David N. Spires

ASSURED ACCESS

A History of the US Air Force Space Launch Enterprise, 1945–2020

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Dedication

To General Thomas S. Moorman Jr., Space Pioneer
16 November 1940–18 June 2020
And to the men and women who made Air Force space launch history and to those who recorded their achievements.

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Preface

Assured Access: A History of the United States Air Force Space Launch Enterprise, 1945–2020 is a study of more than six decades of Air Force launch support for the nation's military, intelligence, and civilian space communities. From their inception as refurbished ballistic missiles, Air Force boosters have launched national security space payloads for the Defense Department (DOD) and the National Reconnaissance Office (NRO), as well as for the National Aeronautics and Space Administration (NASA) and commercial and other civilian elements. Throughout this period, Air Force launch strategy has been to provide assured access to space by means of affordable, reliable, and responsive launch.

Basic technology that produced the expendable launch space boosters of the early Cold War era changed little in fundamental engineering and manufacturing processes from that period until the advent of the evolved expendable launch vehicle (EELV) program at the turn of the new century. Expendable launch vehicles (ELV) had been the backbone of Air Force space flight until the arrival of the space shuttle, with its promise of routine access to space. By the early 1980s, that promise had become increasingly problematical as space shuttle development and launch rate promises failed to meet projected targets. To protect their launch requirements, Air Force leaders, led by Secretary of the Air Force Edward C. "Pete" Aldridge, championed the concept of a "mixed fleet" of ELVs to back up the space shuttle. After 1986, in the wake of the *Challenger* disaster, the Air Force shifted its focus back to ELVs and saw in the EELV families of Delta IV and Atlas V boosters the prospect of responsive, reliable, and affordable space launch. Although the EELV program had largely achieved those objectives, new competition from SpaceX and other providers created an altered landscape of more efficient launch systems and reusable and partially reusable boosters. The EELV program gave way to the National Security Space Launch program. The emphasis on more responsive space launch to confront a growing threat to US space assets also embraced the small rocket efforts of the Rocket Systems Launch Program directed from Kirtland AFB, New Mexico. Together, the National Security Space Launch program and Rocket Systems Launch Program promised assured access to space well into the future.

Assured Access meets the need of a single-volume overview of the Air Force space launch story, serving as a guide and introduction to interested readers. Throughout, the focus is on the operational aspect of space launch, and the narrative draws on the operational experiences of space launch veterans. Although primary documents are used when relevant, this study is largely based on secondary sources.

Chapter 1 describes the efforts of the Air Force and its fellow service competitors to develop ballistic missiles in the aftermath of World War II. Ballistic missiles provided the foundation for Air Force space launch. In a sense, the Air Force entered the space age on the coattails of intercontinental ballistic missile (ICBM) development and President Dwight D. Eisenhower's determination to protect the nation from surprise attack. Air Force leaders quickly realized that ballistic missiles could also serve as satellite boosters and reconnaissance satellites could provide vital strategic intelligence on Soviet capabilities. Along with the other services, the Air Force pursued missile—and satellite—development by establishing the Western Development Division and giving its commander, Brig Gen Bernard A. Schriever, wide-ranging responsibilities to produce an operational ICBM by the end of the decade. Eventually, these efforts would lead to the Lockheed Agena booster-satellite, the infrared missile warning satellite, the reconnaissance satellites of the NRO, and the Atlas, Titan, and Thor boosters that would launch them.

Chapter 2 focuses on the period from the late 1950s to the early 1970s when Air Force space launch came of age with the triumvirate of Atlas, Thor, and Titan launch vehicles and their upper stages. The national space program the Kennedy administration designed to confront the Soviet challenge accorded the Air Force primary responsibility for space boosters. In response, the service reorganized internally and established the Air Force Systems Command under General Schriever to manage all research, development, and acquisition of space and missile systems. Over the course of the decade and beyond, all three space launch systems benefited from evolutionary improvements in such areas as airframe production, engine thrust and efficiency, guidance and control, and stage and payload adaptors. As satellites increased in size, weight, and complexity, DOD and the Air Force met this challenge in large part by developing more capable Atlas, Thor, and Titan boosters and upper stages and by establishing standardization programs for these vehicles. All three booster–upper stage configurations also supported NASA's lunar and planetary programs and launched the highly classified reconnaissance satellites of the NRO.

Chapter 3 examines the development of Vandenberg Air Force Base, from Camp Cooke Army training site to Air Force missile and space launch base. With the exception of Thor-Agena launches of Corona reconnaissance satellites, the Air Force–administered northern portion of the base supported missile launches. The Navy acquired the southern portion, the Point Arguello peninsula, to serve as the central launch element of its Pacific Missile Range. Air Force–Navy friction intensified when Point Arguello, eventually referred to as Vandenberg South, became the primary launch site for Atlas launches of Missile Launch Detection Alarm System (MIDAS) early warning satellites and Samos reconnaissance satellites. In 1965, the Air Force acquired Point Arguello from the Navy, and soon thereafter the Titan III booster joined the Atlas and Thor in launching the NRO's reconnaissance satellites into polar orbit. Air Force veterans who served as launch controllers and helped establish the Vandenberg launch sites fondly remember their important role at the dawn of the space age. Over the course of 1956–1972, Vandenberg also experienced major growth in space launch activity and infrastructure developments. Indeed, whereas Cape Canaveral had dominated space launch in the early 1960s, by the latter half of the decade Vandenberg had achieved pride of place for launch tempo.

Chapter 4 discusses the development of Cape Canaveral Air Force Station, Patrick Air Force Base, and the Eastern Test Range from WWII to the advent of the space shuttle in the early 1970s. The Florida coast location proved ideal for testing cruise missiles and, later, launching ballistic missiles and spacecraft. Launches in a southeasterly direction avoided important shipping lanes and major population centers by passing over islands that served as tracking stations along a 10,000-mile course that would extend from the Bahamas to Ascension Island in the South Atlantic, to the coast of South Africa, and eventually into the Indian Ocean. As the launch head of the Eastern Test Range, the Cape in the 1960s became the center for Air Force–supported NRO, instrumented nuclear detection, communications, and early warning satellite launches, plus NASA's Mercury, Gemini, and Apollo manned flights and all American spacecraft launched eastward into low-inclination equatorial orbits. By the early 1970s space launch activity at the Eastern Test Range had declined considerably compared to operations at Vandenberg. Moreover, despite the addition of Titan III launches, Air Force operational tempo decreased compared to NASA flights and especially the Navy's submarine-launched ballistic missile test launches. In the years ahead, however, the Space Transportation System, or space shuttle, would transform not only space operations at NASA's Kennedy Space Center but also at Patrick Air Force Base and the Eastern Range.

Chapter 5 describes the promise and the challenge the space shuttle presented for the Air Force. Lauded as the reusable launch vehicle that would provide routine access to space for all DOD and NASA requirements, the shuttle represented the end of Air Force dependence on its fleet of costly, expendable launch vehicles. In their commitment to the shuttle, Air Force leaders agreed to phase out ELVs, to refurbish the old Manned Orbiting Laboratory space launch complex, SLC-6, at Vandenberg, and to develop an upper stage vehicle to "shuttle" spacecraft from the shuttle orbiter to higher orbits. For the Air Force, however, the feasibility of exclusive reliance on the shuttle depended on the veracity of NASA's predictions for the shuttle's capability, cost, and launch rate. By the end of the 1970s, the Air Force came to have serious reservations about the space agency's shuttle mission model that led to considerable tension between NASA and the Air Force and DOD. Led by Secretary of the Air Force Aldrich, the Air Force acted to preserve assured access to space by pursuing a "mixed fleet" strategy—a balance between the space shuttle and expendable launch vehicles—a balance that had not been entirely resolved by the time of the *Challenger* tragedy in January 1986.

Chapter 6 focuses on the Air Force response to the crisis in the military space program caused by the *Challenger* disaster and the loss of two Titan 34Ds with NRO payloads. After those launch vehicle failures, space leaders effectively grounded the space program by prohibiting further flights of the shuttle and ELVs until the problems could be solved. During the 31-month moratorium on shuttle flights, the Air Force moved to reestablish space launch capabilities while reassessing not only its investment in the shuttle but also its entire commitment to space. The post-*Challenger* launch recovery program took two paths. One involved having the heavy-lift Titan IV and three medium launch vehicles operational as soon as possible while relying on the current force to fly out their remaining vehicles. By 1989, both the Titan II and Titan IV, along with the Delta II, had launched their initial payloads, and the Atlas II was to follow three years later. A second recovery path involved a variety of space studies that attempted to understand the present and chart the future of space launch. They provided decision makers a realistic assessment of the current state of space launch, recommendations to improve the current fleet, and potential launch systems for the new century. In a sense, the various studies and proposals charted a course that culminated in the Space Launch Modernization Plan of May 1994. With that plan's EELV option selected by Air Force leaders, the service now had a clear path to ensure assured access to space with what promised to be a responsive, reliable, and affordable family of EELVs in the twenty-first century.

Chapter 7 examines the Air Force effort to achieve and preserve assured access to space in the new century by means of the EELV program. The Air Force expected to realize more efficient, affordable, and responsive space launch from the two families of EELVs through innovation measures, standardization practices, and by purchasing commercial launch services rather than the vehicles themselves. Although the Delta IV and Atlas V EELVs would compile a 100 percent successful launch record, their launches became increasingly expensive when the worldwide commercial market collapsed. In response, the Air Force opened DOD launches to competitors, led by SpaceX, who argued they could provide more cost-effective operations through greater efficiencies and the use of reusable and partially reusable launch vehicles. In March of 2019, the Air Force responded to congressional direction to rename the EELV program the National Security Space Launch (NSSL) program to better reflect the changed landscape created by new launch entrants and more capable boosters under development.

Chapter 8 explores the variety of efforts to improve responsive space launch from the initial Operationally Responsive Space initiative to the myriad small launch vehicle and small satellite programs currently underway. Responsive space also embraced the EELV-class systems, and both were addressed by the Space Enterprise Vision that Air Force Space Command created to provide a resilient space force architecture by 2030 capable of supporting the war fighter and deterring aggression in the space arena. Meanwhile, the newly created Space Force could look to the future with confidence that new NSSL-class providers and small rocket systems could achieve affordability, reliability, and responsiveness objectives and continue to ensure assured access to space for the nation's space enterprise.

The reader is reminded that this survey of recent Air Force space history is based largely on open source materials that include biographies of key figures in the space launch arena and testimony from veterans of the space launch enterprise. For more comprehensive treatments of the topics examined here, the interested reader is encouraged to consult studies listed in the bibliography and, if possible, the classified document record that has become increasingly available through declassification procedures.

In preparing this study, I received help from many people. Above all, I must acknowledge the generous assistance provided by my friends and colleagues in Air Force Space Command's (now Space Force's) History Office: Command historians Mr. George W. "Skip" Bradley and Dr. Gregory W. Ball, Deputy Command Historian Dr. Rick W. Sturdevant, and historians Mr. Wade A. Scrogham and John M. Lacomia. All four read parts or all of the manuscript critically and offered important suggestions. Mr. Bradley initiated the project superbly, provided full use of the command's excellent historical archives, and facilitated my access to archival collections at other institutions. Although Mr. Bradley retired before completion of the project, Dr. Ball, his very able successor, kept the process running smoothly, providing both administrative and academic assistance. I especially benefited greatly from my many discussions of policy and technical issues with Dr. Sturdevant, the leading historian on military space, whose comprehensive knowledge and encouragement invariably kept me on the right track. I am also indebted to Dr. Sturdevant for providing useful documents and for his outstanding editorial contributions.

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provided an informative tour of her museum, and put me in touch with Lt Col John Hilliard, USAF, retired, her outstanding tour guide. John took my wife and me to every launch site and important facility on Cape Canaveral AFS and the Kennedy Space Center and then provided me with many launch images from his comprehensive collection. I also received assistance from Ms. Shawn Riem, 30th Space Wing historian.

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Deserving special mention are first-generation space pioneers, Col Robert W. "Rob" Roy, USAF, retired; Maj Gen Robert A. "Rosie" Rosenberg, USAF, retired; Brig Gen Joseph D. "Don" Mirth, USAF, retired; Lt Col William J. "Bill" Thurneck, USAF, retired; and their immediate successors, Col Thomas E. Maultsby, USAF, retired; Brig Gen Sebastian F. "Seb" Coglitore, USAF, retired; Maj Gen Thomas D. "Tav" Taverney, USAF, retired; Lt Col Frank E. Watkins, USAF, retired; and Col Victor W. Whitehead, USAF, retired. I also received important contributions from Col Richard W. McKinney, USAF, retired; Lt Col Stosh Kowalski, USAF, retired; Col John Stizza, USAF, retired; Brig Gen Glenn C. "Clint" Waltman, USAF, retired; Mr. John Silverstein, General Dynamics; and Colonel Aldrich.

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About the Author

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Chapter 1

Foundations

The Ballistic Missile Force Underpins the Air Force Space Launch Enterprise, 1945–1965

In the aftermath of World War II, Air Force leaders laid the foundation for future operations in the missile and space arena by establishing a clear research and development (R&D) focus for the new service. Commanding General of the Army Air Forces Henry H. "Hap" Arnold and his eminent scientific advisor Theodore von Kármán set the course through their policy statements, organizational decisions, and comprehensive analysis of Air Force scientific requirements for a technological future. Their legacy appeared endangered in the late 1940s when tight budgets and higher priorities confined long-range missile development primarily to low-level studies. Air Force leaders seemed intent on establishing Air Force responsibility for long-range ballistic missiles but remained unwilling to promote their development.

With armed forces undergoing demobilization and the reassertion of domestic priorities, Arnold and other Air Force innovators quickly realized it was one thing to advocate an imaginative, liberally funded R&D program for the Army Air Forces (AAF) and quite another to have it put into practice by a conservative military establishment. In the years after World War II, missiles drew only modest attention from President Harry S. Truman's administration and the defense establishment. Initial postwar interest in long-range guided missiles soon succumbed to an Air Force policy that relied on strategic bombers, to interservice conflicts over roles and missions, and to administration-imposed budget ceilings that compelled Air Force planners to focus on present rather than future service needs.[1]

By the early 1950s, however, change was in the air. New concerns about Soviet political and military activity and technological progress compelled leaders to reexamine the country's defense posture. In doing so, intercontinental ballistic missiles (ICBM) and intermediate range ballistic missiles (IRBM) received new attention. Larger defense budget outlays and successful testing of thermonuclear devices and the prospect that they could be reduced in size and weight offered the promise of a feasible long-range ballistic missile. A number of government officials and Air Force officers who shared Arnold's legacy acted as catalysts for change by creating new organizational structures for missile development and promoting greater awareness of the ICBM. Although they faced strong opposition every step of the way, their strenuous, persistent efforts helped set the Air Force and the nation on the path to an operational ICBM and IRBM by the end of the decade. More germane for this study, the ballistic missiles developed in the early Cold War era proved adaptable for space launch. Indeed, the Air Force's first-generation ballistic missile force also evolved into the initial space booster fleet for launching satellites and other space payloads. Given the close technical and operational relationship between ballistic missiles and space boosters, it is important to focus initially on the development of ballistic missiles in the 1950s.

Air Force Ambivalence Toward Ballistic Missiles

General Arnold was not the only military leader impressed by the German V-2 achievements during the war. In the flush of victory, all the services sought to build on wartime experience by conducting rocket and guided-missile experiments based either on aerodynamic, jet-propelled "cruise" missile principles or on the German V-2 short-range, liquid propellant ballistic rocket technology. Operation Paperclip brought nearly 130 leading German rocket scientists, a vast array of data, and approximately 100 dismantled V-2s to White Sands Proving Ground, New Mexico. There, under Project Hermes, the Army Ordnance Department conducted upper atmospheric research into airborne telemetry, flight control, and two-stage rocket capability with representatives from the Air Force, the Air Force Cambridge Research Center, the General Electric Company, the Naval Research Laboratory, and other scientific institutions, universities, and government agencies. From 1946 to 1951, participants received valuable data from 66 V-2 launches that first carried various scientific instruments, then primates.[2]

Back in early 1949, the Army, which viewed rockets as extensions of artillery, had successfully used a V-2 as the launch vehicle for the Jet Propulsion Laboratory's WAC Corporal second-stage rocket to an altitude of 250 miles. As Frank Malina, the missile's project director, noted, "The WAC Corporal thus became the first man-made object to enter extra-terrestrial space." These early V-2-based, WAC Corporal experiments, referred to as Bumper WAC flights, set the stage for the Army's future missile and space program involving Redstone, Jupiter, and Juno boosters developed by Wernher von Braun's team, under Army supervision, after it moved in 1950 from Fort Bliss, Texas, to Redstone Arsenal at Huntsville, Alabama. Postwar naval rocket research, led by the Applied Physics Laboratory of Johns Hopkins University and the Naval Research Laboratory in Washington, DC, produced two reliable and effective sounding rockets: the fin-stabilized Aerobee, a larger version of the WAC Corporal modified for production as a sounding rocket, which achieved a height of 80 miles; and the more sophisticated Viking, which reached an altitude of 158 miles in May 1954.[3]

Despite General Arnold's interest in developing long-range missiles of the V-2 type, the Air Force followed the path charted by Theodore von Kármán, which stayed within the atmosphere, then the Air Force's only operating environment. Short-range, jet-propulsion weapons seemed to offer faster development and better payload capabilities. They also directly complemented the strategic bomber fleet, the nation's intercontinental strike force of the day. In October 1945, the AAF Air Technical Services Command solicited proposals from 17 aircraft companies for a 10-year R&D program for pilotless aircraft, and the fiscal year 1946 budget included an impressive 26 different projects. Only two, however, involved missiles in the 5,000-mile range, and one of those consisted of a Northrop Aircraft supersonic turbojet vehicle. The other, Project MX-774, a supersonic ballistic rocket design from Consolidated Vultee Aircraft Corporation (Convair), would serve as the precursor of the Atlas ICBM.[4]

If the AAF seemed devoted to shorter-range, air-breathing missiles, it would not concede long-range missile development to the Army or Navy. All three services jealously guarded their prerogatives and jockeyed fiercely over roles and missions in the postwar world. As it looked to a future as an independent service, the AAF proved particularly sensitive to new, unproven weapon fields, such as rockets and missiles. While Maj Gen Curtis E. LeMay, the recently appointed Air Staff deputy chief for R&D, staked out the AAF's claim to any prospective satellite mission in early 1946, he also became embroiled with Army and Navy representatives over which service should be responsible for what types of missiles. Above all, the AAF took special interest in missiles it considered strategic.[5]

Throughout the conflict over roles and missions, the Air Force demonstrated more interest in gaining and preserving its prerogatives than in moving ahead with a strong R&D program for missiles. Paradoxically, as the Air Force's commitment to develop an ICBM diminished, its determination to be designated the sole authority responsible for long-range missiles increased. Even with long-range cruise missiles, for which Air Force leaders sought exclusive control based on the service's strategic mission, the newly independent service normally chose not to implement programs leading to operational missiles. Efforts to garner exclusive control of missiles would continue. In September 1948, for example, the National Military Establishment awarded the Air Force operational control of strategic, surface-to-surface cruise missiles, such as the Snark and Navaho. Eighteen months later, in a very important March 1950 decision, the Air Force received official responsibility for developing long-range strategic missiles and short-range tactical missiles that related to the service's air interdiction and close air support missions. Later, near the end of the Truman administration, the Air Force successfully defeated the Army's bid to develop the Redstone rocket's range beyond 200 miles. The strategic mission would remain with the Air Force.[6]

Already, in the late 1940s, Air Force leaders had signaled their R&D attitude when forced to respond to the Truman administration's drastic economy drive that began in late 1946. In the growing Cold War, the administration increasingly looked to strategic bombers and the atomic bomb as the country's main line of retaliatory defense. Moreover, manned aircraft remained the heart of the Air Force, and an Air Force culture wedded to pilots in the cockpit would long seem threatened by pilotless ballistic and cruise missiles. Compelled to choose between supporting the forces of the present and those of the future, the Air Staff ignored the admonitions of General Arnold and Dr. von Kármán by focusing on manned aircraft to the detriment of guided missiles. Consequently, Air Force R&D programs for missiles suffered severely in the late 1940s. One of the casualties was the MX-774, the service's only long-range ballistic missile project, which it terminated on 1 July 1947. The budget slashers argued that putting scarce funds into a research program that might not be realized for a decade, or possibly never, could not be justified in light of current priorities. They believed the Air Force had to continue with a cautious step-by-step approach to any long-range missile program. Missile advocates found themselves victims of a circular argument: missiles seemed too challenging technologically, but no funds could be spent on solving the technological dilemmas; the problems would go unresolved, and the missile would remain "impossible." To questions about the logic of budgeting for missile programs, the answer always seemed to be the dogmatic response: "the time is not right" for an expanded program.[7]

Fortunately, Convair decided to use its own funds to continue its MX-774 long-range missile project, under imaginative structural engineer Karel J. "Charlie" Bossart.[8] Back in April 1946, the AAF had awarded Convair a $1.4 million contract (increased to $1.893 million two months later) to evaluate two missile proposals, one for a subsonic, aerodynamic missile and the other for a rocket-powered ballistic missile. Both were to be capable of delivering a 5,000-pound warhead anywhere from 1,500 to 5,000 miles to within 5,000 feet of designated targets. Following end-of-the-year budget cuts that included Convair's subsonic missile design, the company would concentrate on the ICBM.[9]

The V-2 represented the point of comparison and departure for Bossart and his team. From the start, they focused on reducing the weight of the missile with innovative concepts and experiments involving internal fuel storage and tank design, swiveling engines, and various methods of separating the nose cone warhead as a solution to the formidable reentry problem. A separating nose cone meant that it, rather than the entire missile, would endure the excessive heat of atmospheric reentry. This would result in a major weight reduction, an increase in the missile's range, and elimination of the need to design engines and fuel tanks able to withstand reentry. Bossart's key innovation, representing another weight savings measure, was to replace the double-walled V-2 fuel tank structure with single-walled, pressure-stabilized propellant tanks made of aluminum no thicker than a dime. Serving as part of the missile structure itself, the dime-thin aluminum "balloon" required pressure either from bottled nitrogen when in storage or from propellants loaded for operational use to avoid collapse. Additionally, the introduction of swiveling engines represented a significant improvement over the V-2's use of movable graphite vanes in the exhaust system, which had reduced its thrust by as much as 17 percent. Responding to commands from a gyro-stabilized, autopilot guidance system, the swiveling engines of the MX-774 provided directional thrust and much improved control of the missile. Built by Reaction Motors Incorporated, each of the four clustered engines produced a thrust of 2,000 pounds and burned a mixture of alcohol and liquid oxygen supplied by a hydrogen-peroxide, pressure-fed turbo pump. Measuring 31 feet in length and 2.5 feet in diameter, the missile weighed 1,200 pounds without propellants.[10]

Despite cancellation of the MX-774 contract, the AAF authorized the company to continue its research on guidance system and nose cone reentry and to launch three completed test vehicles at the White Sands Proving Ground. Although the flight tests achieved only modest success, they validated Bossart's designs and provided Convair a wealth of information that would prove beneficial when the Air Force decided to pursue the Atlas program seriously in 1951. Meanwhile, Convair continued to use company funds to keep the MX-774 project afloat as a low priority item.[11]

The Air Force Renews Interest in Ballistic Missiles

The first signs of a significant change in attitude toward R&D in general—and guided missiles in particular—appeared in 1949. Faced with growing criticism that the Air Force was paying insufficient attention to R&D, Gen Hoyt S. Vandenberg, the AAF's deputy commanding general, authorized two committees, one "civilian" and the other military, to examine the state of the service's R&D capabilities. On 23 January 1950, General Vandenberg acted on the committees' recommendation by creating the Office of the Deputy Chief of Staff, Development, and the Research and Development Command (redesignated the Air Research and Development Command, or ARDC, in April), with headquarters at the Sun Building in Baltimore, Maryland. Significantly, the Air Staff assigned the guided missiles program to the new command.[12]

While the Air Force made organizational changes in the early 1950s, events on the international scene contributed to major reassessments of the country's defensive posture. News that the Soviet Union had successfully detonated an atomic device in August 1949, communism's triumph in China, and alarming reports of Soviet progress in missile development led to calls for increased military preparedness both in and outside the administration. In January 1950, President Truman authorized immediate development of the hydrogen or thermonuclear bomb and directed a comprehensive review of national security policy. In April, the result of that review, National Security Council Paper 68 (NSC 68, officially titled *United States Objectives and Programs for National Security*), called for sharp increases in US military spending; Truman, who was concerned about such a program's cost, did not immediately approve. The outbreak of the Korean War, in June 1950, heightened the growing sense of national weakness. Congress authorized a 70-group Air Force and nearly doubled the administration's defense budget request from $14.4 to $25 billion. After the Chinese entered the war in November, the president approved the force objectives established by NSC 68 and advanced the original target date for completing them from 1954 to mid-1952.[13]

The deteriorating security environment and the Truman administration's decision to rearm elevated the importance of guided-missile programs. At the same time, the Air Force had received reports on the progress of ICBM research from RAND, its think tank established in 1946, initially to determine the feasibility of artificial Earth satellites. In 1949, RAND's comparison of air-breathing and ballistic missiles clearly favored the latter, and its report of December 1950 argued that technical progress with engines, guidance systems, and reentry vehicles had made the long-range ballistic missile viable. Armed with a larger budget and clear evidence of ballistic missile technical progress, the Air Force reconsidered Convair's long-range rocket proposal. The company's presentations helped lead to an Air Force contract, on 23 January 1951, for Project MX-1593. It directed Convair to examine—once again—both the ballistic technique and the "glide" method, by which vehicles would use rocket power to reach the outer atmosphere then use their wings to glide through the atmosphere to their targets. The boost-glide approach signaled enduring Air Force interest in the postwar "X"-series of high-altitude, rocket-powered aircraft.[14]

The Air Force's criteria called for both types of missiles to be capable of launching 8,000-pound warheads 5,000 nautical miles and of achieving a circular error probability (CEP) of 1,500 feet, later modified to one mile when smaller and lighter warheads became available.[15] On 1 September 1951, Convair engineers and the ARDC decided to drop the winged missile in favor of the ballistic-type rocket, primarily because the latter represented a weapon considered unstoppable for the foreseeable future, and they believed the formidable technical problems could be mastered by the early 1960s. Convair had named the ballistic version Atlas. Its specifications clearly envisioned a mighty vehicle, with five or seven large, clustered engines to power a missile 160 feet long and 12 feet in diameter.[16]

Over the next two years, Charlie Bossart continued to wrestle with the engine ignition reliability problems that had affected his test vehicles. Impressed by North American's Navaho booster engine, Convair contracted for a modified version for the Atlas, using a combination of kerosene and liquid oxygen. A major challenge, however, remained the achievement of smooth combustion and consistent ignition of a second-stage engine at altitude. Because the few "staging" tests that were conducted yielded uneven results, Bossart elected to forego a genuine two-stage missile in favor of a more reliable "stage-and-a-half" design. The latter meant that the four booster engines and single sustainer engine would be started together on the ground using propellants from the same pressure-stabilized tanks. Shortly after liftoff, the booster engines would be jettisoned, and the missile would rely on the sustainer engine for the remainder of its powered flight, to the point of nose cone separation. Although the Atlas would be powering empty propellant tanks during the sustainer phase, thus increasing the vehicle's weight and mass, Bossart reasoned that the extra weight penalty could be offset by the lightweight balloon structure. His team also addressed the problem of sustainer engine cutoff, including two small vernier engines that would provide final course correction until nose cone separation.[17]

Despite the Air Force decision to proceed with the ballistic missile, the road ahead proved anything but smooth. ARDC, which had responsibility for the guided missiles program, agreed that the missile deserved greater support. Convincing Air Force headquarters to award it sufficient funding and project priority, however, proved next to impossible. Despite growing evidence to the contrary, skeptics on the Air Staff and in the Office of the Secretary of Defense (OSD) continued to view the ICBM as a weapon system too complex to ever reach the operational stage. Much of the criticism focused on the old issue of warhead weight. In November 1952, however, test results at Eniwetok (renamed Enewetak in 1974) Atoll, involving a 65-ton device with 500 times the explosive power of the Nagasaki atomic bomb, demonstrated the feasibility of thermonuclear technology and confirmed ARDC's optimism. Convinced that a smaller, lighter thermonuclear weapon could be developed soon, ARDC petitioned the Air Staff to reassess the overly restrictive weight and accuracy parameters for the Atlas. While agreeing that anticipated warhead yields called for reducing missile accuracy and guidance requirements, the Air Staff reaffirmed its step-by-step approach of sequential component development that forecasted completion of research in 1956, development in 1961, and prototype testing in 1963.[18]

ARDC designated the Atlas as Weapon System (WS)-107A. Measuring 110 feet in length (50 feet less than Convair's 1951 version), 12 feet in diameter, and with a total weight of 440,000 pounds when fueled with gasoline-liquid oxygen propellants, this "1953 Atlas" was a huge vehicle. The stage-and-a-half missile was to generate 656,100 pounds of thrust from its four booster and sustainer engines, delivering its 3,000-pound warhead a distance of 5,500 nautical miles. Still relying on a fission warhead, its low yield of from 20 to 30 kilotons meant that it needed to impact within 1,500 feet of the target. A ground station and an inertial autopilot transponder-receiver aboard the missile would provide guidance.[19]

After liftoff, the flight plan called for the rocket to ascend to an altitude of 15,000 feet before making a turn toward the target on a ballistic trajectory. Two minutes into the flight the booster engines would cut off and be jettisoned, and the sustainer engine would then continue to power the rocket for an additional 2 minutes and 26 seconds. When the sustainer engine shut down, two small vernier engines, each providing 1,000 pounds of thrust, would make final flight corrections during the last 30 seconds of powered flight. At that point, nearly five minutes after launch, the verniers would shut down, and the nose cone with armed warhead would make an elliptical free-fall descent toward the target.[20]

Looking back over the course of missile development in the late 1940s and early 1950s, the ICBM clearly fell victim to skepticism about its practical military use, to technological challenges, and to fiscal retrenchment that grew unabated through the late 1940s. Strategic bombers represented the key element in the nation's offensive arsenal, while the ICBM project moved painfully forward as a cautious, low-funded, phased study and test program that reflected the Air Staff's traditional skepticism. By the advent of the Eisenhower administration, however, heightened security concerns and further technological progress offered the prospect of breaking with the past and accelerating both missile and emerging satellite programs. Although still a formidable challenge, the 1953 Atlas clearly represented a major improvement over the earlier configurations and convinced missile advocates that the ICBM was feasible.

Eisenhower Endorses a "Crash" Ballistic Missile Development Program

President Dwight D. Eisenhower took office in January 1953 determined to implement a "New Look" defense policy that stressed strategic nuclear striking power at the expense of conventional forces.[21] In order to do this and roll back the Truman administration's Korean War budget from nearly $45 billion to $35 billion, he charged his Defense Department to end waste and duplication throughout the services. Missile programs could be expected to absorb their share of Defense Department cutbacks. Indeed, in early 1953 the administration expressed no particular interest in accelerating the ICBM program. In the space of only four years, however, President Eisenhower would come to preside over a costly expansion of a variety of ballistic missile programs as well as the birth of the American space program. These events have left their mark on the nation ever since.

Early in Eisenhower's administration, three developments galvanized the nation's ICBM effort. One involved the president's determination to take all possible measures to forestall another "Pearl Harbor" surprise attack. Like General Arnold, General Eisenhower could never forget that infamous event. His scientific advisor, James R. Killian Jr., remarked that Eisenhower remained "haunted . . . throughout his presidency" by the threat of surprise nuclear attack on the United States.[22] To avoid this horror, intelligence data on Soviet military capabilities became essential. Yet, neither news of Soviet advances in long-range bombers like the Tu-4 nor reports on Soviet long-range missile progress could be verified. At the same time, the development of a thermonuclear device and its testing in both the United States and the Soviet Union raised alarms about a potentially devastating surprise attack. Several RAND studies in 1952 and 1953 heightened awareness by describing the vulnerability of strategic air bases to attack. The RAND assessments complemented the Central Intelligence Agency's (CIA) national intelligence estimates that forecasted imminent increases in Soviet atomic weapons production and improved delivery capabilities.[23]

But reports remained confusing or contradictory, and the administration quickly realized that current intelligence methods could not provide meaningful data. Pre-hostilities intelligence information became increasingly essential, and all parties realized that aerial reconnaissance offered the most effective means to solve the dilemma. The near-term answer became the U-2 high-altitude reconnaissance plane, while the long-term solution would prove to be the military reconnaissance satellite. Meanwhile, the major defense effort would be devoted to developing medium- and long-range ballistic missiles rapidly for the New Look doctrine of "massive retaliation," considered the best means of deterring surprise nuclear attack.

