buzard, said many years later that tracking stations had not received a verifiable signal. If Discoverer I did not achieve orbit, the distinction of being the first polar-orbiting satellite should go to Discoverer II.

[25] However, the reentered capsule was not recovered by the U.S. The consensus of researchers seems to be that it reentered over or near the island of Spitzbergen, where it may have been found by Russian miners.

[26] Including the 38 Discoverer launches.

President Kennedy, the direction and management of Corona and other satellite reconnaissance programs passed to a new DOD agency, the National Reconnaissance Office (NRO), when it was created in 1961.[27] Corona's first major accomplishment was to provide photographs of Soviet missile launch complexes. It also identified the Plesetsk Missile Test Range, north of Moscow, and provided information about what missiles were being developed, tested, and deployed. These and other accomplishments came to light when the Corona program was declassified in February 1995.

Left: A recovery crew of the 6593rd Test Squadron (Special) performs a practice midair capsule recovery in a JC-119 aircraft in 1959. Recovery crews flew JC-119s for the first 29 Discoverer missions and JC-130s after that. Right: President Dwight D. Eisenhower holds a news conference on 15 August 1960 to exhibit the capsule from Discoverer 13, recovered from the ocean four days earlier. Behind the president, left to right, are Colonel C. Lee Battle (Discoverer program director), General Curtis E. Lemay (Air Force vice chief of staff), Lieutenant General Bernard A. Schriever (commander of Air Research and Development Command), Dudley C. Sharp (Secretary of the Air Force), Thomas Gates (Secretary of Defense), General Thomas White (Air Force Chief of Staff).

SAMOS, the second program that evolved from WS 117L, aimed at developing a heavier reconnaissance payload that would be launched by an Atlas Agena booster rather than the Thor Agena used to launch Discoverer. The payloads were intended to collect photographic and electromagnetic reconnaissance data. The photographic data would be collected by cameras in the Agena spacecraft, like the Corona payloads. However, the film would be scanned electronically in orbit and transmitted to ground stations. SAMOS had three unclassified launches from the west coast: 11 October 1960, 31 January 1961, and 9 September 1961. Only the launch in January 1961 was successful. In 1962, a veil of secrecy was drawn across the SAMOS program, and the Air Force stopped releasing information about it. After several more classified launches, however, it was apparent that the technology required for downloading the imagery was not yet sufficiently advanced, and Air Force undersecretary Joseph V. Charyk canceled further work on the

[27] On 31 August 1960, Secretary of the Air Force Dudley C. Sharp created an Office of Missile and Satellite Systems. Reconnaissance programs under that office reported to the secretary of the Air Force through an undersecretary, Joseph V. Charyk. On 6 September 1961, the new Kennedy Administration established the NRO. Its joint directors, the undersecretary of the Air Force and the deputy director of the CIA, reported directly to the deputy secretary of defense for reconnaissance matters.

payload.[28]

Although SMC did not directly manage the development of imaging reconnaissance satellites after this, it did manage programs that were linked to them or their products. One of the most important was the Defense Dissemination System (DDS), whose broad outlines were declassified in 1996. The Defense Dissemination Program Office (DDPO) was established at SAMSO in July 1974 to develop a means to securely and rapidly provide reconnaissance imagery in nearly original quality to both strategic and tactical users. The DDPO developed a system consisting of segments for processing, transmitting, and receiving. The system was deployed to four strategic sites during 1976-1978, providing the first electronic dissemination of digital imagery for targeting and strategic threat assessment.

The DDS went through three more generations of increasingly sophisticated improvements for compressing, transmitting, receiving, and reconstructing imagery for military users in the field. One of the third-generation DDS units was deployed to the Persian Gulf to support Operations Desert Shield and Desert Storm. Fourth-generation DDS units were fielded to 70 strategic and tactical users by 1998. However, the DDPO itself ceased to exist as a program office on 1 October 1996,[29] when it was combined with other agencies to create the National Imagery and Mapping Agency (later renamed the National Geospatial-Intelligence Agency).

Infrared Early Warning Systems

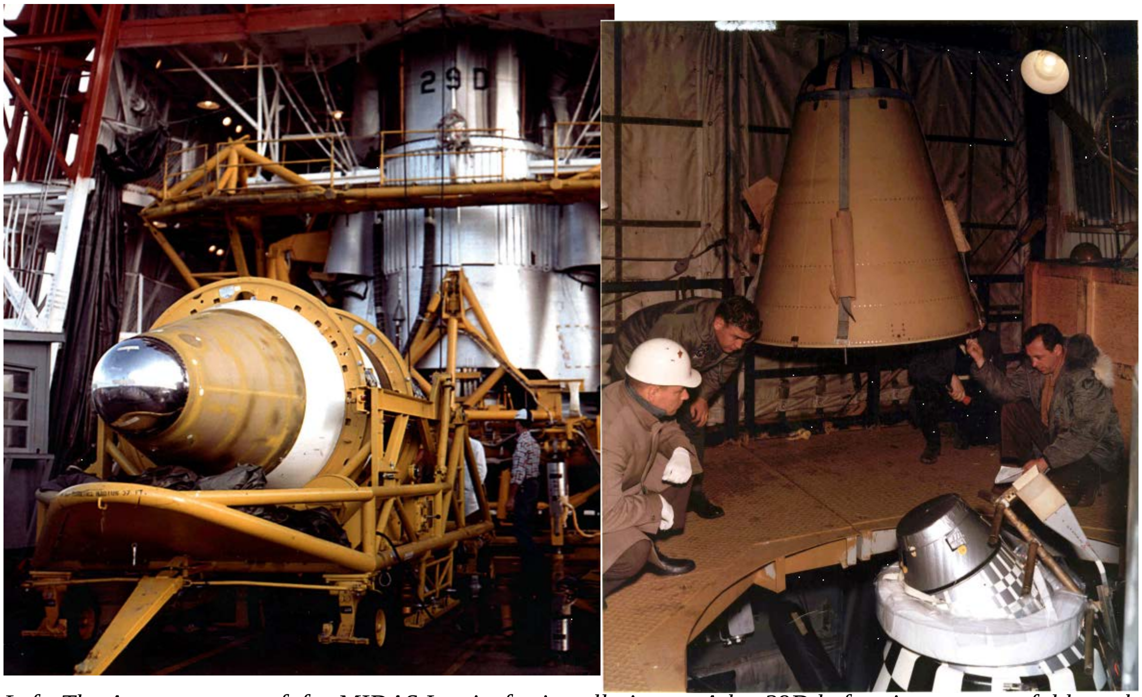
The MIDAS program, the third offshoot of WS 117L, focused on developing a satellite with an infrared sensor to detect hostile ICBM launches. It began its life as a separate program when AFBMD placed the infrared portion of WS 117L (Subsystem under a separate contract with Lockheed effective 1 July 1959. The payload consisted of an infrared sensor array and telescope inside a rotating turret mounted in the nose of an Agena spacecraft. Plans which were never carried out called for an operational constellation of eight satellites in polar orbits to constantly monitor launches from the Soviet Union. Unfortunately, the program's first four test satellites launched in 1960 and 1961 ended in a launch failure and early on-orbit failures.

DOD kept the program in a research and development phase rather than approve an operational system in 1962. The MIDAS program was lengthened and renamed Program 461. The next two launches in 1962 also ended in an early on-orbit failure and a launch failure. Finally, a satellite launched on 9 May 1963 operated long enough to detect 9 missile launches. After another launch failure in 1963, the last Program 461 satellite, launched on 18 July 1963, operated long enough to detect a missile and some Soviet ground tests. Data collection and analysis continued until 1968 under Lockheed's contract for Program 461 to support the next early warning program. Additional launches in 1966, using improved spacecraft and sensors, demonstrated the system's increasing reliability and longevity. Although a launch on 9 June 1966 failed, launches on 19

[28] However, the technology was secretly transferred to NASA, which used it successfully in its Lunar Orbiter imaging lunar satellites. See R. Cargill Hall, "SAMOS to the Moon: The Clandestine Transfer of Reconnaissance Technology Between Federal Agencies," NRO Office of the Historian, October 2001.

[29] As an organization, the DDPO was characterized by unusually high *esprit de corps*. It received a larger number of Air Force Organizational Excellence Awards than any other program office in SMC's history.

August and 5 October 1966 placed their spacecraft into highly useful orbits, where their infrared sensors gathered data for a year, reporting on 139 American and Soviet launches. The MIDAS program and its successors were declassified in November 1998.



Left: The Agena spacecraft for MIDAS I waits for installation on Atlas 29D before its unsuccessful launch on 26 February 1960. Right: The payload for an advanced version of MIDAS, known as AFP 461, is covered with the Agena's nose cone before its unsuccessful launch as MIDAS 6 on 17 December 1962.

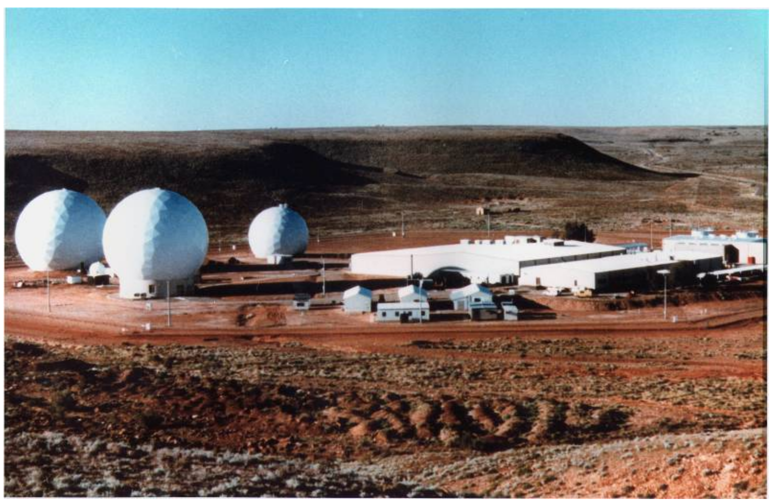
DOD initiated a new program late in 1963 to develop an improved infrared early warning system, which ultimately became the Defense Support Program. After an early phase known as Program 266, contracts for development of Program 949, the Defense Support Program (DSP), were awarded to TRW for the spacecraft on 6 March 1967 and to Aerojet for the infrared sensor on 1 March 1967. The new concept involved placing the satellites into orbits at geosynchronous altitude (22,237 miles), where only three or four would be necessary for global surveillance. Like MIDAS, the satellites would employ telescopes and IR detectors, but the necessary scanning motion would be accomplished by rotating the entire satellite around its axis in space several times per minute. An evolving network of two, and later three, large ground stations in Australia, Europe, and the continental U.S. controlled the spacecraft and data.

The first DSP satellite was launched on 6 November 1970, using a Titan IIIC launch vehicle. A long series of increasingly larger, more sophisticated, and more reliable satellites followed,[30] all of them except two launched on Titan III or Titan IV

[30] DSP satellites launched during 1970-1973 weighed 2,000 pounds, had a design life of 1.25 years, and incorporated 2,000 lead sulfide detectors operating in the short wave infrared range; they could see targets only below the line of the earth's horizon. After undergoing five major upgrades, satellites launched beginning in 1989 weighed 5,250 pounds, had a design life of 3 years, and incorporated 6,000 lead sulfide detectors with an additional set of mercury cadmium telluride detectors operating in the short wave and medium wave infrared range; they could see targets both below and above the line of the earth's horizon. See Major James Rosolanka, "The Defense Support Program (DSP): A Pictorial Chronology, 1970-1998," SBIRS Program Office.

vehicles.[31] The 23rd and final DSP satellite was successfully launched on the first operational Delta IV Heavy EELV in November 2007.

Right: The first DSP satellite, known as DSP Flight 1, is shown in testing at the facilities of TRW, the prime contractor. SAMSO's DSP program director, Colonel Frederick S. Porter, Jr., stands at the right of the satellite. It was launched successfully on 6 November 1970 from Cape Canaveral.



Left: The first operational fixed ground station for DSP, known as the Overseas Ground Station (OGS), was located at Woomera Air Station, Australia. It became operational in 1971.

DSP provided a level of early warning that soon became indispensable for both military and civil defense. The spacecraft also carried sensors that performed nuclear surveillance, a mission inherited from the Vela system (following in this chapter). Although designed for strategic uses, DSP proved to be more versatile. During the Persian Gulf War, it provided early warning against tactical missiles as well. By 1997, SMC and Air Force Space Command had exploited that capability by adding central processing facilities and tactical ground stations to provide tactical data from DSP to battlefield commanders more rapidly and efficiently.

During the early 1990s, SMC began to pursue concepts and technologies for follow-on systems to replace DSP. By 1994, the concept for a system to succeed DSP was known as the Space-Based Infrared System (SBIRS) and was identified as a requirement by DoD in a "Space-Based Warning Summer Study" issued in September

[31] DSP-16 was launched on a Space Shuttle (STS-44) on 24 November 1991.

1994. SBIRS was to be an integrated system that would support several missions: missile warning, missile defense, battlespace characterization, and technical intelligence.

The SBIRS concept actually included two planned satellite systems, referred to as SBIRS High[32] and SBIRS Low.[33] Both were heirs of infrared technology developed for the Ballistic Missile Defense Program (earlier known as the Strategic Defense Initiative) during 1983-1995. SBIRS High was focused on the detection and tracking of missiles during the earlier phase of their flight, while their motors were generating heat and infrared signatures in short wave lengths. SBIRS Low would add the capability of tracking and reporting other data about missiles during the middle portions of their flight, when their infrared signatures were at longer wave lengths.

To prepare for the development of SBIRS Low, SMC awarded contracts for on-orbit demonstrations to TRW on 2 May 1995 and to Boeing on 2 September 1996. However, oversight of the SBIRS Low program was transferred back to the Missile Defense Agency (MDA) during 2001, where it was renamed the Space Tracking and Surveillance System (STSS). The MDA developed STSS demonstration satellites to test the feasibility of providing midcourse surveillance of ballistic missile launches, and it launched the first two demonstration satellites together on 25 September 2009 using a Delta II vehicle. By the end of 2013, the STSS demonstration satellites were participating in successful missile intercept tests by the MDA.

SMC awarded a ten-year development contract for SBIRS High to Lockheed Martin on 8 November 1996. The SBIRS High program had to be restructured during 2001 and again in 2005 to deal with potential cost and schedule overruns, but its technical progress continued. On 18 December 2001, a consolidated SBIRS Mission Control Station (MCS) at Buckley AFB, Colorado, was declared operational. The MCS provided a central capability for command and control of all operational DSP satellites and other infrared data sources. The completion of this first segment of the ground system upgrade allowed older DSP ground stations to be closed. Afterward, the ground system continued to evolve to support satellites of the SBIRS High system.

The space segment of SBIRS High consisted of two kinds of satellites occupying very different orbits. Payloads known as SBIRS HEO flew in highly elliptical orbits and were designed to detect ballistic missiles launched from submarines in the region of the Arctic Ocean as well as certain other targets. HEO payloads, which were equipped with scanning IR sensors, were carried on host satellites from other programs. Payloads known as SBIRS GEO flew on their own satellites in geosynchronous orbit and were designed to carry out strategic missile warning and detection with scanning IR sensors as well as tactical missile warning and detection (and other technical intelligence) in focus

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[32] The technological basis for the high-altitude follow-on system to detect missile launches was an earlier program under OSD's Strategic Defense Initiative (SDI) known as the Boost Surveillance and Tracking System (BSTS). It had been transferred to the Air Force in FY 1992 and had gone through several conceptual changes known as the Advanced Warning System (AWS), the Follow-on Early Warning System (FEWS), and the Alert Locate and Report Missiles (ALARM) program.

[33] The technological basis for the low-altitude follow-on system to track missiles in the middle portion of their trajectories had also been an SDI program. It had been known as the Space Surveillance and Tracking System (SSTS) during the mid and late 1980s and as Brilliant Eyes during the early 1990s.

areas using staring IR sensors. The satellite's sensors featured greatly improved sensitivity and revisit rates compared to DSP.

Left: SBIRS HEO-1 payload in testing at Northrup Grumman's Azusa facility in 2005
Below: SBIRS GEO-2 payload during encapsulation for launch in March 2013
(Photographs courtesy Lockheed Martin)

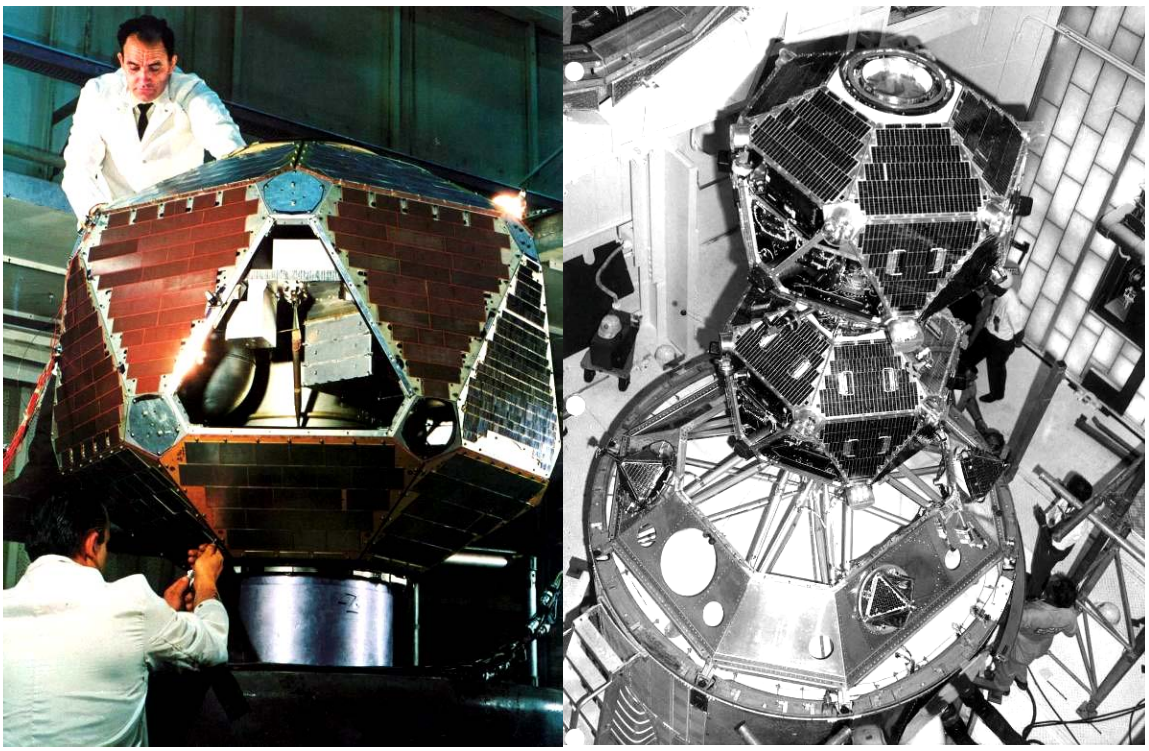
The restructured SBIRS program after 2005 called for delivery of two developmental GEO satellites, two HEO payloads, and associated ground systems. Based on the success of the developmental hardware in testing, SMC awarded a follow-on production contract for the third GEO satellite and the third HEO payload to Lockheed Martin in 2009. It exercised options for the fourth GEO satellite and HEO payload in 2011.

By the end of 2013, operational results after the initial launches of SBIRS HEO and GEO were proving the systems to be highly successful, and the new SBIRS constellations continued to grow. The first two orbiting HEO payloads were operationally certified by US Strategic Command on 5 December 2008 and 7 August 2009. SMC accepted delivery of the HEO-3 payload in July 2013 and approved its shipment for integration with the host spacecraft. The GEO-1 and GEO-2 satellites were launched on 7 May 2011 and 19 March 2013 using Atlas V vehicles. Air Force Space Command accepted both GEO satellites for operations during 2013.