A technological "thermonuclear breakthrough" that solved much of the ICBM payload weight dilemma also accelerated the ICBM effort. Operation Castle tests in the spring of 1953 suggested the advent of thermonuclear warheads, weighing only 1,500 pounds, with a yield of one megaton. This amounted to 50 times the yield of the much heavier Atlas warhead proposed by Convair, which meant the size, weight, and accuracy requirements of the Atlas could be reduced, making its development more feasible within the state of the art. On 1 March 1954, additional Castle results involving the first "droppable" thermonuclear bomb confirmed the viability of a lightweight, higher-yield weapon with extensive radioactive fallout coverage.[24]

Finally, several determined, reform-minded government officials streamlined and energized the decision-making process. Throughout this period, the leader of this reform group was Trevor Gardner, the "technologically evangelical" special assistant to the secretary of the Air Force for R&D.[25] While President Eisenhower and his advisors worried about intelligence data, Trevor Gardner made it his public mission to convince the government that the nation must pursue a crash program to develop an operational Air Force ICBM or face nuclear disaster. Ironically, he assumed his office with the mandate to implement the expected economy agenda in the Defense Department by ending waste and duplication in the Air Force missile program.[26]

Gardner Stimulates the Missile Program

In April 1953, Gardner called for review of all Air Force missile programs. He instinctively rebelled against what he regarded as ARDC's overly cautious approach and Strategic Air Command's (SAC) and the Air Staff's persistent delaying tactics. Gardner, who had heard reports of the "thermonuclear breakthrough," knew that accuracy and guidance performance requirements now could be relaxed and the missile was no longer "impossible."[27] Fortunately, to accelerate missile development he found willing allies among middle-echelon ARDC and Air Staff officers, the Convair group promoting Atlas, and from long-time proponent Gen Donald L. Putt, who became commander of ARDC in June 1953. At this point Gardner decided to bypass the Air Force bureaucracy and appoint a full-time group of experts on whom he would rely for advice. Late in the fall of 1953, he convened the Strategic Missiles Evaluation Committee under the chairmanship of renowned Princeton Institute for Advanced Study mathematician and activist John von Neumann.[28] The von Neumann committee, popularly known as the "Teapot" committee, comprised an impressive assemblage of scientists and engineers, all of whom had been handpicked by Gardner for their "progressive" views on ICBM requirements as well as their technical brilliance. Gardner also engaged the newly formed Ramo-Wooldridge Corporation to provide technical support on questions involving missile propulsion, guidance, and warhead reentry. Specifically, Gardner charged von Neumann's committee to determine the measures necessary to accelerate development of the Atlas missile.[29]

Von Neumann's subsequent report confirmed a concurrent RAND analysis that determined an Atlas initial operational capability (IOC) could be achieved by the early 1960s, if the project received increased funding, became a national priority, and had its demanding performance requirements relaxed. Both studies favored a drastic revision of the Atlas ICBM program in light of Soviet missile progress and newly available thermonuclear warhead technology. The Teapot Committee's report would also help convince President Eisenhower later that year to convene the Surprise Attack Panel or, as it was soon renamed, the Technological Capabilities Panel (TCP) chaired by Killian, then president of the Massachusetts Institute of Technology.[30]

Armed with the findings of the RAND and von Neumann committee studies, Gardner set out to win support throughout the Air Force hierarchy to expedite an expanded ballistic missile development effort through creation of a separate development-management agency that would bypass established administrative channels. By May 1954, his tireless advocacy had convinced Air Force leaders to form a West Coast project office at Inglewood, California. Organized as the Western Development Division (WDD), the latter represented the central von Neumann committee recommendation, and Gardner ensured that the new organization's chief would be his ally, Brig Gen Bernard A. Schriever.[31] Shortly after the WDD began functioning in

August, Schriever arranged for the Air Force to contract with the Ramo-Wooldridge Corporation as full-time technical consultant to his command.[32]

Schriever proved to be a brilliant choice to head a crash ICBM program. A young disciple of Hap Arnold, whom he considered "one of the most farsighted persons" he had ever known, Schriever had joined Trevor Gardner's reform group in early 1953 while serving on the Air Staff as assistant for development planning in the Office of the Deputy Chief of Staff for Development. He used his intelligence, patience, and superb negotiating skills with military and other government and private industry leaders to become an outstanding advocate for missile and space systems. He handpicked his initial group of officers, and, given the priority of the missile program, he was able to recruit from among the most capable officers in the Air Force.[33]

When General Schriever surveyed the state of his command in the spring of 1954, he realized that he faced a major battle within the Air Force to retain control of his project. Even though the Air Force had accorded the Atlas its highest R&D priority, 1-A, and the secretary of defense had declared Atlas of "critical importance" in early 1955, the bureaucratic labyrinth at the Air Staff and the OSD continued to cause bottlenecks and delays because of the multiple program review levels. Once again Gardner—actively supported by General Schriever—decided to bypass the Air Force bureaucracy by going directly to Senators Clinton P. Anderson and Henry M. "Scoop" Jackson, the two most influential members of the Joint Committee on Atomic Energy. After visits to Schriever's suburban Los Angeles headquarters and news of additional reports of new Soviet long-range bombers and missile tests, the senators wrote President Eisenhower, in late June 1955, about their concerns and recommended immediate action on the Atlas program to avoid funding delays, overcome interference from major Air Force commands, and bypass the multiple review levels.[34]

Back in February 1955, the president had also received the momentous report, "Meeting the Threat of Surprise Attack," of the TCP, chaired by James Killian. Confirming the vital need for pre-hostilities strategic intelligence on Soviet military capabilities, the Killian panel supported development of the Lockheed U-2 high-altitude reconnaissance plane and rapid development of IRBMs as a stopgap security measure until the ICBM force became operational. On 8 September 1955, President Eisenhower responded by assigning the Atlas program "the highest priority above all others," and "not . . . [tolerating] . . . any of the delays which may attend normal development or procurement programs."[35]

Although the Atlas ICBM had now been designated the "highest national priority" weapon system, administrative procedures remained cumbersome, prompting Gardner again to seize the initiative by directing Hyde Gillette, Air Force deputy for budget and program management, to form a committee and recommend measures to make the decision-making process for the missile program more effective. In October 1955, the Gillette committee's recommendations led to establishment of two ballistic missiles committees, one at OSD and another in the Office of the Secretary of the Air Force, to function as the sole reviewing authorities for WDD programs. Gone were the various separate offices Schriever had to consult individually. Now, he submitted a yearly development plan to a single committee, one consisting of representatives from the offices concerned with the ICBM program.[36]

To produce an operational missile by the end of the decade, Schriever's command adopted managerial innovations that would become common practice for the Air Force in future years. One involved reliance on outside technical experts rather than continuing with the prime contractor method, which charged the airframe manufacturer with responsibility for all aspects of weapon system design, development, and testing. Referring to Convair, General Schriever observed that "existing industrial organizations generally lack the across-the-board competence in the physical sciences [for] the complex systems engineering job" needed for the ICBM.[37]

Doubts about Convair's competence arose in the summer of 1954, when Convair opposed designing a smaller missile capable of carrying the lighter, powerful hydrogen warhead. Lessening the payload to 1,500 pounds could mean a three- rather than five-engine propulsion configuration, resulting in an overall missile weighing 220,000 pounds rather than 440,000 pounds. Convair, however, continued to favor the five-engine vehicle and lobbied to begin work immediately on the missile as prime contractor. That fall, when Schriever chose Ramo-Wooldridge as contractor for Atlas systems engineering and technical direction, a very unhappy Convair was left with responsibility for airframe construction, subsystems integration, and the static and flight test program. Looking ahead, Ramo-Wooldridge would later become Thompson-Ramo-Wooldridge (TRW) and serve as the Air Force's technical arm for the Minuteman and Peacekeeper ICBMs.[38]

The crash program also reflected what came to be called parallel development. In the summer of 1954 the Atlas Scientific Advisory Committee, which favored developing a multi-stage ICBM, had recommended that WDD award alternate subsystem contracts, whereby each Atlas component would be "backed up" by an alternate relying on different technology. Still skeptical of Convair's capabilities and the as yet unproven Atlas stage-and-a-half design, Air Force officials applied this parallel development concept on a larger scale by producing at the same time a second, more sophisticated "backup" ICBM, the Titan. Designers configured the new Titan as a two-stage, liquid propellant missile, with a more advanced guidance system and a rigid frame to permit underground deployment. Parallel or dual-source development also brought competition into the process and served as an effective risk mitigation approach. This allowed Atlas and Titan program managers to replace subsystems in case of failure or technological breakthrough, while advanced designs could be pursued without risk to the overall ICBM program.[39]

This costlier parallel development approach meshed effectively with the so-called concurrent procedures applied on an unprecedented scale by Schriever and his staff. The Air Force had traditionally followed a sequential weapon system development process, whereby managers completed each system component in turn, while prototypes subsequently underwent deliberate and rigorous testing before production.[40] Under concurrency and the systems engineering approach, all measures necessary to construct and deploy the weapon system would proceed simultaneously. In effect, research, development, testing, production, base construction, training, and support infrastructure requirements would be integrated into a master schedule with specific milestones. As General Schriever explained, concurrency "may be defined as moving ahead with everything and everybody, altogether and all at once, toward a specific goal. . . . Our aim," he continued, "was to bring all elements of our program along so that they all would be ready, at each successive stage, to be dovetailed into each other." As a rapid implementation of the systems method, concurrency promised to compress the acquisition cycle significantly—an absolute necessity if the program managers were to field an operational missile by 1960.[41]

By 1955, the Atlas design for "concurrent development" differed markedly from its earlier versions. On 14 January 1955, when the Air Force approved full-scale development of the Atlas, the revised design entailed a three-engine rocket, 82.5 feet long, 10 feet in diameter, and weighing 267,000 pounds when fully loaded. Given the continued uncertainty of being able to ignite an engine in the vacuum of space, Convair and the Air Force agreed to retain the stage-and-a-half propulsion configuration, with the two boosters and single sustainer engine, as well as the vernier engines igniting simultaneously at liftoff. Representing 80 percent of the Atlas's mass, the two stacked fuel tanks consisted of a top oxidizer tank holding 175,196 pounds of liquid oxygen separated by a bulkhead from the bottom tank containing 77,833 pounds of refined kerosene, or rocket grade propellant RP-1. The 1955 Atlas retained Charlie Bossart's unique monocoque fuselage design, although in place of aluminum, the "pressurized steel balloon" now had a series of stainless steel bands measuring between 0.010 and 0.051 inches in thickness. With the Atlas design in hand, the WDD devised a five-year development program that called for the first of three test vehicles to begin flight testing in the spring of 1957, followed in early 1959 by initial flight tests of the Atlas D, the first operational ICBM.[42]

General Schriever's task grew more daunting when, by the close of 1955, in addition to a second ICBM, the Titan, his command gained responsibility for developing the nation's initial military reconnaissance satellite and the Thor IRBM.[43] The challenge of producing an operational Atlas by 1960, an operational Titan shortly thereafter, and an operational Thor before either ICBM certainly would prove formidable. In the summer of 1956, Schriever's task became more difficult when the Eisenhower administration began an austerity program to limit defense spending in fiscal years 1957 and 1958. The Soviet Union's launch of Sputnik satellites in October and November 1957, however, compelled the Eisenhower administration to address the "missile gap" controversy. Sputnik precipitated widespread anxiety, with critics asserting that the administration's cuts in defense spending had endangered national security by creating a gap that had the Soviet Union far ahead of the United States in development of operational IRBMs and ICBMs. After Sputnik, President Eisenhower agreed to end economic restrictions on the missile programs and to accelerate and enlarge the ICBM program. The program had already become an enormous undertaking, and the figures are staggering. By 1957, two years into the program, Atlas embraced 17 major contractors and as many as 200 subcontractors across 32 states and employing 70,000 workers.[44]

Developing and Testing the Atlas, Titan, and Thor

The integrated concurrency procedures included establishing force levels, missile site selection, site construction, operational and maintenance crew selection and training, and missile organizational structure, while simultaneously developing and testing the missiles.[45] In March 1956, only 14 months after receiving the Atlas contract, Convair had produced its first Atlas Series A prototype missile for static testing, the first category of ICBM testing. Ably directed by Col Otto J. Glasser, the Air Force missile-testing program consisted of four phases, or categories.[46] Category I involved subsystem development testing by the contractor, while Category II, comprising R&D subsystem and component integration tests, was conducted by contractor and Air Force personnel at the Eastern Missile Test Center at Cape Canaveral, Florida. The latter readied the weapon system for comprehensive Category III tests by SAC under operational conditions. These initial operational tests were to guarantee missile readiness, accuracy, and reliability. Then, SAC performed additional Category IV operational tests at the Western Missile Test Range at Vandenberg Air Force Base, California, to ensure performance objectives would be maintained.[47]

After integrating the booster engines delivered by North American Aviation, Convair transported the missile to its new Sycamore Canyon test area northeast of San Diego, California, in August. By December, with the Atlas 1A missile secured to one of two enormous test stands, Convair engineers looked on with observers from Ramo-Wooldridge and the WDD as a brief but successful firing of the engines demonstrated airframe strength and subsystems compatibility. That same month, Atlas 4A, the first flight test version, arrived by cross-country truck transport for Category II testing at the Air Force Missile Test Center at Cape Canaveral.[48]

The Series A flight missiles did not incorporate a nose cone or sustainer engine because the tests evaluated only airframe and booster engine performance. The first two flights, on 11 June and 25 September 1957, lasted only 30 and 32 seconds, respectively, before the range safety officer destroyed the missiles following engine failure in both cases. The third, however, on 17 December, performed its short-range 575-mile flight flawlessly over the South Atlantic. Coming shortly after the Soviet Union's two Sputnik flights and the embarrassing failure of America's Vanguard launch on 16 December, the Atlas flight served as an important morale boost. The Series A tests concluded with the eighth R&D flight on 11 June. Although five of the eight had been considered unsuccessful, each flight had provided a wealth of important data.[49]

The Air Force Ballistic Missile Division (AFBMD), which had superseded the WDD on 1 June 1957, conducted two additional series of Atlas flight tests. Series B missiles included three more systems integrated into the basic A series airframe: North American Aviation's complete MA-1 two-booster and sustainer engine cluster and General Electric's Mod I radio-inertial guidance system and Mark 2 nose cone. Although the initial launch on 19 July 1958 ended in failure when the missile blew up a minute after liftoff, a 2 August flight effectively demonstrated staging and sustainer operations on its 2,500-mile journey. In the Atlas launch sequence, its two-booster and single sustainer engines all fired on the ground, while the two small vernier engines ignited 2.5 seconds following liftoff. Accelerating rapidly from the launchpad, the missile gradually nosed over on its flight to the target. A command from the ground station jettisoned the booster engines and turbopumps after 140 seconds, well into its trajectory; then the sustainer engine propelled the missile for another 130 seconds until achieving a velocity of 16,000 miles per hour. The two vernier engines then made necessary course and velocity corrections, after which the nose cone separated from the rocket framework and followed an unguided, ballistic course to the target.[50]

The remaining four successful Series B flights included the Air Force's first space mission, Project SCORE (Signal Communications by Orbiting Relay Equipment), the placing in orbit on 18 December 1958 of Atlas 10B, with an onboard radio relay transmitter that broadcasted President Eisenhower's worldwide Christmas message of peace. Beginning on 23 December 1958, the first of six Series C flights stressed weight reduction and improved accuracy with the General Electric Mod II and Mod III radio guidance systems and Burroughs computers. The three successful flights also included the first major test of the RVX-2 ablative reentry vehicle, which was recovered, on 21 July 1959, after a 4,385-nautical mile trip into the South Atlantic.[51]

Operationally, the Air Force would deploy three models of the Atlas ICBM. The Atlas D included the upgrades made to the A, B, and C series missiles and was deployed at three bases: Vandenberg AFB, California; F. E. Warren AFB, Wyoming; and Offutt AFB, Nebraska. With the missile stored horizontally above ground and requiring an elaborate ground-antenna system for its radio-inertial guidance system, survivability of the Atlas D became a major concern. The Atlas E and F missiles incorporated an upgraded engine and all-inertial guidance. For the Atlas E, designers increased missile survivability by constructing heavier, semi-hardened coffin storage shelters. First used at Vandenberg, those shelters widely dispersed the missiles because the inertial guidance system did not require the ground-antenna system. The Air Force deployed the E model at these bases: F. E. Warren; Fairchild AFB, Washington; and Forbes AFB, Kansas. Efforts to enhance Atlas survivability culminated in the silo-lift Atlas F, which housed an improved all-inertial guidance system. The Atlas F was deployed at six bases: Schilling AFB, Kansas; Lincoln AFB, Nebraska; Altus AFB, Oklahoma; Dyess AFB, Texas; Walker AFB, New Mexico; and Plattsburgh AFB, New York.[52]

While the Atlas finished its initial test-flight program in mid-1959, the Titan had completed its first successful flight test in February of that year—nearly two years after the Atlas Series A tests began. Titan had benefited from a less strenuous deployment timetable and its perceived role as a more sophisticated weapon system. In effect, it would become the equivalent of the most capable Atlas, the Series F missile, having taken advantage of its better design and incorporation of Atlas improvements.[53]

Back in April 1955, when Air Force Secretary Harold Talbott authorized General Schriever's WDD to proceed with an alternative ICBM, he specified that the new missile's R&D be concentrated in the central part of the country rather than on the East or West Coast. That October, the Air Force authorized the Glenn L. Martin Company, based in Baltimore, Maryland, to construct the airframe for a two-stage missile designated XSM-68, WS 107A-2 (later labelled the Titan) and plan its comprehensive development, with Ramo-Wooldridge providing technical support. Martin considered 94 cities before breaking ground, in February 1956, for a 300,000 sq. ft. fabrication facility with associated test equipment at the Waterton Canyon site near Littleton, Colorado, southwest of Denver.[54]

Initially conceived as a source of alternate ICBM subsystems, the Titan liquid propellant missile differed significantly from the Atlas. Measuring 98 feet in length, 16 feet longer than the Atlas, the Titan was a genuine two-stage missile. Unlike the pressurized steel balloon design of Atlas, the airframe for Titan incorporated structural elements in the propellant tank walls, thereby producing a rigid self-supporting airframe. Using liquid oxygen and RP-1, Aerojet's powerful two-stage propulsion system consisted of two first stage engines producing 300,000 pounds of thrust at sea level and a second stage engine generating 80,000 pounds when ignited in the vacuum of space. The two-stage configuration enabled the Titan to achieve a range of 6,350 miles with a payload of 3,825 pounds, over twice that of the Atlas. Bell Telephone Laboratories developed the radio-inertial guidance system used in the Titan I, while the Bosch Arma Corporation continued to work on an all-inertial guidance system. In the spring of 1958, however, the Air Force transferred the Bosch Arma inertial guidance system contract to the Atlas, where it would be incorporated into Atlas E and F series missiles. By early 1959, the Titan program had a new inertial guidance system from General Motors Corporation's AC Spark Plug Division under development and scheduled for completion in late 1962. In August 1958, AVCO Corporation had ceased work on a copper-sheathed, heat-sink vehicle for reentry protection in favor of an ablative Mark 4 nose cone that also would be used in the Atlas D and F series missiles. By this time, planners had decided on silo-hardened sites designed to withstand a nuclear blast equal to 100 pounds per square inch (psi) overpressure and were looking ahead to the Titan's capability as a space booster. Meanwhile, by 1959, the Ballistic Missile Division had authorized improvements to the Titan, beginning with the fifth squadron, that would include storable propellants, an in-silo launch capability, and a larger, more powerful second-stage engine. Looking ahead, this upgraded Titan would be deployed as the Titan II beginning with the seventh rather than the fifth squadron.[55]

The Air Force accepted the first Titan I on 17 June 1958 and scheduled its initial flight for that December, after captive (hold-down) tests at the Martin facility. Martin fabricated the Titan I in eight lots, totaling 163 missiles. Six Lot A limited-range missiles consisted of a simplified first stage and dummy second stage filled with water. The first flight blew up on its Cape Canaveral pad before the launch attempt on 20 December 1958. By the end of the Lot A testing on 4 May 1959, four of the six flights had demonstrated successful stage separation and excellent performance of the radio guidance system.[56]

The Lot B missile experience proved far less encouraging. Using complete first and second stages, these missile tests would evaluate stage separation and a brief second-stage flight as well as compatibility of the airframe and subsystems. A series of accidents during Martin's static testing delayed the initial launch of Titan B-5 until 14 August 1959. Unfortunately, following normal first stage engine ignition, premature release of the hold-down bolts allowed the missile to launch with insufficient thrust. When the first stage umbilical lanyard pulled free, it caused an engine shutdown, and the missile fell back to the pad after rising about 12 feet. The resulting explosion severely damaged the service tower.[57]

Additional test failures at the Denver site after the 14 August 1959 disaster rekindled earlier Air Force concerns that Titan program manager Col Benjamin P. "Paul" Blasingame had expressed about Martin's management and organization.[58] Following several meetings between key Air Force missile officers and top Martin officials, the company's vice president took over the Denver operation. Unfortunately, the initial Lot C missile, designed to test key subsystems and separation of a modified reentry vehicle, blew up shortly after launch, on 12 December, due to an unintentional triggering of the range safety destruct package. This failure precipitated a major Air Force review of Martin's Titan program management as well as another series of Air Force, OSD, and congressional assessments of whether to continue with the Titan. The Air Force report on Martin's management strongly recommended centralization of the company's effort and implementation of new procedures. After meeting with Air Force representatives in early January 1960, Martin president George M. Bunker personally assumed control of the Denver operation.[59]

The new management arrangement seemed vindicated with the next Titan launch, on 2 February 1960. Completing a 2,200-nautical mile flight, it achieved a successful high-altitude, second-stage separation and engine ignition, with the nose cone impacting within two nautical miles of the target. During the following nine months, a variety of Lot C, G, and J missiles achieved 10 successful flights, with an additional 5 partially successful, and 3 failures. The Lot G and J missiles, especially, showed consistent engine operation of both stages and a high level of guidance system accuracy. The flawless launch and flight of Titan M-7 on 19 January 1962 concluded the test-flight program at Cape Canaveral. Of the total 47 Titan I missiles launched, the Air Force classified 32 completely successful, 10 partially successful, and 5 failures. Further Titan test flights would take place at Vandenberg, the newly completed dual training-operational missile base.[60]

Meanwhile, the Thor IRBM already had been developed, tested, and deployed to the United Kingdom. On 27 May 1955, the Air Force had directed WDD to begin a high-risk program that would deploy 60 missiles by January 1960.[61] That summer of 1955, General Schriever assigned the project to Cdr Robert C. Truax, a brilliant propulsion officer on loan from the Navy. Working rapidly with a team from Ramo-Wooldridge led by Dr. Adolf K. Thiel, Truax submitted a design plan in August, and on 27 December 1955, the Truax-chaired IRBM Selection Board chose Douglas Aircraft Company as prime contractor. Directed to produce a missile within a year, Douglas Aircraft delivered the first Thor test missile on 26 October 1956, just 10 months after the contract had been signed.[62]

The Thor IRBM stood 63 feet high and was 8 feet in diameter. With its Atlas-derived Rocketdyne MB-3 Block II engine, the Thor burned RJ-1 kerosene and liquid oxygen to produce 150,000 pounds of thrust at sea level to achieve a range of 1,500 nautical miles. With Colonel Blasingame's support, AC Spark Plug furnished an all-inertial guidance and control system, consisting of a three-gyro-stabilized platform to provide the autopilot data for gimballing of the main and two vernier engines that corrected the trajectory.[63]

The Thor underwent a three-phased flight test regimen that focused on airframe, engine, and autopilot in phase 1, the all-inertial guidance system in phase 2, and the heat-sink reentry vehicle in the third phase. After many countdown and propellant-loading exercises, the initial Thor launched from Complex 17 at Cape Canaveral on 25 January 1957. Unfortunately, the missile exploded on liftoff, and investigators later identified the cause as a contaminated liquid oxygen fill-and-check valve. Three more test flights also ended in failure: one due to faulty wiring in the range safety officer's console, which convinced him to destroy the missile when it, mistakenly, seemed to be heading inland rather than out to sea; another when a malfunctioning main fuel valve caused the Thor to explode on the pad; and a third when failure of the mechanism controlling yaw produced violent maneuvers that broke the missile apart less than two minutes after liftoff. Finally, on 20 September, Thor 105 successfully reached its 10,000-mph operational speed as it flew 1,100 miles downrange with onboard telemetry working effectively. Without the required heavy test-flight instrumentation, analysts believed that the missile could have reached its targeted range of 1,500 miles.[64]

The Thor team experienced only six complete successes with the first 18 R&D launches in 1957 and 1958. Most of the failures could be traced to turbopump deficiencies, which had affected the Atlas as well. By the spring of 1958, Rocketdyne had a design improvement underway and planned to install the upgraded turbopumps on the next group of engines. The question became whether to halt testing and modify the existing engines or to continue testing and await the next batch of improved engines. Given the urgency of meeting the Thor's early 1960 deployment schedule, Schriever decided against the safer route and agreed that testing should continue in order to collect the data on inertial guidance and nose cone performance as soon as possible. By September 1958, at the end of the program's 18 test launches, the Air Force considered the Thor ready for operational deployment. On 19 September, a C-124 Globemaster delivered the first Thor to the Royal Air Force at Feltwell, England. In June 1959, the first Thor squadron became operational, with the last of the four-squadron unit achieving alert status on 22 April 1960.[65]

The Thor IRBM achieved operational status two years before SAC declared the full complement of Atlas and Titan ICBMs operational. The initial Atlas D squadron at F. E. Warren AFB had achieved operational status on 1 July 1958, and the entire Atlas missile force had been turned over to SAC by 20 December 1962. The initial Titan I squadron at Lowry AFB, Colorado, became operational on 18 April 1962 and, by 28 September of that year, SAC had declared all Titan I squadrons operational.

Phaseout: The First-Generation Ballistic Missile Force and the Balance Sheet

Although officially operational, the Atlas and Titan missiles were beset by reliability problems throughout their deployment. With over 40,000 identifiable parts, the sheer complexity of the Atlas, for example, made operating and maintaining the missile extremely challenging. The dangerous propellant-loading system prevented both the Atlas and Titan I from meeting the rapid 15-minute reaction time prescribed by SAC, while hydrocarbon contamination presented an unsolvable dilemma for the Atlas F and Titan I silo-based force. Several explosions, including three within a year at Walker AFB near Roswell, New Mexico, followed by one in May 1964 at Altus AFB, shortly after the third Walker explosion, convinced Secretary of Defense Robert S. McNamara to accelerate deactivation of the entire first-generation ICBM force that had been planned since the spring of 1963.[66]

Deactivation became imperative with the arrival at the operational units of the more capable Titan II and especially the solid-propellant Minuteman. In the spring of 1963, the first of the Titan II squadrons became operational, with the first Minuteman wing, the 341st Strategic Missile Wing at Malmstrom Air Force Base, Montana, to follow in July. The first 10 Minuteman ICBMs became operational on 27 October 1962, in time to support the Cuban Missile Crisis. The Minuteman ICBM owes its emergence and development to the "near-fanatic determination" of Col Edward N. "Ed" Hall, a brilliant if contentious engineer who became the champion of solid-propellant research in the Air Force R&D community.[67]

Assigned to the WDD in August 1954 as head of the propulsion branch, Hall initially played a key role in both the Atlas and Thor programs. At the same time, he also led the WDD effort to develop large solid-propellant motors and suitable ignitors. Working closely with Barnet R. Adelman, Ramo-Wooldridge Corporation's vehicle engineering director assigned to the WDD, Hall developed WS "Q," his proposal for a solid-propellant, three-stage ICBM. With the backing of General Schriever and his deputy, Col Charles H. Terhune Jr., Hall, in early 1958, sold Air Force leaders on his Minuteman ICBM.[68]

More cost effective, safe, flexible, survivable, and reliable than the first-generation ICBMs or the Titan II, the solid-propellant Minuteman represented the major ICBM deterrent force of the future. In the fall of 1964, when Secretary of Defense McNamara decided to deactivate the Atlas and Titan I force by 1965, he did so knowing that 600 Minuteman and 54 Titan II missiles had already achieved operational status.[69] Looking ahead, solid-propellant motors would have a major impact on space launch, with large, segmented, solid-propellant rockets powering space launchers and providing a variety of upper stage boosters.[70]

Of the 216 surplus missiles, the Air Force selected 133 Atlas missiles for suborbital space flights, R&D projects that included 54 Atlas E/F and 18 D models for advanced ballistic missile reentry research for the Minuteman, and 30 Atlas D targets for the Army's Nike Zeus missile defense test program.[71] With no interest expressed in retaining the Titan I missiles, the Aerospace Corporation recommended against their continued storage at Mira Loma Air Force Station, near

Vandenberg. Atlas ICBMs had been sent for storage to the San Bernardino Air Materiel Area at Norton Air Force Base, also in California.[72] In a very unfortunate decision, Norton officials decided to save storage costs by destroying approximately 40 unmodified Atlas E and Atlas F ICBMs in the early 1970s. On the other hand, the Air Force refurbished 22 Atlas F and 22 Atlas E missiles for use as space launchers from 1968 (Atlas F models) to 1995 (Atlas E models).[73] As for the Atlas D, this version served as the primary configuration for development of most General Dynamics production Atlas space launch vehicles.[74]

Thor deactivation occurred before the ICBM retirement. In May 1962, Secretary McNamara decided to retire the entire United Kingdom force when the bilateral agreement ended, in November 1964. His British counterpart, Defence Minister Peter Thorneycroft, however, chose to phase out the force in the spring and summer of 1963. Both sides had concerns about the IRBM's extremely volatile liquid fuel, slow reaction time, and exposed above-ground deployment. Now that the more capable ICBMs were entering the inventory, retiring the Thor became imperative. By 15 August 1963, the last Thor had gone off alert, and the entire contingent had been returned to the United States by 27 September. Subsequently, the Air Force had Douglas Aircraft convert the 60 Thor missiles to space launch vehicles for both orbital and suborbital missions.[75]

Despite the many problems with the short-lived Atlas and Titan I ICBMs, they remain a remarkable achievement. Not only were the Atlas and Titan totally new and extremely complex weapon systems, but they also required a completely novel working environment. Writing in 1958, General Schriever declared "the USAF ballistic missile program . . . the largest military development program ever undertaken by this nation in peacetime." Others involved in the program considered it more complex and ambitious than even the wartime Manhattan Project in terms of scope, personnel, and resources.[76] The Atlas and Titan I, together with the Thor IRBM, provided the nation its initial, effective Cold War land-based missile deterrent while establishing the precedent for development and deployment of their Titan II and Minuteman successors. Equally important, these first-generation missiles also served as the foundation of the nation's space booster fleet and national security space program. The Atlas, Titan, and Thor space booster triumvirate would not only provide the initial launch capability for intelligence, military, and civilian spacecraft but also continue in various configurations to support space launch requirements into the twenty-first century.

Notes

(All notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

1. It also should be noted that the Key West Agreement worked out by the Joint Chiefs of Staff at Key West, Florida, in March of 1948 accorded the Air Force operations in air space but did not address activities in outer space. Logically, the Air Force thus devoted its attention and budget priorities to air-breathing cruise missiles. Futrell, *Ideas, Concepts, Doctrine*, vol. 1, 198.

2. For postwar V-2 experiments, see especially DeVorkin, *Science with a Vengeance*; Neufeld, *Development of Ballistic Missiles*, 36; Malina, "Origins and First Decade of the Jet Propulsion Laboratory," 48–66; and House, *Government Operations in Space*, 24–26. The Army's wartime project to develop a 20,000-pound liquid-propellant rocket with a 40-mile range was organized under Caltech's Frank Malina as ORDCIT (Ordnance, California Institute of Technology). In 1943, ORDCIT was renamed the Jet Propulsion Laboratory. See Spires, *Beyond Horizons*, 7–8. WAC is the acronym for Women's Army Corps.

3. DeVorkin, *Science with a Vengeance*, 168–82; and Green and Lomask, *Vanguard: A History*, 10–11. A modified Viking would provide the booster for the four-stage Project Vanguard, the nation's first "civilian" space program. Despite development by the Office of Naval Research, the Vanguard generally is regarded as a largely civilian program in contrast with its competitors for America's scientific satellite entry in the International Geophysical Year program.

4. Neufeld, *Development of Ballistic Missiles*, 24–27, 44–50; and Beard, *Developing the ICBM*, 43–82. In the spring of 1943 Consolidated Aircraft Corporation merged with Aviation Corporation to form Consolidated Vultee Aircraft Corporation, later known by the acronym Convair. See Walker, *Atlas: The Ultimate Weapon*, 22.

5. Spires, *Beyond Horizons*, 18–20.

6. Beard, *Developing the ICBM*, 17–29; and Neufeld, *Development of Ballistic Missiles*, 13–23, 50–56.

7. Beard, *Developing the ICBM*, 52–55, 61; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 204; and Bulkeley, *Sputniks Crisis*, 71.

8. See an expanded biography of Karel J. "Charlie" Bossart in the appendix.

9. Neufeld, *Development of Ballistic Missiles*, 45; and Chapman, *Atlas: The Story of a Missile*, 27–28. Chapman argues that the AAF was interested in a preliminary assessment, with development perhaps occurring 5 to 10 years hence. This helps to explain why Convair's missile was to have only a 5,000-pound delivery capability when the two types of existing atomic bombs weighed approximately 9,000 and 10,000 pounds, respectively.

10. Neufeld, *Development of Ballistic Missiles*, 44–47; and Pike, "Atlas," 92–93.

11. Neufeld, *Development of Ballistic Missiles*, 48–49; Hughes, *Rescuing Prometheus*, 79; Lonnquest, "Face of Atlas," 16; Pike, "Atlas," 93; and Walker, *Atlas: The Ultimate Weapon*, 19.

12. Beard, *Developing the ICBM*, 107–13; Futrell, *Ideas, Concepts, Doctrine*, vol. 1, 275–78; and Neufeld, *Development of Ballistic Missiles*, 67.

13. Bulkeley, *Sputniks Crisis*, 74–77; Neufeld, *Development of Ballistic Missiles*, 79–83; Sheehan, *A Fiery Peace in a Cold War*, 104–6; Lonnquest and Winkler, *To Defend and Deter*, 29; and Condit, *The Test of War*, 5–11.

14. Lonnquest, "Face of Atlas," 25–26. It also should be noted that radio guidance seemed more feasible at this point, given the heavy weight of the inertial systems and Air Force skeptics who questioned the reliability of Draper's product. Later, Col B. Paul Blasingame, Titan program manager, convinced Brig Gen Bernard A. Schriever, commander of the Western Development Division, to experiment with inertial guidance. Initially, he did so on the Thor rather than the Atlas or Titan. Sturdevant, email; Futrell, *Ideas, Concepts, Doctrine*, vol. 1, 488–89; and Beard, *Developing the ICBM*, 129–30.

15. The CEP represented "the radius of the circle within which half the missiles aimed at the center may be expected to fall." Gantz, *United States Air Force Report on the Ballistic Missile*, 311.

16. Lonnquest, "Face of Atlas," 30, 32; and Jenkins, "Stage-and-a-Half," 74–75. Neufeld attributes the name to Convair's parent company, Atlas Corporation. See Neufeld, *Development of Ballistic Missiles*, 70 (asterisk notation). Pike ascribes the name to Charlie Bossart's direct reference to the Greek mythological character with the weight of the world on his shoulders. See Pike, "Atlas," 94.

17. Hughes, *Rescuing Prometheus*, 74–75; Walker, *Atlas: The Ultimate Weapon*, 25; Jenkins, "Stage-and-a-Half," 74–75; and Pike, "Atlas," 93–94.

18. Beard, *Developing the ICBM*, 129–51. Ongoing doubts about the project's technical feasibility rather than roles and missions concerns apparently prompted the Air Staff to refer ARDC's request to the Guided Missiles Committee. Since spring 1950, the Air Force had been authorized exclusive development of long-range strategic missiles, although the Army and Navy continued to contest both development and operational responsibility for missiles. Neufeld, *Development of Ballistic Missiles*, 56, 74–79. Lonnquest describes the advantages offered by "dry" fusion weapons; see Lonnquest, "Face of Atlas," 67–69. The more cautious approach of the Scientific Advisory Board likely reflects the position of the incoming Eisenhower administration, which had severely criticized the Truman military buildup for its waste that had resulted from accelerating weapons programs and initiating production before completing development and adequate testing. See Converse, *Rearming for the Cold War*, 404, 465. It should be noted that the weight of the Eniwetok Mike device cited by Lonnquest is 60,000 pounds (approximately 30 tons). He references Hansen, *U.S. Nuclear Weapons*, 59–60. Yet, Hansen provides the weight on p. 56 as between 62 and 65 tons when fully loaded. This differs considerably from the 82-ton device described in Rhodes, *Dark Sun*, 493–95, 510. Rhodes's reference for the device's weight is not listed.

19. Neufeld, *Development of Ballistic Missiles*, 78–79; and Lonnquest, "Face of Atlas," 65–66.

20. Neufeld, *Development of Ballistic Missiles*, 78–79; and Lonnquest, "Face of Atlas," 39.

21. The administration also favored the "New Look" for its impact on the defense budget. By focusing on nuclear forces, defense planners could lessen the country's reliance on conventional forces with their high personnel costs. Divine, *Sputnik Challenge*, 424–28; and Greenstein, *Hidden-Hand Presidency*, 70.

22. Killian, *Sputnik, Scientists, and Eisenhower*, 68; and Hall, "Origins of U.S. Space Policy," 5–6, 19–24.

23. Davies and Harris, *RAND's Role*, 48–56; and Prados, *Soviet Estimate*, 57–60.

24. Davies and Harris, 48–56; and Prados, 57–60.

25. See an expanded biography of Trevor Gardner in the appendix.

26. Greenwood, "Air Force Ballistic Missile and Space Program," 191; Killian, *Sputnik, Scientists, and Eisenhower*, 68; and Hall, "Origins of U.S. Space Policy," 19–20. On Gardner's professional background and personal characteristics, see especially Lonnquest, "Face of Atlas," 43–48; Beard, *Developing the ICBM*, 166; and Taubman, *Secret Empire*, 11–14.

27. Divine, *Sputnik Challenge*, 18; Futrell, *Ideas, Concepts, Doctrine*, 22–23; and Beard, *Developing the ICBM*, 145–51.

28. See an expanded biography of John von Neumann in the appendix.

29. For the most comprehensive study of the missile program and Gardner's role, see Lonnquest, "Face of Atlas," 43–143; Johnson, *United States Air Force and the Culture of Innovation*, 60–62; Lonnquest and Winkler, *To Defend and Deter*, 33; Beard, *Developing the ICBM*, 143–94; Neufeld, *Development of Ballistic Missiles*, 95–151; and Greenwood, "Air Force Ballistic Missile and Space Program," 190–97. The von Neumann Committee is often referred to as the Teapot Committee. According to Dr. Simon Ramo, however, this designation applies only to a second committee, which Gardner formed at the same time, to examine nonstrategic missile programs. The latter received the name Teapot committee when Gardner objected to Ramo's first suggestion, Tea Garden, because he believed the association with his own name was too close. By contrast, the von Neumann Committee should receive no other designation than Strategic Missile Evaluation Committee. Dr. Simon Ramo, interview.

30. Augenstein, *Evolution of the U.S. Military Space Program*, 6–7; Davies, *RAND's Role*, 48–56; Lonnquest, "Face of Atlas," 97–98; Ballistic Missile Organization (BMO), *Chronology of the Ballistic Missile Organization*, 9; Prados, *Soviet Estimate*, 57–60; and Mieczkowski, *Eisenhower's Sputnik Moment*, 41–44.

31. See an expanded biography of Bernard A. Schriever in the appendix.

32. Neufeld, *Development of Ballistic Missiles*, 106–8; and Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 206–11. Eventually, the systems engineering role played by Ramo-Wooldridge Corporation generated criticism from aerospace firms and Congress about its privileged position. When, on 31 October 1958, it merged with Thompson Products Inc. to become Thompson-Ramo-Wooldridge (TRW) Inc., its Space Technology Laboratory (STL) became an "independent" subsidiary of TRW. Nevertheless, conflict-of-interest charges and congressional scrutiny compelled General Schriever to seek an alternative based on a nonprofit, noncompetitive arrangement. Taking this approach, the Air Force established The Aerospace Corporation on 3 June 1960. By the end of the year, the new corporation had acquired more than 1,700 employees and responsibility for 12 major Air Force programs. Eventually, the Aerospace Corporation would provide general systems engineering and technical direction (GSE/TD) for every missile and space program undertaken by the Air Force. Spires, *Beyond Horizons*, 85–86; Kalic, *US Presidents and the Militarization of Space*, 36–40; and Dienesch, *Eyeing the Red Storm*, xiii, 115–36. Dienesch focuses on the WS-117 reconnaissance program and asserts that "we know very little about it, and discussions in the literature are inaccurate and severely limited." Dienesch, *Eyeing the Red Storm*, xiii. Yet, his references for chapter five would suggest otherwise, and his argument would benefit from more of the unclassified source record beyond the three sources he cites.

33. On Schriever's background and experience in the Air Force research arena, especially with long-range planning, see Lonnquest, "Face of Atlas," 50–55, 114–16.

34. Schriever et al., *Reflections on Research and Development in the United States Air Force*, 53–58; Beard, *Developing the ICBM*, 185–94; Divine, *Sputnik Challenge*, 22–23; and BMO, *Chronology of the Ballistic Missile Organization*, 17.

35. The report also recommended what became the solid-propellant Polaris sea-based ballistic missile and more rapid construction of the Distant Early Warning (DEW) Line across northern Canada. Hall, "Origins of U.S. Space Policy," 19–21; Killian, *Sputnik, Scientists, and Eisenhower*, 67–86; Temple, *Shades of Gray*, 60–63; Bulkeley, *Sputniks Crisis*, 147–48; Rosenberg, *USAF Ballistic Missiles*, 5; Hall, "Origins of U.S. Space Policy," 19–21; and Killian, *Sputnik, Scientists, and Eisenhower*, 67–86. To the initial consternation of Gardner and Schriever, in December President Eisenhower declared the IRBM programs to be coequal with the ICBM.

36. Schriever et al., *Reflections on Research and Development*, 53–58; Greenwood, "Air Force Ballistic Missile and Space Program," 190–97; Beard, *Developing the ICBM*, 185–94; and Divine, *Sputnik Challenge*, 22–23.

37. Schriever is quoted in Dyer, "Necessity as the Mother of Convention," 201. See also Johnson, *United States Air Force and the Culture of Innovation*, 64–71.

38. Lonnquest, "Face of Atlas," 125–39; and Hughes, *Rescuing Prometheus*, 90–93; See also Sheehan, *A Fiery Peace in a Cold War*, 234–35. Sheehan sees Ramo-Wooldridge's new SE/TD role as a revolutionary development, without recognizing that the prime contractor approach—first applied in the B-58 program—proved to be the major advance in acquisition practices. Converse, *Rearming for the Cold War*, 479–90. See an expanded biography of Simon Ramo in the appendix.

39. Beard, *Developing the ICBM*, 184; Neufeld, *Development of Ballistic Missiles*, 122–23; and Perry, "Atlas, Thor, Titan, and Minuteman," 145–46.

40. Often, this process reflected a "philosophy of gradualism," as illustrated by the fate of the Snark and Navaho cruise missiles, whose completion date slippages averaged five years and cost increases approached 300 percent of initial estimates. Lonnquest and Winkler, *To Defend and Deter*, 44; Greenwood, "Air Force Ballistic Missile and Space Program (1954–1974)," 193; and Greene, *Development of the SM-68 Titan*, 4.

41. It should be understood, however, that Schriever's application of concurrency reflected an evolutionary rather than a revolutionary approach to weapon system acquisition. Schriever, "US Ballistic Missile Program," 31; Perry, "Atlas, Thor, Titan, and Minuteman," 148–49; Converse, *Rearming for the Cold War*, 204–58, 457–521; and Johnson, *United States Air Force and the Culture of Innovation*, 50–52, 77–87. Johnson describes Schriever's early role in promoting the weapon system concept, particularly as key author of the April 1951 "Combat Ready Aircraft" study. This important staff paper proposed methods to accelerate the development cycle yet also deploy a fully operational weapon system to the field units. These methods included concurrency and, by the end of the Korean War, had been adopted by the Air Research and Development Command. Lonnquest argues that the term "concurrency" was not part of the Air Force acquisition community's vocabulary in the 1940s and 1950s. Even Schriever's Western Development Division did not use the term. See Lonnquest, "Building Missiles," 97–110.

42. RP-1 stands for Rocket Propellant-1. Lonnquest, "Face of Atlas," 140–43; Pike, "Atlas," 94–95; and Jenkins, "Stage-and-a-Half," 76.

43. Perry, "Atlas, Thor, Titan, and Minuteman," 150.

44. Neufeld, *Development of Ballistic Missiles*, 155; Greene, *Development of the SM-68 Titan*, 37–44; and Rosenberg, *USAF Ballistic Missiles, 1958–1959*, 8–11; Eisenhower officials responded to the critics by arguing that, while the Soviets might have a modest superiority in number of ICBMs, this did not constitute a "deterrent gap" in view of the US retaliatory strategic arsenal. Watson, *Into the Missile Age*, 179–80; Kaplan, Landa, and Drea, *McNamara Ascendancy, 1961–1965*, 288–89; Lonnquest and

Winkler, *To Defend and Deter*, 65–66; and van Staaveren, *USAF Intercontinental Ballistic Missiles*, I-1, I-5.

45. For a discussion of these elements, see Spires, *On Alert*, 27–50.

46. See an expanded biography of Otto J. Glasser in the appendix.

47. Van Staaveren, *USAF Intercontinental Ballistic Missiles*, 50; and Martin, "Brief History of the Atlas Rocket Vehicle," part 1, 57–58. Camp Cooke was renamed Cooke AFB on 21 June 1957, then Vandenberg AFB on 4 October 1958.

48. Lonnquest, "Face of Atlas," 209–11; and Jenkins, "Stage-and-a-Half," 77.

49. Jenkins, "Stage-and-a-Half," 77–78; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 229; Lonnquest, "Face of Atlas," 211, 263; Walker, *Atlas: The Ultimate Weapon*, 143–51; and Chapman, *Atlas*, 118–33.

50. Jenkins, "Stage-and-a-Half," 78–80; Turhollow, *History of the Los Angeles District, U.S. Army Corps of Engineers*, 1898–1965, 1-1 to 1-2; and Lonnquest and Winkler, *To Defend and Deter*, 211.

51. Lonnquest and Winkler, *To Defend and Deter*, 33. Engineers determined that an ablative, blunt-body nose cone that dissipated heat by shedding its outer layers during reentry proved superior to the heat sink nose cone, whose large copper alloy core absorbed heat. The president's message declared, "This is the President of the United States speaking. Through the marvels of scientific advance, my voice is coming to you via a satellite circling in outer space. My message is a simple one: Through this unique means I convey to you and all mankind, America's wish for peace on Earth and goodwill toward men everywhere." See Federation of American Scientists, "SCORE"; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 229; Lonnquest, "Face of Atlas," 263–64; Neufeld, *Development of Ballistic Missiles*, 205–6; and Johnson, *United States Air Force and the Culture of Innovation*, 92. Johnson states that the Atlas D achieved a reliability figure of 68 percent, with 13 failures, but does not indicate the period under consideration. Hunley's figures for the D missile include a total of 117 launches, with 27 failures.

52. Spires, *On Alert*, 38–41; and Martin, "Brief History of the Atlas Rocket Vehicle," part 1, 59–60.

53. Stumpf, *Titan II*, 13–14; and Greene, *Development of the SM-68 Titan*, 72.

54. Stumpf, *Titan II*, 14–15; and Harwood, *Raise Heaven and Earth*, 299–305. The Waterton Canyon site is still in use today, by Lockheed Martin.

55. Stumpf, *Titan II*, 17–18, 35–36; and Encyclopedia Astronautica, "Titan II," accessed 19 May 2021. Overpressure is in addition to normal atmospheric pressure of 15 psi (pounds per square inch) at sea level produced by blast or shock wave in the wake of a major explosion. On overpressure, Lonnquest references Ali, *The Peace and Nuclear War Dictionary*, 208–9. Lonnquest, "Face of Atlas," 212. The seventh Titan I squadron would become the first Titan II squadron, based at Davis-Monthan Air Force Base, near Tucson, Arizona. Eventually, Davis-Monthan, McConnell Air Force Base, near Wichita, Kansas, and Little Rock Air Force Base, Arkansas, would each host two squadrons of nine missiles per squadron. The total force of 54 missiles would remain unchanged and the most powerful American ICBM deterrent on alert until their deactivation in the 1980s. Spires, *On Alert*, 68.

56. Stumpf, *Titan II*, 20–22; and Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 256–58.

57. See note 54.

58. See an expanded biography of Benjamin P. "Paul" Blasingame in the appendix.

59. Harwood, *Raise Heaven and Earth*, 316–17; Van Staaveren, *USAF Intercontinental Ballistic Missiles*, 20; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 258–60; and Stumpf, *Titan II*, 21.

60. Stumpf, *Titan II*, 21; and Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 260–62. Stumpf argues that, with the contract stipulating a 77 percent in-flight reliability figure, the Titan I met its requirement with a 78 percent reliability record. He cites Greene, who does not explain precisely how in-flight reliability was measured. See Greene, *Development of the SM-68 Titan*, 97. Hunley states that the Titan I's R&D flights totaled 57, with 38 successful, 19 failures or partially successful, for a 67 percent success rate.

61. Originally regarded by the Air Force as a tactical ballistic missile, the initial Thor deployment plan for the United Kingdom called for 120 missiles. Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 232–34; and Forsyth, "Delta: The Ultimate Thor," 103–5.

62. See next note. Sturdevant, "Retrospective on a Rocket Pioneer," 8–9.

63. Hunley notes that the Thor technical manual depicts the missile as being 63 feet long rather than the fact sheet figure of 65 feet. Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 233; for Truax and Thiel's initial design plan, see Forsyth, "Delta: The Ultimate Thor," 104.

64. Greenwood, "Air Force Missile and Space Program," 194–95; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 236; and Forsyth, "Delta: The Ultimate Thor," 105–6.

65. Perry, "Atlas, Thor, Titan, and Minuteman," 151; Hunley, *Preludes to U.S. Space-Launch Vehicle Technology*, 236–40; and Forsyth, "Delta: The Ultimate Thor," 105–6.

66. Spires, *On Alert*, 50–55.

67. Perry, "Atlas, Thor, Titan, and Minuteman," 151. Solid-propellant motors require a fuel, often aluminum powder, in conjunction with an oxidizer, such as ammonium perchlorate, in an organic binder that allows the mixture to be cast in a rocket motor casing. Williamson, "Access to Space," 12; and Spires, *On Alert*, 95–96. See an expanded biography of Edward N. "Ed" Hall in the appendix.

68. Spires, *On Alert*, 96–103.

69. Whereas a Minuteman missile had a unit cost of $5 million, comparable figures for the Atlas D were $18.5 million, the Atlas E $15.3 million, the Atlas F $17.5 million, and the Titan I $26.5 million. Moreover, the annual cost to keep each first-generation missile combat ready approached $1 million, while the Air Force spent ten times less on each Minuteman ICBM. The latter also represented a substantial cost savings in personnel, as each Minuteman required a contingent of 12 rather than the 80 men needed to support the Atlas and Titan. It should be recognized, however, that concurrent development and accelerated schedules proved expensive for Minuteman development. By 1963, a Minuteman cost of $1,450,000 per missile for a production run of 800 missiles was five times the initial 1958 estimate. See Poole, *Adapting to Flexible Response*, 249–84; BMO, *Chronology of the Ballistic Missile Organization*, 102; Van Staaveren, *USAF Intercontinental Ballistic Missile*, 35; Nalty, *USAF Ballistic Missile Programs*, 30–32; and Stumpf, *Minuteman*.

70. It should also be noted that residual Minuteman II first and second stage motors have been used with commercial boosters on Orbital ATK's Minotaur space launch vehicle. "Minotaur I Fact Sheet," Orbital ATK, 2017.

71. Hunley, *U.S. Space-Launch Vehicle Technology*, 122; Martin, "Brief History of the Atlas Rocket Vehicle," part 1, 59–61; Nalty, *USAF Ballistic Missile Programs*, 1–4; and Jacquet, "What We Are Doing with Surplus ICBM Complexes," 88–94. The Air Force ultimately modified 113 of the surplus Atlas missiles for its own use, as well as for Army Navy, and National Air and Space Administration projects. See Lonnquest, "Face of Atlas," 272; BMO, *Chronology of the Ballistic Missile Organization*, 112, 114, 128; and Hammond, *Space Transportation*, 235.

72. Nalty, *USAF Ballistic Missile Programs*, 1–4; and Jacquet, "What We Are Doing with Surplus ICBM Complexes," 88–94. See Lonnquest, "Face of Atlas," 272; and BMO, *Chronology of the Ballistic Missile Organization*, 112, 114, 128.

73. Martin, "Brief History of the Atlas Rocket Vehicle," part 2, 44. Encyclopedia Astronautica's number of scrapped missiles is 35; Encyclopedia Astronautica, "Atlas," accessed 19 May 2021. The first Atlas F space launch occurred on 6 April 1968 and the last on 23 June 1981. The initial Atlas E was launched on 18 December 1981 and the last on 24 March 1995. For the Atlas F and Atlas E launch record, see *TRW Space Log 1996*, 115–320.

74. Martin, "Brief History of the Atlas Rocket Vehicle," part 1, 59.

75. Neufeld, *Development of Ballistic Missiles*, 232–33; and Encyclopedia Astronautica, "Thor," accessed 11 July 2017. Of the 60 modified missiles, 6 were assigned to the ASSET (Aerothermodynamic/elastic Structural Systems Experimental Test) program—a ballistic reentry lifting body—flown from Cape Canaveral Air Force Station. Another 30 were allocated to the Thor Burner program for launching Defense Meteorological Satellite Program (DMSP) spacecraft, and 24 supported the Air Force P-437 program (nuclear ASAT out of Johnston Island). Maultsby, email.

76. Schriever, "USAF Ballistic Missile Program," 25.

Chapter 2

The Atlas, Thor, and Titan Triumvirate

From Ballistic Missiles to Space Launch Vehicles, 1957–1972

National security space came of age in the 1960s. Before 1960 the Advanced Research Projects Agency (ARPA), National Aeronautics and Space Administration (NASA), and the Army and Navy carried out all but two of America's space launches. In 1960, the Air Force began its dominance of the space launch business with 14 of the 29 service-sponsored flights that year, a trend that would continue.[1] When the Air Force initiated its space program, it had a ready-made advantage in the liquid propellant ballistic missile force designed and built in the 1950s. The Thor IRBM and Atlas ICBM could not compete favorably with their heavier Soviet counterparts and soon were superseded by the more capable solid-fueled Minuteman ICBM and Polaris submarine-launched ballistic missile (SLBM). Nevertheless, the Thor and Atlas would continue to serve as effective, reliable medium-lift space boosters for a wide variety of unmanned space flights well into the era of the space shuttle. In the mid-1960s, they would be joined by the heavy-lift Titan III, the "DC-3 of the space age."[2] The multiple versions of the three space lifters and their upper stages that appeared in the 1960s reflected evolutionary technical improvements and the response to launching payloads of increasing weight and complexity.

The Kennedy Administration Establishes a National Space Program

Much of the development and maturity of space vehicles, payloads, and supporting infrastructure resulted from the Kennedy administration's determination to elevate the nation's defense posture across the board. Unlike its predecessor, the Kennedy administration promised the nation an integrated, national space program retooled to overtake the Soviet lead in space. Senator John F. Kennedy had made space an issue in the 1960 presidential election campaign. Referring to Soviet "firsts," he cautioned that "if the Soviets control space they can control the earth, as in past centuries the nation that controlled the seas dominated the continents. . . . We cannot run second in this vital race. To ensure peace and freedom, we must be first." He called for a national space program as part of the administration's program to rapidly expand US military capabilities. Indeed, over the first two years of the new administration the defense budget increased to 125 percent of the 1960 total.[3]

After his narrow victory over Vice President Richard M. Nixon, Kennedy appointed a committee to review the country's space program. Chaired by MIT's Jerome B. Wiesner, the Wiesner Report, issued on 10 January 1961,[4] severely criticized the organization and management of NASA and what it termed a "fractionated military space program." It recommended that one agency or military service be made responsible for all military space development and cited the Air Force as the logical choice. Already providing 90 percent of the space support and resources for other military agencies, the Air Force, said the report's authors, represented the nation's "principal resource for the development and operation of future space systems, except those of a purely scientific nature assigned by law to NASA."[5]

Once he took office, Secretary of Defense Robert S. McNamara directed his staff to review the military space program in light of the Wiesner Report's criticism of the "fractionated military space program." After studying the issue and soliciting comments from important Defense Department officials, McNamara decided to centralize space system development within the DOD. Since September 1959, the DOD had accorded the Air Force "responsibility for the development, production and launching of space boosters and the necessary systems integration."[6] McNamara confirmed this decision by his directive, *Development of Space Systems,* issued on 1 March 1961, which assigned the Air Force responsibility for "research, development, test, and engineering of Department of Defense space development programs or projects." Although the Army and Navy would continue with their existing satellite projects and conduct preliminary space research, the Air Force became responsible for nearly all future defense space research and development, with exceptions authorized only by the secretary of defense. For all intents and purposes, the Defense Department directive made the Air Force the leading military space service and effectively muted the rivalry among the three services over space issues that had plagued the Eisenhower administration.[7]

In response, the Air Force reorganized internally to provide the desired focus for leadership of the military space program. On 17 March, Air Force Chief of Staff Gen Thomas D. White announced a major reorganization to better manage the missile and space programs. The centerpiece of the Air Force reorganization in the spring of 1961 involved creation of Air Force Systems Command (AFSC), to replace Air Research and Development Command, with responsibility for all research, development, and acquisition of aerospace and missile systems. With the inactivation of the Air Materiel Command (AMC), a new Logistics Command was established to handle maintenance and supply only. To carry out this challenging assignment, AFSC received four subordinate divisions: Electronics, Aeronautical Systems, Ballistic Missile, and Space Systems. The new arrangement reflected the separation of missile and space management functions that Gen Bernard A. Schriever had favored for the previous two years to better address what he believed would be an expansive military space program. The new Space Systems Division would be formed at the Los Angeles site from elements of ARDC's Ballistic Missile Division and AMC's Ballistic Missiles Center. The Ballistic Missile Division, also comprising elements from ARDC's Ballistic Missile Division and AMC's Ballistic Missiles Center as well as the Army Corps of Engineers Ballistic Missile Construction Office, would relocate to Norton Air Force Base, California. An additional measure involved establishment of an Office of Aerospace Research on the Air Staff for basic research elements. General Schriever's newly formed AFSC now controlled release of new weapon systems from R&D to operational status, while its subordinate Space Systems Division on the West Coast prepared to direct the service's space effort with strong technical support from the Aerospace Corporation.[8]

A Standardized Launch Vehicle Program Takes Shape

The Wiesner Report also addressed the country's booster inferiority vis-à-vis the Soviet Union. "The inability of our rockets to lift large payloads into space," the report asserted, "is the key to the serious limitations of our space program." The committee considered development of large boosters "a matter of national urgency."[9] In fact, for several years the Air Force had been pursuing large booster development, especially in the area of solid rocket motors after the success of the Minuteman solid propellant program. Somewhat limited by

NASA's responsibility for "superbooster" development, the Air Force nevertheless persisted by awarding contracts for programs that demonstrated the feasibility of large solid rocket motors. At the same time, the service promoted a study called "Phoenix" that initially considered a broad range of potential launch vehicles, both solid and liquid propellant, characterized by relatively low cost and wide versatility. By the end of the Eisenhower administration, after a major assessment of the Phoenix concept by six aerospace companies the previous year, the Phoenix initiative recommended development of a large, high performance, economical, standardized space booster with segmented solid motors for the first stage and liquid engines for the second stage.[10]

In the winter and early spring of 1961, both the concept of a heavy-lift, standardized space booster and the prospect of developing large solid propellant rocket motors gained momentum. In February, White House pressure convinced NASA and the DOD to combine efforts on what the new administration termed a National Launch Vehicle Program. A letter from Deputy Secretary of Defense Roswell L. Gilpatric to NASA Administrator James E. Webb confirmed that neither NASA nor the Department of Defense would initiate a new space booster program unilaterally and they would coordinate all measures through the newly created Aeronautics and Astronautics Coordinating Board (AACB). With continued Soviet space successes in the spring of 1961, the large booster program received increased support. In April, President Kennedy instructed Vice President Lyndon B. Johnson, as chair of the National Space Council, to conduct "an overall survey of where we stand in space."[11] Responding to the vice president's call for input, on 8 May McNamara and Webb jointly recommended an expanded, integrated space program. Prominent among DOD's recommendations was its plan for developing large boosters that could also support NASA's manned lunar landing and return initiative. Both agreed to parallel development of solid propulsion motors and liquid engines, with DOD responsible for the former and NASA the latter.[12]

By the spring of 1961, studies of vehicles of varying sizes, stages, and fuel combinations designed to satisfy multi-ton thrust requirements focused on two basic options. One was a new vehicle with solid propulsion for the first stage and a liquid propellent second stage. The other grew out of booster proposals for the Dyna-Soar space plane and recommended a Titan II with strap-on solid motors for stage one.[13] These proposals became incorporated into the Unified Program Concept proposed by John H. Rubel, director of Defense Research and Engineering (DDR&E) to develop standardized launch vehicles and standardized upper stages. Rubel became the driving force behind McNamara's DOD effort to promote efficiency and control costs of space booster programs. After attending a meeting of the AACB's Unmanned Spacecraft Panel on 3 May, he described his Unified Program Concept in a 15 May 1961 memorandum for Secretary of the Air Force Eugene M. Zuckert. "The creation of standardized, 'workhorse' spacecraft and launch vehicles, suitable for many payload (project) applications but specifically optimized for few or none would be the goal." Because these vehicles should be used for many years, he explained, "It is important . . . to stress reliability, simplicity, over-all utility, the potential for repetitive use and similar factors." The vehicle should be capable of lofting a 10,000-pound spacecraft into a 300-mile, high Earth orbit and a payload weighing 1,500 pounds into a synchronous equatorial orbit. He suggested as a potential workhorse vehicle a Titan II with a new upper stage, as well as the "obvious candidate," Atlas-Centaur. He directed the Air Force to submit, by 16 June, a comprehensive study of potential workhorse booster candidates that would meet Air Force needs over the next two to three years.[14] In the following months, Rubel's Unified Program Concept would eventually lead to the heavy-lift, standardized Titan III. Meanwhile, his concept of space vehicle standardization also embraced the existing medium launch vehicles, Atlas and Thor, and their most important upper stages, Agena and Centaur.[15]

Standardizing the Mighty Atlas and Its Upper Stages

The General Dynamics Atlas actually began its space booster role before it became an operational ICBM. As noted in chapter 1, through Project SCORE a B-model Atlas had lofted 150 pounds of communications equipment and the booster's entire tank section into low Earth orbit (LEO) on 18 December 1958. With the broadcast of President Eisenhower's prerecorded Christmas message, his voice was the first to be heard from space. The Atlas remained in orbit nearly a month before reentering the atmosphere and burning up over the Pacific Ocean on 21 January 1959. Shortly thereafter, on 9 September 1959, the day SAC commander-in-chief Gen Thomas S. Power declared the Atlas D ICBM to be operational, a modified Atlas D missile successfully launched the first, "boilerplate" prototype of NASA's Mercury capsule from Cape Canaveral in preparation for the nation's first human spaceflight effort. By this time, the Air Force had designated its space launch vehicles by number, with 3 for Atlas, 2 for Thor, 1 for Scout, and eventually 5 for the future Titan III.[16]

LV-3B Atlas-Mercury

The Mercury-Atlas booster, designated Launch Vehicle-3B (LV-3B), was a standard Atlas D ICBM, "man-rated" for launching the 3,000-pound, single-astronaut spacecraft capsule into a 150-by-100-mile elliptical orbit. The key Atlas modification was the Abort Sensing and Implementation System, designed to detect any malfunction with the Atlas and activate the Mercury capsule's escape system. Because the Mercury capsule lengthened the booster by 20 feet to a total length of 82 feet, technicians relocated the rate gyro package 20 feet higher in the airframe. The two vernier engines not needed for attitude correction after sustainer engine cutoff were removed for weight reduction. Additionally, a retrofitted fiberglass shield attached to the mating ring protected the top of the liquid oxygen tank during capsule separation, and thicker aluminum skin gauges applied to the conical tank area under the capsule provided stronger support during periods of maximum dynamic stress. These modifications and the extensive quality control needed for the man-rated Mercury-Atlas made the LV-3B booster 40 percent more expensive than the ICBM.[17]

For the Mercury flight program, NASA officials scheduled five test flights before launching four missions with astronauts. Two of the first four flights failed. Launched on 29 July 1960, Mercury-Atlas 1 (MA-1) experienced a structural problem and exploded after nearly a minute into the flight. After liftoff of MA-3 on 25 April 1961, the Atlas experienced an autopilot problem and had to be destroyed by the range safety officer. The abort system, however, effectively initiated capsule separation, and the Navy retrieved the capsule for refurbishment and use on the MA-4 mission. After the success of MA-5 with Enos the chimp, John Glenn made his historic flight in *Friendship 7* on 20 February 1962, followed by astronauts Scott Carpenter, Walter "Wally" Schirra, and Gordon Cooper.[18]

In addition to supporting NASA's Project Mercury, the Air Force began producing modified Atlas D-model ICBM launch vehicles, optimized for payloads and missions, to support a wide variety of DOD and NASA missions. Several authors identify two distinct branches of Atlas vehicles developing from the Atlas D. One included the Atlas E and Atlas F ICBMs, while the other evolved from the Atlas D used as a space launch vehicle, beginning with the LV-3 series.[19] While the Atlas had successfully lofted the four Mercury astronauts into Earth orbit, its initial efforts to launch spacecraft beyond the Earth's atmosphere, using Able as the upper stage vehicle, failed in spectacular fashion.

Atlas-Able

With the Thor-Able lunar missions as precedent, NASA initially proposed taking advantage of Atlas, with its nearly 50 percent greater thrust, to loft a Pioneer probe to Venus. After reassessing the challenges, however, it decided instead to launch the 372-pound satellite into lunar orbit. Managed by NASA and conducted by the Air Force Ballistic Missile Division, the program called for a launch stack consisting of a modified Atlas D booster (LV-3A), an Able second stage, and the Pioneer satellite atop the Altair third stage. The Able was a modified upper stage Vanguard powered by an Aerojet AJ10-40 engine that generated 7,799 pounds of thrust. The Altair third stage used an Alleghany Ballistics Laboratory X248 Altair motor that produced 2,799 pounds of thrust.[20]

All three Atlas-Able missions failed. On the first flight, which occurred on 26 November 1959, the payload shroud (fairing) detached early, causing the third stage to disconnect from the second and explode. On 25 September 1960, the second Atlas-Able launch failed when an oxidizer leak developed during the second stage burn; the subsequent deviation in trajectory prevented the spacecraft from achieving lunar orbit. A third Atlas-Able, launched on 15 December 1960, exploded approximately 70 seconds after liftoff, possibly the result of a liquid oxygen tank failure.[21]

Although the Air Force considered the three Atlas-Able vehicle failures unrelated and publicly declared the Able structurally sound, it never again paired the Atlas with the Able upper stage. Instead, the Air Force had a far more capable replacement available in the Agena, which served as both a booster and a satellite once on orbit. The importance of the Agena is captured in the words of one space historian, who declared that between 1958 and 1982, the Agena, perhaps more than any other space vehicle, "put the Air Force in space."[22]

Fig. 1. The Atlas 80D Able (Pioneer P-30) launches from Launch Complex (LC) 12, 25 September 1960. (Photograph courtesy of John Hilliard)

Atlas-Agena A

On 29 October 1956, the Air Force contracted with Lockheed Missile Systems Division, in Sunnyvale, California, to develop both the WS-117L reconnaissance satellite system and a related upper stage vehicle, later termed Agena.[23] The initial Agena A model, measuring 5 feet in diameter and approximately 19 feet in length, used a Bell Aerospace modified Hustler engine system originally intended for the B-58 bomber's air-to-surface missile. The pump-fed rocket engine burned storable unsymmetrical dimethyl hydrazine (UDMH) fuel that ignited spontaneously with the inhibited red fuming nitric acid (IRFNA) oxidizer to produce 16,000 pounds of thrust. As with Project Mercury, the Atlas D received additional aluminum skin in the upper section to support the greater loads with the Agena.[24]

The Air Force used the LV-3A Atlas D-Agena A combination only four times. The first of two early warning MIDAS (Missile Defense Alarm System) satellites, designed to detect missile exhaust plumes with infrared sensors, launched on 26 February 1960 from Cape Canaveral but failed when the Agena second stage did not separate. A second MIDAS mission from the Cape on 24 May 1960 achieved orbit only to have the satellite's telemetry system stop functioning two days later. Although the MIDAS satellites never became operational, they established "proof of concept" for the Defense Support Program (DSP) spacecraft to follow in the early 1970s. The other two Atlas-Agena A missions, on 11 October 1960 and 31 January 1961, launched the first two Samos (named for the Greek island home of King Midas; also later known as the satellite and missile observation system) reconnaissance spacecraft from the Navy's Point Arguello launch facility adjacent to Vandenberg Air Force Base. Samos represented the Air Force's attempt to provide direct readout of photography from spacecraft to ground station. The first Samos failed to achieve orbit after damage to the control system at liftoff, but the second and last Agena A used with the Atlas succeeded in placing the 4,100-pound satellite on orbit. Because the Air Force had been concerned about the A model's small size and inability to restart in space, it had charged Lockheed two years earlier (on 16 January 1959) to develop a second stage Agena with lengthened tankage and the capability of restarting the engine in space. Lockheed delivered its upgraded Agena B for its first flight on 12 July 1961.[25]

Atlas-Agena B

The LV-3A Atlas D-Agena B improvements included larger propellant tanks that lengthened the vehicle to 25–37 feet, depending on the payload shroud and particular mission, and the Agena extended to 20 feet 8 inches. With the Atlas-Agena B's fifth launch, of *Samos 6,* on 7 March 1962, the Atlas MA-2 engine had been replaced by an uprated MA-5 unit that used baffled injectors and a hypergolic ignition system. With the boosters capable of generating 370,000 pounds of thrust and the sustainer engine 60,000 pounds, the upgraded Atlas-Agena B could loft 5,000 pounds into a 115-mile "parking" or coasting orbit and then restart its Agena engine for a second burn to send the satellite into its programmed orbit.[26]

The Air Force and NASA used the Agena B for 27 missions between 12 July 1961 and 7 June 1966. As part of its lunar program, NASA had selected the Atlas-Agena B combination for its Project Ranger to photograph the moon during the spacecraft's descent to the surface. The first Ranger flight, on 23 August 1961, failed when the Agena did not restart and *Ranger 1* remained in its parking orbit. Likewise, *Ranger 2,* on 18 November 1961, failed due to the Agena's inability to restart and send the spacecraft into its required higher orbit. After these losses, however, the Agena B experienced only minor issues. *Ranger 3* achieved solar orbit only to miss the moon by nearly 22,991 miles. Beginning with *Ranger 4,* NASA achieved remarkable results with six Ranger flights as well as with two Orbiting Geophysical Observatories to measure Earth's atmosphere and solar phenomena and with the launch of one Mariner probe. After *Mariner 1*, NASA's Venus probe, was destroyed on 22 July 1962 when a guidance error created an erroneous trajectory, *Mariner 2* launched the following month, and its Venus flyby made it the first successful interplanetary mission.[27]

Beginning on 12 July 1961 with *MIDAS 3,* the Air Force used the Atlas D-Agena B vehicle pairing to launch both its MIDAS and *Samos* satellites into polar orbits from its west coast launch facility. With *Samos* spacecraft weighing 4,100 pounds and MIDAS from 3,500 to 4,400 pounds depending on configuration, these were the heaviest American satellites orbited thus far. Two of the seven Agena B MIDAS satellites failed to orbit, and, likewise, two of the nine Samos missions failed when *Samos 3* blew up on the pad and *Samos 4* did not orbit. The Samos photo surveillance program had experienced consistently poor results in its effort to relay images directly to a ground station, and after the *Samos 11* launch on 11 November 1962, the Air Force cancelled the program. The Air Force launched its final Atlas-Agena B payload, *MIDAS 9,* into polar orbit on 19 July 1963. Although NASA would continue to use the remaining six Agena Bs in the inventory, both NASA and the Air Force had already turned to the improved, standardized Agena D that would play a central role in space launch for the next 15 years.[28]

Standardized Agena D

The launch vehicle discussions between Air Force and NASA officials in early 1961 included interest in standardizing Lockheed's Agena upper stage booster-satellite. For Agena A and B models, Lockheed custom built the individual vehicle to meet the specifications of each flight project. This meant that for diverse missions, elements such as wiring, various equipment locations, and the dimensions of the equipment rack differed considerably, and the specific Agena configuration could not be transferred to another mission without major, expensive modifications. To acquire a reliable, standard Agena that featured common equipment and interfaces and could be procured at a fixed price, the Air Force began a study in early 1961, working with Lockheed for the next several months to develop a new design. By August 1961, Lockheed had produced an acceptable design and on the 25th of that month received a letter contract from the Air Force to proceed with the standard Agena D model. The company responded with a special management and production arrangement that cut the original delivery time and enabled the company to supply the first Agena D on 16 April 1962, eight months earlier than scheduled. It launched atop a Thor booster on 27 June 1962.[29]

The Agena D mirrored the Agena B in weight and dimensions but presented a standard, or common, configuration. After the Air Force took delivery, mission-specific equipment could be added where necessary. The key common elements included individual removeable harnesses; four accessible modules for guidance, telemetry, power, and beacon equipment; a standard payload "interface console"; and a rack above the Bell engine for easy plug-in of solar panels and other optional items. Foremost among the latter were a secondary propulsion system for correcting the Agena's Earth orbit, a solid propellant subsatellite, and an additional pump-fed Bell engine that could be restarted in space as many as 16 times.[30]

The first LV-3A Atlas D-Agena D flight, on 12 July 1963, also inaugurated the National Reconnaissance Office's (NRO) highly classified KH-7 Gambit reconnaissance program for surveillance of Soviet military capabilities. Launched into polar orbit from the West Coast Point Arguello complex, the Gambit system used an Eastman Kodak 77-inch focal length camera with an image resolution of 2 to 3 feet. When the Atlas-Agena D combination flew its final Gambit mission on 4 June 1967, only three of the 34 satellites it launched had failed to orbit. The Air Force used the Agena D for its several additional classified satellite programs, including Snapshot, the only nuclear reactor orbited by the United States, and Canyon communications intelligence and Rhyolite signals intelligence satellites. The Atlas-Agena D boosters also launched the first three pairs of Vela satellites from Cape Canaveral into 64,000- to 72,000-mile orbits to monitor nuclear detonations and thereby support arms control agreements.[31]