SMC also began to examine alternatives and improvements for the SBIRS system. One possibility that led to orbital testing was called the Commercially Hosted Infrared Payload (CHIRP). It consisted of a wide-field-of-view staring infrared sensor built by Science Applications International Corporation. The payload was hosted on a commercial geosynchronous communications satellite called SES-2. It was launched on 21 September 2011 and carried out many demonstrations of possible tactical applications for commercially hosted infrared technology. After several extensions of the contract for additional demonstrations, the sensor was decommissioned on 6 December 2013.

Nuclear Surveillance

In addition to reconnaissance and missile warning, SMC and its predecessors have developed satellites to serve a number of other purposes, among which are nuclear surveillance, weather observation, navigation, and communication. The first space system to accomplish nuclear surveillance was called Vela Hotel—later, simply Vela. Representatives of the Air Force Ballistic Missile Division (AFBMD), the Atomic Energy Commission, and NASA met on 15 December 1960 to initiate a joint program to develop a high-altitude satellite system that could detect nuclear explosions. Its primary purpose was to monitor compliance with the Nuclear Test Ban Treaty then being negotiated in Geneva. During 1961-1962, the Atomic Energy Commission developed detectors and flew experimental versions on Space Systems Division's Discoverer satellites.



Left: A Vela satellite in fabrication at TRW's facility. Right: A pair of Vela satellites (Vela 5A and 5B) mounted on their Titan IIIC launch vehicle before installation of the fairing. They were launched successfully on 23 May 1969. (U.S. Air Force photographs)

SSD issued a contract for the spacecraft to Space Technology Laboratories (later part of TRW) on 24 November 1961. The first pair of satellites was launched using an Atlas Agena on 16 October 1963, a few days after the Limited Nuclear Test Ban Treaty went into effect, and two more pairs were launched on 16 July 1964 and 17 July 1965. Six Advanced Vela satellites, containing additional, more sophisticated detectors, were launched in pairs on Titan IIIC vehicles on 28 April 1967, 23 May 1969, and 8 April 1970.

The Vela satellites successfully monitored compliance with the Limited Nuclear Test Ban Treaty of 1963, but also with later treaties such as the Outer Space Treaty of 1967 and the Non-ProliferationTreaty of 1968. They also provided scientific data on natural sources of space radiation for many years.[34] The least successful of the original satellites operated for ten times its design lifetime of six months. The last of the advanced Vela satellites was deliberately turned off on 27 September 1984, over fifteen years after it had been launched. However, their mission continued to be performed by payloads of the Nuclear Detection System hosted on DSP and GPS satellites.

Meteorological Systems

Providing the systems with which to conduct military weather observations from space is presently the mission of the Defense Meteorological Satellite Program (DMSP), which maintains a constellation of at least two operational weather satellites in polar orbits about 450 miles above the earth. DMSP satellites now carry primary sensors that provide images of cloud cover over the earth's surface during both day and night, and they also carry other sensors that provide additional types of data on weather and on the space environment.

The first DMSP satellites[35] were developed by a program office physically located with Space Systems Division but reporting to the National Reconnaissance Office (NRO),[36] which needed analyses of cloud cover over Eurasia to plan its photographic reconnaissance.[37] The program office awarded a development contract for weather satellites employing television cameras to RCA in 1961. DMSP Block I began with five launch attempts on Scout launch vehicles during 1962 and 1963, all but one of which failed.[38] Later Block I launches on Thor Agena and Thor Burner I vehicles were more successful. Two launches in 1964 using Thor Agena vehicles placed two Block I satellites in orbit during each launch and provided enough weather imagery for strategic purposes for the first time. Six launch attempts during 1965 and 1966 employed a new Thor upper stage known as Burner I for DMSP payloads, including two more Block I, three Block II, and one Block III.

Besides providing weather information for strategic purposes, early DMSP satellites also provided the earliest tactical uses of space-based weather information. A Block I satellite launched on 18 March 1965 secretly provided weather data for North and

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[34] Vela satellites provided data that led to the discovery of the astronomical sources of gamma ray bursts. They also provided data for studies of radiation in the earth's magnetosphere and studies of atmospheric phenomena such as meteoric fireballs and lightning.

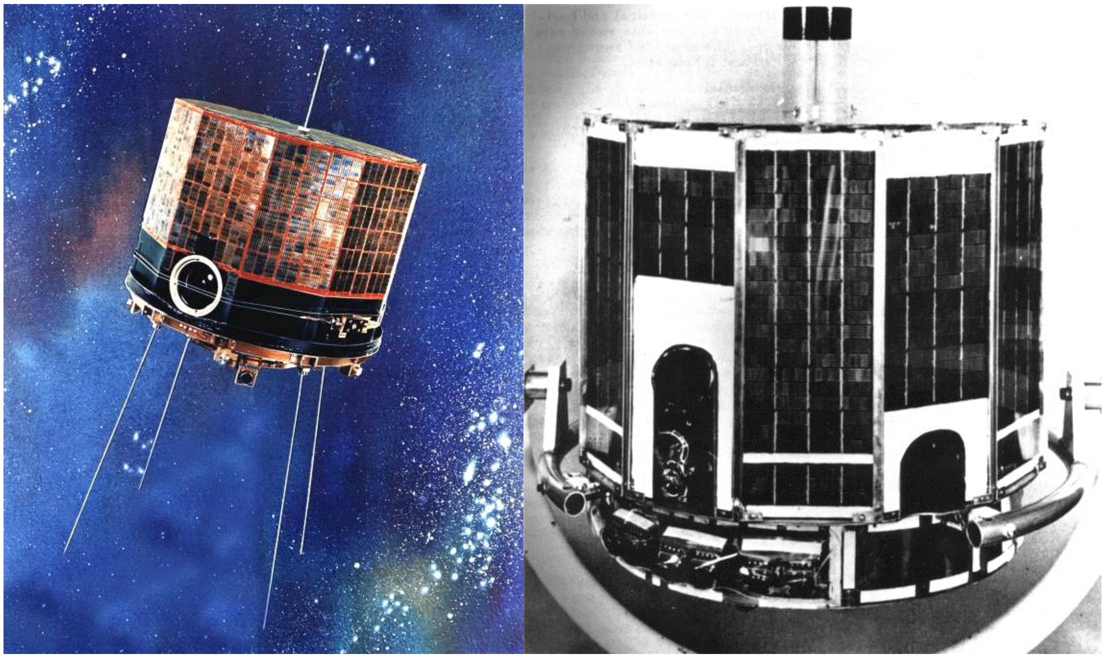
[35] The program was known at first as the Defense System Applications Program (DSAP), which also used the numerical designation Program 35 during 1961-1962 and Program 417 during 1962-1973. In 1973, the program was partially declassified and renamed the Defense Meteorological Satellite Program.

[36] See R. Cargill Hall, A History of the Military Polar Orbiting Meteorological Satellite Program, National Reconnaissance Office, September 2001.

[37] Although NASA was developing a National Operational Meteorological Satellite System, the NRO's director, Under Secretary of the Air Force Joseph V. Charyk, did not believe it would adequately support the NRO's missions.

[38] The first launch attempt took place on 23 May 1962, but it failed. The first successful launch was the second attempt on 23 August 1962. Later unsuccessful Scout launches took place on 19 February 1963, 26 April 1963, and 27 September 1963. Successful Thor Agena D launches were carried out on 19 January 1964 and 17 June 1964. Block I launches on Thor Burner I rockets took place on 18 January 1965 (failure) and 18 March 1965 (success). Block II launches on Thor Burner I vehicles were on 9 September 1965 (success), 7 January 1966 (failure), and 30 March 1966 (success). The only Block III satellite was launched successfully on 20 May 1965 using a Thor Burner I launch vehicle.

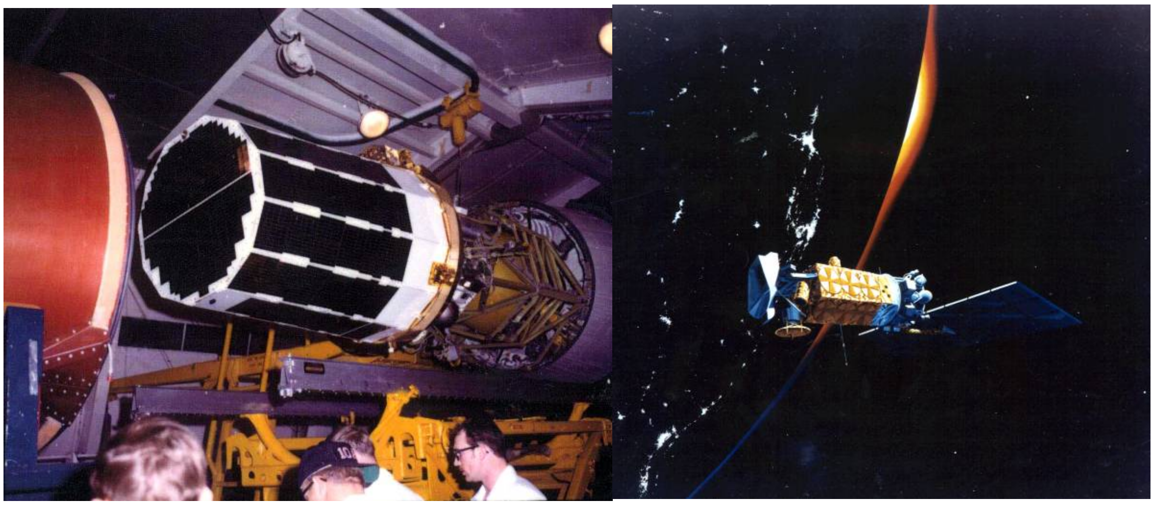
South Vietnam to a ground station at Tan Son Nhut Air Base in Saigon. This was the world's first use of satellite imagery to support tactical military operations. The Block II satellites were also modified for direct readout of meteorological data so that they could be used for planning tactical air operations in Southeast Asia while continuing to provide weather information for strategic reconnaissance. The single Block III satellite, launched in 1965, was equipped only for tactical uses in Southeast Asia.



Left: An artist's concept for the DMSP Block I satellite, launched 1962-1963. Blocks II and III were similar. Right: DMSP Block IV satellites, launched 1966-1969, included the first major improvements in DMSP sensors.

Wider military uses for weather data led to an important change in the program's reporting structure when, on 1 July 1965, it became a program office under Space Systems Division. Development of more capable and more complex satellites also came to fruition with DMSP Block 4 satellites, seven of which were launched during 1966-1969. Television resolution improved from 3 to 4 nautical miles with Blocks I and II to 0.8 to 3 nautical miles with Block 4, along with many other improvements in the sophistication of secondary sensors. Block 5A satellites introduced the Operational Line Scan (OLS) sensor, which provided images of clouds in both visual and infrared spectra. Television resolution improved to 0.3 nautical miles in daylight. Three Block 5A, five 5B, and three 5C satellites were launched during 1970-1976 on Thor Burner II launch vehicles. Larger and much more sophisticated Block 5D-1 satellites were also developed during the 1970s, but only five were built. This proved to be a mistake in 1980, when the fifth 5D-1 satellite was lost in a launch failure, and the operational 5D-1 satellites in orbit ceased to function prematurely. From August 1980 to December 1982, when the first Block 5D-2 satellite was successfully launched, meteorological data was supplied to DOD entirely by civilian satellites. That mistake was not repeated with Block 5D-2 satellites, nine of which were launched during 1982-1997 on Atlas E and Titan II launch vehicles.

In 1989, Space Systems Division began the procurement of five Block 5D-3 satellites from General Electric (later acquired by Lockheed Martin). The 5D-3 satellites featured advanced spacecraft buses as well as significant enhancements in their suite of sensors, power and communications subsystems, and expected lifetimes.[39] Launches of the fully developed 5D-3 satellites began with F-16 in 2003, using the last Titan II vehicle. Satellite F-17 was launched on a Delta IV vehicle in 2006 and F-18 on an Atlas V in 2009. By early 2014, two more Block 5D-3 satellites were waiting to replenish the constellation.



Left: The payload fairing is being installed over a DMSP Block 5A satellite mated to a Burner II upper stage on a Thor Burner (LV-2F) launch vehicle about 1970-1971. Right: This artist's concept depicts a DMSP Block 5D-3 satellite in an early-morning orbit. The DMSP constellation consists of two operational satellites and two spares in sun-synchronous polar orbits. One of the operational satellites crosses the equator (northward) early in the morning, and the other does so at noon local time.

U.S. civilian weather satellites were operated by the National Oceanic and Atmospheric Administration (NOAA). Proposals to merge the civilian and military meteorological systems had been made from time to time since the early 1970s. On 5 May 1994, President Clinton issued a presidential decision directive ordering the convergence and eventual merger of the two programs into a new national space-based system for environmental monitoring. A Tri-Agency Integrated Program Office (IPO) made up of representatives from NOAA, NASA, and DOD would be responsible for carrying out major systems acquisitions, including satellites and launch vehicles. However, NOAA would have overall responsibility for operating the new system, which was soon named the National Polar-orbiting Operational Environmental Satellite System (NPOESS). A major step in convergence occurred in 1998, when the new Satellite Operations Control Center (SOCC) for NPOESS took over control authority of the existing DMSP system.

The merger of the two programs proved to be an unsuccessful experiment. After a phase of competitive development, SMC issued a contract to TRW (acquired by Northrop Grumman) in 2002 to further develop, deploy, and operate NPOESS under the direction of the NPOESS Integrated Program Office (IPO). Unfortunately, the

[39] In the late 1990s, SMC conducted a separate acquisition of another satellite from RCA using the advanced spacecraft but with a suite of sensors closer to the 5D-2 satellites. It was launched as DMSP F-15 in 1999.

development program suffered a long period of cost increases and schedule delays. Despite restructuring by DoD in 2006, the problems continued. A presidential task force formed to examine the problem in 2009 concluded that the IPO's management structure was fundamentally flawed, and it recommended dividing NPOESS into civilian and military programs once again. NOAA began the development of a follow-on system known as the Joint Polar Satellite System (JPSS), and DoD established the Defense Weather Satellite System (DWSS) in 2010 as the follow-on program for DMSP and the DoD replacement for NPOESS.

Nevertheless, Congress cancelled funding for DWSS for 2012, and the Air Force formally terminated design work on the new system in April 2012. Despite the cancellation, Congress provided funding to begin work on a new development program for a space-based military weather system in its appropriations for 2014. Fortunately, the long projected on-orbit lifetimes of Block 5D-3 satellites along with the two satellites not yet launched allowed a cautious approach to a new DoD weather system. One possibility under consideration was a concept known as disaggregation, which would involve placing various weather sensors on different satellites.

Navigation Systems

The world's first space-based navigation system was called Transit. It was developed by scientists at Johns Hopkins University's Applied Physics Laboratory in 1958. DOD's Advanced Research Projects Agency (ARPA) initiated the development program in September 1958 and assigned it to the Navy a year later. The Air Force Ballistic Missile Division launched the Navy's first Transit satellite on 13 April 1960. The system achieved initial operational capability in 1964 and full operational capability in October 1968. It used three operational satellites to produce signals whose Doppler effects and known positions allowed receivers—primarily ships and submarines—to calculate their positions in two dimensions. Transit established the principle and some of the technology of navigation by satellite and prepared military users to rely on such a system. However, it was too slow and imprecise for rapidly moving, three-dimensional platforms such as aircraft. Transit's signals were turned off deliberately in December 1996 because DOD had decided to rely on a newer, faster, and more accurate system.

All of DOD's navigation and position-finding missions are now performed by the Global Positioning System (GPS). The system consists of 24 operational satellites that broadcast navigation signals to the earth, a control segment that maintains the accuracy of the signals, and user equipment that receives and processes the signals. By processing signals from four satellites, a user set is able to derive the location of each satellite and its distance from each one. From that information, it rapidly derives its own location in three dimensions.

Besides Transit, GPS had two immediate programmatic ancestors: a technology program called Project 621B, initiated by SAMSO and the Aerospace Corporation in October 1963, and a parallel program called Timation, undertaken by the Naval Research Laboratory in 1964. Project 621B envisioned a constellation of 20 satellites in synchronous inclined orbits providing continuous three-dimensional positioning information. The satellites would broadcast ranging signals using pseudorandom noise, a technique later incorporated in GPS. The project conducted feasibility tests at White Sands Missile Range in 1972, inverting the planned future direction of the signals by using aircraft with prototype user equipment that received signals broadcast by transmitters on the ground and in balloons.

Left: The second Transit satellite (Transit 1B) undergoes checkout at Cape Canaveral before launch on 13 April 1960. Right: This artist's concept depicts the second Navigation Technology Satellite (NTS-2) in orbit. NTS-2 was used as part of the GPS Block 1 test constellation.

The NRL's Timation Program envisioned a constellation of 21 to 27 satellites in medium altitude orbits providing three-dimensional positioning information. The satellites broadcast passive ranging signals based on highly stable internal clocks, another technique later incorporated in GPS. Experimental Timation satellites 1 and 2, with clocks using quartz-crystal oscillators, were launched in 1967 and 1969. Timation satellites 3 and 4, renamed Navigation Technology Satellites (NTS) 1 and 2, incorporated atomic clocks and were launched in 1974 and 1977 as part of the Phase 1 GPS program.

In 1973, elements of the two programs were combined into the GPS concept, which employed the signal structure and frequencies of 621B with medium altitude orbits and atomic clocks similar to those used for Timation. Deputy Secretary of Defense William P. Clements authorized the start of a program to "test and evaluate the concepts and costs of an advanced navigation system" on 17 April 1973, and he authorized the start of concept validation for the GPS system on 22 December 1973.[40]

[40] The principal proponent of GPS within the Pentagon was the Director of Defense Research and Engineering, Dr. Malcolm Currie. During 1972-1973, Col Bradford Parkinson, the director of the 621B program, briefed Currie on SAMSO's work in improved satellite-based navigation. Currie sponsored the idea for a new satellite navigation system within DoD, with the understanding that a program should include the best features of the competing concepts. After the memo from Deputy Secretary Clements, Parkinson put together a proposed program based mostly on Program 621B and briefed it to the Defense Systems Acquisition Review Council (DSARC) in August 1973. The DSARC disapproved the program, but Currie assured Parkinson privately that he could win approval by including a better mix of features from the other, rival programs along with Program 621B, and Col Parkinson spent the next several months devising a new proposed program that did so. Much of the work on the conceptual design was done by Parkinson assisted by a dozen Air Force and Aerospace Corporation personnel at the Pentagon over Labor

GPS was acquired in the classical three phases: validation, development, and production. During the validation phase, Block I navigation satellites and a prototype control segment were built and deployed, and advanced development models of various types of user equipment were built and tested. During the development phase, additional Block I satellites were launched to maintain the initial satellite constellation, a qualification model Block II satellite was built and tested, and manufacture of additional Block II satellites was initiated.[41] In addition, an operational control segment was activated, and prototype user equipment was developed and tested. During the production phase, a full constellation of 24 Block II and IIA (A for advanced) satellites was deployed. User equipment was also produced and put into operation by issuing it to foot soldiers and installing it in ships, submarines, aircraft, and ground vehicles. The full constellation was completed on 9 March 1994, allowing the system to attain full operational capability in April 1995.

GPS supported a wide variety of military operations, including aerial rendezvous and refueling, all-weather air drops, instrument landings, mine laying and mine sweeping, anti-submarine warfare, bombing and shelling, photo mapping, range instrumentation, rescue missions,[42] and satellite navigation. However, GPS was also the focus of a growing civilian market whose users had become far more numerous than military users by the year 2000. Indeed, it was widely used commercially by the time it reached full operational capability, and some commercial applications, such as airline navigation, were both critical and sensitive. At one time, the GPS signal available to civil users contained intentional inaccuracies, a condition known as selective availability, to provide an advantage to authorized military users. At President Clinton's direction, the intentional inaccuracies were set to zero on 1 May 2000, providing significant improvements in the accuracy available to the system's civil users.