NASA also scheduled the Atlas-Agena D launch system extensively for its lunar and planetary exploration programs. Although the agency's initial *Mariner 3* mission to launch a space probe flyby of Mars failed on 5 November 1964 when the spacecraft's protective fairing did not separate properly, a second attempt with *Mariner 4* met all objectives. Launched only 23 days later, its newly designed metal shroud jettisoned as programmed, and after a 228-day cruise to the planet, Mariner returned the first up-close images of Mars. Other NASA missions using the Atlas-Agena D included five Lunar Orbiters, three Applications Technology Satellites, a *Mariner 5* Venus flyby, an Orbiting Astronomical Observatory, an Orbiting Geophysical Observatory, and six missions in which the Agena D served as the target vehicle for rendezvous with the Gemini spacecraft.[32]

NASA and the Air Force flew the Agena D with the Atlas booster a total of 75 times between July 1963 and April 1978. The final Atlas-Agena D flight occurred on 27 June 1978, when a modified Atlas F missile launched a Seasat oceanographic spacecraft for NASA from Vandenberg Air Force Base. The satellite studied various oceans using an infrared spectrometer, four microwave scanning instruments, and radar sensors. For the first 11 Atlas flights with the Agena D, the Air Force had mated the Agena D with the LV-3A Atlas D booster. On 14 August 1964, however, the Air Force and NASA introduced the standardized Atlas D, Standard Launch Vehicle 3 (SLV-3), which would launch 48 of the remaining 65 Atlas-Agena missions.[33]

SLV-3 Atlas

Demand for a standardized Atlas booster rose in the last half of 1961, as 13 space programs relied on Atlas boosters. By 30 June 1962, the Air Force had 137 boosters on production contract with General Dynamics. Proponents of a common configured Atlas made the same arguments that advocates had used for the Agena D. In short, a standardized Atlas booster would reflect ease of production and greater mission flexibility and reliability and produce significant cost savings.[34]

Yet it was not until January 1962 that Space Systems Division began preparing a development plan for a standardized Atlas booster. On 12 April, the command sent the completed plan to Air Force headquarters, where Secretary of the Air Force Zuckert approved it after only eight days. He also authorized AFSC to initiate contract negotiations with General Dynamics Astronautics, and that same month Aerospace Corporation established a Standard Launch Vehicle Office to provide technical assistance for both the Atlas and the Thor medium launch vehicles.[35]

In early May, the DDR&E reviewed the Atlas development plan and requested more detailed design data and configuration specifications. On the 17th, General Dynamics submitted its proposal to the Air Force, which then sent it to NASA officials for suggestions. Despite NASA's request that the propellant tanks be extended, the Air Force refused. By the end of June, the Air Staff had approved the final plan, and Space Systems Division began contract negotiations with General Dynamics. Finally, on 14 September 1962, the Air Force formalized a contract with General Dynamics for the design and development of the standardized Atlas and modification of launch sites at Cape Canaveral and Point Arguello.[36]

The SLV-3 Atlas configuration was similar to the nonstandardized LV-3A vehicle. While Rocketdyne increased booster engine thrust to 330,000 pounds, the structural dimensions remained the same. The standardized version used the LV-3A's General Electric Mod 3G radio-inertial guidance system and incorporated improved reliability equipment. As one Space Systems Division historian declared, "Configuration management was the very essence of the standardization concept."[37] For successful configuration management, the Air Force and the Aerospace Corporation created configuration control boards, comprising members from all interested organizations and employing a formal flowchart process that embraced designs, hardware, and specifications and procedures. Contracts also included a requirement that the contractor establish its own configuration management process. In this way a configuration control board could effectively manage the complete development cycle.[38]

The Atlas standardization process called for production of the basic launch vehicle and the use of standardization or mission kits as the most expeditious and economical way to satisfy particular flight requirements. Bolt-on subsystems, such as autopilot electronics, required engineers to design, build, and install these kits during vehicle production and assembly, then verify them through extensive testing. As a result, General Dynamics engineers also developed mission analysis requirements and standardized electrical and mechanical interfaces between payload and launch vehicle. On balance, the mission kits simplified both assembly and the configuration control process, which resulted in lower integration costs. According to General Dynamics engineer John Silverstein, mission kits were the best means of easy "missionizing" until the advent of flight computers.[39]

Configuration management of the Atlas, although straightforward in concept, initially proved difficult to achieve in practice during factory production and engineering. Specifications for each mission kit required Air Force approval through what was termed a First Article Configuration Inspection. By December 1963, however, only the Mark II Guidance and Distribution Box kits had passed inspection. Because Air Force inspectors refused to compromise on quality control procedures, delivery of the first standardized Atlas had to be rescheduled from 16 November 1963 to 24 February 1964. Once use of mission kits became routine, however, the process proved very effective. The first flight of the SLV-3 Atlas, on 14 August 1964, carried a standardized Agena D with a KH-7 Gambit reconnaissance satellite.[40]

Launch statistics suggest that standardization produced a more reliable Atlas space launcher. While the LV-3A Atlas D was successful on 43 out of 53 launches for an 81 percent success rate, the SLV-3 launched 49 successful flights out of 51 attempts, for an impressive 96 percent figure. Most of the mission configurations used the Agena as the upper stage vehicle.[41]

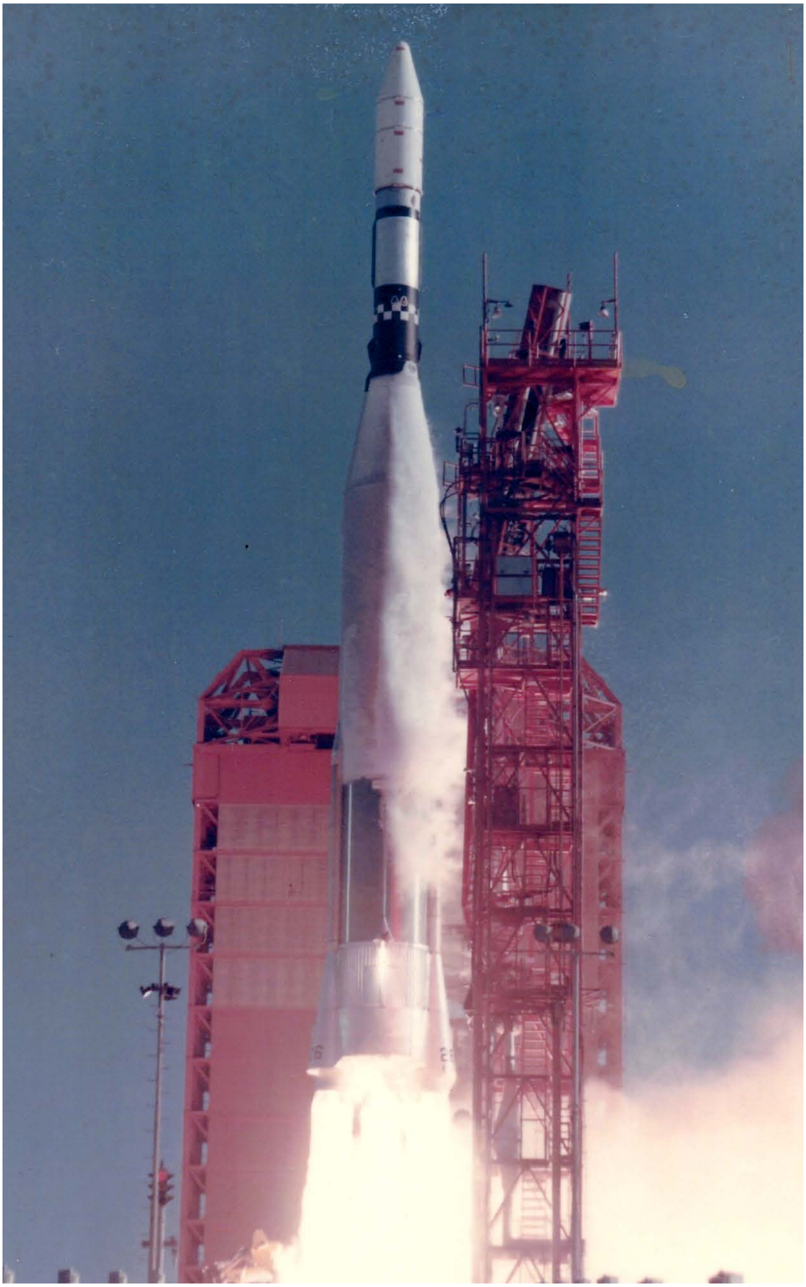


Fig. 2. Initial flight of Atlas 5602A Agena D 6503, LC-13, 4 March 1968. (Photograph courtesy of John Hilliard)

SLV-3A Atlas

A year after the first SLV-3 flight, DOD acceded to NASA's earlier request and agreed to the development of an upgraded standardized Atlas to handle heavier payloads and later versions of the Agena booster. Although propellants and guidance equipment remained the same, General Dynamics extended the propellant tanks 9.75 feet, lengthening the SLV-3A to 78.7 feet, which provided an additional 48,000 pounds of propellant. To support the increased weight, Rocketdyne raised booster engine thrust from the SLV-3's 330,000 pounds to 336,000 pounds for the SLV-3A and sustainer engine thrust from 57,000 pounds to 58,000 pounds. The more powerful SLV-3A Atlas-Agena could loft up to 7,500 pounds into LEO, an increase of 1,500 pounds over the SLV-3's capability.[42]

The SLV-3A Atlas-Agena D made its maiden flight on 4 March 1968 when it launched NASA's 1,397-pound Orbiting Geophysical Observatory into an eccentric orbit to conduct 25 geophysical experiments. Over the next 10 years, however, the SLV-3A flew only 11 more times. All 11 were successful classified NRO missions, comprising 4 Rhyolite and 7 Canyon intelligence satellites. The decline in Atlas-Agena missions can be attributed to the advent of the more capable Centaur upper stage vehicle produced by General Dynamics. The Centaur would prove more suitable for upgraded reconnaissance satellites and for NASA's spacecraft requiring velocities for interplanetary missions with heavier payloads.[43]

Centaur

The powerful Centaur booster burned liquid hydrogen, which provided nearly 40 percent more thrust per pound than conventional hydrocarbon, kerosene-based fuels like RP-1. Whereas the Atlas-Agena D could handle payloads to LEO weighing nearly 2,000 pounds, the Atlas-Centaur could loft spacecraft weighing up to 9,000 pounds.[44]

The Centaur's gestation can be traced back to the pre–World War II German rocket community's interest in liquid hydrogen and postwar experiments at a variety of American civilian and government facilities. Among the more important efforts was the Air Force's highly classified Suntan project to develop a hydrogen-fueled aircraft more capable than the U-2 reconnaissance aircraft. Although the Air Force cancelled the two-year program in the spring of 1958, Pratt &

Whitney's engine work with liquid hydrogen also helped establish the technological foundation for Centaur. At this point, German engineer Krafft Ehricke played the key catalyst role in the development of hydrogen propulsion. He had joined General Dynamics in 1954 to work on the Atlas but soon began studying potential upper stage vehicles propelled by liquid hydrogen and liquid oxygen. Amid heightened interest in space vehicles after the Sputnik flights, in late 1957 he submitted a proposal that led directly to the Centaur program. His design called for an upper stage vehicle for the Atlas powered by a Rocketdyne engine using liquid hydrogen and liquid oxygen propellants. When the Air Force declined to accept the Convair development plan, Ehricke turned to DOD's Advanced Research Projects Agency. Although impressed with the proposal, ARPA officials told Ehricke about Pratt and Whitney's work with pumps to supply liquid hydrogen to the engines and suggested he revise and resubmit his offer. He did so, and near the end of August 1958 ARPA issued a contract for Convair to produce a high-energy upper stage vehicle using liquid hydrogen and liquid oxygen propellants in Pratt & Whitney engines.[45]

Although Centaur would become the nation's premier upper stage booster, it initially suffered from significant managerial and technical problems. ARPA had decided that the Air Force would direct Centaur despite NASA's effort to assume management responsibility. In a compromise arrangement in June 1959, DOD transferred Centaur to NASA and, from NASA's Washington, DC, headquarters, a Centaur project manager directed an Air Force program manager based at the Ballistic Missile Division in Los Angeles. The Air Force selected as program manager Lt Col John D. Seaberg, who had managed the Suntan project. Management problems at General Dynamics surfaced, as Centaur suffered from Atlas's priority for funding and management focus. Ehricke, who served as the Centaur program manager at General Dynamics, proved unable to overcome the problem. A major NASA inspection in December 1961 compelled General Dynamics to replace Ehricke and adopt a project type of management in place of its matrix organization. Centaur also suffered from management problems after NASA, in July 1960, assigned the Marshall Space Flight Center, in Huntsville, Alabama, responsibility for the program. There it had to compete with Saturn for priority and attention, as well as Wernher von Braun's opposition to the basic design of Centaur. When the initial Centaur launch failed on 8 May 1962, Congress held hearings that month on the fate of the launch vehicle. Despite congressional criticism of Centaur's management and von Braun's recommendation to cancel the program, NASA headquarters decided to transfer Centaur to the Lewis Research Center in Cleveland, Ohio, where dynamic director Abe Silverstein could draw on his center's decade-plus experience with liquid hydrogen. Back in January 1962, NASA and DOD had agreed that the civilian agency should take over the Air Force contracts, relocate the program office from the Ballistic Missile Office to the Marshall Space Flight Center, and replace Seaberg with a NASA official. Although NASA assumed full control of the Centaur program, both NASA and the Air Force would continue to use this important upper stage vehicle into the twenty-first century. By the late 1980s, however, the Air Force would be funding Centaur production and development.[46]

The managerial issues also reflected myriad complex technical problems that arose from having to deal with the very low boiling point of –423° F, compared to –299° F for liquid oxygen. A major challenge proved to be Ehricke's innovative design for a double-walled intermediate bulkhead between the liquid hydrogen and liquid oxygen tanks. A vacuum created in the hollow bulkhead was to keep the liquid oxygen from freezing by preventing heat transfer between the liquid hydrogen and the 70-degree-warmer liquid oxygen. But hydrogen leaked through minute holes in the welds and destroyed the vacuum, requiring technicians to apply greater wall thickness at the welding points.[47]

Other problems resulting from the extreme cold of cryogenic fuel involved engine ignition and turbopump lubrication, metal wrinkles that appeared on the lower bulkhead once the liquid hydrogen tank had been filled, and the four removable, 1,350-pound panels made of foam-covered fiberglass approximately a centimeter thick that attached to the vehicle by metal bands. Designed to keep the liquid hydrogen from boiling off before launch, the panels needed to be jettisoned shortly after liftoff to reduce the vehicle's weight. The initial Centaur launch failed when water vapor in the air between the foam insulation and the fuel tanks froze the panels to the tanks, preventing their removal. Technicians solved the problem with a helium purging system.[48]

Structurally based on the "steel balloon" Atlas, the original General Dynamics Centaur D launch vehicle measured 30 feet long and 10 feet in diameter and weighed over 30,000 pounds when fully fueled. Centaur was powered by two Pratt and Whitney RL-10 pump-fed engines, each of which produced 15,000 pounds of thrust. Capable of multiple restarts in space, the Centaur D, when paired with the LV-3C Atlas, could launch 8,500-pound payloads into high Earth orbit. Relying on a General Precision–made rotating drum digital computer, the Centaur's inertial guidance and control system functioned for both stages, with the Atlas providing only attitude and rate sensing. An interstage cylinder attached the Centaur to the Atlas, and the payload adapter could be modified for each type of payload.[49]

On 8 September 1962, after a 15-month delay and 10 launch postponements, the first test Centaur launched from Cape Canaveral and exploded 54 seconds after liftoff. The subsequent congressional hearings led to managerial changes and design changes. On the second launch, on 27 November 1963, a single 380-second burn took the Centaur stage with its dummy payload into the correct orbit. After six more test launches, four of which were unsuccessful, the LV-3C Atlas-Centaur D combination successfully launched the first Surveyor moon lander on 30 May 1966. Designed to determine the feasibility of a soft moon landing in preparation for the Apollo missions, *Surveyor 1* soft landed in the Ocean of Storms and transmitted 11,237 television images to the Jet Propulsion Laboratory. The LV-3C version of the Atlas launched three more 643-pound Surveyor spacecraft before being replaced by the standardized Atlas SLV-3C. With its lengthened propellant tanks, the SLV-3C Atlas, when combined with the Centaur D, could launch 9,100 pounds into high Earth orbit and inject a 2,700-pound payload into a trajectory to escape Earth's gravity. This weight figure for the SLV-3 Atlas represented a 400-pound increase over the LV-3C Atlas-Centaur's Earth escape capability.[50]

Beginning on 8 September 1967, the SLV-3 Atlas-Centaur D booster combination launched 17 missions that included the final three Surveyor spacecraft, four Mariner Mars probes, and *Pioneer 10,* NASA's first flight to the outer planets and beyond the solar system. The SLV-3D booster was successful on all 17 missions before being supplanted on 6 April 1973 by an SLV-3D model that used an upgraded Centaur D1A to launch the *Pioneer 11* spacecraft to Jupiter and Saturn. Although NASA would continue to use the Atlas-Centaur combination, beginning in 1971, launches of commercial communications satellites would total 27 of the remaining 38 Atlas-Centaur flights. General Dynamics increasingly marketed the Atlas-Centaur as ideally sized to launch communications satellites, which it viewed as the space market of the future. Indeed, Atlas-Centaur in the decade of the 1970s would remain primarily a NASA and commercial booster system, with DOD accounting for only seven Fleet Satellite Communications satellite missions.[51]

Atlas F Space Launch Vehicle

When the Air Force deactivated the last of the Atlas ICBM force in 1965 and had the vehicles stored at Norton Air Force Base, California, it fully intended to use them in the future as boosters for space flight and ballistic missile test missions. Although by that time General Dynamics-Convair Division had been producing the standardized SLV-3 version for over a year, the Air Force realized it could have the so-called wheatfield Atlas E and F missiles refurbished at significant cost savings.[52] On 14 January 1966, the Air Force contracted with Convair to modify 23 missiles, beginning with the newer F models. Ultimately, the contractor would refurbish 95 Atlas E and F rockets, with 48 allocated for ballistic missile reentry flights and 47 for orbital missions.[53]

Convair began refurbishment at its Kearny Mesa location near San Diego, first by returning the Rocketdyne engines to the rocket corporation's Los Angeles–based Canoga Park factory for updating or to replace component parts. In 1969 Rocketdyne initiated a more elaborate engine refurbishment program designed to prolong the life of the engines that remained in storage. The process involved first removing the engines, then dismantling the mechanical systems and retesting them to factory acceptance test procedures. Likewise, Convair technicians stripped the vehicles of the electronic systems, including wiring, autopilot hardwire, and inertial guidance system hardware, and replaced all of them with new designs. The most significant change involved removing the inertial guidance system and installing General Electric's Mod 3G radio-inertial system that had been produced for the SLV-3. Eventually General Dynamics opted to have the refurbishment project transferred to Vandenberg AFB when a decline in the projected launch rate made the Kearny Mesa operation too expensive. As it turned out, General Dynamics crews reassembled most of the vehicles at the firm's Vandenberg Booster Assembly Building. According to John Silverstein, the Air Force received the converted Atlas for the bargain price of approximately $5 million, while other authorities asserted that the service saved an estimated $20 million with every launch of a refurbished missile.[54]

On 6 April 1968 the first Atlas F space booster lofted a propulsion module with the first of four solid propellant Orbiting Vehicle One (OV-1) satellites. These satellites conducted a variety of solar radiation and engineering experiments for the Air Force Aerospace Research Support Program. Twelve hydrogen-peroxide thrusters on the satellite's propulsion module facilitated separation of the OV-1 from the booster and then provided attitude control during firing of the solid rocket. The last of the four missions, on 2 October 1972, used a solid propellant Burner II upper stage for a radar research and radar calibration target mission. Looking beyond the OV-1 missions, the Atlas F also would serve as the launch vehicle for the experimental, preoperational Global Positioning System (GPS) satellites in the 1970s.[55]

The Atlas achieved an impressive launch success rate during the 1960s. From 1960 through 1969, the LV-3A, for example, flew 51 launches, with 41 successful, for a success rate of 80.4 percent. As expected, the standardized and improved SLV-3 and SLV-3A achieved much better results. The SLV-3 was successful on all 12 flights, while the SLV-3A experienced only one failure among its 12 launches for a 91.7 success rate. Yet, despite the Atlas's reliability and launch record, demand for Atlas launch vehicles declined considerably by decade's end. The reduced requirement for the medium launch Atlas is depicted by the number of launches per year for the last half of the decade. From an all-time high of 35 Atlas launches in 1966, the number fell to 13 in 1967, 9 in 1968, and 5 in 1969, 3 in 1970, and the downward trend continued into the 1970s. While the lower launch rates reflected a growing preference for the more powerful Titan III, they also resulted from the reality that more capable satellites remained on orbit longer than the projected operational life.[56]

By 1967, the Air Force had flown its final Atlas SLV-3 Agena D KH-7 mission for the NRO. That year, in fact, AFSC Commander-in-Chief Gen James Ferguson and Dr. Alexander Flax, Assistant Air Force Secretary for Research and Development, agreed that the Space and Missile Systems Organization (SAMSO) that had consolidated the Ballistic Systems Division and Space Systems Division into a single organization on 1 July 1967 would stop low-cost procurement of standard Agena Ds for all users. Most Agenas, in fact, were used by the Los Angeles–based Air Force Special Projects Office for classified NRO missions. But because the office found it necessary to modify the standard Agenas for their missions, they would now handle their own vehicle procurement directly with Lockheed, and standard

Agena production would end in July 1968. NASA would also procure any future Agena Ds it needed directly from the contractor.[57]

NASA and the Air Force would continue to launch Atlas boosters in the next decade and beyond, but both agencies preferred the more powerful Titan III that entered the space launch inventory in 1965. For NASA, the Titan III, with the Centaur upper stage, would be more effective launching its planetary and deep space missions, while the Air Force would designate the Titan III for its next-generation satellite reconnaissance programs. Even so, the Air Force would continue to launch Atlas vehicles into the 1990s and, with the Evolved Expendable Launch Vehicle program, the Atlas V family of launchers in the new century.

Developing the Thor "Workhorse of Space"

The Thor's transition from launch vehicle to standardized launch vehicle (SLV) in the 1961–63 period is less straightforward than that of the Atlas. Because the Air Force had used the Thor primarily for the classified reconnaissance program since its inception as a space booster, Douglas Aircraft Company did not have to custom build the individual vehicle to meet specifications for a large number of different flight projects and payloads. The Thor, in effect, could be considered a standard launch vehicle, at least for classified reconnaissance missions, well before its official SLV-2 designation in 1963.[58]

From the late 1950s to the early 1970s, the Thor space launcher's reliability, versatility, and flexibility made it the "workhorse of space." The Air Force had already launched 11 Thor orbital missions before the initial Atlas-Able flight on 24 September 1959. The first three supported NASA's Pioneer lunar probe project, but all three failed to reach the moon. On 28 February 1959, however, the fourth Thor flight and first use of the Thor-Agena A combination initiated Project Corona, the highly classified NRO satellite reconnaissance program to monitor Soviet military capabilities. Although the Thor would loft nonmilitary payloads as well, its central role remained that of booster for Corona reconnaissance satellites. As early as 1959, NASA saw in the Thor the reliable and adaptable medium launch vehicle it needed for its expanding communications, weather, scientific, and planetary exploration programs. First designated Thor-Delta, the modified Thor first stage would support a wide variety of upper stage spacecraft and continue as NASA's Delta in numerous configurations well into the future.[59]

The Thor reflected the general space launch trend of continuous technical advances and consistent evolutionary growth. Performance improvements centered on providing additional liftoff thrust by using solid rocket motors, lengthening the Thor's fuel tanks, upgrading the main engine, and also by using a variety of upper stage rockets. Douglas Aircraft Company produced six major versions of the Thor, comprising two nonstandardized launch vehicles and four standardized launch vehicles. The initial Thor booster was Douglas Model 18A, a Thor IRBM, modified to accept upper stages and their payloads. Measuring 56 feet in length with an 8-foot diameter, the Thor burned liquid oxygen and RJ-1 kerosene fuel in Rocketdyne's MB-3 Block II engine to achieve 150,000 pounds of thrust. Two Rocketdyne vernier engines, each producing 1,000 pounds of thrust, provided roll and pitch adjustment for the main engine.[60]

The Air Force mated the Thor with four upper stages. The Thor-Able launch system supported NASA and naval missions, while the Thor-Able-Star combination supported naval space navigation requirements. Three Thor-Burner booster combinations launched early versions of its Defense Meteorological Satellite Program (DMSP) weather satellites, while the Air Force used the Thor with three versions of the Agena booster-satellite, the most prolific Thor combination, to launch NRO reconnaissance satellites.

Thor-Able

Thor-Able, the first Thor upper stage combination, consisted of a Thor DM-18A first stage, a modified Aerojet Vanguard propulsion unit as the Able second stage, and an ABL X248 Altair solid propellant motor for stage three. Capable of launching 260-pound payloads into LEO, the Thor-Able supported Project Mona, NASA's first attempt to reach the moon, by launching three 83-pound Pioneer moon probes. Considered too heavy for the Pioneer missions, Thor's inertial guidance system was replaced by the Bell Telephone Laboratories radio guidance system that technicians placed in the second stage. Unfortunately, all three missions failed. The first, on 17 August 1958, suffered a first stage turbopump failure and blew up 77 seconds after liftoff. Two months later, the second flight launched successfully, but the third stage did not produce enough thrust to create sufficient speed to reach the moon. The third flight, on 8 November 1958, also launched and performed without incident until the third stage failed to ignite.[61]

The final set of Thor-Able combinations, however, performed as programmed. Between 7 August 1959 and 1 April 1960, the Air Force launched four additional three-stage Thor-Able missions. The first required replacing the 120-pound radio-inertial guidance system with a new, three-axis inertial system weighing just 33.5 pounds in order to place the 140-pound *Explorer 6* spacecraft in its extremely elliptical orbit. The successful mission produced the initial televised cloud-cover photograph, located a large network of electrical currents in the outer atmosphere, and extensively mapped the Van Allen belt for the first time. Although the third stage failed to ignite during the flight of the second Thor-Able launch, on 17 September 1959, the Navy's 265-pound Transit navigation satellite nevertheless transmitted important data before burning up in the atmosphere. The data convinced the Navy that Transit satellites could allow precise positioning of ships and Polaris submarines. The third Thor-Able launch in this series sent 94.5-pound *Pioneer 5* into a solar orbit from which it verified the presence of magnetic fields and continued to transmit useful data from 22.4 million miles from Earth until 26 June 1960. The final Thor-Able flight lofted a 269.5-pound TIROS weather satellite on a 78-day mission, during which it transmitted 22,952 cloud-cover images. This first in the TIROS series laid the groundwork for NASA to eventually be able to provide daily worldwide cloud-cover images.[62]

Thor-Able-Star

Although the Air Force considered Thor-Able "an extremely capable and reliable vehicle combination,"[63] it had decided well before the final launch to upgrade to the Able-Star upper stage. It not only provided two-and-a-half times the total impulse but also the ability to restart after a coasting period in space. With its longer propellant tanks, the Thor-Able-Star measured 95 feet in length and 8 feet in diameter. Although a derivative of the Able's engine, Aerojet's Able-Star second stage (AJ10-104) engine used IRFNA as the oxidizer instead of the Able's more corrosive and less effective IWFNA (inhibited white fuming nitric acid). With the UDMH fuel, the second stage engine now had the same hypergolic propellant used in the Agena. Compared to the Able, the Able-Star's specific impulse rose from just over 260 to nearly 280 lbf-sec/lbm, and its thrust increased from 7,575 to 7,890 pounds, enabling the Thor-Able-Star to loft up to 330 pounds into LEO. Its onboard guidance and control system provided attitude control during its coasting segment after the initial burn while preparing for the second burn.[64]

The Air Force used the DM-18A model Thor for the first Thor-Able-Star mission on 13 April 1960. This launch of a Navy Transit 1B satellite represented the first in-space rocket restart. After completing its initial 258-second burn, the Able-Star coasted with its Transit payload for 19 minutes before its second 13-second burn to raise the orbit. With the second successful launch of Transit 2A on 22 June, naval vessels now had satellite-provided "fixes" accurate "to within a quarter of a mile." The Air Force used the DM-21 version of the Thor for this launch and for the remaining 17 Thor-Able-Star missions that included eight more Transit flights. The Thor DM-21 used the Aerojet MB-3 Block III engine that produced 170,000 pounds of thrust, and the final eight Transit missions with the DM-21 used the DSV-2A standardized Thor.[65]

In addition to Transit missions, the Air Force used the Thor-Able-Star combination to successfully launch a NASA Courier delayed-repeater communications satellite, an ANNA (Army, Navy, NASA, Air Force) geodetic satellite, as well as numerous secondary payloads. Of the four Thor-Able-Star missions that failed, two created special problems. On 30 November 1960, when the Thor carrying Transit 3A shut down prematurely, the range safety officer ordered the destruction of the second stage. Unfortunately, part of the Thor stage landed in Cuba, which eventually passed the engine and thrust vectors to the Soviet Union and China, respectively. After this incident, the Air Force modified the Thor-Able-Star flight path from Cape Canaveral to avoid overflying Cuba. A second failure of special interest occurred on 21 April 1964, when Transit 5BN-3 carrying a SNAP-9A nuclear power source, a radio-isotope thermoelectric generator, failed to orbit. The disintegration of the generator in the atmosphere convinced the Air Force that subsequent Transit flights would be exclusively solar-powered. The launch of Transit 5B7 on 21 April 1965 closed out the series of Thor-Able-Star flights that totaled 19, with a success rate of 79 percent.[66]

Thor-Burner I and II

Three months before the final Thor-Able-Star flight, the Air Force launched another series of upper stages mated to the Thor. Burner I and Burner II represented Air Force and NASA efforts to develop a low-cost, solid propellant booster capable of bridging the gap between the Scout and Able-Star for Burner I and between Able-Star and Agena for Burner II. All Thor boosters for the Burner upper stages were deactivated Project Emily DM-18A IRBMs converted for space launch and given the designation DSV-2U. The Air Force initially sent the missiles to the Douglas facility in Tulsa, Oklahoma, but later Douglas chose to ship them to its main Santa Monica, California, plant to consolidate modification work at a single site.[67]

The Thor-Burner I combination consisted of a Thor Model 18A and the Allegany Ballistics Laboratory's solid propellant X248 Altair motor. Derived from the Vanguard third stage, the Altair contributed approximately 2,600 pounds of thrust to the Thor-Burner I's total thrust of 150,172 pounds. The Air Force used the Thor-Burner I combination only four times, between 18 January 1965 and 30 March 1966, and the third flight on 8 January 1966 failed when the Altair's motor did not ignite. All four missions flew the Block 4A meteorological satellites of the Defense Satellite Applications Program (DSAP) that weighed between 280 and 330 pounds. These relatively inexpensive and unsophisticated satellites produced daytime visual and nighttime infrared weather photographs with resolution of one-third and two nautical miles, respectively. The DSAP began as a classified NRO satellite project with the mission of providing specific weather data to the NRO and Strategic Air Command. But the decision by the Department of Defense to use satellite weather data in the Vietnam conflict and provide it to the Department of Commerce and the general scientific community made it impractical to continue DSAP as a classified program. In 1973 DOD declassified the program and renamed it the DMSP. The brief launch history of Thor-Burner I is explained by the advent of Burner II.[68]

Burner II resulted from the Air Force's desire for an economical upper stage vehicle, adaptable to various boosters, with full control and guidance capability, and able to place smaller payloads in orbit. After working under a study contract for four years, the Boeing Company received a development contract on 1 April 1965 from Space Systems Division (SSD) for the new stage. A year and half later, Burner II was ready for its first flight. For the vehicle's main propulsion, Boeing used the Thiokol Star 37B spherical motor that had served as the retro-rocket for NASA's Surveyor spacecraft. The 37-inch solid propellant motor burned just over 42 seconds in creating an average thrust of 9,680 pounds. Its guidance and control system initiated ignition of the Burner motor, sent steering commands to the Thor's autopilot prior to separation, and accurately placed payloads in orbit. The small Burner II upper stage measured only 68 inches in length and 65 inches in diameter and weighed 315 pounds after payload separation.[69]

The Air Force and Boeing designed Burner II largely to meet the needs of DSAP and DMSP payloads. Between 15 September 1966 and 8 June 1971, the Air Force launched 13 DOD-classified Thor-Burner II missions. Only three of these included scientific satellites that SSD managed as part of the Defense Department's Space Experiments Support Program. The first, on 29 June 1967, lofted into orbit an Army Sequential Collation of Range satellite and the Navy's Aurora magnetosphere satellite. The other two, on 17 February 1971 and 8 June 1971, placed Naval Research Laboratory radar calibration spheres in orbit. Most of the Thor-Burner II flights, however, launched DSAP spacecraft. These included four spin-stabilized Block 4A, three Block 4B, and four Block 5A satellites. All 13 Thor-Burner II launches successfully orbited their payloads. Looking ahead, the new Block 5B DSAP satellites, at nearly twice the weight of the 5A, would require an uprated Burner II, which became Burner IIA.[70]

SAMSO contracted Boeing to produce an improved Burner using a modest number of modifications. Boeing met the requirement with a second stage Thiokol Star 26B motor and by moving Burner II's equipment and subsystems to the second stage. The Star 26B generated an additional 7,745 pounds of thrust and enabled Burner IIA to perform two burns during each mission. Between 14 October 1971 and 18 February 1976, the Thor-Burner IIA combination launched eight DSAP and DMSP missions, including five Block 5B and three Block 5C satellites. The first seven launches were successful, but the last, a Block 5C launch, failed when the Thor malfunctioned, and the payload ended up in a useless orbit and decayed soon thereafter. The final Thor-Burner IIA launch proved to be the final Air Force launch of the Thor, because the heavier DMSP Block 5D satellites would require the Atlas booster. Future DMSP spacecraft would be flown on Atlas Es and refurbished Titan II ICBMs.[71]

Thor DM-18-Agena A

Although the use of the Able and Able-Star upper stages with the Thor proved successful during the first half of the 1960s, the Air Force much preferred the three versions of the Agena for most missions, the majority of which supported Project Corona. On 28 February 1959, over a year before the first Thor-Able-Star launched with a Transit navigation satellite, the Thor-Agena A combination made its inaugural flight, *Discoverer 1*. The two-stage Thor-Agena A consisted of a Thor Model DM-18A with the Corona camera system mounted atop the second stage Agena A.[72]

Under the publicly acknowledged Project Discoverer, the Air Force conducted a biomedical spaceflight program, which continued as the initial, experimental phase of the WS-117L satellite reconnaissance program. This meant that Thor-Agena flights could proceed covertly on an interim basis as the highly classified Project Corona until the Atlas-based Samos reconnaissance satellite project became operational.[73]

Corona satellites were termed Keyhole, abbreviated KH, and initially weighed nearly 1,700 pounds, more than twice that of any US satellite previously launched. Improvements would result in heavier satellite camera systems over the course of the Corona program. The first, KH-1 camera system, referred to as Corona "C," consisted of a single Itek Corporation reciprocating panoramic camera with a 24-inch focal length and a 70-degree scan angle. It used special Kodak 70-millimeter film and achieved a ground resolution of 40 feet. The mission procedure called for the Agena booster-satellite to achieve a polar orbit and then furnish orbital power and stabilization to the satellite. Having completed the mission, the film would move forward into a take-up spool inside a General Electric gold-plated bucket recovery capsule. Once the Agena separated the capsule, the bucket would "spin up" and deorbit by firing its Star 12 retro motor. At 50,000 feet, a parachute would deploy for the remaining descent over the Pacific Ocean near Hawaii, where an Air Force C-119 Flying Boxcar aircraft would capture the capsule in midair.[74]

In this early period of the program, success proved elusive. The Thor-Agena A flight combination launched a total of 15 Discoverer satellites, with the Thor failing twice and the Agena three times. It was not until *Discoverer 13*, on 10 August 1960, that a film bucket was retrieved, by a naval helicopter near Hawaii. Although *Discoverer 13* did not carry a camera, it nevertheless represented the first recovery of a human-made item that had been ejected from a satellite. Eight days later, however, *Discoverer 14* made history when a C-119 caught in midair its 1,870-pound capsule carrying exposed film of the Soviet Union. This first successful mission clearly demonstrated the importance of strategic satellite reconnaissance. On this mission alone, the KH-1 film revealed 26 Soviet surface-to-air missile complexes and 64 airfields that had previously gone undetected. *Discoverer 14* returned more imagery of the Soviet Union than all 24 U-2 aircraft missions combined and confirmed that, in fact, no "missile gap" favoring the Soviet Union existed. Although the last Thor-Agena A mission on 13 September 1960 proved unsuccessful when the capsule sank before recovery forces arrived, the future for Corona seemed promising with the arrival of an improved Agena B and upgraded Corona camera systems.[75]

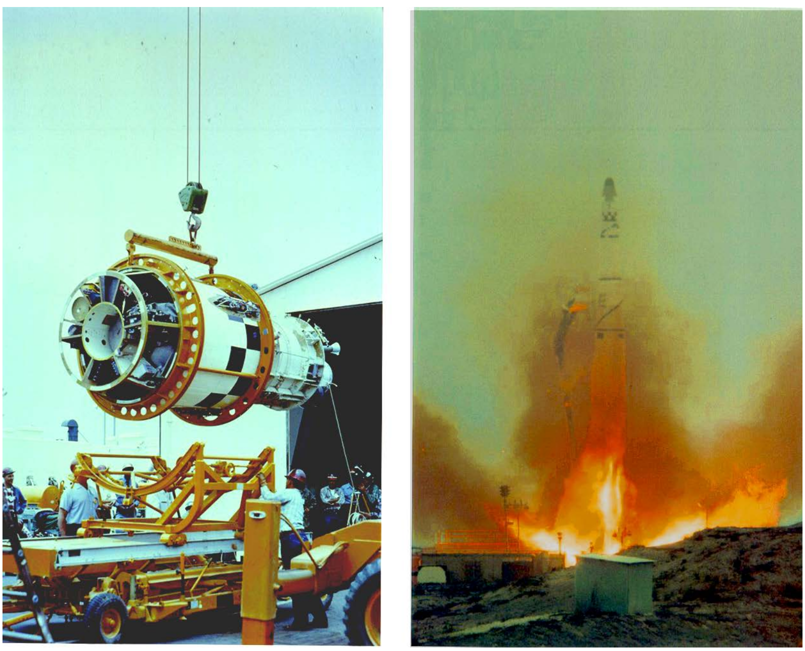


Fig. 3. This two-part image shows the Thor-Agena A 2347/1056, 75-3-4, on the left, with liftoff on the right, 18 August 1960. (Photograph courtesy of John Hilliard)

Thor DM-21-Agena B

The Agena B had propellant tanks extended from 14 feet 3 inches to 20 feet 8 inches, thereby doubling the burn time to 240 seconds. This provided the Agena a dual-start capability that enabled the vehicle to coast in a "parking orbit" before restarting to enter the preferred orbit. The Agena B was also paired with the improved Thor Model DM-21 that had an upgraded engine, the Rocketdyne MB 3 Block III that produced 170,000 pounds of thrust.[76]

Between 26 October 1960 and 16 January 1963, the Thor-Agena B combination experienced nine failed flights out of a total of 44 launches for a success rate of 80 percent. Of the 44 total, only nine were not Corona missions. These included three classified Ferret naval signals intelligence satellites and two Canadian Alouette ionospheric research satellites, the first satellites developed by a country other than the United States and the Soviet Union. The Thor DM-21-Agena B system also orbited NASA's Echo communications satellite and, on 28 August 1964, placed in orbit NASA's first Nimbus meteorological satellite. Nimbus proceeded to transmit nearly 27,000 superb cloud-cover photos during a 27-day period.[77]

The Thor-Agena B vehicles launched four different Corona Itek Keyhole camera systems. The improved and simplified KH-2, or "C Prime," camera retained the 24-inch focal length, but ground resolution improved to 25 feet. Of the ten KH-2 missions, four returned film and four failed to achieve orbit. The KH-3 Corona "Triple C Prime" camera also had a focal length of 24 inches and with its improved Petzval lens achieved ground resolution of 12 to 25 feet. Although the KH-3 flew only six times, four missions returned film. Of the remaining two, one fell into the Pacific and the other achieved orbit, but the capsule failed to separate. Of particular interest, *Discoverer 36,* on 12 December 1961, also successfully launched Oscar, a secondary amateur satellite. Like Oscar, many of the Corona missions included various experimental piggyback or secondary satellites.[78]

The KH-5 camera system, codenamed Argon, provided an area survey component for the Corona program. Its 3-inch focal length single-frame camera had a ground resolution of 460 feet, and it imaged an area 300 by 300 nautical miles. Although the system produced relatively low-resolution images, they proved effective for the Army's mapmaking program. Of the eight KH-5 missions, only two returned film, and three failed to orbit.[79]

The most sophisticated of the Corona cameras launched by the Thor DM-21-Agena B boosters was the KH-4 Corona Mural stereoscopic system, consisting of two Corona "C Triple Prime" panoramic cameras mounted with a 30-degree separation angle that looked forward and to the rear. The Mural camera achieved a ground resolution of from 9 to 25 feet. The satellite also carried an index camera with a 1.5-inch focal length with a ground resolution of approximately 532 feet. The index camera's small-scale photos enabled photo interpreters to match the panoramic swaths to the terrain.[80]

The last Corona Agena B mission took place on 24 November 1962, when a Thor DM-21 booster successfully launched its Agena KH-4 payload into orbit, and Air Force pilots later recovered the capsule in midair. All 12 KH-4 missions achieved orbit, and only three capsules landed in the Pacific Ocean and sank before recovery forces arrived. Although the Thor-Agena B booster combination would be used seven more times, Corona missions would now launch with the improved, standardized Agena D.[81]

SLV-2 (DSV 2A) Thor

The Air Force continued to use the Thor DM-21 booster with the Agena D for 13 missions, beginning with the launch of a Corona KH-4 payload on 28 June 1962. Nine KH-4 and two KH-5 missions were to follow, as well as two missions that launched naval signals intelligence and radar calibration and solar radiation sensors. The last launch of the Thor DM-21-Agena D combination occurred on 19 July 1963. By that time, the Air Force could use the standardized Agena D upper stage with the standardized SLV-2 Thor DSV-2A booster, whose maiden launch occurred on 29 August 1963.[82]

In one sense, standardization of the Thor booster actually began back in early March 1958 when Secretary of Defense Neil H. McElroy directed the Air Force to accelerate the test vehicle program by using Thor boosters. This directive resulted in the first production run of 10 Thor Model 18A boosters designed to mate with the second stage Agena A. Even so, the Air Force used the Thor with other upper stages and for a variety of suborbital test missions. During the spring of 1961, DOD's effort to standardize space launch vehicles embraced the Thor as well as the Atlas and Titan. As with the Atlas, Air Force officials sought to maximize the similarities for various missions and control deviations and that year took specific steps to standardize production hardware.[83]

The Douglas Thor SLV-2 was essentially the Model DM-21 with new electrical wiring and plumbing and a standard adapter to accommodate several upper stage combinations, but especially the Agena D. On 29 August 1963, the first SLV-2 launched with an Agena D carrying a KH-4 camera system. Although unclear, the evidence suggests that the Air Force used the standardized Thor for only eight missions. Two of these flights used the Agena B upper stage to launch NASA's first Geostationary Operational Environmental Satellite and its second Echo communications satellite. The other six missions with the Agena D launched three Corona KH-4 satellites and a variety of naval spacecraft. Among the nine naval satellites orbited on the last SLV-2 flight, on 31 May 1967, was the Naval Research Laboratory's *Timation 1* that would eventually lead to GPS.[84]

SLV-2A Thrust Augmented Thor

The brief launch period of the standardized SLV-2 Thor DSV-2A is explained by the advent of the more capable Thrust Augmented Thor, which had made its initial space launch on 28 February 1963, fully six months before that of the SLV-2 standard Thor space launch vehicle.

Back in February 1962 SSD had requested that Douglas Aircraft Company study ways to improve the Thor's performance. Douglas eventually decided to augment the SLV-2 Thor DSV2A booster with three Thiokol (Castor I) TX 33-52 solid propellant rocket motors strapped to the outside shell at 120-degree intervals. The addition of the solids required only minor modifications to the engine section and the control circuitry in order to incorporate the solid boosters. The strap-on solid boosters provided an additional 163,500 pounds of thrust. Augmenting the Thor's upgraded MB 3 Block III first stage engine, the Thrust Augmented Thor (TAT) produced a liftoff thrust of 317,050 pounds, more than double that of the standard Thor-Agena combination. The solid boosters burned for approximately 40 seconds before being jettisoned into a safe drop zone, and the main engine burned for an additional 110 seconds. With the ability to insert an extra 500 pounds of payload into a 300-mile altitude orbit, the TAT provided a 30 percent increase in payload capacity over the SLV-2 and enabled the Air Force and NASA to launch heavier payloads.[85]

From 28 February 1963 to 17 January 1968, the standardized TAT-Agena D vehicles launched a total of 72 times, with three failures, for a success rate of 97 percent. With the Agena B upper stage, the TAT launched only a Ferret electronic intelligence satellite and NASA's second Nimbus meteorological satellite. The standardized TAT-Agena D system launched the other 66 missions, most of which were Corona flights. Apart from the Corona missions, the TAT-Agena D orbited two Orbiting Geophysical Observatory and one Passive Geodetic Earth Orbiting Satellite for NASA, as well as nine Ferrets and one Quill experimental radar mapping satellite. The remaining 57 flights were Corona launches and included four KH-4, three KH-5, three KH-6, and 47 KH-4A missions.[86]

The KH-6 Lanyard system used a modified Samos Kodak E-5 camera retrieved from storage in an effort to determine whether the Soviets had deployed an operational antiballistic missile (ABM) site near Tallinn, Estonia. The KH-6 panoramic camera had a focal length of 66 inches but a ground resolution of about 6 feet rather than the expected 2 feet. Corona officials cancelled the Lanyard program after three disappointing flights in 1963, when only one of the three produced film, and that one suffered from lens-focusing problems. Only several years later did Corona officials determine that there was no ABM facility at the site.[87]

The new and improved KH-4A Corona system accounted for the bulk of the reconnaissance missions launched by the TAT-Agena D. Its two J-1 cameras used were basically the KH-4 Mural camera with ground resolution improved to 9 to 25 feet. The main upgrade was the addition of a second recovery capsule placed behind the first and now referred to as the "double-bucket" system. This meant that, whereas KH-1 through KH-4 returned 283,472 feet of film, the KH-4A alone produced 1,293,025 feet of film. Earlier systems could fly up to 8,000 feet of film per camera; the KH-4A could carry as much as 16,000 feet per camera. In effect the KH-4A's capability revolutionized intelligence analysis.[88]

The KH-4A camera system proved to be the most prolific and successful of all nine Corona designs. Of the 47 KH-4A missions launched between 25 August 1963 and 30 March 1967, the TAT achieved a 100 percent success rate. The TAT-Agena D combination failed only twice, and in both cases, the Agena experienced power failure and fell into the Pacific Ocean. Most importantly, over the five-year flight period, Air Force and Navy crews recovered all 66 de-orbited KH-4A buckets, most of which provided good- to high-quality film.[89]

SLV-2G (DSV-2L) Long Tank Thrust Augmented Thor (Thorad)[90]

In January 1966, the SSD decided to replace the Thrust Augmented Thor with a stretched or long tank Thor and contracted Douglas Aircraft Company to produce what would become the standardized SLV-2G (DSV-2L) upgraded Thor. Standardization involved attaching a new adapter section to the top of the first stage and continuing to use the Thor's existing transition section and the Agena D adaptor. The stretched fuel tanks extended the length of the Thor to 70 feet, 14 more than the TAT. Each of three upgraded Thiokol Castor II TX354-5 strap-on solid motors provided 51,490 pounds of liftoff thrust. Propellant capacity rose by 43 percent, burn time increased from 146 to 167 seconds, and payload capacity grew by 20 percent. Often referred to as Thorad, the Long Tank Thrust Augmented Thor-Agena D produced 324,625 pounds of liftoff thrust.[91]

The standardized SLV-2G Thorad launched 30 times between 9 May 1967 and 14 December 1971. Corona flights totaled 19 of the 30 missions, and all but one was successful. The KH-4A system flew on 13 of the Corona missions, while the new KH-4B double-bucket camera system accounted for the other 6. The KH-4B camera system consisted of two 24-inch focal length J-3 panoramic cameras that connected the scan arm and lens cell and placed them in a constant rotator drum that eliminated vibration and improved ground resolution to 6 feet. The KH-4B also used a Dual Improved Stellar Index camera with a 3-inch focal length for star sightings. Ground resolution varied between 100 and 400 feet. The KH-4B system produced good imagery on all six SLV-2G missions, with three described as "best image quality to date."[92]

In addition to the Corona flights, the SLV-2G Thorad launched three Ferret and nine Poppy naval intelligence satellites, two NASA Nimbus meteorological satellites, a second Timation satellite, a SECOR (sequential collation of range) geodetic satellite, and a SERT (space electric rocket test) satellite to test ion engine technology. The only mission failure occurred on 18 May 1968, when an SLV-2G-Agena D carrying a Nimbus B satellite, powered by a SNAP-19 nuclear reactor, lost control about two minutes after launch due to an incorrectly installed gyro. But unlike earlier models, the nuclear reactor was designed to survive a launch failure, and naval crews retrieved the reactor from the Pacific and reused its nuclear material.[93]

SLV-2H (DSV-2L-1A) Long Tank Thrust Augmented Thor (Thorad)

On 5 June 1969, the Air Force launched its final upgraded standardized Thor booster. The SLV-2H Thorad had propellant tanks lengthened three feet, resulting in 65 more seconds of burn time. With the three Castor II solid motor boosters, liftoff thrust increased from the SLV-2G's 324,625 pounds to 353,174 pounds, and payload capability rose nearly 15 percent.[94]

After lofting NASA's sixth Orbiting Geophysical Observatory on 5 June 1969, the Air Force launched 12 classified missions that included 1 Ferret naval signals intelligence satellite and 11 KH-4B Corona flights. One of the 13 flights failed on 17 February 1971, when the Thorad lofting a KH-4B apparently lost engine lubrication at start-up, resulting in power failure after 18 seconds; it crashed not far from its Vandenberg AFB launchpad.[95]

With the last launch of a SLV-2H Thorad on 25 May 1972, the Corona project ended. Begun only as an interim intelligence collection program, Corona's effectiveness in imaging denied Soviet territory made it indispensable for 12 years. During that time, it flew 145 missions, returning 167 capsules and more than 2 million feet of film. Corona located every Soviet ICBM, IRBM, and ABM site, as well as all naval bases and military-industrial complexes. The intelligence information removed the uncertainty about Soviet capabilities for military planners, allowing US presidents to conclude arms control treaties that could be monitored effectively. The Thor proved to be an outstanding booster for Project Corona. Of the 145 Corona launches, only 25 failed, and of these just 6 can be attributed to the first stage Thor. Most occurred when the Agena failed to orbit or the spacecraft failed to separate. Despite Corona's continuous improvements to both the Keyhole camera systems and the Thor booster, however, the Air Force and the NRO would choose to rely on the more powerful Titan for future launches of its larger, heavier reconnaissance satellites.[96]

During the 1959–72 period, the workhorse of space compiled a remarkable space launch record. The Thor in both its Air Force and Delta versions compiled a record of 287 successful launches and 37 failures for a success rate of 87 percent. Most of the failures occurred early in the program. Although the Air Force discontinued launching the Thor after 1976, NASA would continue to fly the Thor-based Delta and its many variations. NASA had sought an available, medium-sized, highly versatile booster for launching its many scientific missions. Thor met its requirements, and in 1960, NASA initiated its long launch history with the booster by using used a modified Vanguard for its second stage and an Altair engine for its third stage. The Air Force would use a Delta only occasionally until the *Challenger* tragedy in 1986 compelled the service to rely for much of its launch requirements on the Delta II, Delta III, and, early in the new century, the Delta IV under the Evolved Expendable Launch Vehicle program.[97]

Creating the Titan III, "DC-3 of the Space Age"

The Unified Program Concept that Rubel, DDR&E, outlined in the spring of 1961 precipitated a series of launch vehicle studies that would lead to the standardized, heavy-lift SLV-5 Titan III,[98] the first Air Force vehicle designed specifically to be a space booster. To coordinate a common National Launch Vehicle Program, DOD and NASA created a Large Launch Vehicle Planning Group (LLVPG) under the auspices of the AACB in July 1961. Led by Dr. Nicholas E. Golovin, NASA's Deputy Associate Administrator, and Lawrence L. Kavanau, DDR&E's Special Assistant for Space, the LLVPG immediately set to work examining the best launch vehicle combinations for President Kennedy's lunar landing initiative, various human scientific missions, and expanding military space requirements. Back in May, Rubel had requested that NASA and the Air Force prepare a series of white papers that would include an assessment of a large-scale solid booster development program. This initiative became part of the LLVPG agenda.[99]

In early August 1961, Rubel and Assistant Air Force Secretary for Research and Development Brockway McMillan organized under the auspices of the AACB an ad hoc committee for standardized workhorse launch vehicles to examine alternate approaches for a rugged booster capable of orbiting 10,000-pound payloads at 300-mile altitudes. Later, the committee raised the booster performance requirement, calling for a capability of launching payloads between 5,000 and 25,000 pounds into LEO. By September, the committee and the Air Staff had agreed on the combination of a Titan II upgraded with strap-on solid boosters 120 inches in diameter and a high-energy upper stage for future, heavier satellites. Led by SSD, Air Force agencies immediately began intensive studies of roles, designs, performance capabilities, and reliability, as well as a cost and development schedule, and on 5 October, the SSD sent the Air Staff its report, *Titan III, Stan-*

dardized Space-Launch Vehicle. The LLVPG recommended approval of the concept that same month, and on 13 October 1961 the Air Force received Rubel's permission to start a "Phase I" study for a system "package" comprising "a family of launch vehicles based on the Titan III."[100]

SSD responded by appointing Col Joseph B. Bleymaier as Titan III program director on 27 November 1961 and four days later designating the program as Space Booster Building Block Program 624A. After complying with a request for a Phase I study of the project, the Martin Marietta Corporation received a contract on 19 February 1962 to work with SSD to meet the extensive project definition requirements established by the Office of the Secretary of Defense. Although the Air Force favored the prospect of a standardized booster more powerful than either the Thor or Atlas, the Defense Department's micromanagement soon proved unwelcome. As Secretary McMillan recalled, the Titan project became the "most comprehensive advanced development planning effort ever undertaken by the Air Force." In effect, Secretary McNamara saw in the Titan III booster the ideal test case for applying his innovative management procedures to reduce costs and accelerate development schedules. As a result, DOD officials accorded the booster project the closest scrutiny of any project heretofore developed by the Air Force. Project "definition" required more detail, a strong program office supervised every aspect, and the Air Force received direction to use new program evaluation review techniques and establish special accounting and auditing procedures.[101]

In a 19 March 1962 meeting, SSD briefed Rubel and Air Force Secretary Zuckert on proposed configurations, test elements, vehicle performance, and the progress of solid motor developments. After the briefing, Rubel accepted the division's recommendation that there be two Titan III configurations and a new upper stage vehicle called the "Transtage." The "A" configuration would comprise the basic modified Titan II core, a control module, and the Transtage and be able to launch 5,800-pound payloads into a 115-mile LEO. The "C" configuration would consist of the "A" vehicle with two large strap-on solid rocket boosters capable of launching 5,000 pounds to escape velocity, 2,140 pounds into synchronous equatorial orbit, or nearly 25,000-pound payloads into circular LEO. The two configurations would represent building blocks for additional Titan III configurations. By late spring the repeatedly revised schedule projected an initial

Titan IIIA test flight in May 1964 and the first Titan IIIC flight in January 1965.[102]

Secretary McNamara first described the building-block concept in early 1962 during testimony before Congress on the fiscal year 1963 budget. It subsequently appeared in the President's Aeronautics and Space Activities Report for 1962. As the defense secretary explained, space projects comprise two categories, those with "identifiable military needs and requirements," and those "designed to investigate promising military space capabilities . . . [to insure] . . . a broad flexible technological base" ready for adaptation and development for systems once future military requirements were identified. The latter category represented "building blocks" for future use, and the Titan III, which initially supported no operational requirement, exemplified this approach.[103]

SSD had also awarded a contract to United Technology Corporation (UTC) on 9 May 1962 to develop the solid motors for the Titan III's initial stage boosters, referred to as stage 0. Solid motor development became the major new technology for the Titan booster family. With Polaris and Minuteman as precedents, Aerojet had been experimenting with large solid motor technology since 1957 and successfully demonstrated the feasibility of segmented motors. This meant that solid rocket motors could be transported by means more efficient than barges. Although Aerojet had led the way in testing segmented motors, UTC produced impressive results testing solid propellant motors using a specific propellant based on the PBAN (polybutadiene-acrylic acid-acrylonitrile) used in the Minuteman's first stage. UTC added methyl nadic anhydride to the PBAN for increased toughness. After the contract award, UTC continued testing and overcoming numerous technical challenges.[104]

A major change occurred with the imminent demise of the Dyna-Soar spaceplane. On 23 February 1962, Secretary McNamara set in motion the ultimate cancellation of Dyna-Soar by ending the suborbital elements and requiring that it be considered a research program instead of a weapon prototype. As the only spacecraft programmed for launch by the Titan III rocket, it required four-segmented, slow-burning, solid propellant motors strapped on to the core. A Titan IIIC with four-segment motors, however, could put only 1,400- to 1,700-pound payloads into geosynchronous orbit, whereas planners expected future payloads to be in the range of 8,000 to 20,000 pounds. That spring, when McNamara questioned the spaceplane's survivability, Rubel took the initiative to prioritize the capability of the new booster to place a medium payload into geosynchronous orbit or a heavy payload into LEO. Rubel's move led to the development of fast-burning five-segmented solid motors.[105]

Although Phase II of the Titan III program began on the first of December 1962, two days later Secretary McNamara requested that the Secretary of the Air Force respond to several questions about the Titan that had been raised in a recent meeting of the President's Scientific Advisory Committee. The central question was whether to continue the Titan program given OSD's cost concerns and the availability of NASA's Saturn C-1 booster for heavy-lift missions. The Air Force responded with a three-volume justification that emphasized the Titan's more rapid launch capability because of its hypergolic propellants, its building-block approach that assured it greater flexibility, the minimal training and logistics challenges given previous experience with the Titan II, and the fact that the program included the promising development of large, solid propellant motors. Above all, the Air Force argued that the Titan III would outperform the Saturn and be cheaper. Assuming 50 launches a year over a five-year period and including development costs, the Air Force study argued, each vehicle would cost approximately $11 million per launch compared to $18.9 million for the Saturn C-1. Predictably, NASA objected, leading the AACB's Launch Vehicle Panel to direct newly promoted Brigadier General Bleymaier to resolve differences with a NASA counterpart. Their report admitted that statistical projections of reliability could not be absolute while agreeing that the Titan III alone provided the performance specifications imposed by military requirements. The Air Force argument convinced Secretary McNamara to continue the Titan program.[106]

On 23 February 1963 near Sunnyvale, California, UTC began developmental testing of 120-inch-diameter motors that would be used on the Titan IIIC. After a successful test of the first five-segment motor in July, Bleymaier wrote that the test was "truly an outstanding and significant event in the life of the Titan III Program." On 18 June 1965, just over three years after UTC received the Phase I contract, two solid rocket motors, each 84.65 feet in length, provided 2,647,000 pounds of thrust to the first Titan IIIC before their jettisoning approximately two minutes after launch.[107]

Engines for stages 1 and 2 of the Titan III required little modification because their performance was the same as the engines for the

Titan II and Gemini stages. The core itself measured 10 feet in diameter and 108 feet in length. Both stage airframes, however, required strengthening and other adjustments to support the loads of the solid rocket motors and the Transtage stage 3 vehicle. Like stages 1 and 2, Aerojet's Transtage engine used storable Aerozine 50 fuel and nitrogen tetroxide as the oxidizer for its pressure-fed two-chamber configuration. Each engine measured 6.8 feet in length and from 25.2 to 48.2 inches in diameter and produced 8,000 pounds of thrust for each engine. Weighing only 238 pounds, each engine's rated burning time was an impressive 500 seconds. Planners expected the Transtage, operating as a "switch engine" maneuvering payloads in space, to coast for 6.5 hours in orbit and then be able to perform up to 3 burns. The optimum guidance and control system proved to be a thorny issue. After an Aerospace Corporation assessment concluded that the Titan III needed a new system, the Air Force supported a joint venture with Space Technology Laboratories and the Arma Corporation to develop a highly reliable guidance system. Rubel's Office of Defense Research and Engineering, however, preferred using the more cost-effective Titan II's all-inertial guidance and control system for the initial Titan boosters. SSD then ended efforts to develop a new guidance system and contracted AC Spark Plug for modifications, the most important of which was a new, high-capacity IBM computer to handle the complex orbital requirements.[108]

Titan IIIA

SSD scheduled five flight tests from Cape Kennedy for the Titan IIIA, designated SLV-5A, the modified two-stage Titan II with the Transtage. On the initial flight on 1 September 1964, stage 1 and stage 2 performed as programmed, but the Transtage failed to pressurize when the helium pressure valve malfunctioned, and the 3,750-pound ballast payload fell into the ocean. The next three flights achieved their increasingly ambitious objectives. The second Titan IIIA test flight launched another 3,750-pound dummy payload into the desired LEO, and the Transtage and payload remained in orbit for three days. The third launch, on 11 February 1965, lofted a Lincoln Experimental Satellite (LES-1) communications payload weighing 69 pounds along with a dummy satellite into a low Earth circular orbit. From there, the Transtage executed three programmed burns, ejecting the two satellites on the third burn. The fourth launch, on 6

May 1965, called for the Transtage engines to ignite four separate times. On the successful flight, the Transtage ejected the LES-2 experimental communications satellite, together with a 75-pound radar calibration sphere, and then coasted for three hours before a fourth ignition. The Air Force considered the flight so successful that it concluded the Titan IIIA test program after the fourth launch and configured the fifth core booster for use as a Titan IIIC launcher.[109]

Titan IIIC

Beginning on 18 June 1965, the Titan IIIC SLV-5C test program consisted of 14 flights and was successful on 11 of them for a success rate of 79 percent. On the first Titan IIIC test flight, the huge strap-on solid rocket motors jettisoned successfully, and the core stages performed well. After a coasting flight, the Transtage ejected into a low Earth circular orbit its lead ballast payload weighing 21,098 pounds, considered the heaviest American payload put into orbit by an American space vehicle to that time. Bleymaier received the Legion of Merit on the spot and proclaimed that the Titan III provided "for the first time in our Nation's brief but busy space history, a launch system capable of any kind of mission required of it, within payload weight limits which are significantly higher than any booster presently operational." First Article Configuration Inspection was 90 percent complete by June, with over 500 change proposals processed. But after this launch, changes decreased considerably.[110]

Unfortunately, during the second launch on 15 October 1965, fuel leaks developed in the second stage oxidizer and the Transtage, and a minor explosion occurred at Transtage separation. Then, one of the Transtage engines failed to ignite and eventually the spacecraft exploded, creating nearly 500 pieces of trackable debris in orbit. The third launch on 21 December also experienced problems with the Transtage, when its attitude control system's oxidizer valve remained open, and the long coast after the second burn into a geosynchronous transfer orbit used up the attitude control oxidizer. When the Transtage tumbled, it ejected its two experimental satellites into improper orbits—but they functioned nevertheless. Despite this third Transtage failure, the Air Force felt confident enough to launch seven 100-pound Initial Defense Communications Satellite Program (IDCSP) satellites on 16 June 1966. The Titan IIIC successfully launched the satellites into near-synchronous orbits 21,000 miles

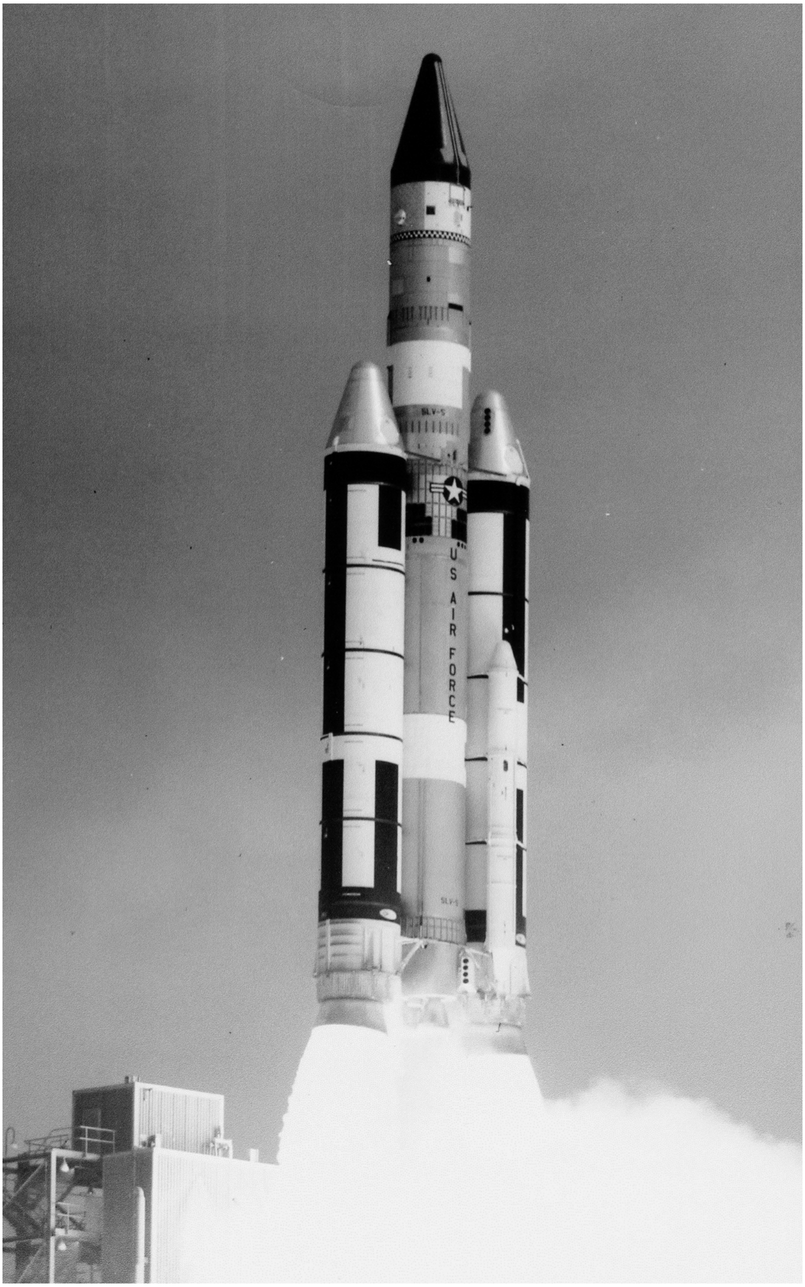


Fig. 4. Titan IIIC launch, from LC-41, 15 June 1966. (Photograph courtesy of John Hilliard)

above the equator. Each satellite could relay 600 voice or 6,000 teletype channels; the following year IDCSP supported operations in Vietnam by providing circuits for transmission of high-resolution photography between Saigon and Washington, DC. A subsequent launch of eight IDCSP satellites on 26 August 1966, however, ended in failure when a structural problem in the payload fairing activated the malfunction detection system 78 seconds after liftoff and destroyed the Titan IIIC. The program office had the phenolic fairing replaced by a metal fairing and awarded McDonnell Douglas Company a contract to manufacture a Titan III universal fairing. The contractor responded by developing eight fairing configurations, 10 feet in diameter, ranging in length from 15 to 50 feet, in 5-foot increments. This failure was followed by nine successful launches, with the last, the launch of the final pair of Vela nuclear detection satellites into circular geocentric orbits, on 8 April 1970.[111]

Titan III(23)C

In the mid-1960s, using the building-block approach, planners proposed development of several versions of the basic Titan III design to expand its versatility and upgrade its capacity to launch payloads of growing weight and complexity. The Titan III(23)C owes its existence in part to the demise of two highly regarded Air Force human spaceflight programs. In 1967, when the Air Force sought an improved version of the Titan IIIC, it funded contractor improvements to their components. When defense secretary McNamara cancelled the Dyna-Soar spaceplane in December 1963, Aerojet could eliminate thrust-termination ports and other human safety features and produce new solid rocket motors with a lighter and simpler thrust vector control system. In June 1969, defense secretary Melvin R. Laird cancelled the Air Force Manned Orbiting Laboratory (MOL) space station and its advanced Titan IIIM launch system. Although never flown, the Titan IIIM uprated stage 1 and stage 2 engines and other technologies were used in the Titan III(23)C and other Titan configurations. For stage 1, thrust improved from 457,000 pounds to 529,000 for the new engine, and specific impulse rose from 275 to 302 seconds, with a more modest increase from 100,000 to 105,000 pounds of thrust for the stage 2 engine. Other improvements included a universal space guidance system to replace the Titan IIIC inertial guidance and control system, an improved attitude control system for the Transtage, and an upgraded thrust vector control system.[112]

The Titan III(23)C maiden mission, on 6 November 1970, called for the launch system to place the first 2,000-pound Defense Support Program satellite into geosynchronous orbit above the Indian Ocean. The early warning infrared detection satellite would become the nation's primary satellite platform to observe the Soviet missile and space threat. Because of a misaligned guidance platform, however, the Transtage ejected the satellite into an elliptical instead of a synchronous orbit. Fortunately, the DSP satellite provided valuable Soviet and American launch data from its erroneous elliptical orbit. The Titan III(23)C launched a total of 22 times over a 10-year period, with its last flight occurring on 6 March 1982. Its important payloads included 10 DSP and 10 Defense Satellite Communications System (DSCS) II satellites. If the initial launch is considered a failure, 2 other failed launches with DSCS payloads totaled 3 failures and 19 successful flights for a success rate of 86 percent. Combining the original IIIC and III(23)C Titan versions, there were six failures, with four the result of Transtage malfunctions, out of 36 total launches, for a success rate of 83 percent.[113]

Titan IIIB (SLV-5B)

The Titan IIIB, another product of the building-block approach, used the standard Titan IIIA core, but without solid rocket boosters and without costly "man-rated" equipment. Requiring a more capable third stage to carry heavier classified satellites, the Agena D replaced the Transtage in the launch stack. With the Agena's 5,800 pounds of thrust compared to 1,600 pounds for the Transtage, the Titan IIIB could loft 7,920-pound payloads to a 115-mile LEO, 660 more pounds than the Titan IIIA. The B version primarily used Western Electric Company's radio guidance system located in an adapter section, but a Titan IIIB also was configured with inertial guidance.[114]

Five versions of the Titan IIIB booster launched classified payloads from Vandenberg Air Force Base for the NRO that the Atlas-Agena could not accommodate. The original Titan IIIB launched the KH-8 Gambit 3 Block 1 camera system, which consisted of a Kodak strip camera coupled to an optical system with a 175-inch focal length and a ground resolution of less than 2 feet across. The Astro-Position Terrain Camera system contained a 3-inch focal length terrain frame camera and two 3.5-inch focal length stellar cameras, and Gambit 3 featured a single film-return capsule. Between 29 July