Day weekend in 1973. The improved, more inclusive program was approved by the DSARC in December 1973. See Dr. Parkinson's autobiographical recollections in "The Origins of GPS," GPS World: "Part 1" (1 May 2010) and "Part 2" (1 June 2010). See also the interview with Parkinson by Steven R. Strom on the Aerospace Corporation's Internet site (www.aerospace.org/about-us/history/in-their-own-words/dr-bradford-parkinson/).

[41] Block I, Block II, and Block IIA satellites were built by Rockwell International, which sold its aerospace and defense divisions to Boeing in 1997.

[42] We should take note of a particularly important military application of GPS known as the Combat Survivor Evader Locator (CSEL) system. CSEL was based on an earlier Air Force Space Command procurement called Hook-112 and was designed to enable rescue forces to find, track, and communicate with downed American pilots in hostile territory while making sure they were truly American personnel in need of assistance. It was a technologically sophisticated combination of hand-held radio unit and GPS receiver. Secretary of Defense William J. Perry approved the program in December 1995, and SMC issued a development contract to Rockwell (later absorbed by Boeing) in February 1996. A series of operational assessments and developmental tests were conducted between 1998 and 2002, and the first limited production units were delivered in late 2002. CSEL entered multiservice operational test and evaluation in June 2003 and was scheduled to begin full-rate production early in 2004.

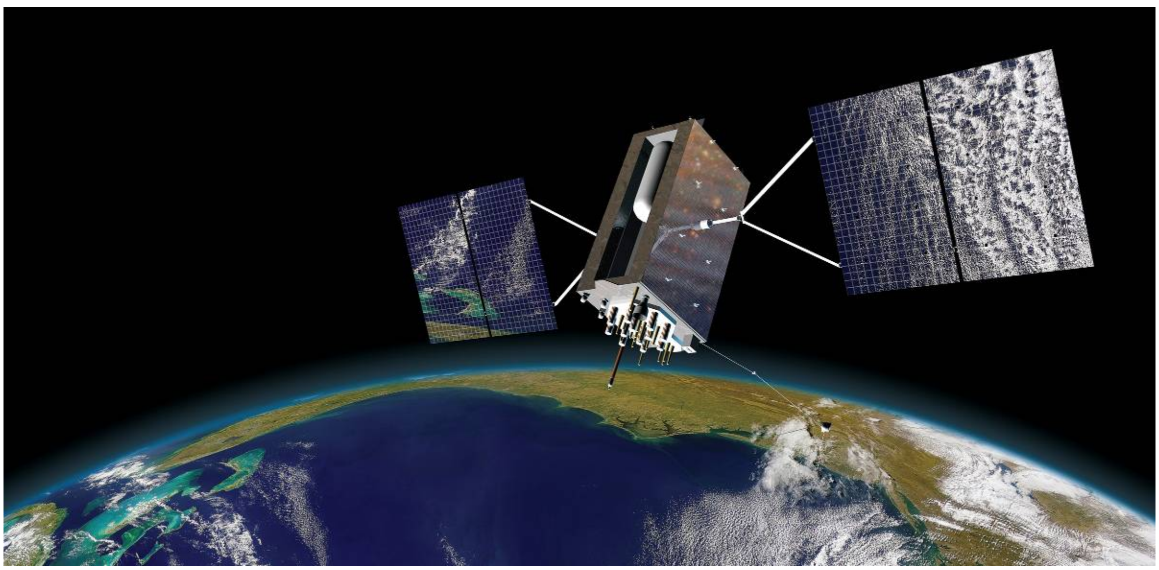

Top: A GPS Block I satellite (left) and a GPS Block II satellite (right) undergo acceptance testing at Arnold Engineering Development Center. Bottom left: An artist's concept depicts a GPS Block IIR satellite in orbit. Bottom right: An artist's concept depicts a GPS Block IIF satellite in orbit.


SMC began launching the next block of GPS satellites, known as IIR (R for replacement), in 1997.[43] The following block of GPS satellites, which incorporated

[43] The launch of the first IIR satellite on 15 January 1997 failed when the Delta launch vehicle exploded. It was the first failure of a Delta II vehicle and only the second launch failure in the history of the GPS program. The first GPS Block IIR satellite to attain orbit and become operational was launched on 23 July 1997.

further improvements, was known as Block IIF (F for follow-on). SMC awarded a contract for the development and production of 33 IIF satellites on 22 April 1996, but it reduced the quantity to 12 in 2000 because the operational lifetimes of GPS satellites were turning out to be longer than expected, and it wished to take advantage of the resulting longer intervals between launches to improve the design of the satellites.[44] Four of the IIF satellites had been launched by early 2014, the first on 27 May 2010 using a Delta IV EELV and the fourth on 15 May 2013 using an Atlas V EELV.

SMC also began the development and initial production of a new and more capable generation of GPS space, control, and user segments known as GPS Block III. It issued competitive system definition and risk reduction contracts to Lockheed Martin and Boeing on 5 January 2004, and it awarded a contract for the first increment of Block III satellites (Block IIIA) to Lockheed Martin on 15 May 2008. The contract provided for development and initial production of two satellites with options for up to 10 additional satellites. By early 2014, the active contract provided for production of six satellites, the first two of which were undergoing integrated testing at Lockheed Martin's facility before delivery.



Artist's concept of GPS Block IIIA satellite in orbit (courtesy Lockheed Martin)

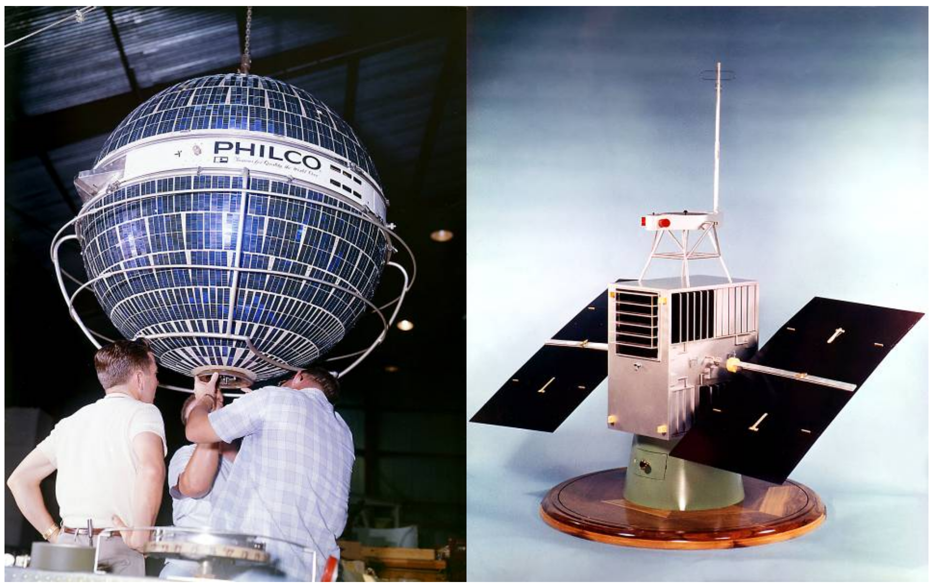
The Block III satellites would be larger and heavier than the Block IIF satellites, and they would have major enhancements in capability. They would have a design life of 15 years (rather than 12 for IIF) and offer three times greater navigational accuracy and signal power. A stronger military signal (M-code) would have greater resistance to jamming, and a new fourth civil signal (L1C) would be compatible with signals from the European Space Agency's navigation satellite system known as Galileo.

Communications Systems

The world's first communications satellite—Project SCORE—was launched by the Air Force Ballistic Missile Division, SMC's predecessor, on 18 December 1958. The

[44] SMC (then called Space Systems Division) had awarded the contract for Block IIR satellites to General Electric (later part of Lockheed Martin) in 1989. It awarded the contract for Block IIF satellites to Rockwell International (later part of Boeing). See note 41 above.

SCORE payload consisted of commercial communications equipment modified by the Army Signal Corps and installed in an Atlas B missile as a proof-of-concept mission for orbiting communications repeaters. The project was executed under ARPA's direction. AFBMD launched the entire missile, minus the spent half stage, into a low orbit, where it remained for about a month,[45] relaying voice and telegraph messages between ground stations in the United States. Among its first experimental transmissions was President Eisenhower's Christmas message to the world, the first time that a human voice had been transmitted from space. The world's second military[46] communications satellite was Courier 1B, developed by the Army Signal Corps under ARPA's direction. AFBMD successfully launched it on 4 October 1960, using a Thor Able Star launch vehicle. Courier further tested the feasibility of orbiting communications repeaters but did so with a spherical, self-contained satellite that included solar cells and rechargeable batteries. Unfortunately, the spacecraft suffered a command system failure after 17 days in orbit.



Left: Courier 1B satellite in testing, 1960. Right: Model of planned Advent satellite, about 1961.

The first military satellite communications system to be used for operational purposes was known as the Initial Defense Communications Satellite Program (IDCSP). The development program began in 1962, following the cancellation of an earlier, unsuccessful development program called Project Advent.[47] The IDCSP system

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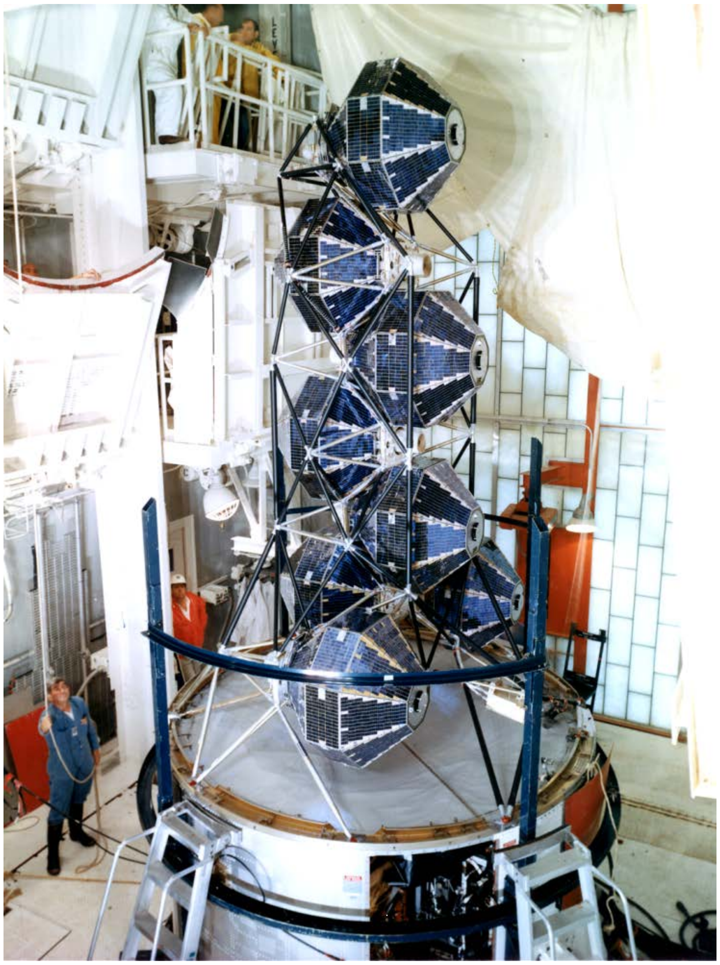
[45] SCORE stopped transmitting when its batteries were exhausted on 31 December 1958. It had no solar cells or other sources of power. It reentered on 21 January 1959.

[46] Echo 1, a metallized balloon that acted as a passive experimental communications satellite, was successfully launched by NASA on 2 August 1960.

[47] Motivated by the necessity of maintaining communications with the Strategic Air Command's large fleet of strategic bombers, ARPA undertook other space-based communications efforts around the same time as Courier. It issued direction to AFBMD on 22 May 1959 to develop a three-part satellite system, with a geosynchronous satellite communications system called Project Decree and two polar satellite communications systems called Project Steer and Project Tackle. All of these were cancelled and replaced by ARPA on 29 February 1960 by a geosynchronous satellite program called Project Advent, for which the Army was to develop the communications payload and AFBMD was to develop the spacecraft. The entire project was transferred to the Army, then transferred to the Air Force and cancelled by DoD in 1962 because of delays.

consisted of small, 100-pound satellites launched in clusters. Twenty-six such satellites were placed into orbit in four launches carried out between June 1966 and June 1968.[48] Two fixed and thirty-four mobile ground terminals also became operational in 1968. IDCSP transmitted both voice and photography to support military operations in Southeast Asia. It provided an experimental but usable worldwide military communications system for the Defense Department for ten years until a more sophisticated system could be developed.



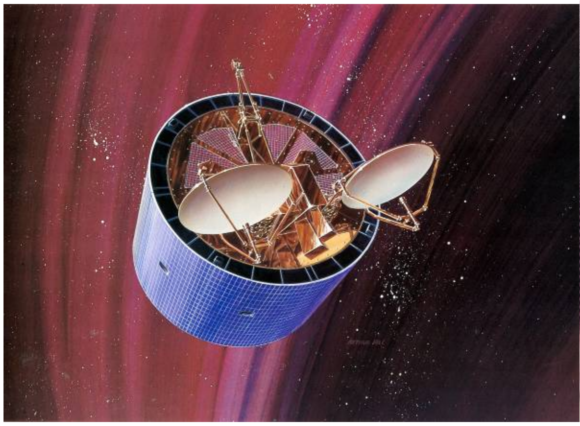
Left: The payload fairing is being installed on Titan IIIC-16 at Cape Canaveral. Enclosed in a dispensing mechanism are the last eight satellites of the Initial Defense Communications Satellite Program (IDCSP), successfully launched on 13 June 1968. The IDCSP satellites were small and very simple, with no batteries and no active attitude control system. The dispenser ejected them one at a time into a near-synchronous orbit.

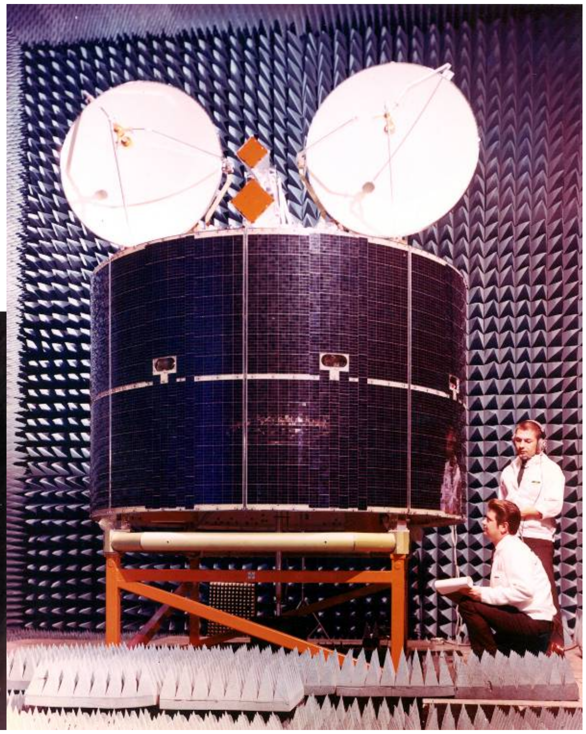
That more sophisticated system was known as the Defense Satellite Communications System, Phase II (DSCS II). The DSCS II satellites were much larger and more sophisticated than the IDCSP satellites, offering increased communications capacity, greater transmission strength, and longer lifetimes. In addition to horn antennas for wide area coverage, they had dish antennas that were steerable by ground command and provided intensified coverage of small areas of the earth's surface. SAMSO awarded a development contract for the DSCS II system to TRW on 3 March 1969, and the first

[48] There were five attempted launches of IDCSP satellites on Titan IIIC launch vehicles during 1966-1968: 16 June 1966, 26 August 1966, 18 January 1967, 1 July 1967, and 13 June 1967. The second launch was unsuccessful because of a structural failure in the Titan. Each launch dispensed from three to eight IDCSP satellites into near-synchronous orbits.

pair of satellites was launched on 2 November 1971. It was the first operational military communications satellite system to occupy a geosynchronous orbit (22,237 miles). Two launch failures delayed completion of the satellite network, but by January 1979, the full constellation of four satellites was in place and in operation. A total of 16 DSCS II satellites was built and launched[49] during the life of the program, with the last launch occurring on 4 September 1989.

Below left: An artist's concept depicts a DSCS II satellite in orbit.
Right: A DSCS II satellite undergoes testing in an anechoic chamber.





In 1973, planning began for the Defense Satellite Communications System, Phase III (DSCS III). DSCS III satellites carried multiple beam antennas to provide flexible coverage and resist jamming, and they offered six active communication channels rather than the four offered by DSCS II. The first DSCS III satellite was successfully launched on 30 October 1982, and a full constellation of five DSCS III satellites was completed on 2 July 1993. Two DSCS IIIs were launched into orbit from a Space Shuttle on 3 October 1985. The constellation was replenished with five launches from 28 November 1993 to 20 October 2000. By early 2003, only two unlaunched DSCS III satellites remained in the inventory. In view of the fact that the DSCS III system would have to support tactical military operations until a follow-on system could be acquired,[50] SMC began an initiative to improve the tactical utility and extend the lifetime of DSCS III satellites. Known as the Service Life Enhancement Program (SLEP), the initiative added improvements to the last four DSCS III satellites before they were launched. Lockheed Martin was placed under contract to carry out the SLEP modifications on 28 March 1996.

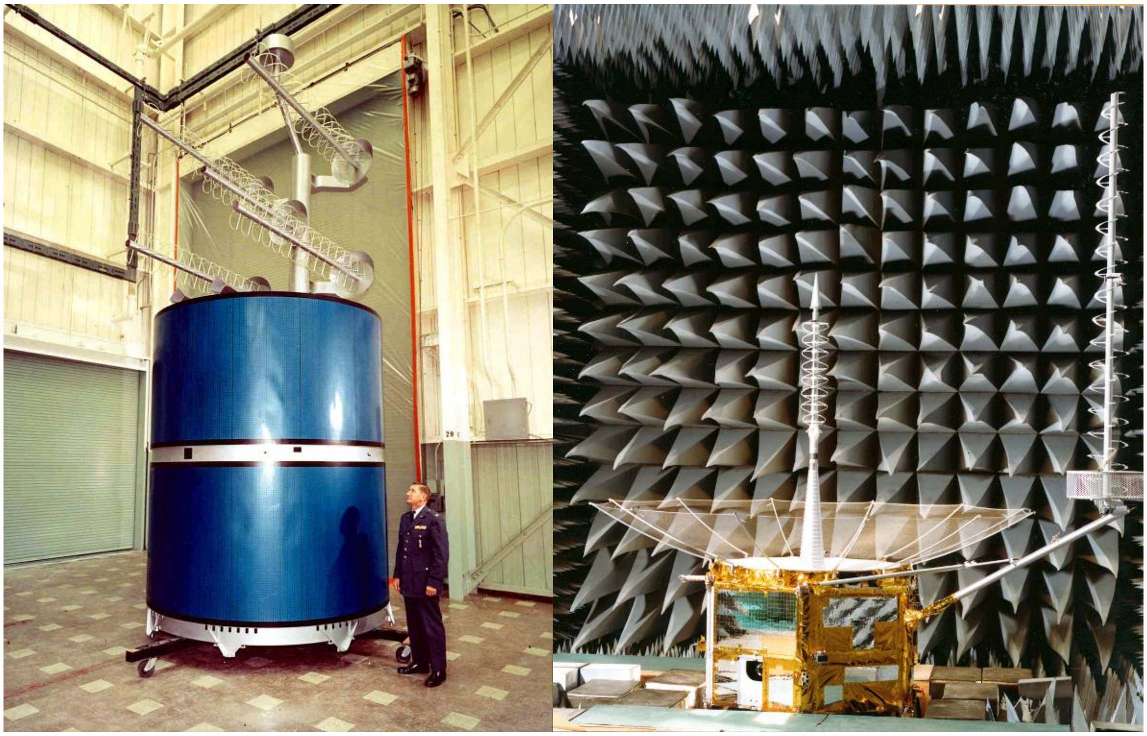
[49] DSCS II satellites were launched in pairs using Titan IIIC vehicles through 1979.

[50] See the Wideband Gapfiller Satellite (WGS) system discussed below.

Left: An artist's concept depicts a DSCS III satellite in orbit.
Below: A DSCS III satellite is prepared for testing.

DSCS satellites were developed to serve users who transmitted message traffic at medium to high data rates using relatively large ground terminals. However, satellites were also needed to serve users who transmitted at low to medium data rates, using small, mobile or transportable terminals. During the 1960s, experimental satellites were placed into orbit to test technology that might perform this tactical communications mission. Lincoln Experimental Satellites 5 and 6, launched on 1 July 1967 and 26 September 1968, were solid-state, ultra high frequency communication satellites built by Lincoln Laboratory. The 1,600 pound Tactical Communications Satellite, launched on 9 February 1969, operated in both ultra high frequency and super high frequency and tested the feasibility of communications with small, mobile, tactical communications equipment that could be used by ground, naval, and air forces. In July 1970, an initial operational capability for tactical communications was established, using the Tactical Communications Satellite and Lincoln Experimental Satellite 6.

These experimental satellites paved the way for the Fleet Satellite Communications System (FLTSATCOM), the first operational system serving tactical users. The Navy managed the overall program, but SAMSO managed acquisition of the satellites. Development of FLTSATCOM was authorized on 27 September 1971, and five satellites were launched from 9 February 1978 to 6 August 1981. Four achieved orbit and went into operation, but one was damaged during launch and never became operational. Three replenishment satellites were launched from 5 December 1986 to 25 September 1989. Two reached orbit, but one was lost when its booster was hit by lightning.



Left: SAMSO's TACSAT program director poses with TACSAT I in the testing facilities of the prime contractor, Hughes Aircraft Company, about 1969. SAMSO launched TACSAT using a Titan IIIC on 9 February 1969, and it operated successfully for 46 months. Right: A FLTSATCOM satellite undergoes testing in an anechoic test chamber.

In addition to the long-haul users served by DSCS and the tactical users served by FLTSATCOM, there was a third group of users—the nuclear capable forces—who could be satisfied at the time with low data rates but required high availability, worldwide coverage, and the maximum degree of survivability. The Air Force Satellite Communications System (AFSATCOM) was developed to serve their needs and allow the Air Force to command and control its strategic forces. The space segment of the system relied on transponders (receiver/transmitters) placed on board FLTSATCOM satellites and other DOD spacecraft. The space segment of AFSATCOM became operational on 15 April 1978, and the terminal segment attained initial operational capability on 22 May 1979.

The communications satellites discussed above were all acquired for the U.S. military, but other communications satellites were acquired for the United Kingdom and the North Atlantic Treaty Organization during the 1960s and 1970s. The British Skynet program began in 1966. The first of two Skynet I satellites was placed into orbit on 21 November 1969 and provided the United Kingdom with its first military communications satellite system. The second Skynet satellite was launched from Cape Canaveral on 19 August 1970, but a malfunction in the launch vehicle caused permanent loss of contact with the satellite. In 1970, SAMSO and the United Kingdom began development of a more advanced Skynet II satellite system. The first Skynet II satellite was launched on 18 January 1974, but a malfunction in the launch vehicle again caused the loss of the satellite. The second Skynet II satellite, launched on 22 November 1974, attained orbit successfully and was turned over to the United Kingdom in January 1975.

Development of the NATO satellites began in April 1968, with the initial series of satellites being known as NATO II. One NATO II satellite was placed in orbit on 20 March 1970 and another on 3 February 1971. Both the Skynet and NATO satellites were designed to be compatible and usable with each other and with the Defense Satellite Communications System. Work on a more advanced system, NATO III, began in 1973, and three NATO III satellites were successfully launched between 1976 and 1978. The constellation was replenished in November 1984, when a fourth satellite was successfully launched.

Left: The first NATO III satellite (NATO IIIA) is prepared for testing by two technicians at Philco-Ford Corporation, the prime contractor. SAMSO launched the satellite successfully on a Delta launch vehicle from Cape Canaveral on 22 April 1976.

The next space communications system to be acquired by SMC was Milstar. Milstar I satellites carry a low data rate payload that provides worldwide, survivable, highly jam-resistant communications for the National Command Authority and the tactical and strategic forces.[51] Advanced processing techniques on board the spacecraft as well as satellite-to-satellite cross linking allow Milstar satellites to be relatively independent of ground relay stations and ground distribution networks. Space Division awarded concept validation contracts for the satellite and mission control segment of Milstar I in March 1982 and a development contract to Lockheed on 25 February 1983. The first Milstar I was successfully launched[52] on 7 February 1994, and the second, on 6 November 1995. In October 1993, SMC awarded a contract for development of the Milstar II satellite, which carried both low and medium data rate payloads. The addition of the medium data rate payload greatly increased the ability of tactical forces to communicate within and across theater boundaries. Only four Milstar II satellites were produced because DOD had decided in 1993 that they were to be replenished by a new,

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51 Unlike DSCS, which operated in the SHF range (superhigh frequency: 3,000-30,000 megaherz), Milstar operated in the EHF range (extremely high frequency: 30,000-300,000 megaherz). EHF had rarely been used for military communications before Milstar. This frequency range provided natural resistance to jamming. EHF also allowed users to employ smaller, highly mobile terminals.

52 All Milstar satellites have been launched on Titan IV or IVB vehicles.

lighter, cheaper series of Advanced EHF satellites. Unfortunately, the first Milstar II satellite went into an unusable orbit on 30 April 1999. The next two Milstar II satellites were successfully launched on 27 February 2001 and 16 January 2002 to complete an on-orbit constellation of four satellites. The sixth and last Milstar satellite was successfully launched on 8 April 2003.

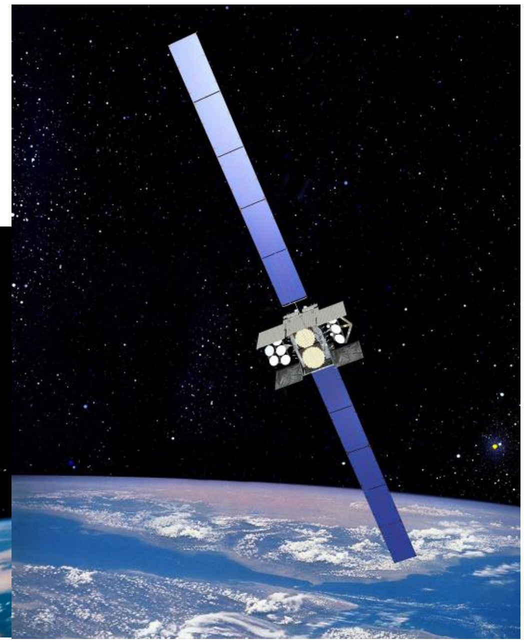

Left: An artist's concept depicts a Milstar II satellite in orbit. Right: The fifth Milstar satellite is enclosed in the payload fairing on top of its Titan IVB launch vehicle. Its successful launch on 15 January 2002 completed the operational constellation of four Milstar satellites. (Images courtesy Lockheed Martin Missiles and Space)

In view of the limited future of the Milstar system, SMC soon began the acquisition of a follow-on EHF[53] military communications system, known as the Advanced EHF system or AEHF. The system was compatible with Milstar elements and incorporated them throughout their useful lifetimes. The completed AEHF constellation would consist of four satellites in geosynchronous orbit. Like Milstar, but greatly enhanced, the AEHF system featured on-board signal processing and satellite crosslinks to eliminate reliance on ground stations for routing data. Data uplinks to the satellites and crosslinks between satellites operated at EHF, and downlinks operated at SHF. Whereas Milstar offered low and medium data rate payloads, AEHF satellites had high data rate payloads as well, providing up to 8.2 Mbps. The AEHF system provided ten times as much data throughput as Milstar for a much larger area of coverage. It enabled a variety of types of communications, including broadcasting, real-time video, data and voice networking, and voice-conferencing. All services used AEHF terminals, which were located on a wide variety of platforms on land, sea, and air.

[53] See note 50 above.

After competitive system definition efforts ending in 1999, SMC awarded a contract to the team of Lockheed Martin and TRW for the System Development and Demonstration phase of the AEHF system, including production of the first two satellites and the Mission Control Segment. A third satellite was added to the contract in 2006 and a fourth in 2010.[54] In 2009, OSD cancelled a planned follow-on program known as the Transformational Satellite Communications System (TSAT) that would have followed the fourth AEHF satellite, and it directed the Air Force to acquire the fifth and sixth AEHF satellites instead.[55] By 2014, the first three AEHF satellites had been successfully launched on Atlas V vehicles.[56]

Below: Artist's concept of Advanced EHF satellite in orbit (courtesy Lockheed Martin);
Right: Artist's concept of WGS satellite in orbit (courtesy Boeing Company)



In 2000, SMC also led a multi-service program to acquire a new series of communications satellites—known eventually as the Wideband Global SATCOM (WGS)[57] system—to augment DSCS III and finally replace it. However, the capabilities of the WGS system were vastly enhanced in comparison to DSCS. WGS provided not only two-way tactical military communications, but also a two-way Ka-band

[54] The gap in production between the third and fourth AEHF satellites caused a shutdown and restart of the production line and resulting cost increases.

[55] For the TSAT program, see below after the discussion of the Wideband Global Satellite Communications (WGS) system.

[56] AEHF-1 was launched on an Atlas V on 14 August 2010. The liquid apogee engine failed to raise the satellite from a transfer orbit to its final geosynchronous orbit, but a mission planning team formed to deal with the anomaly successfully used the satellite's stabilizing thrusters and then the electrical maneuvering thrusters to gradually raise the satellite over the course of about 14 months to its intended orbit, which it reached on 24 October 2011. AEHF-2 was successfully launched on 4 May 2012 and AEHF-3 on 18 September 2013.

[57] WGS was called at first the Wideband Gapfiller Satellite because it would fill the gap between the availability of the existing DSCS III and GBS satellite systems and a planned very advanced system called the Transformational Satellite Communications System (TSAT). The name was changed (but not the abbreviation) in 2007 at the request of HQ USAF. SATCOM is, regrettably, an abbreviation within an abbreviation, and stands for "satellite communications." The TSAT program was cancelled in 2009.

augmentation of the older one-way, wideband satellite broadcast system called the Global Broadcast Service (GBS).[58] Each WGS satellite could provide up to 3.6 Gbps of data transmission, well over ten times the X-band communications capacity of a DSCS satellite, and 4.875 GHz of instantaneously switchable bandwidth. Block II satellites (starting with WGS-4) provided ultra-high bandwidth and data rates using a radio frequency bypass capability to support airborne intelligence, surveillance and reconnaissance platforms such as unmanned aerial vehicles.

SMC awarded a contract[59] for design and advance procurement of the first three WGS satellites, which constituted Block I, as well as ground-based command and control elements to Boeing Satellite Systems in 2001. It awarded a contract for the next three satellites,[60] constituting Block II, to Boeing in 2006 and a Block II follow-on contract for WGS satellites 7 through 10 in 2010. By 2014, the first six WGS satellites had been successfully launched, the first two on Atlas V vehicles and the next four on Delta IVs.[61]

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[58] The Global Broadcast Service, a joint-service program, became operational about 1999, using its own transponders on the Navy's UHF Follow-on satellites. GBS was a system for extremely rapid, one-way transmission of high-volume data such as weather, intelligence, and imagery from higher echelons to large groups of dispersed users with small, mobile receivers.

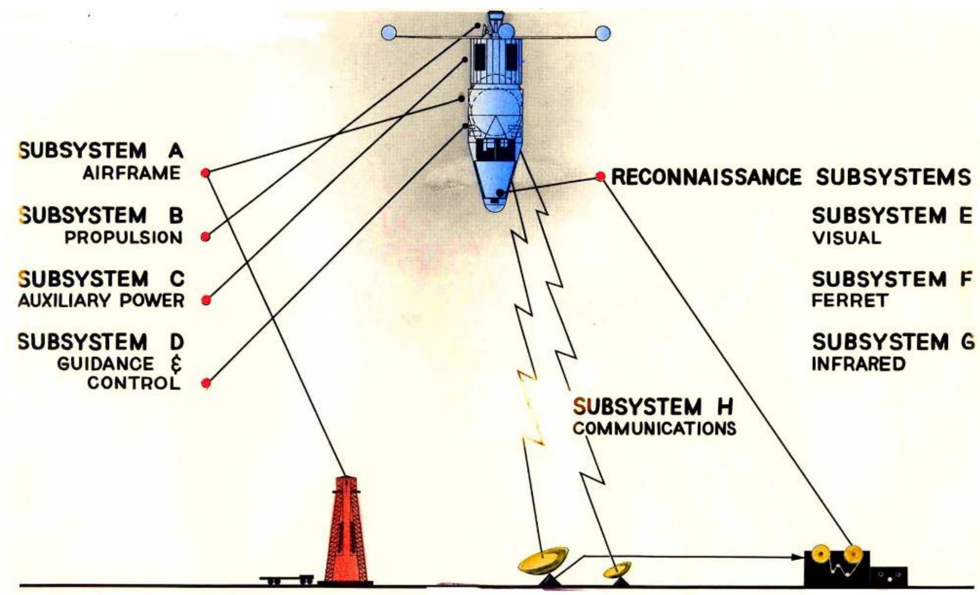
[59] The contract for procurement of WGS Block I was a "near commercial" acquisition, one important feature of which was that little technological development was involved, since most of the components could be obtained commercially.

[60] Australia funded the acquisition of WGS-6 in exchange for allocation of 10 percent of the capacity of the WGS system.

[61] The launch dates in EST were WGS-1: 10 October 2007, WGS-2: 3 April 2009, WGS-3: 5 December 2009, WGS-4: 19 January 2012, WGS-5: 24 May 2013, WGS-6: 7 August 2013.

CHAPTER V: SATELLITE SYSTEMS

The Air Force was the last U.S. military department to launch a satellite, but it was the first to sponsor engineering and conceptual studies of a satellite with specific military applications and the first to undertake the development of such a spacecraft. Its first effort emerged on 2 May 1946, when Douglas Aircraft Company's Project RAND issued a 250-page report called "Preliminary Design of an Experimental World-Circling Spaceship"[15] to support the claim of the Army Air Forces to the proposed new mission area of space.[16] RAND's report not only examined solutions to engineering problems for orbiting a satellite, it also discussed some of the major mission areas for satellites that were later developed by the Air Force, including reconnaissance, communications, and meteorology. Under contract after 1947 to the newly independent Air Force, and especially beginning in 1950 to the new Air Research and Development Command (ARDC), RAND continued to conduct studies that examined engineering solutions to problems involved in developing satellites with specific military missions. One of the most influential of those efforts was Project Feed Back, which culminated in a report issued on 1 March 1954 proposing the development of a reconnaissance satellite to provide photographic data on Soviet military preparations. Before the report was even issued, ARDC established a very small office at Wright Air Development Center[17] on 24 December 1953 to manage preparations to award design and development contracts for



A concept for WS 117L and its subsystems from a briefing given in 1957

[15] A scanned copy of the entire report is available on the RAND Corporation's Internet site.

[16] Major General Curtis E. Lemay, then the Air Staff's Deputy Chief of Staff for Research and Development, issued the direction for the RAND report to counterbalance more general feasibility studies by the Navy that were being considered by the War Department's Aeronautical Board.

[17] The most detailed and interesting description of the activities of the early WS 117L project office is the first-person narrative of James S. Coolbaugh, published as "Genesis of the USAF's First Satellite Programme" in *The Journal of the British Interplanetary Society*, vol. 51 (1998), pp. 283-300. According to his narrative, Maj Coolbaugh became the first manager of the project on 24 December 1953.

the satellite, known at first as Project 1115 and soon afterward as the Advanced Reconnaissance System or Weapon System 117L (WS 117L).

The military satellite project was soon added to the mission of the Western Development Division, largely because of the development's intimate association with ballistic missiles, which rapidly acquired a role as space launchers equal to their role as weapons. The commander of Air Research and Development Command transferred responsibility for the program from Wright Air Development Center to WDD on 17 October 1955[18], and satellites grew into an increasingly important part of the activities of the Division's successors.

WS 117L was, in concept, a family of separate subsystems that could carry out different missions, including photographic reconnaissance and missile warning. After evaluating system design studies from Lockheed, RCA, and Martin, WDD awarded the first Air Force space development contract to Lockheed on 29 October 1956. However, by the end of 1959, WS 117L had evolved into at least three separate satellite programs: the Discoverer Program, the Satellite and Missile Observation System (SAMOS),[19] and the Missile Defense Alarm System (MIDAS).[20] Discoverer and SAMOS undertook the photographic reconnaissance mission, and MIDAS undertook the missile-warning mission.[21]

Reconnaissance Systems

The Discoverer program aimed at developing a film-return photographic reconnaissance satellite. The satellite carried a camera that took pictures from space as it passed over the Soviet Union and China. Film from the camera returned from orbit in a capsule. A parachute deployed to slow the descent of the capsule, and C-119J (later, JC-130) aircraft operated by the 6593rd Test Squadron from Hickam AFB, Hawaii, recovered the capsule in mid-air.[22] However, Discoverer's photo reconnaissance mission was not revealed to the public at the time. It was, instead, presented as an experimental program to develop and test satellite subsystems and explore environmental conditions in space.[23]

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[18] ARDC transferred oversight of the project office to WDD in a revision to System Requirement No. 5, dated 17 October 1955. However, the project's personnel did not physically complete their move to WDD until 1 April 1956.

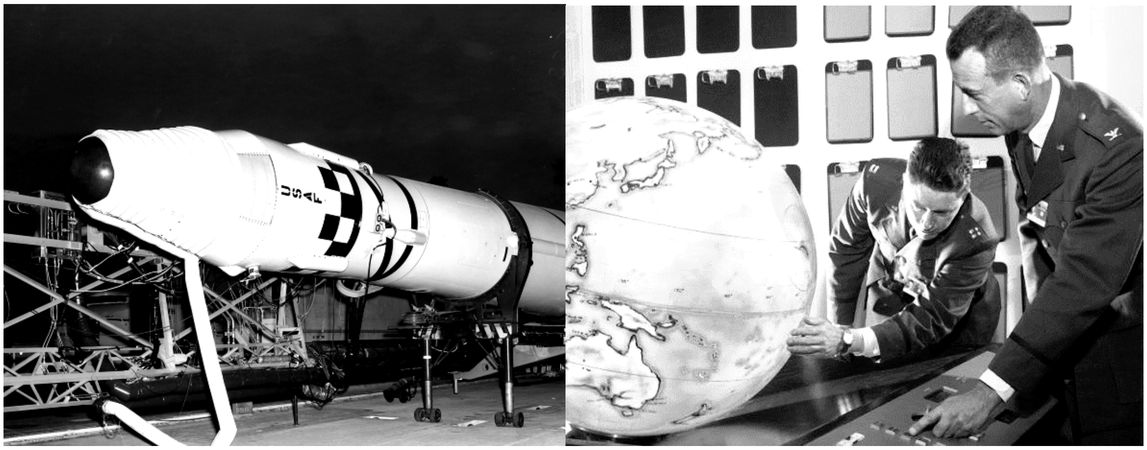
[19] SAMOS may have been made into an acronym after the name had been selected to go with MIDAS.