1966 and 3 June 1969, the original Titan IIIB launched 22 missions with the KH-8 Gambit 3 reconnaissance satellite system. The single failure occurred on 26 April 1967, when the second stage lost thrust apparently due to a fuel line obstruction and the vehicle fell into the Pacific Ocean.[115]

Beginning in 1969, two other versions of the Titan IIIB, the Titan III(23)B and Titan III(24)B, launched the KH-8A Block 2 model of Gambit 3. The Titan III(23)B was basically a Titan IIIB with the upgraded Aerojet engines developed for the defunct Titan IIIM and the Titan III(23)C for its stages 1 and 2, while the Titan III(24) was a Titan III(23)B with the first stage stretched about 71 inches. Compared to the original Titan IIIB, the increased liftoff thrust and specific impulse of these two Titan models enabled them to loft the heavier KH-8A reconnaissance satellites. The KH-8A camera system differed from the KH-8 Block 1 system by adding a second recovery capsule, adding greater memory to the command processor, and upgrading the roll joint that made it capable of a minimum of 7,000 position changes. Improvements continued with Block 3 and Block 4 Gambit 3 satellites. Between 23 August 1969 and 22 April 1971, the Titan III(23)B successfully launched all 13 assigned KH-8A missions, while the record of the Titan III(24)B is 18 successful launches and 1 failure during the period, 12 August 1971 to 17 April 1984. The single failure occurred on 20 May 1972 when the Agena's pneumatic regulator malfunctioned during ascent and the Agena lost pressure. Two additional versions of the Titan IIIB with stretched propellant tanks and with long shrouds housing the Agena and its payload launched classified intelligence and data relay satellites. The Titan III(33)B flew three successful missions with the Jumpseat electronic intelligence satellite, and the Titan III(34)B successfully launched four out of five Jumpseat satellites and all seven Satellite Data System relay satellites. These two Titan IIIB versions used the Ascent Agena, an Agena that functioned only as a third launch stage rather than remaining attached to the payload to furnish power and control while in orbit. The last Titan III(34)B flight on 17 April 1984 also represented the final use in any launch stack of the Agena upper stage booster-satellite that had "put the Air Force in space."[116]

By late 1967, when the Air Force decided to develop the D-model, the proliferation of Titan III versions meant the potential abandonment of the original standardization concept for the Titan III. To recover this posture, SSD produced a number of commonality studies to establish a "common core" for stage 1 and 2 for the Titan B-D-C configurations. In early 1968, the Space and Missile Systems Organization negotiated production contracts that would ensure that 98 percent of the parts for the three models would be standardized. By this point, the program office had begun procuring Titan IIIB, C, and D follow-on engines according to a common specification, while solid motor production had become nearly routine in light of rapid development in mixing and standardizing solid fuels; improvement in case design, fabrication, and insulation; and advanced production engineering. The common core plan also established standardized procedures for analysis systems' effectiveness and logistics. By using identified parts and test procedures, the Air Force expected the common core standardization concept to achieve substantial cost savings and improve reliability.[117]

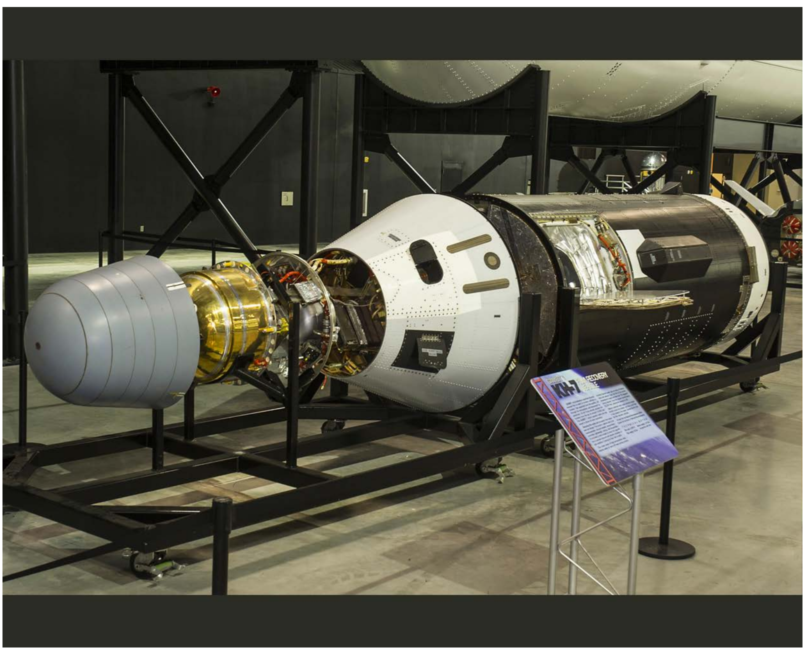


Fig. 5. The Gambit KH-7 camera system, as seen in a static museum display. (Photograph courtesy of the National Museum of the Air Force)

Titan III(23)D (SLV-5D)

On 15 November 1967, the Titan III System Program Office, now under the SAMSO, began development of the Titan III(23)D, a Titan III capable of launching classified satellites too heavy for the Titan IIIB. The Titan III(23)D, in effect, was the Titan IIIC, the standard core with two UTC five-segment solid rockets, but without the Transtage. The Titan IIID family used radio guidance, as did the Titan IIIB-Agena-Gambit missions. It could launch payloads weighing nearly 30,000 pounds into low polar orbit compared to the B-model's capability of 7,920 pounds.[118]

The Air Force developed the Titan III(23)D specifically to launch the NRO's enormous KH-9 Hexagon "Big Bird" camera system, which was designed to replace the KH-4B Corona satellites. Hexagon measured 60 feet by 10 feet and weighed between 25,133 pounds and 29,322 pounds. Its main stereoscopic camera system consisted of two panoramic area surveillance cameras, one looking forward and one aft, with a focal length of 60 inches. Able to scan contiguous areas up to 120 degrees wide, the cameras eventually could attain a ground resolution of better than 2 feet. On 12 of the 17 flights, Hexagon missions included a mapping camera that ultimately achieved a ground resolution of 20 feet. Hexagon's main cameras used four recovery capsules, while the mapping camera had its own recovery bucket. KH-9 missions frequently included secondary hitchhiker payloads that could achieve higher orbits under their own propulsion. The Air Force launched the initial KH-9 Hexagon mission on 15 June 1971. Looking ahead, the Titan III(23)D accounted for 16 more successful launches, with the last occurring on 11 May 1982. Reportedly, the Titan III(23)D also successfully launched five KH-11 reconnaissance satellites, with the first flight on 19 December 1976 and the last on 17 November 1982. Known by the code name Kennen, the KH-11 became the first reconnaissance satellite to use electro-optical digital imaging to produce a direct readout capability to ground stations.[119]

The effectiveness of standardization and a well-designed and developed Titan launch system is apparent in the launch results. The Titan IIIA and C flew a total of 40 times and experienced 5 failures, for a success rate of 87.5 percent. The Titan IIIC booster achieved an operational success rate of 96.8 percent. Even more impressive was the launch record of the Titan IIIB's five versions and the Titan IIID. The Titan IIIB compiled a record of 68 successful launches and one failure for a success rate of 98.5 percent, while the Titan D was successful on all 22 flights.[120]

While General Schriever and other Air Force leaders complained about DOD's micromanagement approach, the Titan III program did, in fact, meet its schedule, budget, and performance requirements. Titan program director Col David Miller, who succeeded General Bleymaier, attributed the program's success to several factors. He gave due credit to OSD's oversight innovations and new AFSC management techniques, like cost-plus-incentive-fee contracting, strong central control, and configuration management. Above all, he stressed that cost, performance, and schedule objectives could only be realized when everyone involved appreciated the importance of the project, and the service program director and industry program managers had strong support from higher headquarters and senior management, respectively. With good reason, Secretary McNamara could call the Titan III "the best managed program in the Department of Defense."[121]

Summary

From the late 1950s to the early 1970s, Air Force space launch vehicles came of age. The Titan III is often portrayed as expressly designed and developed for space launch rather than a modified missile along the lines of the Thor and Atlas medium-lift boosters. Yet, by using the Titan II ICBM core, the Titan III in that sense followed the pattern established earlier. On the other hand, the new element with the Titan IIIC was the use of large, segmented solid rocket motors that would become a major feature in future heavy-lift boosters like the Titan IV and the shuttle.

Over the course of the decade and beyond, all three space launch systems benefited from evolutionary improvements in such areas as airframe production, engine thrust and efficiency, guidance and control, and stage and payload adaptors. The key driving force in booster development was the payload. As satellites increased in size, weight, and complexity, OSD and the Air Force met this challenge in large part by developing more capable boosters and upper stages and establishing standardization programs for these vehicles. At the same time, engineers succeeded in extending the lifetimes of satellites on orbit, thereby reducing the number of spacecraft needed. This development would present a challenge to industry in the future.

To support expanding satellite and booster capabilities, the Air Force created an elaborate space infrastructure of tracking and control networks, research and development offices and laboratories, and especially launch facilities at Vandenberg Air Force Base and Cape Canaveral Air Force Station. Taken together, the enormous growth in space capabilities by the early 1970s increasingly propelled space systems from the realm of research and development to the broader arena of operational applications.

Notes

1. *TRW Space Log 1996*, 65–89.
2. Berger, *The Air Force in Space,* FY 62, 43.
3. Berger, *The Air Force in Space*, FY 61, 2; and Piper, *History of Titan III*, 12.
4. Department of the Air Force, "Report to the President-Elect of the Ad Hoc Committee on Space"; and Stares, *The Militarization of Space*, 60–61.
5. Spires, *Beyond Horizons*, 86–87; and Logsdon, *John F. Kennedy and the Race to the Moon*, 31–34.
6. Spires, *Orbital Futures,* vol. 1, 34.
7. Robert S. McNamara, Secretary of Defense, to the Secretaries of the Military Departments, et al, "Development of Space Systems," with attached: DOD Directive 5160.32, "Development of Space Systems," 6 March 1961, in Spires, *Orbital Futures,* vol. 1, 37–41.
8. For the background of the reorganization, see Berger, *The Air Force in Space*, FY 61, 6–10; Air Research and Development Command (ARDC), *History of Headquarters*, vol. 1, *1 January–31 March 1961;* Air Force Systems Command (AFSC), *History of the Air Force Systems Command, 1 April–30 June 1961,* I-22 to I-52; Schriever, interview, 23–25; and Sturdevant, "The United States Air Force Organizes for Space."
9. Berger, *The Air Force in Space,* FY 61, 59.
10. Berger, *The Air Force in Space*, FY 61, 59; Piper, *History of Titan III*, 7; The Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 108–9; and Space Systems Division (SSD), *History of the Space Systems Division, January–December 1963*, 68.
11. Piper, *History of Titan III*, 14.
12. Spires, *Orbital Futures,* vol. 2, 788–809; and Piper, *History of Titan III*, 14.
13. For the Dyna-Soar space plane, see Spires, *Beyond Horizons*, 120–27.
14. Rubel, "Request for USAF Studies Relative to Space Programs."
15. See an expanded biography of John H. Rubel in appendix A.
16. The Titan II Gemini Launch Vehicle received the designation SLV-4. Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40; Ballistic Missile Organization (BMO), *Chronology of the Ballistic Missile Organization, 1945–1990*, 60; and Hunley, *U.S. Space-Launch Vehicle Technology*, 83–84. The Scout, a small, multistage, solid propellant rocket, was primarily a NASA launch vehicle. For a detailed discussion of the Scout, see Hunley, *U.S. Space-Launch Vehicle Technology*, 127–57.

17. Swenson, Grimwood, and Alexander, *This New Ocean: A History of Project Mercury*, 187–89; Hunley, *U.S. Space-Launch Vehicle Technology*, 276; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40; and Williamson, "Access to Space: Steps to the Saturn V," 15.

18. Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40; and Hunley, *U.S. Space-Launch Vehicle Technology*, 76–279.

19. ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present*, B-1, B-2; Isakowitz, *International Reference Guide to Space Launch Systems*, 1991 ed., 185; and Sturdevant, Darrah, and McCartney, "Space Flight: Long-Range Missiles, Rocket Planes, and Lifting Bodies," 154−56. See the Atlas family tree in appendix B.

20. Thrust is often measured in foot-pounds, the energy needed to raise one pound a distance of one foot. For this study, thrust will be given in pounds. Hunley, *U.S. Space-Launch Vehicle Technology*, 83–85; and Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40.

21. Hunley, *U.S. Space-Launch Vehicle Technology*, 83–86; and Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40.

22. Hall, "The Air Force in Space," 16; information used is unclassified.

23. For coverage of the WS-117L satellite reconnaissance system, see Spires, *Beyond Horizons*, 35–44.

24. Hunley, *U.S. Space-Launch Vehicle Technology*, 87; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40-41; and Hall, "The Air Force in Space," 16–17.

25. Hunley, *U.S. Space-Launch Vehicle Technology*, 87. For discussion of the MIDAS and Samos programs, see Spires, *Orbital Futures*, vol. 2, 956–77, and Spires, *Beyond Horizons*, 71–72.

26. Hunley, *U.S. Space-Launch Vehicle Technology*, 55, 87; and Hall, "The Air Force in Space," 17.

27. *TRW Space Log 1996*, 77–100; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; and Hunley, *U.S. Space-Launch Vehicle Technology*, 55, 87–91.

28. The final three Samos satellites would be launched on Agena Ds. See note 26.

29. Hall, "The Air Force in Space," 17–18; Hunley, *U.S. Space-Launch Vehicle Technology*, 56–57, 91; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 41; and Berger, *The Air Force in Space*, FY 62, 98–100.

30. Hall, "The Air Force in Space," 17–19; and Hunley, *U.S. Space-Launch Vehicle Technology*, 56–57.

31. Hunley, *U.S. Space-Launch Vehicle Technology*, 92; *TRW Space Log 1996*, 80–109; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "US Reconnaissance Programs," part 1, 22–33; McDowell, "US Reconnaissance Satellites Programs," part 2, 40–45; McDowell, "Satellite Catalog," accessed 8 September 2018; and Center for the Study of National Reconnaissance, "Gambit 1 (KH-7) Fact Sheet." The last three pairs of Vela satellites were switched to the Titan IIIC because of their greater weight and complexity. The Navy's Point Arguello complex was officially transferred to the Air Force and annexed to Vandenberg Air Force Base on 1 July 1964.

32. Hunley, *U.S. Space-Launch Vehicle Technology*, 92–94; and Encyclopedia Astronautica, "Atlas," accessed 20 June 2009. For a discussion of Agena D problems in the Gemini program, see Hacker and Grimwood, *On the Shoulders of Titans*, 297–321; for an Air Force perspective, see The Aerospace Corporation, *The Aerospace Corporation*, 100–103.

33. Hunley, *U.S. Space-Launch Vehicle Technology*, 93–94; *TRW Space Log 1996*, 80–186; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

34. Jenkins, "Stage-and-a-Half: The Atlas Launch Vehicle," 84–85; Hunley, *U.S. Space-Launch Vehicle Technology*, 91; and SSD, *History of the Space Systems Division, January–December 1963*, 100.

35. SSD, *History of the Space Systems Division, January–December 1963*, 100; Berger, *The Air Force in Space*, FY 62, 100; and The Aerospace Corporation, *The Aerospace Corporation*, 104.

36. Apparently, the Air Force considered extended tanks unnecessary for its missions. Hunley, *U.S. Space-Launch Vehicle Technology*, 91; SSD, *History of the Space Systems Division, January–December 1963*, 100; Berger, *The Air Force in Space,* FY 62, 100; and The Aerospace Corporation, *The Aerospace Corporation*, 104.

37. Hunley, *U.S. Space-Launch Vehicle Technology*, 91.

38. Hunley, *U.S. Space-Launch Vehicle Technology*, 91; SSD, *History of the Space Systems Division, January–December 1963*, 128–29; Berger, *The Air Force in Space,* FY 62, 100; Johnson, *The United States Air Force and the Culture of Innovation*, 96–97; and Silverstein, email, 25 June 2018.

39. Silverstein, email, 25 June 2018; and SSD, *History of the Space Systems Division, January–December 1963*, 128–29.

40. See note 38; *TRW Space Log 1996*, 85; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

41. *TRW Space Log 1996*, 71–80; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; and ANSER, *A Historical Look at United States Launch Vehicles*, B-21, B-22, B-23, B-25.

42. ANSER, *A Historical Look at United States Launch Vehicles*, B-1, B-3; Hunley, *U.S. Space-Launch Vehicle Technology*, 93; and Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 41.

43. Hunley, *U.S. Space-Launch Vehicle Technology*, 93–94; *TRW Space Log 1996*, 114–86; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "US Reconnaissance Programs," part 1: 22–33; McDowell, "US Reconnaissance Programs," part 2: 40–45; McDowell, "Satellite Catalog," accessed 8 September 2018; and Walker, *Atlas: The Ultimate Weapon*, 210.

44. Hunley, *U.S. Space-Launch Vehicle Technology*, 94; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40–42; and Powell and Richards, "The Centaur Vehicle," 101.

45. Hunley, *U.S. Space-Launch Vehicle Technology*, 94–97; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40–42; and Dawson, "Taming Liquid Hydrogen: The Centaur Saga," 338–42. See an expanded biography of Krafft A. Ehricke in in appendix A.

46. Hunley, *U.S. Space-Launch Vehicle Technology*, 97–107; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40–42; Dawson, "Taming Liquid Hydrogen: The Centaur Saga," 342–48; Powell and Richards, "The Centaur Vehicle," 102–3; and McKinney, "Manuscript Review Comments," 20 January 2020.

47. See note 45.

48. See note 45.

49. Powell and Richards, "The Centaur Vehicle," 99–101; Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 40–42; and Walker, *Atlas: The Ultimate Weapon*, 211–16.

50. Hunley, *U.S. Space-Launch Vehicle Technology*, 112–13; Powell and Richards, "The Centaur Vehicle," 107–10; and Encyclopedia Astronautica, "Atlas," accessed 20 June 2009.

51. *TRW Space Log 1996*, 111–255; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; Powell and

Richards, "The Centaur Vehicle," 107–11; and Hunley, *U.S. Space-Launch Vehicle Technology*, 113–21.

52. So called because of their location in Midwest (a generous designation) wheat producing states.

53. Powell and Richards, "The Atlas E/F Launch Vehicle—An Unsung Workhorse," 229–30; Hunley, *U.S. Space-Launch Vehicle Technology*, 121–22; and Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 44–45.

54. Silverstein, email, 22 March 2018, 25 June 2018. See note 51.

55. Powell and Richards, "The Atlas E/F Launch Vehicle—An Unsung Workhorse," 230–40; Hunley, *U.S. Space-Launch Vehicle Technology*, 121–24; and Martin, "A Brief History of the Atlas Rocket Vehicle," part 2, 44–45.

56. ANSER, *A Historical Look at United States Launch Vehicles*, B-14, B-15, B-16; *TRW Space Log 1996*, 65–151; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

57. Cantwell, *The Air Force in Space, Fiscal Year 1968*, part 1, 22; and Space and Missile Systems Organization (SAMSO), *History of Space and Missile Systems Organization, 1 July 1967–30 June 1969*, 158–59.

58. It should be noted, however, that sources on the Thor often use the terms standard launch vehicle, standardized launch vehicle, and space launch vehicle interchangeably and, chronologically, before the Thor's official SLV designation. The confusion is compounded by use of both the Douglas Aircraft Company designators, DM (Douglas Missile), DSV (Douglas Standard Vehicle), and the Air Force designators, LV (launch vehicle), SLV (standardized launch vehicle). Additionally, Thor and Thor-Delta variants number more than 30. See the Thor booster evolution in appendix B.

59. SSD, *History of the Space Systems Division, 1 January–30 June 1967*, 90; *TRW Space Log 1996*, 65–67; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; Temple, *Shades of Gray*, 142–43, 149–51, 157–58, 163–75; and Sambaluk, *The Other Space Race*, 107–9. For coverage of Corona and subsequent reconnaissance satellite systems, see Richelson, *America's Secret Eyes in Space*.

60. ANSER, *A Historical Look at United States Launch Vehicles*, A-1, A-2; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and Isakowitz, *International Reference Guide to Space Launch Systems*, 1991 ed., 294.

61. Kyle, "Thor: Flown Variants"; Hunley, *U.S. Space-Launch Vehicle Technology*, 41–44; and Encyclopedia Astronautica, "Thor," accessed 11 July 2017.

62. Hunley, *U.S. Space-Launch Vehicle Technology*, 44–48; and Encyclopedia Astronautica, "Thor," accessed 11 July 2017.

63. Hunley, *U.S. Space-Launch Vehicle Technology*, 48.

64. Hunley, *U.S. Space-Launch Vehicle Technology*, 48–49; Encyclopedia Astronautica, "Thor Ablestar," accessed 27 August 2018; Kyle, "Thor: Flown Variants"; and Forsyth, "Delta: The Ultimate Thor," 106–7.

65. See note 62; *TRW Space Log 1996*, 65–93; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

66. See note 64.

67. SSD, *History of the Space Systems Division, January–June 1965*, 35; SSD, *History of the Space Systems Division, July–December 1965*, 18; Wilson, "Burner 2—Boeing's Small Upper Stage," 210; and Maultsby, email, 21 March 2017.

68. *TRW Space Log 1996*, 88–98; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; Spires, *Beyond Horizons*, 147–48; and Hunley, *U.S. Space-Launch Vehicle Technology*, 59.

69. SSD, *History of the Space Systems Division, July–December 1965*, 18; SSD, *History of the Space Systems Division, 1 January–30 June 1967*, 94; Hunley, *U.S. Space-Launch Vehicle Technology*, 60–61; and Wilson, "Burner 2—Boeing's Small Upper Stage," 210–11.

70. Hunley, *U.S. Space-Launch Vehicle Technology*, 60–61; Wilson, "Burner 2—Boeing's Small Upper Stage," 210–11; *TRW Space Log 1996*, 102–40; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

71. Hunley, *U.S. Space-Launch Vehicle Technology*, 61–62; Wilson, "Burner 2—Boeing's Small Upper Stage," 211–13; *TRW Space Log 1996*, 142–71; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

72. Hunley describes the failure of *Discoverer 1* and the changes that Lockheed made to provide an improved engine for *Discoverer 2* and subsequent Agena A flights that could launch payloads 500 pounds heavier. Hunley, *U.S. Space-Launch Vehicle Technology*, 54; Kyle, "Thor: Flown Variants"; and Encyclopedia Astronautica, "Thor Agena A," accessed 27 August 2018.

73. For a discussion of the classified reconnaissance program and its unique management arrangements, see Spires, *Orbital Futures*, vol. 2, 957–77.

74. Day, Logsdon, and Latell, *Eye in the Sky*, 6, 34–37, 231–32. This publication includes appendices with camera specifications and comprehensive launch listings based on NRO sources.

75. Day, Logsdon, Latell, *Eye in the Sky*, 8, 61, 236–37; *TRW Space Log 1996*, 142–71; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

76. Encyclopedia Astronautica, "Thor Agena B," accessed 27 August 2018; Hunley, *U.S. Space-Launch Vehicle Technology*, 54–55; and Kyle, "Thor: Flown Variants."

77. Hunley, *U.S. Space-Launch Vehicle Technology*, 55–56; *TRW Space Log 1996*, 69–77; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; Day, Logsdon, Latell, *Eye in the Sky*, 236–38; and Kyle, "Thor: Flown Variants."

78. Day, Logsdon, Latell, *Eye in the Sky*, 236–38; and Encyclopedia Astronautica, "Thor," accessed 11 July 2017.

79. Day, Logsdon, Latell, *Eye in the Sky*, 63, 233, 238–41.

80. Day, Logsdon, Latell, 66-69, 231–32; 236–39.

81. Day, Logsdon, Latell, 236–39.

82. Of the 11 flights, 9 flew the KH-4 and 2 the KH-5 cameras. Day, Logsdon, Latell, 236–39; *TRW Space Log 1996*, 75–80; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

83. SSD, *History of the Space Systems Division, January–December 1963*, 99.

84. *TRW Space Log 1996*, 80–108; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; Hunley, *U.S. Space-Launch Vehicle Technology*, 57; and Day, Logsdon, Latell, *Eye in the Sky*, 238–43.

85. Berger, *The Air Force in Space, FY 62*, 100–101; SSD, *History of the Space Systems Division, January–December 1963*, 99–100; Hunley, *U.S. Space-Launch Vehicle Technology*, 56–57; Isakowitz, *International Reference Guide to Space Launch Systems*, 1991 edition, 294–95; Kyle, "Thor: Flown Variants"; and The Aerospace Corporation, *The Aerospace Corporation*, 105.

86. Day, Logsdon, Latell, *Eye in the Sky*, 238–43; *TRW Space Log 1996*, 77–113; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

87. Day, Logsdon, Latell, *Eye in the Sky*, 75, 233.

88. The KH-4A missions averaged 15 days. Day, Logsdon, Latell, *Eye in the Sky*, 21, 76–77, 233.

89. On two of the missions, the Agena failed. Day, Logsdon, Latell, *Eye in the Sky*, 238–43; *TRW Space Log 1996*, 80-106; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

90. This author agrees with sources that use the term Thorad to depict both the SLV-2G (DSV-2L-1A) Long Tank Thrust Augmented Thor and the SLV-2H (DSV-2L-1A) Long Tank Thrust-Augmented Thor rather than designate only the SLV-2H as the Thorad. Launch records have treated the two Thor variants both separately and as one common vehicle and also have considered only the SLV-2H as the Thorad. For this study, Thorad will describe both long tank thrust-augmented Thors.

91. The first SLV-2G was delivered to Vandenberg AFB on 30 May 1966. SSD, *History of the Space Systems Division, January–June, 1966*, 48–49; ANSER, *A Historical Look at United States Launch Vehicles*, A-6; Kyle, "Thor: Flown Variants"; Hunley, *U.S. Space-Launch Vehicle Technology*, 56–57; Isakowitz, *International Reference Guide to Space Launch Systems*, 1991 ed., 295; and Global Security, "Thor," 3.

92. Day, Logsdon, Latell, *Eye in the Sky*, 80–83, 233, 242–45; *TRW Space Log 1996*, 107–44; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; and ANSER, *A Historical Look at United States Launch Vehicles*, A-9.

93. *TRW Space Log 1996*, 107–44; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; and Kyle, "Thor: Flown Variants."

94. SSD, *History of the Space Systems Division, July–December 1966*, 36; ANSER, *A Historical Look at United States Launch Vehicles*, A-6; and The Aerospace Corporation, *The Aerospace Corporation*, 105.

95. Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and Day, Logsdon, Latell, *Eye in the Sky*, 242–45.

96. Day, Logsdon, Latell, *Eye in the Sky*, 7–8, 47, 85, 236–45.

97. Hunley, *U.S. Space-Launch Vehicle Technology*, 62–64; Forsyth "Delta: The Ultimate Thor," 107–10; ANSER, *A Historical Look at United States Launch Vehicles*, A-7, A-8, A-9, A-10; *TRW Space Log 1996*, 66–150; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 8 September 2018.

98. The Air Force never produced an SLV-4 vehicle. At one point, planners envisioned developing a large, heavy-lift booster at the end of the 1960s, but the modular Titan III filled the requirement for a heavy-lift launcher; Encyclopedia Astronautica, "Titan," accessed 20 June 2009.

99. Piper, *History of Titan III*, 18–22; Berger, *The Air Force in Space,* FY 62, 43–44; and Poole, *Adapting to Flexible Response*, vol. 2, 332.

100. Piper, *History of Titan III*, 22–25, 30–32; Berger, *The Air Force in Space,* FY 62, 44–46; SAMSO, "Titan III Program"; SSD, *History of the Space Systems Division, January–December 1963*, 68–69; and Hunley, *U.S. Space-Launch Vehicle Technology*, 221–24. It should be noted that the Large Launch Vehicle Planning Group's year-long effort to coordinate a common large booster program ultimately proved unproductive, and NASA and the Air Force continued to pursue separate space booster programs. For discussion of the LLVPG, see Spires, *Orbital Futures*, vol. 2, 788–89.

101. Berger, *The Air Force in Space,* FY 62, 45–48; Piper, *History of Titan III*, 41; and Spires, *Beyond Horizons*, 113–15. See an expanded biography of Joseph B. Bleymaier in appendix A.

102. Cantwell, *The Air Force in Space, FY* 1968, 20–21; Berger, *The Air Force in Space*, 49–50; and Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 221–24. See the Titan series heritage in appendix B.

103. Report to the Congress from the President of the United States, *United States Aeronautics and Space Activities, 1962*, 33.

104. Hunley, *U.S. Space-Launch Vehicle Technology*, 224–30.

105. Piper, *History of Titan III*, 53–60; and Poole, *Adapting to Flexible Response*, 334.

106. Piper, *History of Titan III*, 84–87; Poole, *Adapting to Flexible Response*, 335; Launius, "Titan: Some Heavy Lifting Required," 166–67; and The Aerospace Corporation, *The Aerospace Corporation*, 110.

107. Brig Gen Bleymaier is quoted in Hunley, *U.S. Space-Launch Vehicle Technology*, 227–30.

108. Hunley, *U.S. Space-Launch Vehicle Technology*, 230–35; AFSC, *History of the Air Force Systems Command, 1 July 1964–30 June 1965*, 200–201; Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 123–27; and The Aerospace Corporation, *The Aerospace Corporation*, 109.

109. For the first time, a US space launch vehicle configured with an ablative thrust chamber engine was successfully restarted on orbit. SAMSO, "Titan III Program," 54; AFSC, *History of the Air Force Systems Command, 1 July 1964–30 June 1965*, 200–201; Hunley, *U.S. Space-Launch Vehicle Technology*, 235–36; and Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 129–30.

110. SAMSO, "Titan III Program"; SSD, *History of the Space Division, January–June 1965*, 49–50; Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 130–33; Hunley, *U.S. Space-Launch Vehicle Technology*, 236–39; and AFSC, *History of the Air Force Systems Command, 1 July 1964–30 June 1965*, 201–4.

111. The last pair of Vela satellites operated until 1985, when they were finally shut down, and the Air Force claimed them to be the world's longest operating satellites. They remained in orbit until decaying at the end of 1992. SSD, *History of the Space Systems Division, January–June 1965*, 21–22; Spires, *Beyond Horizons*, 139–41, 170; SSD, *History of the Space Systems Division, July-December 1966*, 52–53; SAMSO, *History of Space and Missile Systems Organization, 1 July 1967–30 June 1969*, 187; AFSC, *History of the Air Force Systems Command, 1 July 1964–30 June 1965*, 201–4; and Hunley, *U.S. Space-Launch Vehicle Technology*, 236–39.

112. Hunley, *U.S. Space-Launch Vehicle Technology*, 239–40; SSD, *History of the Space Systems Division, January–June 1966*, 67; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1967–30 June 1969*, 192. For a brief discussion of the Titan IIIM, see Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 134.

113. DSP satellites would eventually weigh 5,300 pounds. For a brief discussion of DSP, see Spires, *Beyond Horizons*, 160; Hunley, *U.S. Space-Launch Vehicle Technology*, 240–42; Launius, "Titan: Some Heavy Lifting Required," 167–68; Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 135–36; *TRW Space Log 1996*, 135–212; Encyclopedia Astronautica, "Titan," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; and ANSER, *A Historical Look at United States Launch Vehicles*, C-23, C-24.

114. SSD, *History of the Space Division, January–June 1965*, 51; SSD, *History of the Space Division, January–June 1966*, 68; ANSER, *A Historical Look at United States Launch Vehicles*, C-3; Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 133–34; Hunley, *U.S. Space-Launch Vehicle Technology*, 242–43; and Launius, "Titan: Some Heavy Lifting Required," 168.

115. Cantwell, *The Air Force in Space, FY* 1968, part 1, 21; Center for the Study of National Reconnaissance, "Gambit 3 (KH-8) Fact Sheet"; TRW Space Log 1996, 101–25; Encyclopedia Astronautica, "Titan," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

116. It should be noted that on two Titan III(23)B flights the second film bucket could not be recovered. Center for the Study of National Reconnaissance, "Gambit 3 (KH-8) Fact Sheet"; Hunley, *U.S. Space-Launch Vehicle Technology*, 242–43; Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 137; Encyclopedia Astronautica, "Titan," accessed 20 June 2009; McDowell, "US Reconnaissance Programs," part 1, 22–33; McDowell, "US Reconnaissance Programs," part 2, 40–45; and McDowell, "Satellite Catalog," accessed 8 September 2018.

117. Cantwell, *The Air Force in Space, FY 1968*, part I, 21; SSD, *History of the Space Systems Division, July–December 1965*, 80; SSD, *History of the Space Systems Division, July–December 1966*, 54; and SSD, *History of the Space Systems Division, 1 January–30 June 1967*, 81–82. NASA's version of the Titan III was the Titan IIIE, which was a Titan IIID with a Centaur D-1T upper stage. The Titan IIIE launched the impressive Viking mission to Mars and the Voyager spacecraft to the outer planets. Between February 1974 and September 1977, the Titan IIIE launched seven times for a 100 percent success rate. For development of the Titan IIIE, see Hunley, *U.S. Space-Launch Vehicle Technology*, 244–47; and ANSER, *A Historical Look at United States Launch Vehicles*, C-28.

118. Hunley, *U.S. Space-Launch Vehicle Technology*, 243; Cantwell, *The Air Force in Space, FY 1968,* part I, 21; and Richards and Powell, "Titan 3 and Titan 4 Space Launch Vehicles," 136.

119. Center for the Study of National Reconnaissance, "Hexagon (KH-9) Fact Sheet"; Federation of American Scientists, "KH-11 Kennan/Crystal"; Encyclopedia Astronautica, "Titan," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018. The final three Hexagon missions were launched by the Titan 34D. The last flight, on 18 April 1986, failed when one of the solid boosters burned through the launcher and exploded 8 seconds after liftoff. For discussion of the Titan 34D, see Chapter 5.

120. ANSER, *A Historical Look at United States Launch Vehicles*, C-21, C-22, C-23, C-24, C-25, C-26, C-27; and McDowell, "Satellite Catalog," accessed 8 September 2018.

121. Miller, "How the Air Force Maintained Cost, Schedule on Titan III," 64–66; and AFSC, *History of the Air Force Systems Command, 1 July 1964–30 June 1965*, 4.