[20] The newly created Advanced Research Projects Agency (ARPA) was primarily responsible for the division of WS 117L into separate satellite programs. It issued separate directives for these and other military space programs from June 1958 to September 1959. ARPA's purpose was to accelerate near-term achievements in military space, and it succeeded in doing so.

[21] Under the WS 117L program, the visual reconnaissance payloads (which became the Discoverer and SAMOS programs) were known as Subsystem E, and the infrared reconnaissance payload (which became the MIDAS early warning program) was called Subsystem G. The spacecraft, which finally became the Agena combined upper stage and spacecraft, was called Subsystem A for the airframe and Subsystem B for the propulsion elements. Subsystem H for communications led eventually to the early Air Force Satellite Control Network.

[22] Not all capsule recoveries were nominal, however. A few were not recovered successfully in midair and had to be secured by air-dropped divers, rafts, and ships. For first-person accounts of recovery techniques and missions, see Robert Mulcahy, ed., *Corona Star Catchers*, GPO: June 2012.

[23] Nevertheless, some Discoverer missions carried experimental payloads instead of or in addition to their normal reconnaissance payloads. Mission 2 carried simulated biological experiments, but its payload was



Left: The Agena spacecraft for Discoverer 13, mated to its Thor launch vehicle, waits on the pad at Vandenberg AFB before being erected. The covering cooled and protected the spacecraft. Right: Colonel C. Lee Battle, Discoverer program director, and Captain Albert W. Johnson observe the ground track of a Discoverer (Corona) satellite in 1960, taking care not to look at the Soviet Union.

The Discoverer Program carried out 38 public launches and achieved many technological breakthroughs. Discoverer I, launched on 28 February 1959, may have been the world's first polar orbiting satellite.[24] Discoverer II, launched on 13 April 1959, was the first satellite to be stabilized in orbit in all three axes, to be maneuvered on command from the earth, to separate a reentry vehicle on command, and to send its reentry vehicle back to earth.[25] Discoverer XIII, launched on 10 August 1960, ejected a capsule that was subsequently recovered in the water near Hawaii, the first successful recovery of a man-made object ejected from an orbiting satellite. Discoverer XIV, launched on 18 August 1960, ejected a capsule that was recovered in midair northwest of Hawaii by a JC-119 aircraft, the first successful aerial recovery of an object returned from orbit. The capsule from Discoverer XIV was the first to return film from orbit, inaugurating the age of satellite reconnaissance. Satellite reconnaissance filled a crucial need because President Eisenhower had suspended aerial reconnaissance of the Soviet Union just three months earlier after the Soviets had shot down the U-2 spy plane piloted by Francis Gary Powers.

The Discoverer Program ostensibly ended after the launch of Discoverer XXXVIII on 27 February 1962. In reality, however, it continued in clandestine form until 31 May 1972 (the date of the last film recovery), carrying out 145 launches[26] under the secret code name Corona. At the direction first of President Eisenhower and later of

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not recovered (at least, not by the U.S.). Mission 3 carried actual biological experiments, but its payload did not attain orbit. Missions 19, 21, 49, 52, 57, 73, 92, and 99 gathered infrared background data for the MIDAS program. Other missions carried geodetic payloads. For short descriptions of all Corona payloads, see Curtis Peebles, The Corona Project, Naval Institute Press, 1997.

[24] The Air Force officially claimed that Discoverer I had reached orbit, but the program's operations officer, Col Frank Buzard, said many years later that tracking stations had not received a verifiable signal. If Discoverer I did not achieve orbit, the distinction of being the first polar-orbiting satellite should go to Discoverer II.

[25] However, the reentered capsule was not recovered by the U.S. The consensus of researchers seems to be that it reentered over or near the island of Spitzbergen, where it may have been found by Russian miners.

[26] Including the 38 Discoverer launches.

President Kennedy, the direction and management of Corona and other satellite reconnaissance programs passed to a new DOD agency, the National Reconnaissance Office (NRO), when it was created in 1961.[27] Corona's first major accomplishment was to provide photographs of Soviet missile launch complexes. It also identified the Plesetsk Missile Test Range, north of Moscow, and provided information about what missiles were being developed, tested, and deployed. These and other accomplishments came to light when the Corona program was declassified in February 1995.

Left: A recovery crew of the 6593rd Test Squadron (Special) performs a practice midair capsule recovery in a JC-119 aircraft in 1959. Recovery crews flew JC-119s for the first 29 Discoverer missions and JC-130s after that. Right: President Dwight D. Eisenhower holds a news conference on 15 August 1960 to exhibit the capsule from Discoverer 13, recovered from the ocean four days earlier. Behind the president, left to right, are Colonel C. Lee Battle (Discoverer program director), General Curtis E. Lemay (Air Force vice chief of staff), Lieutenant General Bernard A. Schriever (commander of Air Research and Development Command), Dudley C. Sharp (Secretary of the Air Force), Thomas Gates (Secretary of Defense), General Thomas White (Air Force Chief of Staff).

SAMOS, the second program that evolved from WS 117L, aimed at developing a heavier reconnaissance payload that would be launched by an Atlas Agena booster rather than the Thor Agena used to launch Discoverer. The payloads were intended to collect photographic and electromagnetic reconnaissance data. The photographic data would be collected by cameras in the Agena spacecraft, like the Corona payloads. However, the film would be scanned electronically in orbit and transmitted to ground stations. SAMOS had three unclassified launches from the west coast: 11 October 1960, 31 January 1961, and 9 September 1961. Only the launch in January 1961 was successful. In 1962, a veil of secrecy was drawn across the SAMOS program, and the Air Force stopped releasing information about it. After several more classified launches, however, it was apparent that the technology required for downloading the imagery was not yet sufficiently advanced, and Air Force undersecretary Joseph V. Charyk canceled further work on the

[27] On 31 August 1960, Secretary of the Air Force Dudley C. Sharp created an Office of Missile and Satellite Systems. Reconnaissance programs under that office reported to the secretary of the Air Force through an undersecretary, Joseph V. Charyk. On 6 September 1961, the new Kennedy Administration established the NRO. Its joint directors, the undersecretary of the Air Force and the deputy director of the CIA, reported directly to the deputy secretary of defense for reconnaissance matters.

payload.[28]

Although SMC did not directly manage the development of imaging reconnaissance satellites after this, it did manage programs that were linked to them or their products. One of the most important was the Defense Dissemination System (DDS), whose broad outlines were declassified in 1996. The Defense Dissemination Program Office (DDPO) was established at SAMSO in July 1974 to develop a means to securely and rapidly provide reconnaissance imagery in nearly original quality to both strategic and tactical users. The DDPO developed a system consisting of segments for processing, transmitting, and receiving. The system was deployed to four strategic sites during 1976-1978, providing the first electronic dissemination of digital imagery for targeting and strategic threat assessment.

The DDS went through three more generations of increasingly sophisticated improvements for compressing, transmitting, receiving, and reconstructing imagery for military users in the field. One of the third-generation DDS units was deployed to the Persian Gulf to support Operations Desert Shield and Desert Storm. Fourth-generation DDS units were fielded to 70 strategic and tactical users by 1998. However, the DDPO itself ceased to exist as a program office on 1 October 1996,[29] when it was combined with other agencies to create the National Imagery and Mapping Agency (later renamed the National Geospatial-Intelligence Agency).

Infrared Early Warning Systems

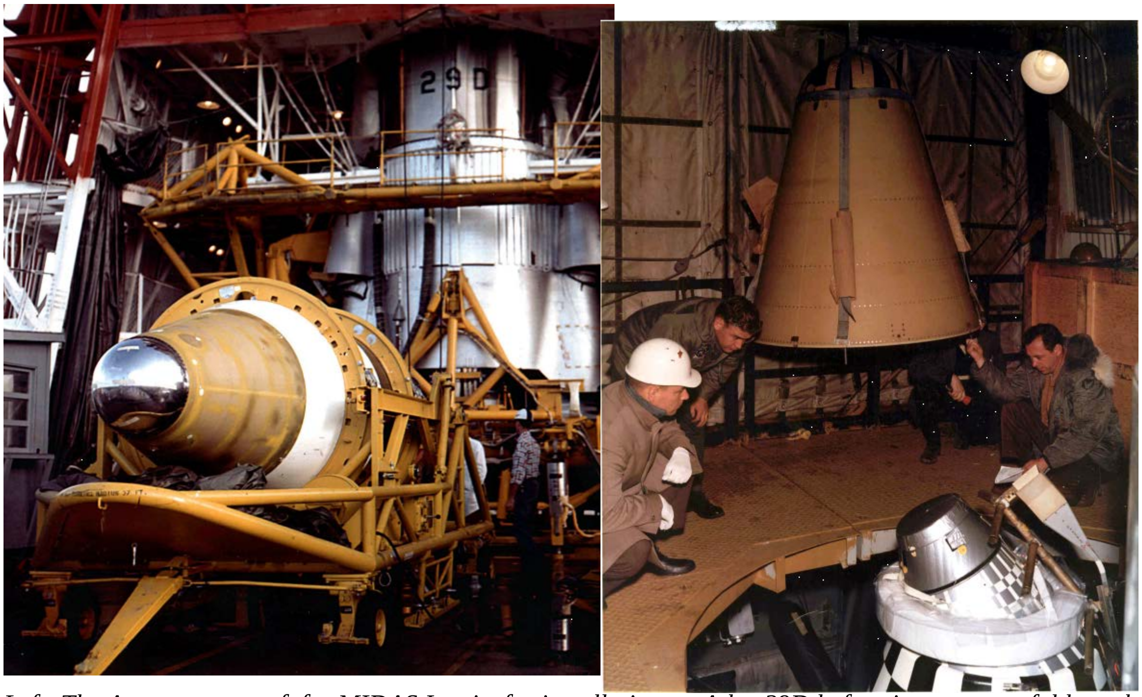
The MIDAS program, the third offshoot of WS 117L, focused on developing a satellite with an infrared sensor to detect hostile ICBM launches. It began its life as a separate program when AFBMD placed the infrared portion of WS 117L (Subsystem under a separate contract with Lockheed effective 1 July 1959. The payload consisted of an infrared sensor array and telescope inside a rotating turret mounted in the nose of an Agena spacecraft. Plans which were never carried out called for an operational constellation of eight satellites in polar orbits to constantly monitor launches from the Soviet Union. Unfortunately, the program's first four test satellites launched in 1960 and 1961 ended in a launch failure and early on-orbit failures.

DOD kept the program in a research and development phase rather than approve an operational system in 1962. The MIDAS program was lengthened and renamed Program 461. The next two launches in 1962 also ended in an early on-orbit failure and a launch failure. Finally, a satellite launched on 9 May 1963 operated long enough to detect 9 missile launches. After another launch failure in 1963, the last Program 461 satellite, launched on 18 July 1963, operated long enough to detect a missile and some Soviet ground tests. Data collection and analysis continued until 1968 under Lockheed's contract for Program 461 to support the next early warning program. Additional launches in 1966, using improved spacecraft and sensors, demonstrated the system's increasing reliability and longevity. Although a launch on 9 June 1966 failed, launches on 19

[28] However, the technology was secretly transferred to NASA, which used it successfully in its Lunar Orbiter imaging lunar satellites. See R. Cargill Hall, "SAMOS to the Moon: The Clandestine Transfer of Reconnaissance Technology Between Federal Agencies," NRO Office of the Historian, October 2001.

[29] As an organization, the DDPO was characterized by unusually high *esprit de corps*. It received a larger number of Air Force Organizational Excellence Awards than any other program office in SMC's history.

August and 5 October 1966 placed their spacecraft into highly useful orbits, where their infrared sensors gathered data for a year, reporting on 139 American and Soviet launches. The MIDAS program and its successors were declassified in November 1998.



Left: The Agena spacecraft for MIDAS I waits for installation on Atlas 29D before its unsuccessful launch on 26 February 1960. Right: The payload for an advanced version of MIDAS, known as AFP 461, is covered with the Agena's nose cone before its unsuccessful launch as MIDAS 6 on 17 December 1962.

DOD initiated a new program late in 1963 to develop an improved infrared early warning system, which ultimately became the Defense Support Program. After an early phase known as Program 266, contracts for development of Program 949, the Defense Support Program (DSP), were awarded to TRW for the spacecraft on 6 March 1967 and to Aerojet for the infrared sensor on 1 March 1967. The new concept involved placing the satellites into orbits at geosynchronous altitude (22,237 miles), where only three or four would be necessary for global surveillance. Like MIDAS, the satellites would employ telescopes and IR detectors, but the necessary scanning motion would be accomplished by rotating the entire satellite around its axis in space several times per minute. An evolving network of two, and later three, large ground stations in Australia, Europe, and the continental U.S. controlled the spacecraft and data.

The first DSP satellite was launched on 6 November 1970, using a Titan IIIC launch vehicle. A long series of increasingly larger, more sophisticated, and more reliable satellites followed,[30] all of them except two launched on Titan III or Titan IV

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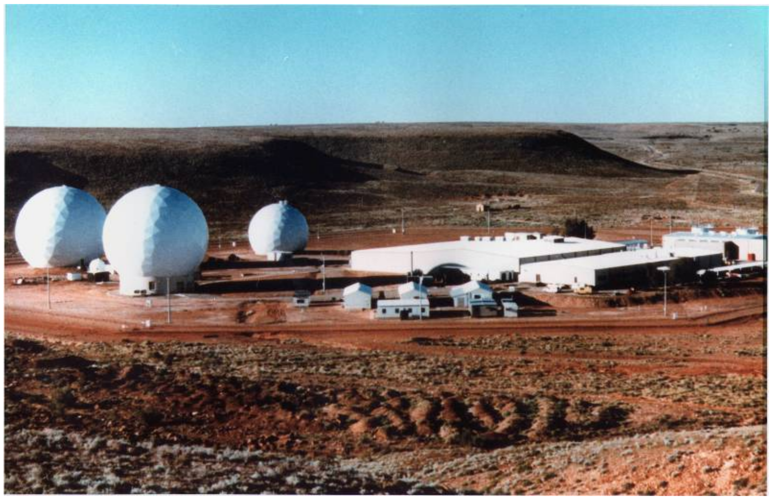
[30] DSP satellites launched during 1970-1973 weighed 2,000 pounds, had a design life of 1.25 years, and incorporated 2,000 lead sulfide detectors operating in the short wave infrared range; they could see targets only below the line of the earth's horizon. After undergoing five major upgrades, satellites launched beginning in 1989 weighed 5,250 pounds, had a design life of 3 years, and incorporated 6,000 lead sulfide detectors with an additional set of mercury cadmium telluride detectors operating in the short wave and medium wave infrared range; they could see targets both below and above the line of the earth's horizon. See Major James Rosolanka, "The Defense Support Program (DSP): A Pictorial Chronology, 1970-1998," SBIRS Program Office.

vehicles.[31] The 23rd and final DSP satellite was successfully launched on the first operational Delta IV Heavy EELV in November 2007.

Right: The first DSP satellite, known as DSP Flight 1, is shown in testing at the facilities of TRW, the prime contractor. SAMSO's DSP program director, Colonel Frederick S. Porter, Jr., stands at the right of the satellite. It was launched successfully on 6 November 1970 from Cape Canaveral.



Left: The first operational fixed ground station for DSP, known as the Overseas Ground Station (OGS), was located at Woomera Air Station, Australia. It became operational in 1971.

DSP provided a level of early warning that soon became indispensable for both military and civil defense. The spacecraft also carried sensors that performed nuclear surveillance, a mission inherited from the Vela system (following in this chapter). Although designed for strategic uses, DSP proved to be more versatile. During the Persian Gulf War, it provided early warning against tactical missiles as well. By 1997, SMC and Air Force Space Command had exploited that capability by adding central processing facilities and tactical ground stations to provide tactical data from DSP to battlefield commanders more rapidly and efficiently.

During the early 1990s, SMC began to pursue concepts and technologies for follow-on systems to replace DSP. By 1994, the concept for a system to succeed DSP was known as the Space-Based Infrared System (SBIRS) and was identified as a requirement by DoD in a "Space-Based Warning Summer Study" issued in September

[31] DSP-16 was launched on a Space Shuttle (STS-44) on 24 November 1991.

1994. SBIRS was to be an integrated system that would support several missions: missile warning, missile defense, battlespace characterization, and technical intelligence.

The SBIRS concept actually included two planned satellite systems, referred to as SBIRS High[32] and SBIRS Low.[33] Both were heirs of infrared technology developed for the Ballistic Missile Defense Program (earlier known as the Strategic Defense Initiative) during 1983-1995. SBIRS High was focused on the detection and tracking of missiles during the earlier phase of their flight, while their motors were generating heat and infrared signatures in short wave lengths. SBIRS Low would add the capability of tracking and reporting other data about missiles during the middle portions of their flight, when their infrared signatures were at longer wave lengths.

To prepare for the development of SBIRS Low, SMC awarded contracts for on-orbit demonstrations to TRW on 2 May 1995 and to Boeing on 2 September 1996. However, oversight of the SBIRS Low program was transferred back to the Missile Defense Agency (MDA) during 2001, where it was renamed the Space Tracking and Surveillance System (STSS). The MDA developed STSS demonstration satellites to test the feasibility of providing midcourse surveillance of ballistic missile launches, and it launched the first two demonstration satellites together on 25 September 2009 using a Delta II vehicle. By the end of 2013, the STSS demonstration satellites were participating in successful missile intercept tests by the MDA.

SMC awarded a ten-year development contract for SBIRS High to Lockheed Martin on 8 November 1996. The SBIRS High program had to be restructured during 2001 and again in 2005 to deal with potential cost and schedule overruns, but its technical progress continued. On 18 December 2001, a consolidated SBIRS Mission Control Station (MCS) at Buckley AFB, Colorado, was declared operational. The MCS provided a central capability for command and control of all operational DSP satellites and other infrared data sources. The completion of this first segment of the ground system upgrade allowed older DSP ground stations to be closed. Afterward, the ground system continued to evolve to support satellites of the SBIRS High system.

The space segment of SBIRS High consisted of two kinds of satellites occupying very different orbits. Payloads known as SBIRS HEO flew in highly elliptical orbits and were designed to detect ballistic missiles launched from submarines in the region of the Arctic Ocean as well as certain other targets. HEO payloads, which were equipped with scanning IR sensors, were carried on host satellites from other programs. Payloads known as SBIRS GEO flew on their own satellites in geosynchronous orbit and were designed to carry out strategic missile warning and detection with scanning IR sensors as well as tactical missile warning and detection (and other technical intelligence) in focus

[32] The technological basis for the high-altitude follow-on system to detect missile launches was an earlier program under OSD's Strategic Defense Initiative (SDI) known as the Boost Surveillance and Tracking System (BSTS). It had been transferred to the Air Force in FY 1992 and had gone through several conceptual changes known as the Advanced Warning System (AWS), the Follow-on Early Warning System (FEWS), and the Alert Locate and Report Missiles (ALARM) program.

[33] The technological basis for the low-altitude follow-on system to track missiles in the middle portion of their trajectories had also been an SDI program. It had been known as the Space Surveillance and Tracking System (SSTS) during the mid and late 1980s and as Brilliant Eyes during the early 1990s.

areas using staring IR sensors. The satellite's sensors featured greatly improved sensitivity and revisit rates compared to DSP.

Left: SBIRS HEO-1 payload in testing at Northrup Grumman's Azusa facility in 2005
Below: SBIRS GEO-2 payload during encapsulation for launch in March 2013
(Photographs courtesy Lockheed Martin)

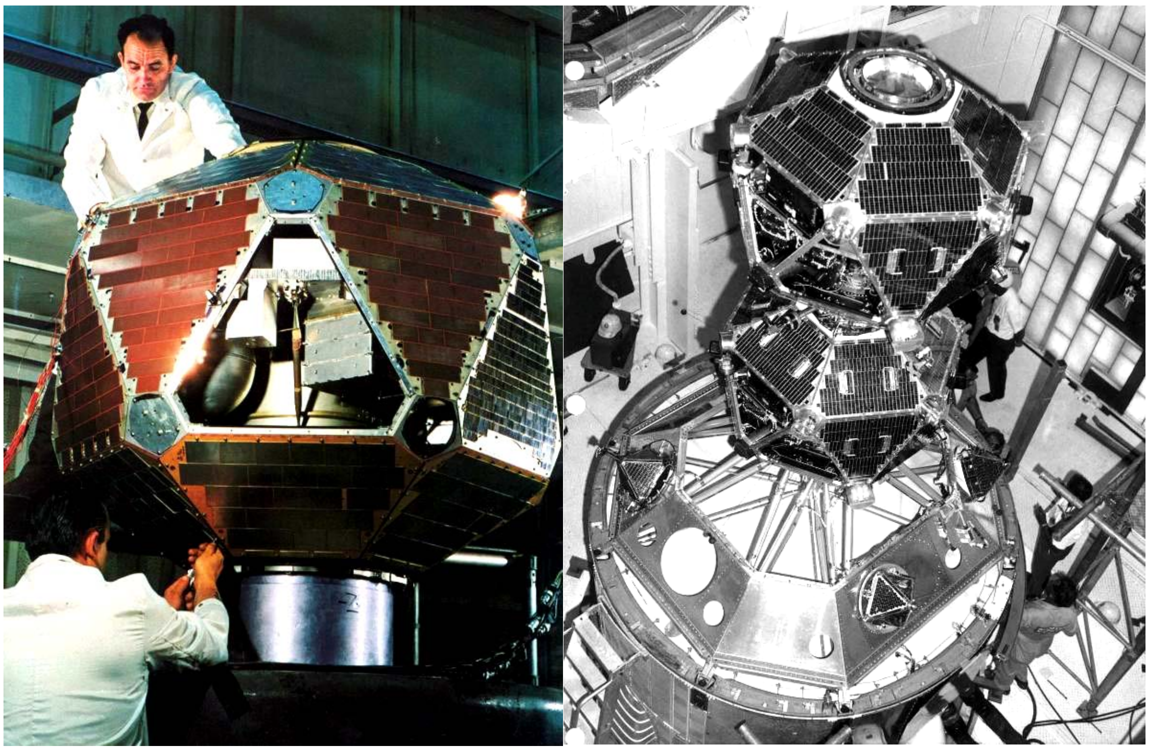
The restructured SBIRS program after 2005 called for delivery of two developmental GEO satellites, two HEO payloads, and associated ground systems. Based on the success of the developmental hardware in testing, SMC awarded a follow-on production contract for the third GEO satellite and the third HEO payload to Lockheed Martin in 2009. It exercised options for the fourth GEO satellite and HEO payload in 2011.

By the end of 2013, operational results after the initial launches of SBIRS HEO and GEO were proving the systems to be highly successful, and the new SBIRS constellations continued to grow. The first two orbiting HEO payloads were operationally certified by US Strategic Command on 5 December 2008 and 7 August 2009. SMC accepted delivery of the HEO-3 payload in July 2013 and approved its shipment for integration with the host spacecraft. The GEO-1 and GEO-2 satellites were launched on 7 May 2011 and 19 March 2013 using Atlas V vehicles. Air Force Space Command accepted both GEO satellites for operations during 2013.

SMC also began to examine alternatives and improvements for the SBIRS system. One possibility that led to orbital testing was called the Commercially Hosted Infrared Payload (CHIRP). It consisted of a wide-field-of-view staring infrared sensor built by Science Applications International Corporation. The payload was hosted on a commercial geosynchronous communications satellite called SES-2. It was launched on 21 September 2011 and carried out many demonstrations of possible tactical applications for commercially hosted infrared technology. After several extensions of the contract for additional demonstrations, the sensor was decommissioned on 6 December 2013.

Nuclear Surveillance

In addition to reconnaissance and missile warning, SMC and its predecessors have developed satellites to serve a number of other purposes, among which are nuclear surveillance, weather observation, navigation, and communication. The first space system to accomplish nuclear surveillance was called Vela Hotel—later, simply Vela. Representatives of the Air Force Ballistic Missile Division (AFBMD), the Atomic Energy Commission, and NASA met on 15 December 1960 to initiate a joint program to develop a high-altitude satellite system that could detect nuclear explosions. Its primary purpose was to monitor compliance with the Nuclear Test Ban Treaty then being negotiated in Geneva. During 1961-1962, the Atomic Energy Commission developed detectors and flew experimental versions on Space Systems Division's Discoverer satellites.



Left: A Vela satellite in fabrication at TRW's facility. Right: A pair of Vela satellites (Vela 5A and 5B) mounted on their Titan IIIC launch vehicle before installation of the fairing. They were launched successfully on 23 May 1969. (U.S. Air Force photographs)

SSD issued a contract for the spacecraft to Space Technology Laboratories (later part of TRW) on 24 November 1961. The first pair of satellites was launched using an Atlas Agena on 16 October 1963, a few days after the Limited Nuclear Test Ban Treaty went into effect, and two more pairs were launched on 16 July 1964 and 17 July 1965. Six Advanced Vela satellites, containing additional, more sophisticated detectors, were launched in pairs on Titan IIIC vehicles on 28 April 1967, 23 May 1969, and 8 April 1970.

The Vela satellites successfully monitored compliance with the Limited Nuclear Test Ban Treaty of 1963, but also with later treaties such as the Outer Space Treaty of 1967 and the Non-ProliferationTreaty of 1968. They also provided scientific data on natural sources of space radiation for many years.[34] The least successful of the original satellites operated for ten times its design lifetime of six months. The last of the advanced Vela satellites was deliberately turned off on 27 September 1984, over fifteen years after it had been launched. However, their mission continued to be performed by payloads of the Nuclear Detection System hosted on DSP and GPS satellites.

Meteorological Systems

Providing the systems with which to conduct military weather observations from space is presently the mission of the Defense Meteorological Satellite Program (DMSP), which maintains a constellation of at least two operational weather satellites in polar orbits about 450 miles above the earth. DMSP satellites now carry primary sensors that provide images of cloud cover over the earth's surface during both day and night, and they also carry other sensors that provide additional types of data on weather and on the space environment.

The first DMSP satellites[35] were developed by a program office physically located with Space Systems Division but reporting to the National Reconnaissance Office (NRO),[36] which needed analyses of cloud cover over Eurasia to plan its photographic reconnaissance.[37] The program office awarded a development contract for weather satellites employing television cameras to RCA in 1961. DMSP Block I began with five launch attempts on Scout launch vehicles during 1962 and 1963, all but one of which failed.[38] Later Block I launches on Thor Agena and Thor Burner I vehicles were more successful. Two launches in 1964 using Thor Agena vehicles placed two Block I satellites in orbit during each launch and provided enough weather imagery for strategic purposes for the first time. Six launch attempts during 1965 and 1966 employed a new Thor upper stage known as Burner I for DMSP payloads, including two more Block I, three Block II, and one Block III.

Besides providing weather information for strategic purposes, early DMSP satellites also provided the earliest tactical uses of space-based weather information. A Block I satellite launched on 18 March 1965 secretly provided weather data for North and

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[34] Vela satellites provided data that led to the discovery of the astronomical sources of gamma ray bursts. They also provided data for studies of radiation in the earth’s magnetosphere and studies of atmospheric phenomena such as meteoric fireballs and lightning.

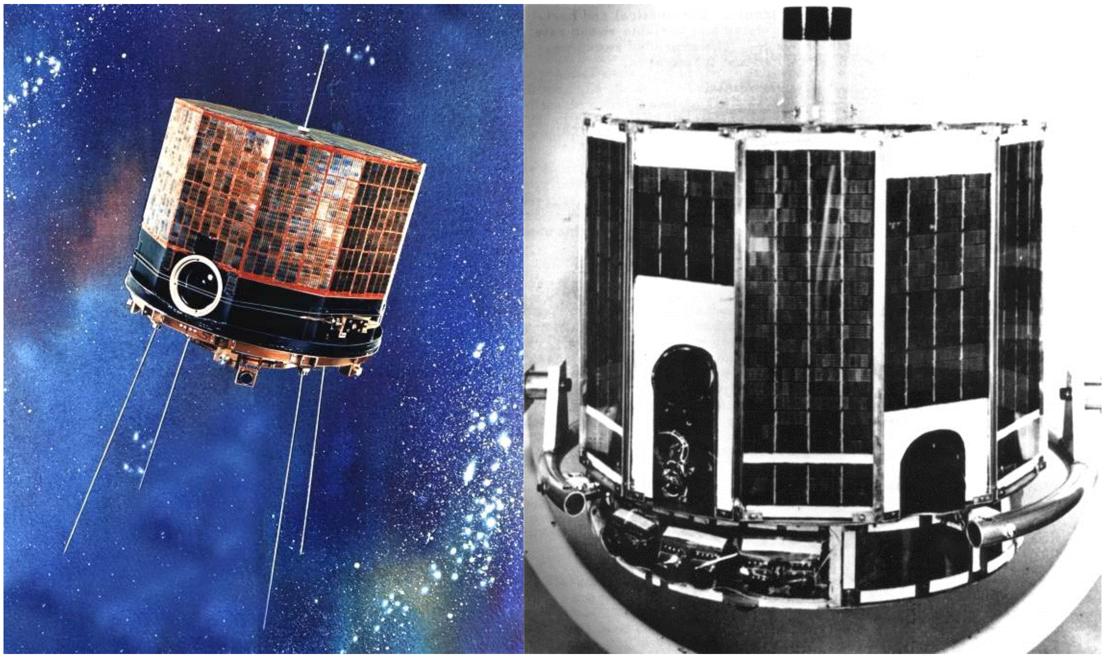
[35] The program was known at first as the Defense System Applications Program (DSAP), which also used the numerical designation Program 35 during 1961-1962 and Program 417 during 1962-1973. In 1973, the program was partially declassified and renamed the Defense Meteorological Satellite Program.

[36] See R. Cargill Hall, A History of the Military Polar Orbiting Meteorological Satellite Program, National Reconnaissance Office, September 2001.

[37] Although NASA was developing a National Operational Meteorological Satellite System, the NRO’s director, Under Secretary of the Air Force Joseph V. Charyk, did not believe it would adequately support the NRO’s missions.

[38] The first launch attempt took place on 23 May 1962, but it failed. The first successful launch was the second attempt on 23 August 1962. Later unsuccessful Scout launches took place on 19 February 1963, 26 April 1963, and 27 September 1963. Successful Thor Agena D launches were carried out on 19 January 1964 and 17 June 1964. Block I launches on Thor Burner I rockets took place on 18 January 1965 (failure) and 18 March 1965 (success). Block II launches on Thor Burner I vehicles were on 9 September 1965 (success), 7 January 1966 (failure), and 30 March 1966 (success). The only Block III satellite was launched successfully on 20 May 1965 using a Thor Burner I launch vehicle.

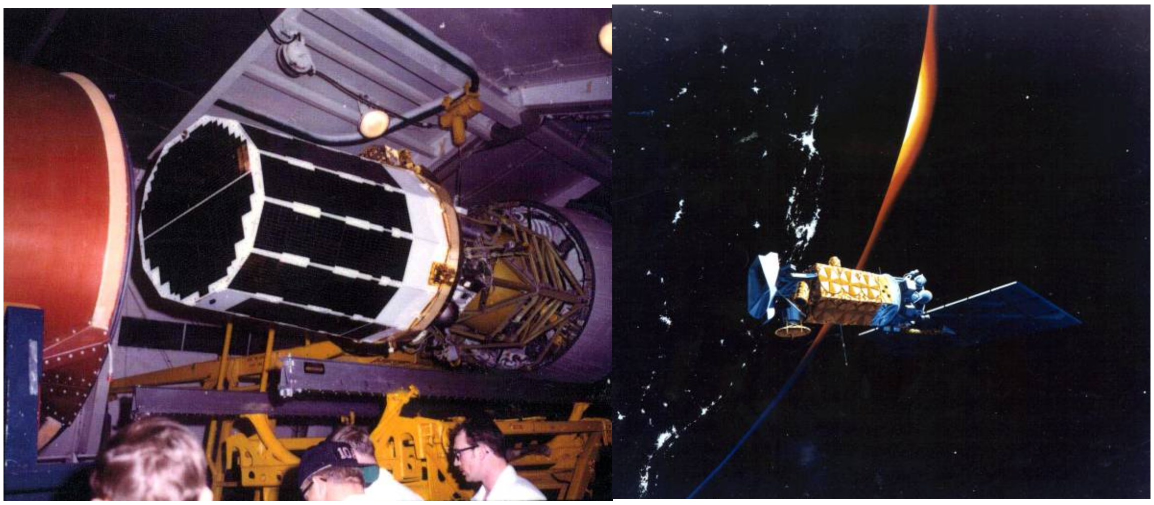
South Vietnam to a ground station at Tan Son Nhut Air Base in Saigon. This was the world's first use of satellite imagery to support tactical military operations. The Block II satellites were also modified for direct readout of meteorological data so that they could be used for planning tactical air operations in Southeast Asia while continuing to provide weather information for strategic reconnaissance. The single Block III satellite, launched in 1965, was equipped only for tactical uses in Southeast Asia.



Left: An artist's concept for the DMSP Block I satellite, launched 1962-1963. Blocks II and III were similar. Right: DMSP Block IV satellites, launched 1966-1969, included the first major improvements in DMSP sensors.

Wider military uses for weather data led to an important change in the program's reporting structure when, on 1 July 1965, it became a program office under Space Systems Division. Development of more capable and more complex satellites also came to fruition with DMSP Block 4 satellites, seven of which were launched during 1966-1969. Television resolution improved from 3 to 4 nautical miles with Blocks I and II to 0.8 to 3 nautical miles with Block 4, along with many other improvements in the sophistication of secondary sensors. Block 5A satellites introduced the Operational Line Scan (OLS) sensor, which provided images of clouds in both visual and infrared spectra. Television resolution improved to 0.3 nautical miles in daylight. Three Block 5A, five 5B, and three 5C satellites were launched during 1970-1976 on Thor Burner II launch vehicles. Larger and much more sophisticated Block 5D-1 satellites were also developed during the 1970s, but only five were built. This proved to be a mistake in 1980, when the fifth 5D-1 satellite was lost in a launch failure, and the operational 5D-1 satellites in orbit ceased to function prematurely. From August 1980 to December 1982, when the first Block 5D-2 satellite was successfully launched, meteorological data was supplied to DOD entirely by civilian satellites. That mistake was not repeated with Block 5D-2 satellites, nine of which were launched during 1982-1997 on Atlas E and Titan II launch vehicles.

In 1989, Space Systems Division began the procurement of five Block 5D-3 satellites from General Electric (later acquired by Lockheed Martin). The 5D-3 satellites featured advanced spacecraft buses as well as significant enhancements in their suite of sensors, power and communications subsystems, and expected lifetimes.[39] Launches of the fully developed 5D-3 satellites began with F-16 in 2003, using the last Titan II vehicle. Satellite F-17 was launched on a Delta IV vehicle in 2006 and F-18 on an Atlas V in 2009. By early 2014, two more Block 5D-3 satellites were waiting to replenish the constellation.



Left: The payload fairing is being installed over a DMSP Block 5A satellite mated to a Burner II upper stage on a Thor Burner (LV-2F) launch vehicle about 1970-1971. Right: This artist's concept depicts a DMSP Block 5D-3 satellite in an early-morning orbit. The DMSP constellation consists of two operational satellites and two spares in sun-synchronous polar orbits. One of the operational satellites crosses the equator (northward) early in the morning, and the other does so at noon local time.

U.S. civilian weather satellites were operated by the National Oceanic and Atmospheric Administration (NOAA). Proposals to merge the civilian and military meteorological systems had been made from time to time since the early 1970s. On 5 May 1994, President Clinton issued a presidential decision directive ordering the convergence and eventual merger of the two programs into a new national space-based system for environmental monitoring. A Tri-Agency Integrated Program Office (IPO) made up of representatives from NOAA, NASA, and DOD would be responsible for carrying out major systems acquisitions, including satellites and launch vehicles. However, NOAA would have overall responsibility for operating the new system, which was soon named the National Polar-orbiting Operational Environmental Satellite System (NPOESS). A major step in convergence occurred in 1998, when the new Satellite Operations Control Center (SOCC) for NPOESS took over control authority of the existing DMSP system.

The merger of the two programs proved to be an unsuccessful experiment. After a phase of competitive development, SMC issued a contract to TRW (acquired by Northrop Grumman) in 2002 to further develop, deploy, and operate NPOESS under the direction of the NPOESS Integrated Program Office (IPO). Unfortunately, the

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[39] In the late 1990s, SMC conducted a separate acquisition of another satellite from RCA using the advanced spacecraft but with a suite of sensors closer to the 5D-2 satellites. It was launched as DMSP F-15 in 1999.

development program suffered a long period of cost increases and schedule delays. Despite restructuring by DoD in 2006, the problems continued. A presidential task force formed to examine the problem in 2009 concluded that the IPO's management structure was fundamentally flawed, and it recommended dividing NPOESS into civilian and military programs once again. NOAA began the development of a follow-on system known as the Joint Polar Satellite System (JPSS), and DoD established the Defense Weather Satellite System (DWSS) in 2010 as the follow-on program for DMSP and the DoD replacement for NPOESS.

Nevertheless, Congress cancelled funding for DWSS for 2012, and the Air Force formally terminated design work on the new system in April 2012. Despite the cancellation, Congress provided funding to begin work on a new development program for a space-based military weather system in its appropriations for 2014. Fortunately, the long projected on-orbit lifetimes of Block 5D-3 satellites along with the two satellites not yet launched allowed a cautious approach to a new DoD weather system. One possibility under consideration was a concept known as disaggregation, which would involve placing various weather sensors on different satellites.

Navigation Systems

The world's first space-based navigation system was called Transit. It was developed by scientists at Johns Hopkins University's Applied Physics Laboratory in 1958. DOD's Advanced Research Projects Agency (ARPA) initiated the development program in September 1958 and assigned it to the Navy a year later. The Air Force Ballistic Missile Division launched the Navy's first Transit satellite on 13 April 1960. The system achieved initial operational capability in 1964 and full operational capability in October 1968. It used three operational satellites to produce signals whose Doppler effects and known positions allowed receivers—primarily ships and submarines—to calculate their positions in two dimensions. Transit established the principle and some of the technology of navigation by satellite and prepared military users to rely on such a system. However, it was too slow and imprecise for rapidly moving, three-dimensional platforms such as aircraft. Transit's signals were turned off deliberately in December 1996 because DOD had decided to rely on a newer, faster, and more accurate system.

All of DOD's navigation and position-finding missions are now performed by the Global Positioning System (GPS). The system consists of 24 operational satellites that broadcast navigation signals to the earth, a control segment that maintains the accuracy of the signals, and user equipment that receives and processes the signals. By processing signals from four satellites, a user set is able to derive the location of each satellite and its distance from each one. From that information, it rapidly derives its own location in three dimensions.

Besides Transit, GPS had two immediate programmatic ancestors: a technology program called Project 621B, initiated by SAMSO and the Aerospace Corporation in October 1963, and a parallel program called Timation, undertaken by the Naval Research Laboratory in 1964. Project 621B envisioned a constellation of 20 satellites in synchronous inclined orbits providing continuous three-dimensional positioning information. The satellites would broadcast ranging signals using pseudorandom noise, a technique later incorporated in GPS. The project conducted feasibility tests at White Sands Missile Range in 1972, inverting the planned future direction of the signals by using aircraft with prototype user equipment that received signals broadcast by transmitters on the ground and in balloons.