Chapter 3

West Coast Development

Vandenberg Air Force Base and the Western Test Range, 1956–1972

Vandenberg Air Force Base on the California coast has provided an ideal location for launch operations for the past 65 years. The base's north coastline faces west and supports ballistic missile launches into broad areas of the Pacific Ocean and the Kwajalein Atoll test site. From the southern portion of the base, the Air Force has conducted space launches to insert satellites into polar orbit, primarily for classified reconnaissance operations. Significantly, both missile and space launch flight paths have avoided endangering populated areas.[1]

From Army Training Site to Air Force Missile and Space Launch Base

Vandenberg AFB can trace its origin to a decision taken in 1956, when the Air Force selected the Army's moribund Camp Cooke as the home of its embryonic guided missile program. The 86,000-acre site, approximately 150 miles northwest of Los Angeles, had been an Army armor and infantry training facility during the Second World War, after which it was inactivated, placed in the hands of caretaker personnel, and leased for grazing and agriculture. In August 1950, three months after the outbreak of the Korean War, the Army reactivated Camp Cooke to support infantry and armor units training for combat operations in that conflict. In February 1953, the camp returned to inactive status and functioned as the site of a detention center until the Air Force expressed interest in the land three years later.[2]

The Air Force had found it difficult to test missiles under operational conditions at the increasingly crowded Cape Canaveral Auxiliary Air Force Base on Florida's East Coast in the mid-1950s. This led SAC's commander-in-chief, Gen Curtis E. LeMay, to meet with Air Research and Defense Command commander Gen Thomas S. Power on 20 December 1955 to confirm the requirement for an alternative combined training and operational base for the ICBM force and to establish a site-screening group to examine potential bases for the operational force. On 7 May 1956, Gen Bernard A. Schriever's Western Development Division (WDD) responded by forming the Weapon System 107A (Atlas) Site Selection Board.[3]

In June 1956, after examining over 200 locations, the board recommended Camp Cooke as its choice for the composite training-operational base. Positioned close to the state's aerospace industry and the WDD's Los Angeles headquarters, the site also was situated in a relatively unpopulated region, offered ocean access for missile range operations, and benefited from a moderate climate year-round. Convincing Secretary of the Air Force Donald A. Quarles, a budget hawk, to approve the selection proved difficult, however.[4]

As chief of the site selection team, Lt Col Vernon L. Hastings attended a long, contentious meeting on 20 August 1956 between Quarles and his staff and key representatives from Air Force headquarters, ARDC, WDD, and SAC. While Quarles argued for continuing training at Cape Canaveral, several Air Force leaders strongly supported Camp Cooke as a solution to the Cape's overcrowding and hazardous overflight conditions. As noted by General Power, the Air Force needed "some place . . . to exercise the operational crews, to explode an atomic warhead and to utilize the thousands of missiles that would be built." Eventually, the Air Staff presented a case to sufficiently justify the need of a missile proving range. It received Quarles's approval on 1 September 1956, and on 16 November 1956, OSD approved the transfer of the northern portion of Camp Cooke to the Air Force. When the formal transfer took place the next spring, on 7 June, the service renamed the facility Cooke Air Force Base.[5]

The development of Cooke AFB is well documented. The initial transfer comprised 64,000 acres north of the Santa Ynez River. By the next spring, on 15 April 1957, the ARDC had activated the 1st Missile Division, and groundbreaking for missile launch sites took place on 9 May. Five months later, on 23 November 1957, OSD approved Cooke AFB for peacetime missile launches. A year later, on 4 October 1958, the Air Force redesignated Cooke AFB as Vandenberg AFB in an elaborate ceremony to honor the late Gen Hoyt S. Vandenberg, who had been the service's second chief of staff.[6]

Because constructing a test and operational ICBM capability had been their highest priority, Air Force leaders had shown little interest in a space launch operation at the southern portion of Camp Cooke. The Navy already had a radar site on the peninsula to support its Naval

Missile Test Center, with headquarters 90 miles to the south at Point Mugu, and on 4 April 1958 established the US Naval Missile Facility, Point Arguello (NMFPA). The next month, on 27 May, OSD formally transferred the remaining 19,861 acres of Camp Cooke south of the Ynez River—Point Arguello—to the Navy. On 16 June, the Navy activated the Pacific Missile Range (PMR), with Point Mugu its headquarters and Point Arguello its major launch head. Naval leaders envisioned the PMR as a future tri-service national firing range open to all the services.[7]

The historical record suggests that, with the launching of Thor-Agena Discoverer flights from Vandenberg North over the Navy's Arguello area, Air Force officials grew to see the need for constructing new Atlas, Samos, and MIDAS launch sites on Arguello to eliminate the Navy's safety and overflight concerns. By October 1960, the Air Force had the first of its two Atlas space launch complexes operational, with the second to follow in July 1963. Designated Point Arguello Launch Complex 1 (PALC-1) and Point Arguello Launch Complex 2 (PALC-2), respectively, they would later be renamed Space Launch Complex 3 (SLC-3) and Space Launch Complex 4 (SLC-4), respectively. With the major Air Force space launch complexes now located on Point Arguello, it seemed logical that, with the Air Force becoming the dominant service for space, it would eventually acquire Point Arguello and the PMR.[8]

A Complementary Vandenberg South Origins Story

Although the basic elements of the Vandenberg story are accurate, a more complete account must include the role of the brilliant rocket propulsion officer, Navy Cdr Robert C. Truax, who had been assigned to the WDD to work on the Thor IRBM and later direct the first Air Force satellite reconnaissance program. In the spring of 1956, the same time that Hastings's missile site selection committee chose what became Vandenberg North, Truax and Capt James S. Coolbaugh, the first member of Truax's WDD satellite team, decided to search for the best possible site to launch satellites from the West Coast. Truax remembered, "As the only aviators attached to the [WDD] program office, Jim Coolbaugh and I cruised the California coast in our B-25, looking for a site suitable for polar launches." He later succinctly explained, "Reconnaissance is best conducted from satellites that travel more or less over the poles, for the orbit stays fixed in space, and the earth rotates beneath it, allowing a polar satellite to survey the entire earth."[9]

After eliminating a potential site near Santa Cruz that later became Lockheed's Santa Cruz test facility for Agena upper stage vehicles, they settled on Point Arguello, the southern area of Camp Cooke. Truax was already familiar with the Arguello peninsula. The Navy had constructed a radar site on Arguello to track missiles launched from the Naval Air Missile Test Center at Point Mugu, where Truax had been assigned earlier, after relocating the Navy's Propulsion Laboratory from Annapolis to Point Mugu. "Fortunately," Truax said, "it was commanded by my old friend Bob Freitag [Cdr Robert F. Freitag]. He and I arranged to *allow* the Air Force to build its launch site there" (emphasis added).[10]

Circumstantial evidence suggests that the story is largely accurate. Both officers recounted the same story many years afterward, Truax in the 1985 version of his autobiography and Coolbaugh in a 1998 article for the British Interplanetary Society. The timing of events, however, is more problematical. Coolbaugh states that their spring 1956 flight took place about nine months before the Air Force's acquisition of Camp Cooke. But the latter occurred on 7 June 1957, nearly 12 months later than the reported spring 1956 flight. After the flight, Truax may well have spoken to his friend Commander Freitag, who in fact served as special assistant to the PMR commander and was an influential figure in the naval space community. Coolbaugh is less precise, noting that "when the dust settled, the Air Force was authorized to build a launch base for satellites there [on Arguello]."[11]

In a 12 September 1956 WDD memo, Truax argued that Camp Cooke ideally met the requirements he had outlined in a memo from 7 May calling for "construction of an independent WS 117L launch complex, probably at the extreme southern end of the Camp Cooke area [on Point Arguello]." A week later, on 19 September, however, Hastings responded to the Truax memo, noting that construction of such a launch complex "may be influenced by a requirement presented by the Navy on 28 August 1956 to the OSD Ballistic Missiles Committee, for use of full area south of Site No. 1 [on the northern portion of Camp Cooke]."[12]

From this correspondence, Truax clearly raised the issue of Arguello as a space launch location after his flight, but Navy interest precluded further Air Force action. The Navy, in fact, had been under pressure for several months from Rep. Carl Vinson (D-GA), chair of the House Armed Forces Committee, to locate a naval air station at Camp Cooke. Concerned that foggy conditions at Camp Cooke would limit flying time, however, the Navy had preferred Lemoore in central California. Meanwhile, the initial Project Corona reconnaissance flights would launch from north Vandenberg Thor sites, while Air Force priority would remain focused on developing ICBM and IRBM operational capability.[13]

The decision to construct the Atlas space launch sites on Arguello, in fact, came two years later, in the spring of 1958, and was made by the Advanced Research Projects Agency, not the Air Force. ARPA had been formed on 7 February 1958 by the Eisenhower administration to coordinate service space efforts in response to Sputnik. It was bitterly opposed by the Air Force, which lost full control of programs like Samos and MIDAS.[14]

In May 1958, Truax joined ARPA, where he became responsible for the Advanced Reconnaissance System satellites. It is likely that Truax, now clearly well positioned to directly influence ARPA's decision to have Atlas sites built on Arguello, contacted Freitag. Freitag would no doubt have assured him of naval support. The Navy saw that having sites on Arguello would give them more control as the range authority and end the problems caused by the overflights from Vandenberg North. This was also when the Navy officially activated the PMR.[15]

ARPA's decision to construct the Atlas launch complexes on Arguello came in ARPA Order no. 41-59, issued to the commander of ARDC on 17 November 1958. In authorizing the project, the order cites a WDD proposal transmitted in a Ballistic Missile Division (BMD) memo of 2 September. Back in April of that year, WDD had proposed constructing a WS 117L/SM-65 launch complex in the Cooke-Navy area, and it continued to support such a project. Despite what appears to have been Air Force support for construction of Atlas sites on the Navy's Arguello peninsula, however, Freitag offered a contrary opinion in a 16 September 1959 memo, "for Navy use only." Reviewing the decision, Freitag asserted that "AF was forced by ARPA to place Sentry (Samos) satellite pads at Arguello."[16]

Freitag's memo came during the dispute between the Air Force and Navy regarding use of the PMR and delays in Atlas site construction when the Navy evacuated all civilian personnel from Arguello during Thor-Agena Corona launches from Vandenberg North. These concerns compelled General Schriever, ARDC commander, to complain to then Chief of Staff Gen Thomas D. White, in a 15 September 1959 letter, about problems at Arguello and to lobby for using Launch Complex 65-1 on Vandenberg North for Atlas launches of Samos satellites. For some time, Schriever and other Air Force leaders had preferred to keep the Thor-Agena operation on Vandenberg North and have three Atlas ICBM pads at Launch Complex 65-1 converted for Samos launches. In doing so, the Air Force, not the Navy, would have more control of Thor and Atlas space launches.[17]

By the time of Schriever's September 1959 letter, Truax had departed ARPA. Looking back on his role, considerable evidence strongly suggests that Truax had much to do with the selection of Vandenberg South as the primary West Coast region for Air Force space launch activity.

The Air Force–Navy PMR Dispute

ARPA's decision in 1958 to authorize construction of space launch sites at Arguello occurred against the backdrop of an intense dispute between Navy and Air Force leaders over PMR operating procedures and space launch prerogatives. The local dispute also reflected the larger issue of Air Force–Navy rivalry for military space supremacy.

OSD created the PMR as a national range, as recommended by the Special Committee on Adequacy of Range Facilities that OSD had established in July 1956. With the policy of a "common user" range for tri-service support, the PMR would serve all agencies requiring its unique facilities. This made it highly likely that Air Force and Navy interests would overlap in terms of prerogatives and operational activities and requirements. While missiles launched westward from Camp Cooke sparked periodic disagreements, polar satellite launches southward directly over Arguello became a major source of conflict between the two services.[18]

Recognizing the potential for discord and misunderstandings, Air Force Chief of Staff General White and Adm Arleigh Burke, Chief of Naval Operations, signed the "Agreement for Coordinated Peacetime Operation of the Pacific Missile Range" on 5 March 1958. The accord provided for coordination between the 1st Missile Division and PMR officials to fix radio frequencies, establish launch schedules, and to "prevent undesirable duplication of facilities and equipment." The accord also specifically authorized the use of joint tenancy agreements to locate facilities on each other's property when necessary. In a key provision, the service sponsoring the flight was to control flight operations, including missile preparation and launch equipment, control of the flight through impact, and operation of range safety equipment associated with the launch phase. This provision appeared to conflict with the Navy's responsibility for overall range safety, including activation of inflight destruction devices.[19]

That spring, the Navy proposed to greatly expand the scope of PMR activities. In addition to the ballistic missile range and sea test range, it effectively opened the door to establishing equatorial and polar satellite ranges, "including the concept of a test and operational base at Arguello" to be managed by the PMR. As the Navy expanded its activities in the area, the 1st Missile Division became concerned about their effect on Vandenberg's mission. Annoyances included the Navy's request to have its drones stationed at Vandenberg and its proposed operational plan that listed action requirements for the division "without basis of official agreements or proper coordination." A particularly thorny issue involved the Southern Pacific railroad, which ran an average of 18 trains daily through both Vandenberg and Arguello. Despite the railroad operating on 20 miles of track through Vandenberg, the Navy claimed jurisdiction in ensuring safety for the railway passing through both Vandenberg and Arguello as well as the authority to reimburse the railway company for schedule interruptions and the right of PMR to negotiate a unilateral agreement with the railway without Air Force participation. Indeed, Rear Adm J. P. Monroe, the PMR commander, concluded a unilateral agreement with the railroad, declaring that "it is entirely appropriate for the Commander, Pacific Missile Range, to speak for both the Navy and the Air Force insofar as safety and other precautionary measures are concerned." In response, the Strategic Air Command agreed that the PMR should negotiate with the Southern Pacific on reimbursement settlements and reaffirmed that the PMR was responsible for range safety procedures, but for Arguello only.[20]

In another effort to overcome these irritants, 1st Missile Division commander Maj Gen David Wade and his PMR counterpart, Rear Admiral Monroe, concluded a bilateral agreement on 9 October 1958. This agreement reiterated the elements of division and range responsibility as described in the Burke-White agreement and, most importantly, created several joint committees to address procedures, communications, safety, and other areas of mutual concern. Nonetheless, conflict and mistrust continued.[21]

From the Air Force perspective, the PMR-Vandenberg disputes at the local level reflected the larger issue of the future roles and responsibilities of the Navy and Air Force in space. Air Force leaders fretted over their perception of naval efforts to expand the service's space role and make the PMR the Cape Canaveral of the West. Writing to General White on 13 December 1958, Gen Thomas S. Power, SAC commander, expressed his concern, arguing that "the Navy appears to be using custodianship of the PMR to develop an ambitious space program centering on this range." As if to give credence to General Power's concerns, in the spring of 1959, the Navy's Connolly Committee, named after its chair, Rear Adm Thomas F. Connolly, described naval interests in space and advocated further expansion of the Navy's PMR to provide the central launching and control organization for space systems. That January, Admiral Burke announced OSD's concurrence in the Navy's 15-year expansion plan for the PMR. Part of the PMR expansion plan called for additional territory; on 30 January, Navy range officials requested that the Air Force provide a 400-acre portion of Vandenberg adjacent to Arguello for naval use in support of the Arguello Atlas complexes. Wade refused, declaring that no surplus property was available on the Air Force base. The Navy's proposal intensified suspicion that the Navy was continuing its effort to encroach on Vandenberg. It came as no surprise that SAC, the operational command at Vandenberg, declared to Headquarters USAF "that the best interests of the AF will be served by acquiring full ownership, control and operation of Pt. Arguello."[22]

A more contentious problem arose when ARPA directed the Air Force to launch four Discoverer-Corona satellites from Thor launchpads on Vandenberg North beginning on 28 February 1959. Lofted into polar orbits, the flight trajectory took the launch vehicle directly over Arguello, "thereby bringing the NMF [Naval Missile Facility] directly within the launch and climb-out corridor." Even when the BMD provided a new exit azimuth of 182 degrees and 48 minutes, which avoided all of Arguello except the western tip of the peninsula, the Navy remained dissatisfied. Citing the dangers of "overflight," PMR officials responded by closing the PMR, halting construction of the Air Force's Atlas launchpads at PALC-1, and evacuating the approximately 30 residents of Surf, a railroad village on the border between Vandenberg and PMR, together with Coast Guard families at the area Loran station and a few residents at Sudden Ranch. Navy officials also halted train travel through Arguello during overflights. The expense and work delays annoyed the Air Force, which considered the evacuations unnecessary and projected the odds of fatalities in a launch accident to be 200,000 to 1. The central point at issue was safety and responsibility, with both sides arguing that the other should fund civilian evacuations for Air Force polar launches.[23]

In January 1959, Wade had proposed establishing a joint facilities review committee to prevent duplication of facilities on Vandenberg and the PMR. On 4 February, shortly before the initial Discoverer flight, Monroe responded favorably, arguing that duplication could be avoided by long-range Air Force planning directed at ending southward flights from Vandenberg. "I trust," he said, "that the Air Force has no . . . plans to continue polar satellite shots from Vandenberg . . . once facilities are available at Arguello." He went on to recommend the Sudden Ranch, abutting the southern boundary of Arguello, as the ideal, southernmost site for polar launches, and "our planning should locate future sites there." That April, PMR representatives signed a lease agreement with Sudden Estate Company that provided access to ranch property, permission to apply certain security and safety regulations, and reimbursement to the company. The agreement also stipulated that access could not be granted to other entities. Naval leaders would continue to press for an end to polar launches from Vandenberg North, and Air Force leaders would invariably refuse to do so.[24]

In its argument for ending polar launches from Vandenberg North, the Navy cited the 22 November 1957 memo from the director of guided missiles that stated, "Firings for research and development or other than training purposes are not authorized." Considered R&D activities, Discoverer satellite launches, they contended, had been approved informally as an expedient only until completion of the Arguello facilities. Air Force leaders, in turn, would repeatedly decline to commit to terminating polar launches from Vandenberg. In fact, the Navy was aware that Wade had written to William M. Holaday, director of guided missiles, recommending that "development of NMF Pt. Arguello be ceased." In short, the Navy wanted Vandenberg to remain a ballistic missile training base, while the NMF at Point Arguello would become a national satellite launching site, under Navy control.[25]

On 22 April 1959, in the middle of the dispute over polar launches, Burke made "a bold bid for a major share" of the space mission by proposing to his Joint Chiefs of Staff colleagues the creation of a joint military space agency. In effect, he advocated a unified command for space based on the "very indivisibility of space," projected large-scale space operations in the future, and the interests in space of all three services. Air Force leaders, recognizing the threat to Air Force prerogatives, mounted a vigorous and ultimately successful campaign in opposition, as tensions between the Air Force and Navy mounted over the late spring and summer.[26]

By the fall of 1959, both sides sought revision of the 5 March 1958 Burke-White agreement as a means of consolidating their positions and easing tension. Air Force negotiators centered on what they referred to as "weapon system integrity," whereby the "commander responsible for launching operational vehicles possesses single direction and control." The Navy considered this argument a smoke screen for the Air Force to claim everything essential to support satellite operations, thereby duplicating available naval facilities. As Freitag, now the astronautics officer in the Bureau of Naval Weapons, explained in a memo to the deputy chief of naval operations, under this concept the Air Force refused to use PMR services. Air Force leaders, he said, "demand their own control, safety (from VAFB [Vandenberg AFB]) and private (and duplicate) communications and cables from Arguello pads to AF 'weapon system control center' in VAFB." With the weapon system integrity concept, the Air Force has "justified, and gotten away with, duplicating most of PMR capabilities."[27]

Negotiations between the two sides, at various levels, continually broke down. Freitag declared, "the differences were considered so fundamental that the problem was passed to the Secretaries of the two services." Although at one point it looked like the issue would have to be decided by Secretary of Defense Neil McElroy, LeMay (now Air Force vice chief of staff) and Burke managed to conclude a new agreement on 22 September 1959. The "Burke-LeMay Agreement for Coordinated Peacetime Operation of the Pacific Missile Range" confirmed the Navy's responsibility for range safety criteria, including inflight destruction, as well as coordination to prevent duplication and all common-use facilities. The Air Force, nevertheless, retained control of its own flight preparation, launch devices, and the space vehicles from launch until impact or the last-stage burnout of satellites and space vehicles.[28]

Although the agreement seemed a compromise in the Navy's favor, the Air Force position had improved, because the agreement also allowed satellite launches from Vandenberg North to continue and recognized Point Arguello as a range-managed launch area for R&D flights. Moreover, four days before the agreement was issued, McElroy agreed to return Samos, MIDAS, and later Discoverer satellites from ARPA to Air Force control. Together with warding off a joint operational agency for space and receiving designation as the nation's "military space booster service," the Air Force had found itself in a relatively strong position in its rivalry with the Navy for space superiority. Now—with Air Force rather than ARPA money financing space launch—the service would be less inclined to compromise with its naval counterparts.[29]

As these developments unfolded, the Advisory Group on Ranges and Space Ground Support, established in August 1959 by the secretary of defense, continued its investigations. Led by Walker L. Cisler, a widely respected founding member of the National Academy of Engineering, the committee kept the services busy with requests for reports, briefings, and facility tours. The Navy had not given up its interest in tri-service space operations centered on Arguello, as shown by Monroe's lobbying of the Cisler committee. Citing the continued safety problems posed by Discoverer flights over Arguello, he argued that the Sudden Ranch area presented the ideal launch area for polar flights. Its canyons would provide "the optimum satellite launching facilities in this country" and eliminate the overflight and safety problems caused by Discoverer firings. "The entire polar orbiting capability of this country should be located there," he said, and should consist of multipurpose launchpads operating as a national facility for all users. Meanwhile, Air Force leaders remained concerned that the Navy still planned to implement the "master plan" for expansion described in the Connolly Report.[30]

The Cisler reports that appeared during December 1959 and January 1960 recommended creating a high-level coordinating element to supervise the entire range and space ground support program. After considerable review, Director, Defense Research and Engineering (DDR&E) established two new offices in April 1960: Deputy to the Director, Defense Research and Engineering, under Air Force Lt Gen Donald N. Yates; and Assistant Director, Defense, Research and Engineering for Ranges and Space Ground Support, under Alvin G. Waggoner. With these two offices in place, an effective high-level authority now handled many local Arguello-Vandenberg problems. Yates addressed the overflight issue, for example, by authorizing a relaxation of safety criteria in special circumstances and directing negotiations with the railroad for track clearance well ahead of scheduled launch windows.[31]

As one observer concluded, "Policies were made, conferences were held, and the situation gradually subsided to the day-to-day problems that normally exist between ranges and range users." Indeed, over the next three years, Air Force and Navy disputes remained mostly minor and quickly resolved, even though Thor-Agena flights from Vandenberg North continued and the Navy responded by evacuating Arguello. It should also be recognized that the long-running Air Force–Navy dispute over Vandenberg and PMR operations and responsibilities remained largely confined to the higher echelons locally and seldom affected operational personnel. For working level launch controllers like Air Force 1st Lt Bill Thurneck, for example, the Navy played no role. Looking back over his experience at the Arguello launch complexes, he said, "I don't recall the Navy being involved at all in our operations."[32]

Vandenberg South Atlas Launch Sites for Samos and MIDAS

The development of Vandenberg South began with the construction of the initial Atlas launch complex, referred to by the Navy as Point Arguello Launch Complex 1 (PALC-1) and later, after the Air Force annexation of the PMR, as Space Launch Complex 3 (SLC-3).[33]

In the summer of 1958, the Air Force Ballistic Missile Division (AFBMD) established a field office that would be responsible for all aspects of preparing for and conducting WS-117L satellite launch operations at Vandenberg North and at Point Arguello. Affectionately referring to themselves as the "Dirty Dozen," the original 12-member field office "blue suit" contingent oversaw the construction of the launch sites, served as launch controllers, and assumed the role of prime integrator of missile launch systems. Although chosen for their high-level skills and training in selected areas, the Dirty Dozen pioneers still had to deal with new equipment and develop new procedures. Because most of the field office personnel had very limited experience with actual test and launch preparation, they learned "on-the-job" and focused their efforts on speed, innovation, and end-to-end testing to ensure reliability.[34]

On 2 September 1958, the AFBMD transmitted a memorandum to ARPA, "Preliminary Construction Proposal Pt. Arguello Launch Complex," with the original design drawings prepared by the Ralph M. Parsons architectural-engineering firm the previous year. Three months later, on 17 November, ARPA authorized ARDC to construct a launch complex for Sentry (Samos) based on the 2 September proposal. Funded by ARPA and administered by the Navy's Eleventh Naval District, the contract was awarded in January 1959 to Wells-Benz Inc. of Phoenix, Arizona, and the company began construction on 1 April 1959.[35]

No one played a more important role in these early days than Capt Robert W. "Rob" Roy, an original member of the Dirty Dozen, who arrived at Vandenberg in September 1958 from Patrick AFB, Florida. At Patrick, he had been the launch controller for both Matador guided missiles and Thor IRBMs and had served as AFBMD staff officer there for Samos and MIDAS programs. At Cape Canaveral he also had been involved in establishing end-to-end testing under a military officer as prime integrator of the missile systems. Up to that point, Air Force officers had simply been onlookers while a civilian contractor had served as prime integrator. At Vandenberg he became the BMD field office contingent's assistant operations officer and chief of launch operations, responsible for training all launch controllers during his six-year assignment. Roy prided himself on his work in establishing space launch operations, commenting that "the initiation of mission operations was my forte."[36]

Given his Matador and Thor experience at the Cape, Roy spent the first six months at Vandenberg as military liaison for the construction of the Vandenberg North Thor pads and for installing blockhouse, or launch operations, equipment. As one of only two officers cleared for the highly classified Corona program, he also served as launch controller for the first 13 Thor-Agena Discoverer missions. Security presented a special challenge, as payload security clearance between participants, both civilian and military, did not exist. Furthermore, he recalled, "the military pad personnel did not have manuals or training material. . . . We learned from . . . [contractors and their company manuals] . . . as the launch pads were built." Captain Roy realized immediately that what previously had been separate countdown procedures for the different subsystems required system integration, incorporating the disparate elements into a single integrated mission countdown. To accomplish this, Roy explained, "I developed what I called a binaural communications console. I could listen to any selected subsystem countdown with one earpiece and to others with the other earpiece. . . . The purpose was to be able to detect a problem or issue and focus in upon the issue until it was cleared." This became the standard console at the Arguello Atlas sites, too.[37]

While heavily involved with Thor-Agena operations on Vandenberg North, Roy also oversaw the construction of the more complex Atlas launch sites on Point Arguello. After the launch of *Discoverer 13* on 10 August 1960 and having trained two replacement controllers for Thor-Agena operations, Roy now could devote himself entirely to Atlas-Agena issues. In January 1961, 2nd Lt William Thurneck joined Roy, "who was still pretty much the entire launch team for the Atlas-Agena program." With two other junior officers, Roy's crew worked 12-hour shifts preparing the Arguello complexes.[38]

In June 1959, two months after construction began on the first Atlas site, the Navy initiated Operation Burn, whereby a "burn-over" of nearly 5,000 acres set the stage for a demolition squad from Point Mugu to clear the area of unexploded shells left over from WWII and Korean War training operations. On 10 September 1959, with completion of brick and mortar construction under the supervision of Roy and his military crew, the Air Force accepted the 40-acre PALC-1 complex, including both pads, from the facility construction contractor. Work continued on the "infrastructure." Six months later, on 18 March 1960, the Navy turned PALC-1 over to the BMD, and the first Atlas-Agena launch occurred on 11 October 1960.[39]

The west (PALC-1-1) and east (PALC-1-2) launchpads, configured for Samos and MIDAS satellite launches, respectively, were essentially identical and shared several key buildings and structures. A 41,384-square-foot, earth-covered Launch Operations Building (Bldg. 763), or blockhouse, contained consoles and communication equipment used to control and monitor the launch. Roy's binaural communications console facilitated operation of the master countdown network and the system network between the launch controller, range operations, and Mission Control. Above-ground cable trays connected the launch operations building to each launchpad.[40]

Two single-level, 15-foot high concrete launch service buildings (Bldg. 751, Bldg. 770) supplied mechanical, pneumatic, and electrical interfaces to the vehicle and payload while also supporting the elevated concrete pad, or launch deck, with the stationary launcher. The launch service buildings also housed the umbilical mast trench when not in use and a concrete flame deflector, or bucket, under the launcher to direct water through a deluge channel to a retention basin. A retractable umbilical mast of welded steel 98 feet 7 inches long and 6 feet 6 inches wide, a unique feature of PALC-1 among Atlas pads, enabled servicing of the vehicle with fuel, air conditioning, electricity, and pressure during launch preparation and launch.[41]

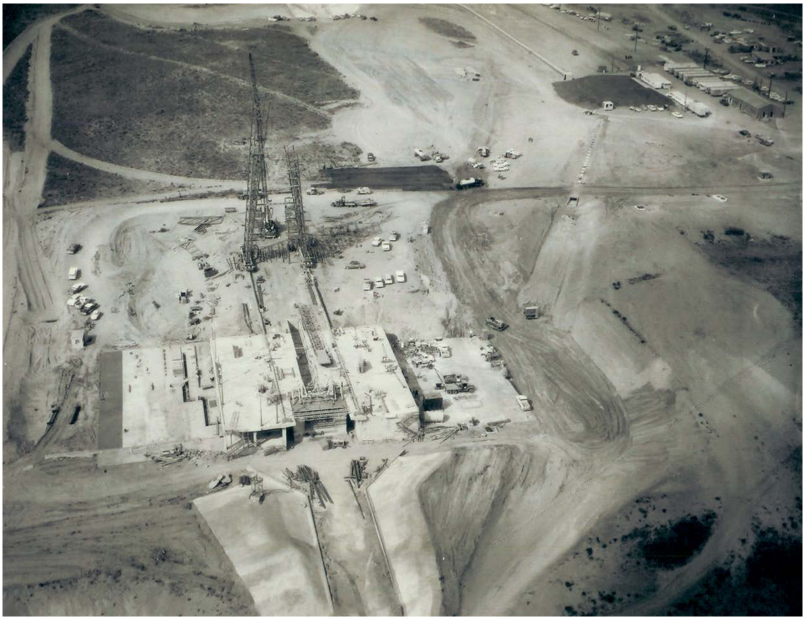


Fig. 6. Point Arguello Launch Complex (PALC) 1-2 (SLC-3E) under construction, 3 November 1959. (Photo courtesy of John Hilliard)

The most recognizable features of PALC-1 were the two mobile service towers, or "A" frame gantries, with cranes measuring 135 feet high and 50 feet wide at the base. They facilitated the erection, assembling, and servicing of the launch vehicles. As Roy explained, "We first installed the elevator, instrumentation, and power cables to pad tunnels, . . . followed by installing work stations . . . communications, power sources, and equipment at different levels. Thorough testing followed." Mounted on steel wheels, the gantries moved east on rails in front of the Launch Service Building from their parking position on the north end of the launchpad to their service position over the flame bucket.[42]

The Atlas complex also included a 2,613-square-foot vehicle support building (Bldg. 766); a 10,320-square-foot complex service building (Bldg. 762); a 2,628-square-foot technical support building (Bldg. 761); three 48-square-foot traffic check houses; four 36-square-foot theodolite shelters; fuel and oxidizer storage tanks on ground-level "aprons" on each side of the launch deck; and a "package" sewage plant. A six-foot high barbed wire security fence surrounded the complex.[43]

Launch Operations at PALC-1/SLC-3

SLC-3 operations involved two types of Air Force "blue suit" personnel, referred to as the project team officers and launch controllers. Project officers worked in the Missile Assembly Building (MAB), Bldg. 8310, with Lockheed, General Electric, Kodak, and Itek contractors on Agena and payload preparation. Capt Joseph D. "Don" Mirth arrived at Vandenberg in June 1960 after a year at Lockheed's Sunnyvale, California, space systems facility, where he worked with contractors testing Agenas. As a member of the project team, he frequently visited contractor facilities to accept the satellites from the contractors after a rigorous testing program agreed to by the Air Force team and the contractors. Once the Air Force contingent approved subsystem test results and the all-important combined (simulated) systems test, or "sim flight," the contractor shipped the vehicle to its MAB on Vandenberg North. There, the Air Force–contractor team integrated the payload with the Agena and then repeated the subsystem and full integrated system testing program before sending the vehicle to the pad. Nearly identical sim flights were run at the contractor's factory, the MAB, and at the launchpad. For several programs, the MAB cycle represented the initial testing of the satellite payload and Agena upper stage together. After delivery of the vehicle to the pad, the project officers took part in the further testing of the Agena and payload.[44]

As Mirth remembered, "I spent very many miserable, cold, windy hours, days and nights in those towers at the pad." An especially hazardous task in the towers was detecting highly toxic propellant leaks from the Agena. Because the leak detection sensors frequently failed, officers relied on their sense of smell. Mirth recalled sniffing the "rotten egg" smell of the red fuming nitric acid or the hydrazine, then locating the leak, wiping it off with a rag, and discarding it in a barrel next to him on the tower. Current procedures would require evacuating the base, but in those days "we were all young and infallible."[45]

The second blue suit contingent comprised the launch control team that directed everything that took place at the launchpad. As Roy explained, his crew lacked extensive training, and he challenged them with high expectations and demanding requirements. He spent a lot of time training, he said, and "passing on my preparation, test, and launch experience and philosophy. . . . I was confident that I was right, and they had to *prove* otherwise if they did not agree with me" (emphasis in original). As with the Thor-Agena vehicle system, the basic procedure called for the contractor to propose a test and the Air Force controllers to modify as necessary and approve the procedures. These involved the booster, Agena, satellite payload, and ground support equipment. The satellite's arrival at the pad was the first time the Agena encountered the booster and, in certain cases, the satellite as well. In the blockhouse, each major contractor had a launch conductor responsible for their part of the launch cycle during end-to-end all-systems testing and the countdown. They reported to the Air Force launch controller, who managed the testing countdown and ensured system integration that embraced separate contractor, range, operations, and integration of classified payloads.[46]

Another project officer, 1st Lt Robert A. "Rosie" Rosenberg, arrived at Vandenberg as guidance specialist in September 1959 after an assignment at the Lockheed Sunnyvale, California, factory where he, like Mirth, tested and certified the Agena vehicles before they were shipped to Vandenberg. He remembers that there was no orientation for space launch operations, training, or operations material, stating, "We were there to make it happen at the beginning . . . so I guess it would be fair to say we were the generation that led to creation of manuals." Mirth confirmed, "We started with whatever info we could find that told us how this new system was designed and how it was going to operate in orbit." He elaborated, "We were always creating new plans and procedures and running new tests [at SLC-3]," Mirth said, because "we dealt with multiple launches of six new systems, and four or five different booster and Agena configurations."[47]

Samos

On 11 October 1960, an Atlas-Agena A initiated the west pad of PALC-1 when it launched the first Samos E-1 satellite. Samos, formerly known as Sentry, represented the reconnaissance element of the original WS-117L program and at first involved collecting photographic and electromagnetic reconnaissance data and transmitting the information via a "readout" system. Termed electro-optical readout, the photographic data was to be collected by cameras in the Agena spacecraft, like the Corona payloads. However, unlike Corona's film retrieval procedures, the Samos film would be scanned electronically in orbit and converted to electrical impulses for transmission to ground stations. Like the Atlas, Agena, and MIDAS programs, Samos was entirely an Air Force project and represented the BMD's largest space program. Corona, by contrast, was considered only an interim program until the more complex and sophisticated Samos became operational and could provide "real-time" intelligence to users like the Strategic Air Command. Moreover, management of Corona involved three entities: the director of the NRO, normally the undersecretary of the Air Force; the CIA; and the uniformed Air Force.[48]

The first two Samos flights carried the E-1 Eastman Kodak camera system, consisting of a 6-inch strip camera with a ground resolution of 100 feet on a side. These flights were considered component demonstration flights designed to confirm the operational capability of the electro-optical readout system. The 11 October 1960 Atlas lifted off successfully, but faulty installation of the pad umbilical release lanyard led to the nitrogen fill line being ripped out at launch. With the nitrogen pressure gas escaping, the Agena had no attitude control and failed to achieve orbit. The second E-1 test launch, on 31 January 1961, achieved its 200 nautical mile orbit and successfully transmitted images until the twenty-first orbit, when an attempt to jettison the accompanying F-1 ferret electronic intelligence system antenna partially blocking the camera apparently destroyed the satellite vehicle.[49]

Nine months later, on 9 September 1961, the third Samos launched the E-2, a more capable camera system with a 36-inch focal length lens and ground resolution of 20 feet. Engineers had also developed a method to provide stereo imaging, if only of a limited area on either side of the ground track. The E-2 also acquired a large nose cone in the shape of a mushroom, given Air Force interest in flying a manned capsule shaped like the Mercury spacecraft.[50]