Left: The second Transit satellite (Transit 1B) undergoes checkout at Cape Canaveral before launch on 13 April 1960. Right: This artist's concept depicts the second Navigation Technology Satellite (NTS-2) in orbit. NTS-2 was used as part of the GPS Block 1 test constellation.

The NRL's Timation Program envisioned a constellation of 21 to 27 satellites in medium altitude orbits providing three-dimensional positioning information. The satellites broadcast passive ranging signals based on highly stable internal clocks, another technique later incorporated in GPS. Experimental Timation satellites 1 and 2, with clocks using quartz-crystal oscillators, were launched in 1967 and 1969. Timation satellites 3 and 4, renamed Navigation Technology Satellites (NTS) 1 and 2, incorporated atomic clocks and were launched in 1974 and 1977 as part of the Phase 1 GPS program.

In 1973, elements of the two programs were combined into the GPS concept, which employed the signal structure and frequencies of 621B with medium altitude orbits and atomic clocks similar to those used for Timation. Deputy Secretary of Defense William P. Clements authorized the start of a program to "test and evaluate the concepts and costs of an advanced navigation system" on 17 April 1973, and he authorized the start of concept validation for the GPS system on 22 December 1973.[40]

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[40] The principal proponent of GPS within the Pentagon was the Director of Defense Research and Engineering, Dr. Malcolm Currie. During 1972-1973, Col Bradford Parkinson, the director of the 621B program, briefed Currie on SAMSO's work in improved satellite-based navigation. Currie sponsored the idea for a new satellite navigation system within DoD, with the understanding that a program should include the best features of the competing concepts. After the memo from Deputy Secretary Clements, Parkinson put together a proposed program based mostly on Program 621B and briefed it to the Defense Systems Acquisition Review Council (DSARC) in August 1973. The DSARC disapproved the program, but Currie assured Parkinson privately that he could win approval by including a better mix of features from the other, rival programs along with Program 621B, and Col Parkinson spent the next several months devising a new proposed program that did so. Much of the work on the conceptual design was done by Parkinson assisted by a dozen Air Force and Aerospace Corporation personnel at the Pentagon over Labor

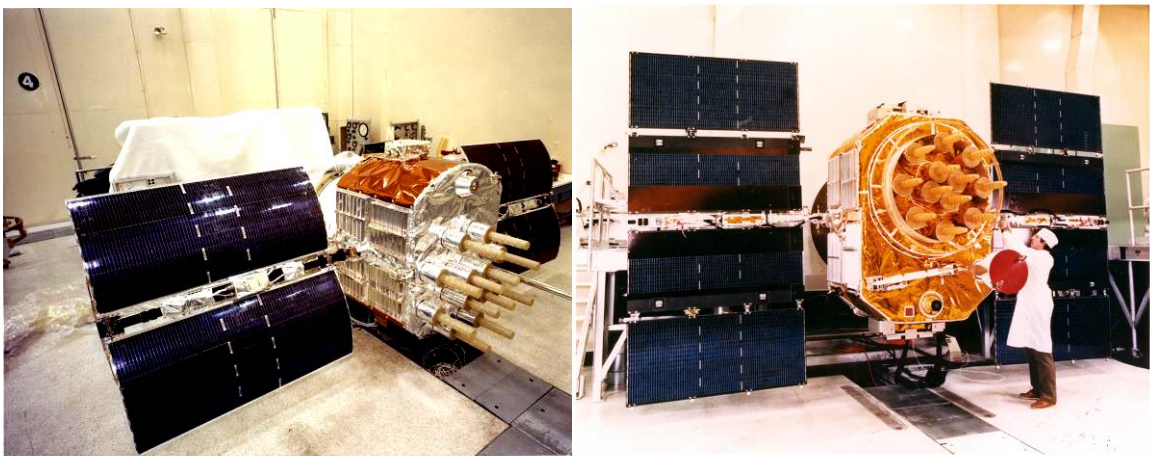
GPS was acquired in the classical three phases: validation, development, and production. During the validation phase, Block I navigation satellites and a prototype control segment were built and deployed, and advanced development models of various types of user equipment were built and tested. During the development phase, additional Block I satellites were launched to maintain the initial satellite constellation, a qualification model Block II satellite was built and tested, and manufacture of additional Block II satellites was initiated.[41] In addition, an operational control segment was activated, and prototype user equipment was developed and tested. During the production phase, a full constellation of 24 Block II and IIA (A for advanced) satellites was deployed. User equipment was also produced and put into operation by issuing it to foot soldiers and installing it in ships, submarines, aircraft, and ground vehicles. The full constellation was completed on 9 March 1994, allowing the system to attain full operational capability in April 1995.

GPS supported a wide variety of military operations, including aerial rendezvous and refueling, all-weather air drops, instrument landings, mine laying and mine sweeping, anti-submarine warfare, bombing and shelling, photo mapping, range instrumentation, rescue missions,[42] and satellite navigation. However, GPS was also the focus of a growing civilian market whose users had become far more numerous than military users by the year 2000. Indeed, it was widely used commercially by the time it reached full operational capability, and some commercial applications, such as airline navigation, were both critical and sensitive. At one time, the GPS signal available to civil users contained intentional inaccuracies, a condition known as selective availability, to provide an advantage to authorized military users. At President Clinton's direction, the intentional inaccuracies were set to zero on 1 May 2000, providing significant improvements in the accuracy available to the system's civil users.

Day weekend in 1973. The improved, more inclusive program was approved by the DSARC in December 1973. See Dr. Parkinson's autobiographical recollections in "The Origins of GPS," GPS World: "Part 1" (1 May 2010) and "Part 2" (1 June 2010). See also the interview with Parkinson by Steven R. Strom on the Aerospace Corporation's Internet site (www.aerospace.org/about-us/history/in-their-own-words/dr-bradford-parkinson/).

[41] Block I, Block II, and Block IIA satellites were built by Rockwell International, which sold its aerospace and defense divisions to Boeing in 1997.

[42] We should take note of a particularly important military application of GPS known as the Combat Survivor Evader Locator (CSEL) system. CSEL was based on an earlier Air Force Space Command procurement called Hook-112 and was designed to enable rescue forces to find, track, and communicate with downed American pilots in hostile territory while making sure they were truly American personnel in need of assistance. It was a technologically sophisticated combination of hand-held radio unit and GPS receiver. Secretary of Defense William J. Perry approved the program in December 1995, and SMC issued a development contract to Rockwell (later absorbed by Boeing) in February 1996. A series of operational assessments and developmental tests were conducted between 1998 and 2002, and the first limited production units were delivered in late 2002. CSEL entered multiservice operational test and evaluation in June 2003 and was scheduled to begin full-rate production early in 2004.



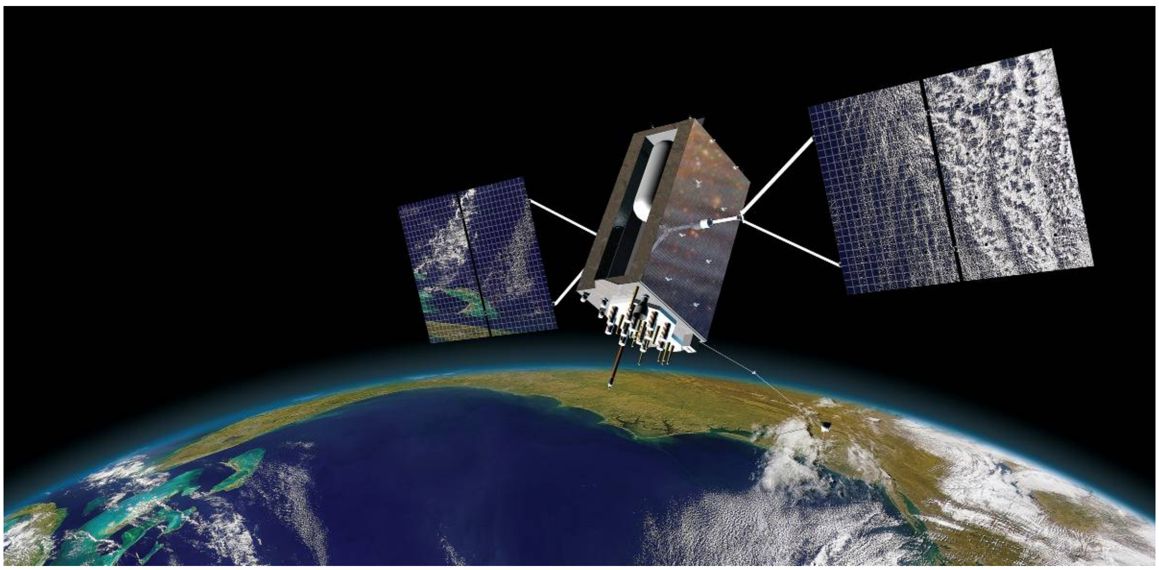
Top: A GPS Block I satellite (left) and a GPS Block II satellite (right) undergo acceptance testing at Arnold Engineering Development Center. Bottom left: An artist's concept depicts a GPS Block IIR satellite in orbit. Bottom right: An artist's concept depicts a GPS Block IIF satellite in orbit.

SMC began launching the next block of GPS satellites, known as IIR (R for replacement), in 1997.[43] The following block of GPS satellites, which incorporated

[43] The launch of the first IIR satellite on 15 January 1997 failed when the Delta launch vehicle exploded. It was the first failure of a Delta II vehicle and only the second launch failure in the history of the GPS program. The first GPS Block IIR satellite to attain orbit and become operational was launched on 23 July 1997.

further improvements, was known as Block IIF (F for follow-on). SMC awarded a contract for the development and production of 33 IIF satellites on 22 April 1996, but it reduced the quantity to 12 in 2000 because the operational lifetimes of GPS satellites were turning out to be longer than expected, and it wished to take advantage of the resulting longer intervals between launches to improve the design of the satellites.[44] Four of the IIF satellites had been launched by early 2014, the first on 27 May 2010 using a Delta IV EELV and the fourth on 15 May 2013 using an Atlas V EELV.

SMC also began the development and initial production of a new and more capable generation of GPS space, control, and user segments known as GPS Block III. It issued competitive system definition and risk reduction contracts to Lockheed Martin and Boeing on 5 January 2004, and it awarded a contract for the first increment of Block III satellites (Block IIIA) to Lockheed Martin on 15 May 2008. The contract provided for development and initial production of two satellites with options for up to 10 additional satellites. By early 2014, the active contract provided for production of six satellites, the first two of which were undergoing integrated testing at Lockheed Martin's facility before delivery.



Artist's concept of GPS Block IIIA satellite in orbit (courtesy Lockheed Martin)

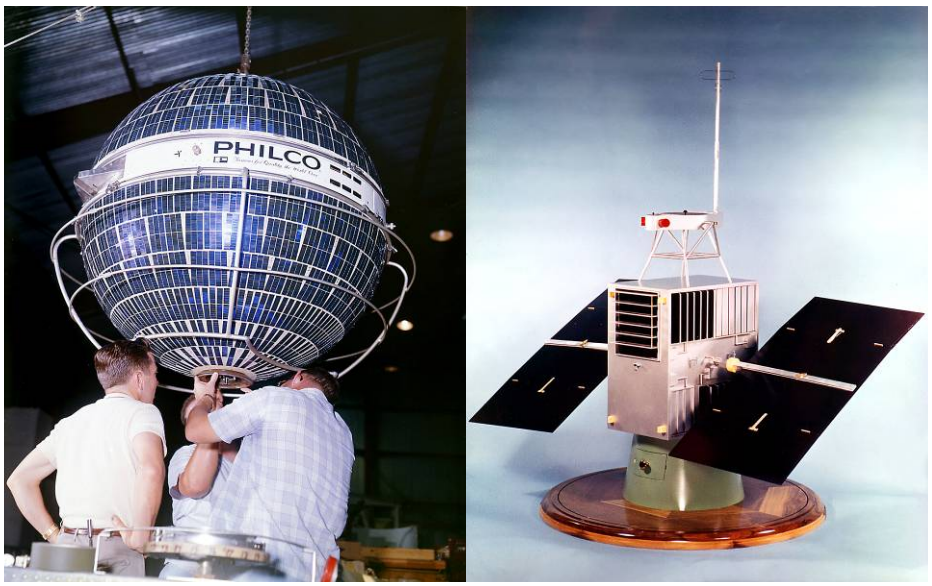
The Block III satellites would be larger and heavier than the Block IIF satellites, and they would have major enhancements in capability. They would have a design life of 15 years (rather than 12 for IIF) and offer three times greater navigational accuracy and signal power. A stronger military signal (M-code) would have greater resistance to jamming, and a new fourth civil signal (L1C) would be compatible with signals from the European Space Agency's navigation satellite system known as Galileo.

Communications Systems

The world's first communications satellite—Project SCORE—was launched by the Air Force Ballistic Missile Division, SMC's predecessor, on 18 December 1958. The

[44] SMC (then called Space Systems Division) had awarded the contract for Block IIR satellites to General Electric (later part of Lockheed Martin) in 1989. It awarded the contract for Block IIF satellites to Rockwell International (later part of Boeing). See note 41 above.

SCORE payload consisted of commercial communications equipment modified by the Army Signal Corps and installed in an Atlas B missile as a proof-of-concept mission for orbiting communications repeaters. The project was executed under ARPA's direction. AFBMD launched the entire missile, minus the spent half stage, into a low orbit, where it remained for about a month,[45] relaying voice and telegraph messages between ground stations in the United States. Among its first experimental transmissions was President Eisenhower's Christmas message to the world, the first time that a human voice had been transmitted from space. The world's second military[46] communications satellite was Courier 1B, developed by the Army Signal Corps under ARPA's direction. AFBMD successfully launched it on 4 October 1960, using a Thor Able Star launch vehicle. Courier further tested the feasibility of orbiting communications repeaters but did so with a spherical, self-contained satellite that included solar cells and rechargeable batteries. Unfortunately, the spacecraft suffered a command system failure after 17 days in orbit.



Left: Courier 1B satellite in testing, 1960. Right: Model of planned Advent satellite, about 1961.

The first military satellite communications system to be used for operational purposes was known as the Initial Defense Communications Satellite Program (IDCSP). The development program began in 1962, following the cancellation of an earlier, unsuccessful development program called Project Advent.[47] The IDCSP system

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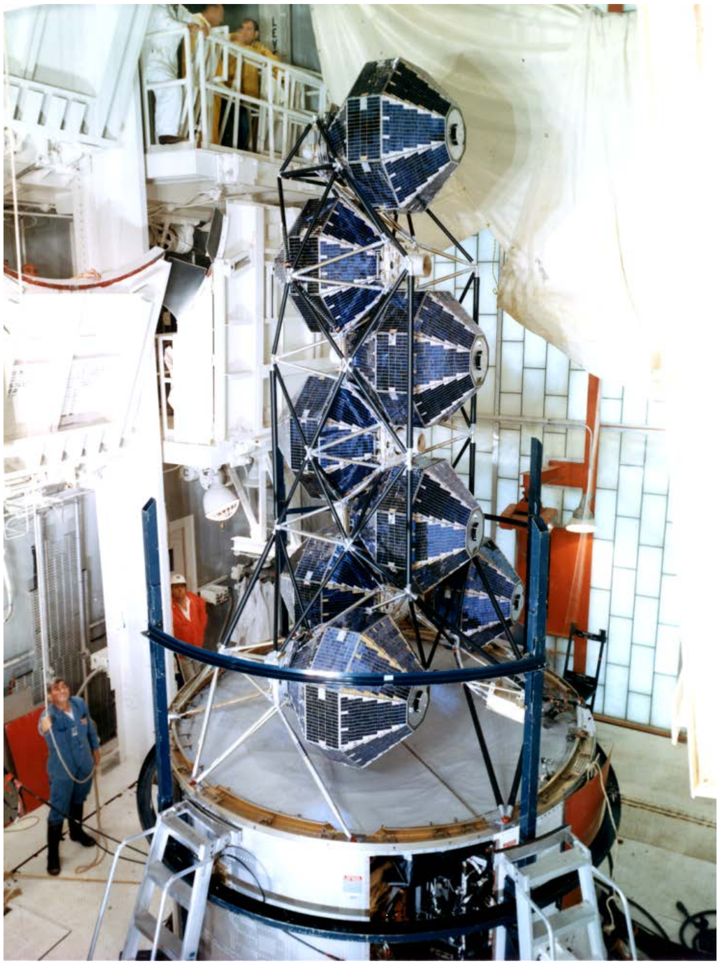
[45] SCORE stopped transmitting when its batteries were exhausted on 31 December 1958. It had no solar cells or other sources of power. It reentered on 21 January 1959.

[46] Echo 1, a metallized balloon that acted as a passive experimental communications satellite, was successfully launched by NASA on 2 August 1960.

[47] Motivated by the necessity of maintaining communications with the Strategic Air Command's large fleet of strategic bombers, ARPA undertook other space-based communications efforts around the same time as Courier. It issued direction to AFBMD on 22 May 1959 to develop a three-part satellite system, with a geosynchronous satellite communications system called Project Decree and two polar satellite communications systems called Project Steer and Project Tackle. All of these were cancelled and replaced by ARPA on 29 February 1960 by a geosynchronous satellite program called Project Advent, for which the Army was to develop the communications payload and AFBMD was to develop the spacecraft. The entire project was transferred to the Army, then transferred to the Air Force and cancelled by DoD in 1962 because of delays.

consisted of small, 100-pound satellites launched in clusters. Twenty-six such satellites were placed into orbit in four launches carried out between June 1966 and June 1968.[48] Two fixed and thirty-four mobile ground terminals also became operational in 1968. IDCSP transmitted both voice and photography to support military operations in Southeast Asia. It provided an experimental but usable worldwide military communications system for the Defense Department for ten years until a more sophisticated system could be developed.

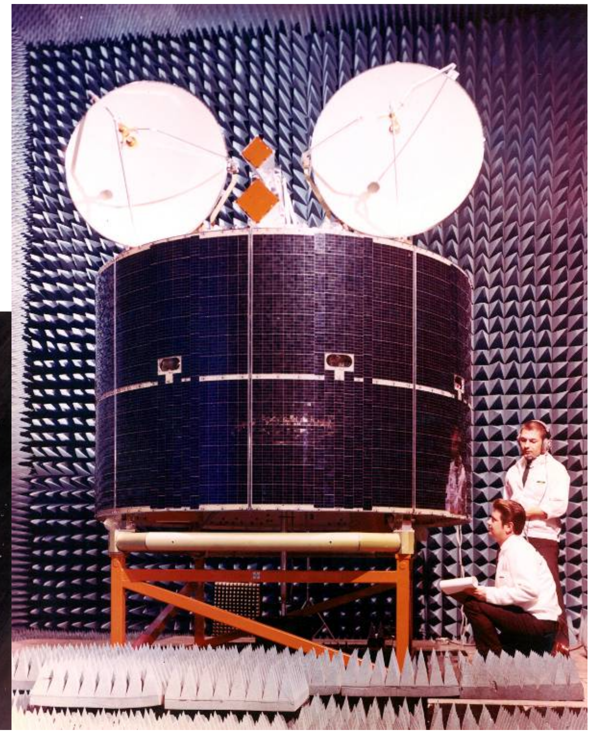


Left: The payload fairing is being installed on Titan IIIC-16 at Cape Canaveral. Enclosed in a dispensing mechanism are the last eight satellites of the Initial Defense Communications Satellite Program (IDCSP), successfully launched on 13 June 1968. The IDCSP satellites were small and very simple, with no batteries and no active attitude control system. The dispenser ejected them one at a time into a near-synchronous orbit.

That more sophisticated system was known as the Defense Satellite Communications System, Phase II (DSCS II). The DSCS II satellites were much larger and more sophisticated than the IDCSP satellites, offering increased communications capacity, greater transmission strength, and longer lifetimes. In addition to horn antennas for wide area coverage, they had dish antennas that were steerable by ground command and provided intensified coverage of small areas of the earth's surface. SAMSO awarded a development contract for the DSCS II system to TRW on 3 March 1969, and the first

[48] There were five attempted launches of IDCSP satellites on Titan IIIC launch vehicles during 1966-1968: 16 June 1966, 26 August 1966, 18 January 1967, 1 July 1967, and 13 June 1967. The second launch was unsuccessful because of a structural failure in the Titan. Each launch dispensed from three to eight IDCSP satellites into near-synchronous orbits.

pair of satellites was launched on 2 November 1971. It was the first operational military communications satellite system to occupy a geosynchronous orbit (22,237 miles). Two launch failures delayed completion of the satellite network, but by January 1979, the full constellation of four satellites was in place and in operation. A total of 16 DSCS II satellites was built and launched[49] during the life of the program, with the last launch occurring on 4 September 1989.



Below left: An artist's concept depicts a DSCS II satellite in orbit.
Right: A DSCS II satellite undergoes testing in an anechoic chamber.

In 1973, planning began for the Defense Satellite Communications System, Phase III (DSCS III). DSCS III satellites carried multiple beam antennas to provide flexible coverage and resist jamming, and they offered six active communication channels rather than the four offered by DSCS II. The first DSCS III satellite was successfully launched on 30 October 1982, and a full constellation of five DSCS III satellites was completed on 2 July 1993. Two DSCS IIIs were launched into orbit from a Space Shuttle on 3 October 1985. The constellation was replenished with five launches from 28 November 1993 to 20 October 2000. By early 2003, only two unlaunched DSCS III satellites remained in the inventory. In view of the fact that the DSCS III system would have to support tactical military operations until a follow-on system could be acquired,[50] SMC began an initiative to improve the tactical utility and extend the lifetime of DSCS III satellites. Known as the Service Life Enhancement Program (SLEP), the initiative added improvements to the last four DSCS III satellites before they were launched. Lockheed Martin was placed under contract to carry out the SLEP modifications on 28 March 1996.

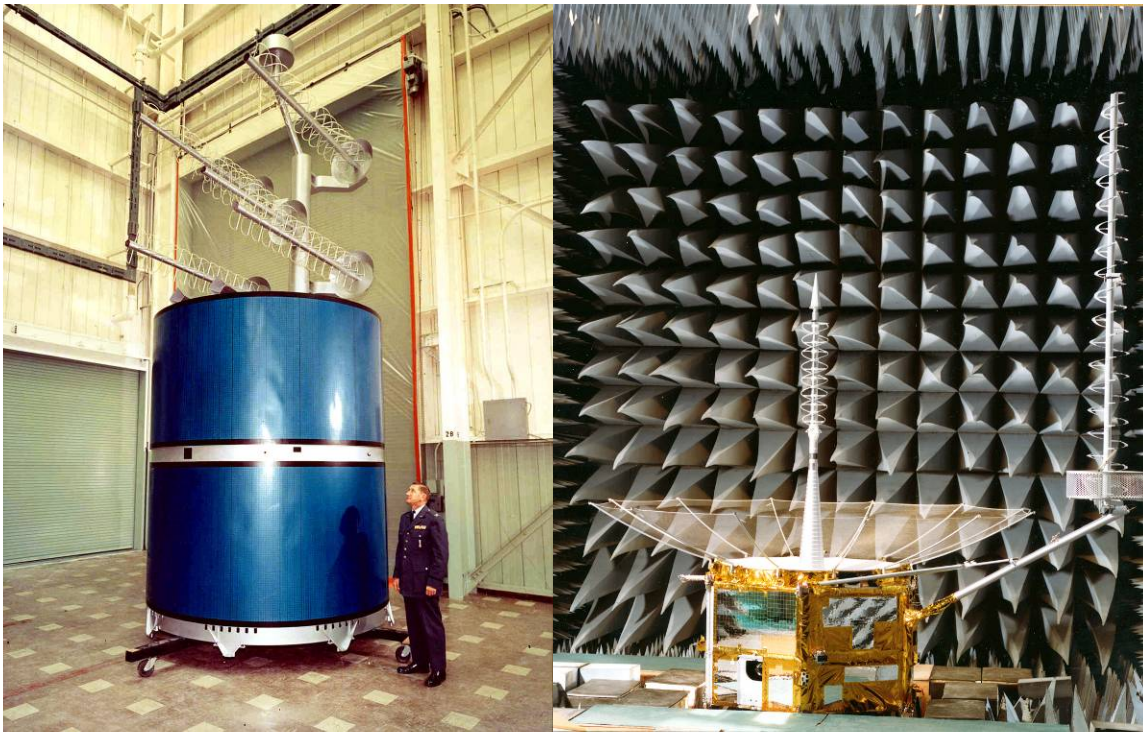
[49] DSCS II satellites were launched in pairs using Titan IIIC vehicles through 1979.

[50] See the Wideband Gapfiller Satellite (WGS) system discussed below.

Left: An artist's concept depicts a DSCS III satellite in orbit.
Below: A DSCS III satellite is prepared for testing.

DSCS satellites were developed to serve users who transmitted message traffic at medium to high data rates using relatively large ground terminals. However, satellites were also needed to serve users who transmitted at low to medium data rates, using small, mobile or transportable terminals. During the 1960s, experimental satellites were placed into orbit to test technology that might perform this tactical communications mission. Lincoln Experimental Satellites 5 and 6, launched on 1 July 1967 and 26 September 1968, were solid-state, ultra high frequency communication satellites built by Lincoln Laboratory. The 1,600 pound Tactical Communications Satellite, launched on 9 February 1969, operated in both ultra high frequency and super high frequency and tested the feasibility of communications with small, mobile, tactical communications equipment that could be used by ground, naval, and air forces. In July 1970, an initial operational capability for tactical communications was established, using the Tactical Communications Satellite and Lincoln Experimental Satellite 6.

These experimental satellites paved the way for the Fleet Satellite Communications System (FLTSATCOM), the first operational system serving tactical users. The Navy managed the overall program, but SAMSO managed acquisition of the satellites. Development of FLTSATCOM was authorized on 27 September 1971, and five satellites were launched from 9 February 1978 to 6 August 1981. Four achieved orbit and went into operation, but one was damaged during launch and never became operational. Three replenishment satellites were launched from 5 December 1986 to 25 September 1989. Two reached orbit, but one was lost when its booster was hit by lightning.



Left: SAMSO's TACSAT program director poses with TACSAT I in the testing facilities of the prime contractor, Hughes Aircraft Company, about 1969. SAMSO launched TACSAT using a Titan IIIC on 9 February 1969, and it operated successfully for 46 months. Right: A FLTSATCOM satellite undergoes testing in an anechoic test chamber.

In addition to the long-haul users served by DSCS and the tactical users served by FLTSATCOM, there was a third group of users—the nuclear capable forces—who could be satisfied at the time with low data rates but required high availability, worldwide coverage, and the maximum degree of survivability. The Air Force Satellite Communications System (AFSATCOM) was developed to serve their needs and allow the Air Force to command and control its strategic forces. The space segment of the system relied on transponders (receiver/transmitters) placed on board FLTSATCOM satellites and other DOD spacecraft. The space segment of AFSATCOM became operational on 15 April 1978, and the terminal segment attained initial operational capability on 22 May 1979.

The communications satellites discussed above were all acquired for the U.S. military, but other communications satellites were acquired for the United Kingdom and the North Atlantic Treaty Organization during the 1960s and 1970s. The British Skynet program began in 1966. The first of two Skynet I satellites was placed into orbit on 21 November 1969 and provided the United Kingdom with its first military communications satellite system. The second Skynet satellite was launched from Cape Canaveral on 19 August 1970, but a malfunction in the launch vehicle caused permanent loss of contact with the satellite. In 1970, SAMSO and the United Kingdom began development of a more advanced Skynet II satellite system. The first Skynet II satellite was launched on 18 January 1974, but a malfunction in the launch vehicle again caused the loss of the satellite. The second Skynet II satellite, launched on 22 November 1974, attained orbit successfully and was turned over to the United Kingdom in January 1975.

Development of the NATO satellites began in April 1968, with the initial series of satellites being known as NATO II. One NATO II satellite was placed in orbit on 20 March 1970 and another on 3 February 1971. Both the Skynet and NATO satellites were designed to be compatible and usable with each other and with the Defense Satellite Communications System. Work on a more advanced system, NATO III, began in 1973, and three NATO III satellites were successfully launched between 1976 and 1978. The constellation was replenished in November 1984, when a fourth satellite was successfully launched.

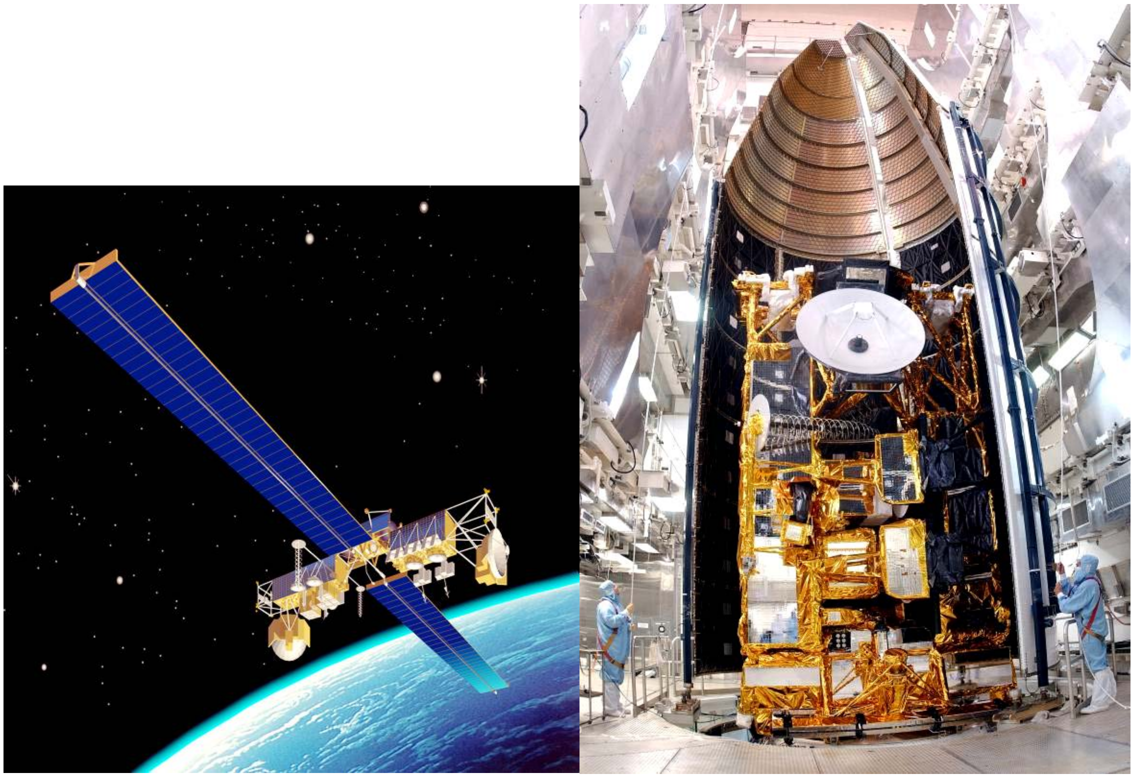
Left: The first NATO III satellite (NATO IIIA) is prepared for testing by two technicians at Philco-Ford Corporation, the prime contractor. SAMSO launched the satellite successfully on a Delta launch vehicle from Cape Canaveral on 22 April 1976.

The next space communications system to be acquired by SMC was Milstar. Milstar I satellites carry a low data rate payload that provides worldwide, survivable, highly jam-resistant communications for the National Command Authority and the tactical and strategic forces.[51] Advanced processing techniques on board the spacecraft as well as satellite-to-satellite cross linking allow Milstar satellites to be relatively independent of ground relay stations and ground distribution networks. Space Division awarded concept validation contracts for the satellite and mission control segment of Milstar I in March 1982 and a development contract to Lockheed on 25 February 1983. The first Milstar I was successfully launched[52] on 7 February 1994, and the second, on 6 November 1995. In October 1993, SMC awarded a contract for development of the Milstar II satellite, which carried both low and medium data rate payloads. The addition of the medium data rate payload greatly increased the ability of tactical forces to communicate within and across theater boundaries. Only four Milstar II satellites were produced because DOD had decided in 1993 that they were to be replenished by a new,

[51] Unlike DSCS, which operated in the SHF range (superhigh frequency: 3,000-30,000 megaherz), Milstar operated in the EHF range (extremely high frequency: 30,000-300,000 megaherz). EHF had rarely been used for military communications before Milstar. This frequency range provided natural resistance to jamming. EHF also allowed users to employ smaller, highly mobile terminals.

[52] All Milstar satellites have been launched on Titan IV or IVB vehicles.

lighter, cheaper series of Advanced EHF satellites. Unfortunately, the first Milstar II satellite went into an unusable orbit on 30 April 1999. The next two Milstar II satellites were successfully launched on 27 February 2001 and 16 January 2002 to complete an on-orbit constellation of four satellites. The sixth and last Milstar satellite was successfully launched on 8 April 2003.



Left: An artist's concept depicts a Milstar II satellite in orbit. Right: The fifth Milstar satellite is enclosed in the payload fairing on top of its Titan IVB launch vehicle. Its successful launch on 15 January 2002 completed the operational constellation of four Milstar satellites. (Images courtesy Lockheed Martin Missiles and Space)

In view of the limited future of the Milstar system, SMC soon began the acquisition of a follow-on EHF[53] military communications system, known as the Advanced EHF system or AEHF. The system was compatible with Milstar elements and incorporated them throughout their useful lifetimes. The completed AEHF constellation would consist of four satellites in geosynchronous orbit. Like Milstar, but greatly enhanced, the AEHF system featured on-board signal processing and satellite crosslinks to eliminate reliance on ground stations for routing data. Data uplinks to the satellites and crosslinks between satellites operated at EHF, and downlinks operated at SHF. Whereas Milstar offered low and medium data rate payloads, AEHF satellites had high data rate payloads as well, providing up to 8.2 Mbps. The AEHF system provided ten times as much data throughput as Milstar for a much larger area of coverage. It enabled a variety of types of communications, including broadcasting, real-time video, data and voice networking, and voice-conferencing. All services used AEHF terminals, which were located on a wide variety of platforms on land, sea, and air.

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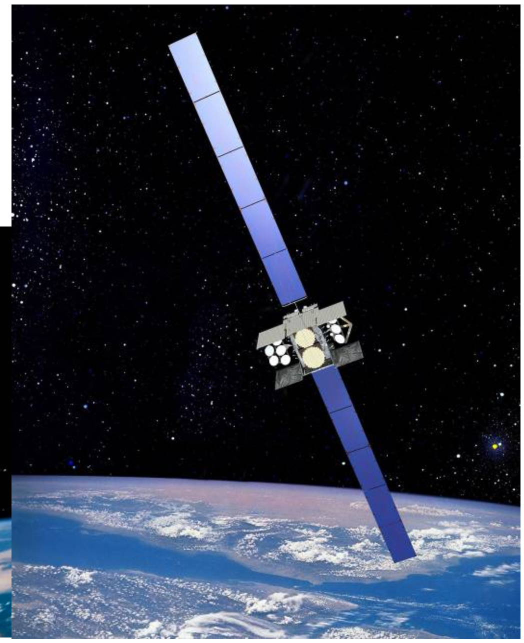
[53] See note 50 above.

After competitive system definition efforts ending in 1999, SMC awarded a contract to the team of Lockheed Martin and TRW for the System Development and Demonstration phase of the AEHF system, including production of the first two satellites and the Mission Control Segment. A third satellite was added to the contract in 2006 and a fourth in 2010.[54] In 2009, OSD cancelled a planned follow-on program known as the Transformational Satellite Communications System (TSAT) that would have followed the fourth AEHF satellite, and it directed the Air Force to acquire the fifth and sixth AEHF satellites instead.[55] By 2014, the first three AEHF satellites had been successfully launched on Atlas V vehicles.[56]



Below: Artist's concept of Advanced EHF satellite in orbit (courtesy Lockheed Martin);
Right: Artist's concept of WGS satellite in orbit (courtesy Boeing Company)

In 2000, SMC also led a multi-service program to acquire a new series of communications satellites—known eventually as the Wideband Global SATCOM (WGS)[57] system—to augment DSCS III and finally replace it. However, the capabilities of the WGS system were vastly enhanced in comparison to DSCS. WGS provided not only two-way tactical military communications, but also a two-way Ka-band

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[54] The gap in production between the third and fourth AEHF satellites caused a shutdown and restart of the production line and resulting cost increases.

[55] For the TSAT program, see below after the discussion of the Wideband Global Satellite Communications (WGS) system.

[56] AEHF-1 was launched on an Atlas V on 14 August 2010. The liquid apogee engine failed to raise the satellite from a transfer orbit to its final geosynchronous orbit, but a mission planning team formed to deal with the anomaly successfully used the satellite's stabilizing thrusters and then the electrical maneuvering thrusters to gradually raise the satellite over the course of about 14 months to its intended orbit, which it reached on 24 October 2011. AEHF-2 was successfully launched on 4 May 2012 and AEHF-3 on 18 September 2013.

[57] WGS was called at first the Wideband Gapfiller Satellite because it would fill the gap between the availability of the existing DSCS III and GBS satellite systems and a planned very advanced system called the Transformational Satellite Communications System (TSAT). The name was changed (but not the abbreviation) in 2007 at the request of HQ USAF. SATCOM is, regrettably, an abbreviation within an abbreviation, and stands for "satellite communications." The TSAT program was cancelled in 2009.

augmentation of the older one-way, wideband satellite broadcast system called the Global Broadcast Service (GBS).[58] Each WGS satellite could provide up to 3.6 Gbps of data transmission, well over ten times the X-band communications capacity of a DSCS satellite, and 4.875 GHz of instantaneously switchable bandwidth. Block II satellites (starting with WGS-4) provided ultra-high bandwidth and data rates using a radio frequency bypass capability to support airborne intelligence, surveillance and reconnaissance platforms such as unmanned aerial vehicles.

SMC awarded a contract[59] for design and advance procurement of the first three WGS satellites, which constituted Block I, as well as ground-based command and control elements to Boeing Satellite Systems in 2001. It awarded a contract for the next three satellites,[60] constituting Block II, to Boeing in 2006 and a Block II follow-on contract for WGS satellites 7 through 10 in 2010. By 2014, the first six WGS satellites had been successfully launched, the first two on Atlas V vehicles and the next four on Delta IVs.[61]

[58] The Global Broadcast Service, a joint-service program, became operational about 1999, using its own transponders on the Navy's UHF Follow-on satellites. GBS was a system for extremely rapid, one-way transmission of high-volume data such as weather, intelligence, and imagery from higher echelons to large groups of dispersed users with small, mobile receivers.

[59] The contract for procurement of WGS Block I was a "near commercial" acquisition, one important feature of which was that little technological development was involved, since most of the components could be obtained commercially.

[60] Australia funded the acquisition of WGS-6 in exchange for allocation of 10 percent of the capacity of the WGS system.

[61] The launch dates in EST were WGS-1: 10 October 2007, WGS-2: 3 April 2009, WGS-3: 5 December 2009, WGS-4: 19 January 2012, WGS-5: 24 May 2013, WGS-6: 7 August 2013.