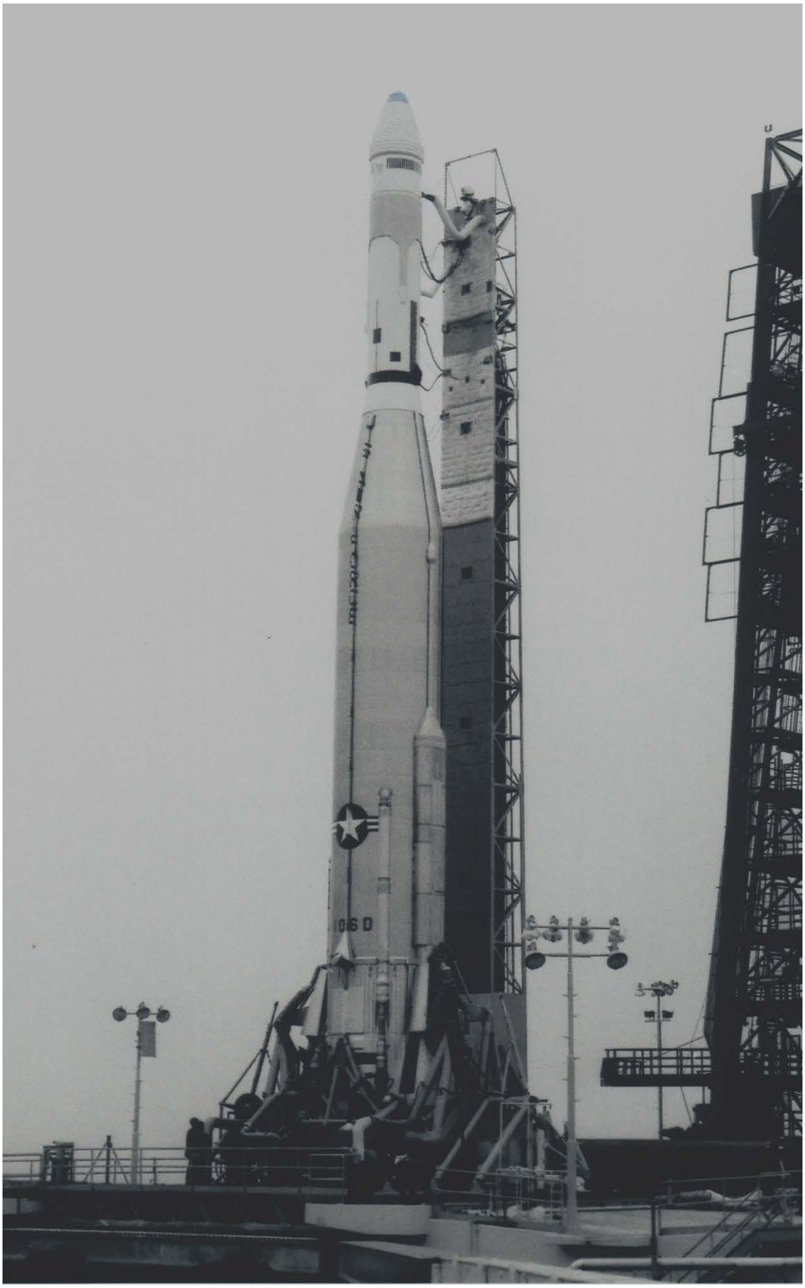


Fig. 7. The Atlas 106D-Agena B, Samos 3, at PALC-1-1, 9 September 1961. (Photo courtesy of John Hilliard)

As the project officer for the E-2 satellite, Mirth recalled no particular problem with his "baby" during combined system or sim flight testing at the MAB and on the pad. As with all Samos, MIDAS, and later Gambit satellites, most challenging were the orbital command-and-control system test and validation requirements that differed considerably with each system. Mirth noted that the Samos and MIDAS systems functioned similarly during the boost phase but were significantly different once they reached orbit. Because little commonality existed between orbital guidance requirements of the different systems (and their variations), test procedures needed to reflect those differences. Unfortunately, the E-2 launch was a spectacular failure. Investigators determined that the Atlas lost electrical power when the pad umbilical disconnected a fraction of a second too late. After ascending approximately 12 inches, it fell back to the pad and exploded in a massive fireball. With fires burning and hypergolic puddles and debris all around him, Roy (by this time a newly appointed major) ventured into the flame bucket with a tarp to cover the classified payload and controlled this very dangerous situation.[51]

Although the film-readout method offered the promise of timely intelligence imagery from a satellite that could remain on orbit for weeks, the readout system could only transmit several dozen images per day, with inadequate resolution. Moreover, some images of the Soviet Union could not be transmitted because of insufficient time when in sight of the ground station. Full coverage would require additional satellites on orbit and more ground stations, thereby substantially increasing the project's cost. Faced with these issues, Undersecretary of the Air Force Joseph V. Charyk in September 1961 decided to reorient Samos by replacing the readout project with the E-5 satellite, a film and camera retrieval system that would be more sophisticated than that of the pioneering Corona.[52]

The E-5 used a 66-inch focal length Itek panoramic camera, with expected resolution of 5 feet and limited area stereo capability. The camera was positioned inside a Lockheed-designed pressurized recoverable, man-sized spacecraft capsule. Pressurized to one atmosphere with temperature approximately 70 degrees Fahrenheit with relative humidity of nearly 50 percent, the capsule also had weight and volume constraints. Unlike Corona procedures, both camera and film were deorbited in the capsule for mid-air recovery.[53]

The Samos camera and film retrieval program began with three E-5 flights, the first two consisting of diagnostic payloads. On 22

November 1961, the first E-5 Samos flight experienced a guidance failure T+245 seconds into launch. Later investigation determined that the heat shield covering the Atlas's retrorockets accidentally separated. The resulting loss of pitch control and improper booster and sustainer engine cutoff signals placed the Agena in the wrong direction for orbital insertion and sent it into the Pacific Ocean when its engine fired. With this flight, the veil of secrecy closed over Samos and all DOD reconnaissance programs, as President Kennedy issued an executive order that November that effectively removed classified programs from public view.[54]

The Air Force launched the next two Samos E-5 satellites from PALC-1-2/SLC-3E due to schedule availability. Although both achieved orbit, their capsules could not be recovered. On the 22 December 1961 Samos E-5 mission, the sustainer engine did not cut off as programmed, resulting in the draining of the liquid oxygen. The Agena satellite ended up in a high orbit, which prevented a successful deorbit maneuver. Although the capsule could survive reentry and land nearly anywhere, its descent would be too rapid for air recovery. On 6 January, data suggested that *Samos 5* had landed somewhere in northwestern Canada. But when an American recovery party requested permission to search the area without explaining its purpose, the Canadian government, suspecting that the target was a nuclear warhead accidentally lost by a B-52, refused permission. The satellite debris was never located.[55]

Dismayed by the lack of success, Charyk canceled the Samos E-5 program on 4 December 1961. Nevertheless, the third and final Samos E-5 mission proceeded as scheduled. Launched on 7 March 1962 with the first operational camera system, the flight experienced no problems with the launch and the first 13 passes. A few incorrect ground commands, however, led to depletion of the satellite's attitude control gas by pass 21. The satellite then entered a high apogee orbit when the Agena fired for the deorbit maneuver. With no functioning electrical system, air recovery again was not possible. The satellite fell, on 17 July, into the Arabian Sea, where it sank without any effort to retrieve it.[56]

Back in July 1960, after the downing of Francis Gary Powers's U-2 in May, a United States Intelligence Board analysis had called for a reconnaissance satellite capable of high-resolution images and the capability of searching the entire Soviet Union for ICBM launch sites. The Air Force, in fact, had already begun planning for such a system, as the E-5 had insufficiently high resolution needed for technical intelligence on Soviet ICBMs and covered too small of an area to acquire new targets. The upgraded Samos camera system, designated E-6, had a 28-inch focal length, ground resolution of 8 to 10 feet, and covered a swath 174 miles in width. In what became a postscript for Samos, after the third E-5 capsule recovery mission, Samos controllers launched five E-6 missions between 26 April and 11 November 1962. Although all five launched successfully, no imagery was recovered. The Air Force terminated the Samos recoverable capsule project after the last mission.[57]

The Samos E-1 and E-2 electro-optical readout systems were overly ambitious for the technology of the era and never reached the lofty predictions of high-resolution images and adequate coverage. In fact, the E-2 camera could only image 64,000 square miles of Soviet territory each day, whereas a Corona camera could photograph up to 1.5 million square miles daily. Not until the KH-11 Kennen (Crystal) reconnaissance system became operational on 19 December 1976 did an effective readout capability become operational.[58]

Resolution and coverage limitations, compounded by Atlas and Agena problems, also affected the E-5 recoverable film retrieval Samos satellites. The E-5 could never achieve the high-quality, high-resolution imagery or coverage of all Soviet ICBM sites required for intelligence analysis. Any effort to improve camera capabilities was constrained by the recoverable capsule's weight and volume restrictions; but reconnaissance imaging may very well not have been the Air Force's top priority for the E-5. Indeed, space historian Dwayne Day persuasively argues that the Air Force was more interested in developing a manned space flight capability than the reconnaissance mission. Instead of allowing the camera designers full rein in developing the system, both Lockheed and the Air Force agreed on a contract requiring a man-sized, pressurized spacecraft. "To some members of the CIA," Day asserts, "the Air Force development of the Samos E-5 was a two-strike lesson in why the Air Force could not be trusted to lead in satellite reconnaissance—not only had the Air Force failed again to produce a useful reconnaissance system, but it had allowed its other priorities to get in the way of reconnaissance requirements." In an interesting turn of events, the E-5 manned spaceflight elements would disappear, while the NRO's KH-6 Lanyard program would revive its reconnaissance camera.[59]

With the failure of Samos E-6 to provide the intelligence imagery that the E-5 could not, reconnaissance planners turned to their second alternative, Gambit, which Atlas-Agenas and later Titan IIIBs would launch from Vandenberg's PALC-2/SLC-4, the second Arguello Atlas launch complex. Meanwhile, with the demise of Samos, the PALC-1 West pad was reconfigured for Thor-Agena launches of the increasingly successful Corona reconnaissance satellites.[60]

MIDAS

Like Samos, the MIDAS early warning satellite program experienced a troubled history and never became operational. Unlike Samos, however, MIDAS proved able to lay the groundwork for the immensely successful operational Defense Support Program (DSP) system to follow. MIDAS also relied on the Atlas-Agena booster satellite combination and was launched exclusively from PALC-1 East.

When it came time to select the East pad, the Navy preferred to have the three (later reduced to two) MIDAS sites located in La Honda Canyon, more than nine miles southeast of the PALC-1 West complex. The Air Force much preferred a site more contiguous with PALC-1 West. The Navy argued that their choice would preclude any interference with their Terrier, Sunflare, and Tumbleweed launch operations, and their proposed MIDAS pad and infrastructure location would put it within several hundred feet of their planned road and infrastructure construction currently underway. Most importantly, being situated as far south and west as possible would diminish safety concerns by requiring only minimum evacuation of personnel. Air Force representatives argued that having the MIDAS facility essentially contiguous with the Samos West operation would produce economies in equipment and personnel, minimize pollution of Arguello land, and avoid the redesign and additional site development work required by the proposed Navy site. In June and July 1959, 1st Missile Division and PMR representatives met to agree on site selection. When agreement could not be reached at the local level, higher authorities stepped in and eventually endorsed the Air Force position of contiguous PALC-1 West and East launchpads.[61]

The program experienced problems from its inception. MIDAS relied on advanced electronic and cryogenic technology to move beyond the visual spectrum to the spectrum of much longer infrared wavelengths. By recording heat emissions from objects on Earth, infrared radiometers in aircraft could produce thermal pictures during darkness and identify camouflaged targets. MIDAS envisioned using polar orbiting Agena satellites with infrared scanners mounted on a rotating turret that scanned the earth continuously to detect ICBM exhaust flames within moments of their launch and provide command centers a 30-minute warning of an ICBM attack. Initially, planners expected to launch MIDAS satellites into polar orbits at 300 miles altitude, but the high-intensity background radiation from sunlit clouds and other phenomena convinced officials to raise the altitude to 2,000 miles. Even so, the challenges remained formidable.[62]

The MIDAS story illustrates complexities faced by Air Force space planners determined to develop a much needed but technologically challenging system during the tenure of Secretary of Defense Robert S. McNamara. Air Force operational commands favored early operational capability for MIDAS and, because of early failure, the Defense Department preferred a more deliberate, research-oriented focus. As a result, MIDAS experienced a rocky development road, often appearing to end in premature cancelation of the project.

When the Kennedy administration took office in early 1961, MIDAS already faced major survival hurdles. Early technical difficulties convinced DOD officials to reemphasize technical development, while Air Force leaders, concerned about the growing Soviet ICBM threat, lobbied hard for an early operational date for the infrared detection system. The disparity of opinion convinced DDR&E chief Herbert York to authorize two radiometric tests aboard upcoming Discoverer/Project Corona flights. The planners hoped that these experiments would answer the basic question surrounding the future of MIDAS: could the infrared detectors distinguish between missile radiation in the boost phase and high-intensity natural background radiation? Meanwhile, in September 1960, Dr. W. K. H. Panofsky of Stanford University headed a panel of the President's Scientific Advisory Committee, which concluded that the MIDAS concept remained sound and that every effort should be pursued to overcome engineering problems and produce an operational system by 1963.[63]

Early in 1961, after a considerable number of program revisions, BMD planners continued work on a "final" development plan that excluded any reference to operational funding or capabilities in favor of concentration on research and development. The plan appeared on 31 March 1961. It scheduled 27 development launches rather than the 24 proposed earlier, with initial operational capability set for

January 1964. Planners hoped to achieve a 24-month satellite lifespan, but by mid-June 1961 Charyk balked at authorizing an operational configuration without additional infrared sensor data from forthcoming flights. Operational and logistic planning priorities gave way to emphasis on demonstrating acceptable early warning techniques.[64]

The technical and political uncertainties, along with Air Force criticism, compelled Harold Brown (the Kennedy administration's new DDR&E chief) in the summer of 1961 to appoint a study group headed by his deputy, John Ruina, to examine the issues of MIDAS technical capabilities and mission importance. Although the Air Force considered the Ruina study just one more in a long line of investigations that had delayed MIDAS development, Schriever went to the heart of the matter when in the fall of 1961 he told General LeMay that "complete satisfaction can only be achieved by a conclusive demonstration of system feasibility through an orbital flight test that detects and reports the launch of ballistic missiles and has a reasonable orbital life." Such capability appeared far in the future. The first two flights, under the auspices of Project Corona, launched from Cape Canaveral on 26 February and 24 May 1960 but produced little significant data. The first launch failed after an explosion occurred upon separation of the second stage Agena from the Atlas booster, while *MIDAS 2*'s sensors operated successfully for two days from its 300-mile-high orbit before its attitude control system failed.[65]

After the second flight, Air Force planners decided to move operations to the new Point Arguello complex and launch MIDAS satellites into polar and orbit from the PALC-1 East pad. The third MIDAS spacecraft, launched on 12 July 1961, returned data from its experimental infrared telescope for only five orbits before failure of the solar array auxiliary power. Although *MIDAS 4* successfully achieved a near circular polar orbit at a 2,200 nautical mile altitude on 21 October 1961, it lost attitude control after the retrorocket package heat shield broke off and operated for only seven days without meeting any of the flight's objectives. The early MIDAS failures led to a six-month hiatus, during which time two Samos E5 satellites launched from PALC-1 East.[66]

Even before the Ruina group issued its report, the Office of the Secretary of Defense deleted all fiscal year 1963 MIDAS nondevelopmental funds and refused to sanction an operational system. The Ruina report deepened a mood of doom and gloom. Issued on 30 November 1961, it faulted the current MIDAS design as too complex for reliable use, expressed skepticism regarding the system's ability to detect solid-propellant missiles, and criticized the Air Force for focusing on immediate operational capability to the detriment of essential research and development. The report recommended a major reassessment to produce a simplified MIDAS with more attention directed to R&D. In December, Brown directed the Air Force to implement the group's findings. SSD moved quickly to form an advisory group under Clark Millikan of the California Institute of Technology to assess the Ruina report. The Millikan group faulted the Ruina panel for being unaware of the scope of available test data and for erroneously analyzing the cloud-background-clutter data in assessing the infrared sensor's capability. A simplified system, the group asserted, could be operational before 1966.[67]

Of the various plans Air Force Systems Command prepared, the most convincing one stressed R&D and more test flights. Then, on 9 April 1962, the Air Force finally found itself in a position to break the logjam on MIDAS development: a fifth MIDAS flight achieved polar orbit and began transmitting data that demonstrated it could discriminate between cloud background and rocket exhaust plumes. In response, Brown released funds to sustain the program through the fiscal year, but he declined to authorize development. Meanwhile, MIDAS reviews continued. At the same time, Brown again criticized the Air Force for focusing on an early operational capability without first solving basic questions about low-radiance, noise background, and system reliability. By the summer of 1962, MIDAS supporters had little reason for optimism, and in early August, Secretary McNamara announced reduction of MIDAS to a limited R&D program because of its expected slow development, high costs, available early warning alternatives, and the decreased value of early warning occasioned by the growing importance of hardened missile sites compared to the strategic bomber force.[68]

Further disappointment came on 17 December 1962 when, after eight months of preflight changes and improved gyroscope package testing, the sixth MIDAS flight failed after controllers lost Atlas telemetry during terminal count but went ahead with the launch anyway. The Atlas lost engine hydraulic fluid, became unstable, and self-destructed at T+80 seconds. By the spring of 1963 it appeared that MIDAS might be doomed to extinction as another system too ambitious technologically to warrant operational development. Then, in May 1963, the fortunes of MIDAS seemed to make an abrupt recovery along the lines forecast by General Schriever two years earlier. On 9 May, an Atlas-Agena launched *MIDAS 7,* Flight Test Vehicle 1206, from Vandenberg AFB into a near-perfect 2,000-mile-altitude circular orbit. Over the next six weeks, the satellite, the first with the upgraded Aerojet W-37 sensor, vindicated its supporters by detecting nine launches of solid propellant Minuteman and Polaris as well as liquid propellant Atlas and Titan missiles. As MIDAS project officer Mirth declared, the "rousing success" of *MIDAS 7* provided proof of concept assurance that a satellite infrared detection system could provide effective early warning of missile threats.[69]

On 12 June 1963, however, *MIDAS 8* experienced the same failure that affected the sixth *MIDAS* flight months earlier, when the mission's Atlas lost hydraulic fluid and self-destructed at T+93 seconds. A few days after the *MIDAS 8* failure, Roy came into Mirth's office, exclaiming, "We have solved the problem!" He showed pad camera film that depicted a small object moving quickly across the screen that proved to be the fly-away heat shield. It had blown off on both *MIDAS 6* and *MIDAS 8* flights, resulting in loss of hydraulic pressure and control. After installing a redesigned heat shield, a subsequent flight on 18 July, *MIDAS 9,* confirmed "real-time" detection of an Atlas E launch as well as the ability to monitor Soviet missile activity. Above all, the flights convinced officials that MIDAS could provide real-time data on missile launches without interference from Earth background "noise." The successful flights prompted Secretary McNamara to reevaluate the possibilities for tactical warning and the future of MIDAS.[70]

The reevaluation period resulted in a three-year hiatus of MIDAS flights. During this time MIDAS received more requirements, as the Air Staff called for a prototype approach on the assumption that neither current technology nor funding constraints warranted an entirely operational system. The Air Staff Board recommended that Air Force Systems Command improve system tracking and launch site identification techniques as well as the real-time detection of low-radiance, short-burning solid-fuel missiles, and that it consider additional defense applications. Most interesting, the Air Staff—in the name of cost-effectiveness—favored the development of more simplified, more reliable satellites with longer orbital lifespans; such satellites also would orbit at higher altitudes to provide greater coverage of the earth with fewer spacecraft.[71]

In early 1964, Secretary Brown agreed to release only half the fiscal year 1964 MIDAS budget allocation, explaining that the "drastic reduction" resulted from alternative early warning systems and anticipated high deployment costs for MIDAS, now referred to as Program 461. Nevertheless, he agreed that the recent flight successes warranted continuing the program, but with four objectives beyond its initial strategic warning function. His list included reliability, global coverage, launch point determination, and real-time detection of nuclear detonations as well as SLBMs and medium-range ballistic launches, presumably IRBMs. The latest modification of the MIDAS effort, the DDR&E chief admitted, envisioned a major deviation from a system originally designed to detect a mass raid of Soviet missiles.[72]

Given the budget cutback, the Air Force remained concerned about the program's future. Scheduled flights would have to be canceled, resulting in termination of contracts, substantial investment losses, and a four-year break between the series of radiometric and system detection flights. Throughout the spring of 1964, Air Force officials negotiated with DDR&E to reach an acceptable compromise. By late spring, the Air Staff proposed a minimal program designed to preserve both near- and long-term objectives by the increasingly prevalent method of slipping the flight schedule and accepting greater technical risk.[73]

Budget cuts and skepticism within DOD circles continued to plague the infrared detection satellite early warning program. In late 1964 and throughout 1965, the Defense Department's proposed fiscal year 1966 through 1969 budget reductions prompted major efforts by the SSD to keep MIDAS afloat without having it revert to development status. Their dilemma did not benefit from delays caused by Lockheed's difficulties with sensor components, a labor walkout at payload producer Aerojet-General Corporation, and reported launch site availability problems at Vandenberg Air Force Base. As revised, the MIDAS program in the latter half of the decade called for two phases of tests. Between 1966 and 1968, flights would conduct a variety of experiments in three stages at altitudes from 2,000 to 6,000 miles; in 1969 and 1970 more tests and a final operational assessment would occur with satellites launched by Titan IIICs to a 6,500-mile orbit. In fact, only three more MIDAS flights took place, in a five-month period in 1966 from June to October, before OSD canceled the program for good.[74]

Throughout its lifespan, MIDAS remained a test program. Although Program 461 had shown conclusively that satellites could provide early warning of a missile attack by detecting and tracking missiles of all sizes, in the late 1960s mounting costs, low budgets, and technical problems—along with ambitious expectations—outpaced the original MIDAS program. Moreover, with the advent of the Titan III booster, it became increasingly possible to contemplate launching larger, more capable infrared detection satellites into geosynchronous orbits, where fewer satellites could cover more ocean and Earth areas. As a result, DDR&E in August 1966 approved Program 949. Originally designed to monitor the Soviet Fractional Orbital Bombardment (FOB) threat, it soon came to be regarded as the replacement for ground-based warning systems such as the Ballistic Missile Early Warning System (BMEWS). As the MIDAS successor, it could ensure simultaneous warning of all three potential space and missile threats: ICBMs, FOBs, and SLBMs. In the spring of 1969, a breach in security eventually led officials to rename Program 949 the DSP. Nevertheless, for all its troubled history, MIDAS had established the groundwork for its incredibly successful successor, which would become the central component in the nation's global missile warning network.[75]

PALC-2/SLC-4 Launch Sites for Gambit

The selection of the second Point Arguello Atlas launch complex, PALC-2, designated Space Launch Complex 4 (SLC-4) in July 1964, offers an example of the influence of junior officers in this early era of space launch. Rosenberg recounted how, in early 1960, several months after arriving at Vandenberg, he was chosen to pick optimum sites for the second Atlas launch complex because the Navy owners of Point Arguello had selected locations that Air Force leadership considered unacceptable. As with the selection of the Arguello MIDAS sites, evidence suggests that the Navy's choice for the second Atlas complex was La Honda Canyon. Rosenberg remembers that the area was on the wrong side of a canyon wall and not visible from the Vandenberg tracking station. For his foray, he mounted an Agena "skin" (frame) with appropriate antennas and test equipment on a weapons carrier and, with his Lockheed engineer crew, drove throughout the "snake infested bush" of Point Arguello testing signals to and from the Vandenberg tracking station. "When we went to the sites the Navy wanted," he said, "I reached over the shoulders of the team and detuned the receivers to show very poor signal strength and unusable signals." He tuned the receivers perfectly at the sites he and his team preferred, and they were selected when his commander showed his Navy counterpart the results. Looking back on the selection of what became SLC-4, Naval Academy graduate Rosenberg commented, "Score Air Force One, Navy Zero."[76]

The development of PALC-2 mirrored that of the initial PALC-1 complex. As with PALC-1, the second launch complex constructed on Point Arguello was designed specifically to launch Atlas vehicles, this time for Agena-Gambit spacecraft. After a contract signing in June 1961, Paul Hardeman Inc. began construction in late 1961. The Air Force accepted the brick and mortar west pad on 6 November 1962, and about eight months later, on 13 July 1963, controllers launched the initial Gambit KH-7 film return satellite from the west pad. Eleven more successful Gambit 1 launches followed, with the last flight from SLC-4W occurring on 12 March 1965. Of these 12 KH-7 flights, the Atlas LV-3 launched 10 and the Atlas SLV-3 the final two. Producing images with two to three feet resolution, Gambit provided photo interpreters the first high-resolution imagery of denied Soviet areas.[77]

For Gambit's project officers and controllers, like Mirth and Thurneck, the satellite operation presented significant security concerns. The highly classified payload arrived from Kodak's Rochester, New York, plant aboard a C-5 Galaxy aircraft. Only the one person accompanying the satellite aboard the aircraft knew of the payload, and weather concerns, especially the infamous Vandenberg fog, periodically forced the nonstop flight to land at an interim airfield. Fortunately, the high priority of the flight mitigated potential security problems. At PALC-2/SLC-4, the few people cleared for Gambit worked in the blockhouse but used a separate room with its own entrance. Payload personnel arrived at SLC-4 from their offices on the base in the "Black Mariah," a van so named for its blackened windows. Kodak representatives operated under a company cover name, and the name Kodak was not mentioned at Vandenberg. As Mirth explained, because Gambit's launch dates and times remained classified, "we couldn't even tell our families that we were going to work in the middle of the night."[78]

While the Gambit 1 flights from SLC-4W experienced no failures, quick thinking by Roy and his crew contained another potential explosion when faced with the collapse of an Atlas-Agena on the pad. While conducting a full dress rehearsal of the Atlas-Agena on 11 May 1963, before the first Gambit launch, the Atlas began to collapse because of an "air hammer" in the liquid oxygen line during on-loading. With oxygen leaking out, the Atlas could not hold pressure. As Roy remembered, "We tried everything we could think of, working in a very unknown environment without procedures or time references" and finally decided to disconnect the power sources and hope for the best. Fortunately, despite sparks and considerable fuel everywhere, there was no explosion when the Atlas collapsed but failed to ignite. Thurneck, a member of Roy's crew who spent the night on guard after the accident, attributed the lack of an explosion to Roy's yelling to cut all power to the vehicle as it began to collapse. As in the aftermath of the Samos E-2 explosion, Roy entered the dangerous area of the flame bucket to cover the classified payload with tarp. He later declared, "I will never forget the odor [of the excessively rich fuel-oxygen atmosphere] when I got to the pad to cover up the payload." As for the Agena, in the aftermath, contractors refurbished the vehicle and it flew on a later flight without incident.[79]

Beginning on 14 August 1964, SLV-3 Atlas-Agena Ds launched Gambit 1 satellites from the SLC-4 East pad, too. Only two of the 26 flights failed. An 8 October 1964 mission failed when an electrical short shut down Agena 1.5 seconds after ignition, while a programmer error on the 12 July 1965 launch shut the sustainer engine off at booster engine cutoff.[80]

The early flight history of SLC-4E is also notable for supporting the only unclassified space mission launched from either of the Vandenberg South Atlas launch complexes over the course of 1960–1972. On 3 April 1965, an Atlas-Agena D lofted SNAP-10 A into a low Earth polar orbit. The only fission nuclear-powered satellite ever launched into space by the United States, SNAPSHOT, developed by North American Aviation's Atomics International division, provided electrical power for a 2.2-pound ion engine but shut down after only 43 days when an onboard voltage regulator failed. Although expected to remain in its 700 nautical mile orbit for 4,000 years, SNAPSHOT began shedding pieces of traceable debris in 1979. Even so, the main body remains in polar orbit. For Mirth, SNAPSHOT's chief project officer, the unusual mission was an "exciting and fun launch because it was open with almost no security restrictions." After the final Gambit 1 launch on 4 June 1967, the Air Force inactivated the East site, and it remained unused until June 1971. On the fifteenth of that month, a Titan III(23)D lofted the first KH-9 Hexagon satellite, with 19 more to follow.[81]

The SLC-4 West pad experienced no deactivation after the Gambit 1 missions concluded on 12 March 1965. Instead, the pad was reconfigured for Titan IIIBs to launch Gambit 3 satellites. The improved Gambit 3's camera system produced images with ground resolution of less than 2 feet across. Between 19 July 1966 and 3 June 1969, Titan IIIBs successfully launched 19 of 20 KH-8 Gambit 3 Block 1 missions. The lone failure occurred on 26 April 1967, when a fuel-line obstruction caused the second stage to lose thrust and the vehicle plunged into the Pacific Ocean 600 miles downrange.[82]

On 23 August 1969, Titan IIIBs began launching the first of 32 KH-8A Gambit 3 Block 2 double bucket satellites from SLC-4W. With the last flight on 17 April 1984, this successful reconnaissance program had recorded only two failures, with both attributed to Agena pressurization problems. During this period, Titan IIIs also launched seven Jumpseat signals intelligence satellites from SLC-4W as well as some secondary payloads.[83]

With Gambit 3, Air Force launch personnel initiated a new procedure, termed factory to pad, whereby the satellite manufacturer—with considerable Air Force oversight—sent the spacecraft directly to the launchpad rather than first to the Mission Assembly Building for testing and assembly. Air Force officers were now stationed at the contractor's facility, because eliminating the MAB cycle made acceptance testing at the factory more critical. Several reasons have been given for the factory to pad innovation that Col William G. "Bill" King Jr., Gambit's program director, initiated with Gambit 3. Most colorful is the "cockroach" anecdote. According to Rosenberg, King declared, "The cockroaches in the MAB are the problem . . . they can't stay out of the Bird . . . so I want to bypass the cockroaches by going direct from factory to pad." Mirth likewise recalled a night when he and Colonel King observed a battery charging sequence in a dark corner of the MAB, accompanied by a considerable number of cockroaches, and "he [King] was pretty 'grossed out' about them."[84]

Apart from avoiding cockroaches, Mirth argued that bypassing the MAB cycle saved considerable money while, most importantly, the nature of Gambit 3 made factory to pad the best option. He explained that the Gambit 3 satellite consisted of the Agena, the roll joint, the camera, and the film return buckets, with the Agena's command system controlling all elements and providing the only interface among the four sections. "We could verify those interfaces on the pad," he said, while the large nature of the satellite made it difficult to integrate all sections and produce "full flight simulation mode on the ground."[85]

At the same time, the new procedure did not mean that special equipment could not be installed after the hardware arrived at Vandenberg. As Roy described, in these special cases, "checkout and evaluation that followed . . . was appropriately folded into the countdown test and evaluation and would be rechecked when the launch system was at the launch pad." Roy also believed that it was he and his capable launch crew, along with Lt Col William F. Heisler, chief of the Dirty Dozen's WS-117L group, that proposed the innovation that King authorized. In any event, the factory to pad procedure proved successful from its inception.[86]

Looking back on their experiences at the "dawn of the space launch" age, Vandenberg veterans knew that they were a part of something very special. They embraced responsibility seldom given to junior officers and initiated reconnaissance satellite operations that have remained an essential element in the nation's national security endeavor. "In the early days," said Rosenberg, "we all were founders, builders, and activators. The higher ranking officers just let us run things and we embraced the task. It was just incredible to be a part of that." Morale among the project officers and controllers was exceptionally high throughout their Vandenberg experience. Mirth spoke for all in saying, "We knew how important our mission was and we were proud and honored to be able to make a contribution." And Roy, reminiscing about his six-year Vandenberg assignment, simply stated, "I had the best job in the Air Force."[87]

On 29 October 1963, three months after the initial KH-7 launch from SLC-4W, the DOD notified the Navy that the PMR would be transferred to the Air Force. The transfer occurred officially on 1 July 1964, when the Air Force annexed the nearly 20,000 acres to Vandenberg Air Force Base and referred to the area as Vandenberg South. Vandenberg's final land acquisition took place on 1 March 1966, when the Air Force purchased and annexed the 14,890 acres of the Sudden Ranch on the south end of Point Arguello after contentious negotiations and eventual condemnation. This area would provide the location for Space Launch Complex 6 (SLC-6), the projected launch site for the Air Force's unrealized Manned Orbiting Laboratory and space shuttle operations. This acquisition completed Vandenberg South as the principal Air Force space launch area and brought the size of Vandenberg Air Force Base to its current 98,400 acres (154 square miles). The PMR had already been redesignated the Air Force Western Test Range. In addition to the land consolidation of Vandenberg Air Force Base by 1966, the newly formed Western Test Range incorporated the Navy's PMR contingent of fixed and mobile range sites spread across California and the Pacific and its fleet of six instrumented ships.[88]

Over the course of 1956–1972, Vandenberg had also experienced major growth in space launch activity and infrastructure developments. Whereas Cape Canaveral had dominated space launch in the early 1960s, by the latter half of the decade Air Force operations had shifted toward Vandenberg while NASA dominated Cape Canaveral's facilities and programs. By 1967, NASA's space programs represented 50 percent of the Eastern Test Range's entire effort, while the Navy's ballistic missile testing comprised 30 percent and the Space and Missile Systems Organization (SAMSO) launches only 11 percent of the range's activity. By contrast, SAMSO made up 45 percent of Western Test Range activity, followed by SAC at 30 percent and NASA accounting for the remaining 25 percent. The disparity between Vandenberg and the Cape would continue into the 1970s.[89]

The new prominence of Vandenberg was reflected in organizational changes as well. The Air Force activated the Space and Missile Test Center (SAMTEC) at Vandenberg and assigned it to SAMSO, based in Los Angeles. Vandenberg's 6595th Aerospace Test Wing was reassigned from SAMSO to SAMTEC, while Patrick Air Force Base's 6555th Aerospace Test Wing was downgraded to group status and, as the 6555th Aerospace Test Group, reassigned from SAMSO to the 6595th Aerospace Test Wing.[90] Looking ahead, while Vandenberg Air Force Base would continue its crucial role as the launch site for classified reconnaissance satellite programs, Cape Canaveral would regain a central role in space launch activity, becoming the location for space shuttle operations as well as geosynchronous launches of communications and early warning satellites.

Notes

1. The main overflight concerns were Cuba to the south and the Eastern seaboard states to the north. Although it is possible to fly a polar mission from Florida, it takes much more energy to avoid the populated areas in what is known as a "dogleg" flight profile. The concerns are where first and second stages would impact as they drop off or if there was an anomaly and debris fell on populated areas or foreign countries. Flights out of Vandenberg made it easy to avoid both of these situations.

McKinney, "Manuscript Review Comments," 21 January 2020; Historic American Engineering Record (HAER), National Park Service, *Vandenberg Air Force Base, Space Launch Complex 3 (SLC-3)*, HAER No. CA-133-1 (hereinafter cited as HAER No. CA-133-1), 16–17; and 30th Space Wing, "Capabilities Handbook December 2001," 1.

2. Geiger, "Heritage of the 30th Space Wing and Vandenberg Air Force Base," 15–18; and Geiger, *Camp Cooke and Vandenberg Air Force Base*, chaps. 1–6, 154.

3. Neufeld, *Development of Ballistic Missiles in the United States Air Force*, 177; Stumpf, "Birth of the Test Ranges, Part II," 55; and Stumpf, "Birth of the Test Ranges, Part III," 45.

4. This being a period of budget cutbacks, Quarles had balked at authorizing a new West Coast site whose estimated costs would increase from $42 million in fiscal year 1957 to $400 million in fiscal year 1958. Lonnquest and Winkler, *To Defend and Deter*, 313–14; HAER No. CA-133-1, 16–17; and Stumpf, "Birth of the Test Ranges, Part III," 45–46. Stumpf lists 11 site selection criteria for the final 15 candidates.

5. Hastings, "Site Selection Briefing for Secretary Quarles"; Lonnquest and Winkler, *To Defend and Deter*, 315; Turhollow, *History of the Los Angeles District*, 301–2; and Stumpf, "Birth of the Test Ranges, Part III," 46–47.

6. Geiger, "Heritage of the 30th Space Wing and Vandenberg Air Force Base," 1, 18–19; Geiger, *Camp Cooke and Vandenberg Air Force Base*, 156; Vandenberg AFB, "Background of Vandenberg/Arguello Relationships," 1; District Public Works Office, "Navy Facilities to Be Located at Cooke Air Force Base"; US Naval Missile Facility, "Introduction to Naval Missile Facility Point Arguello"; and Stumpf, "Birth of the Test Ranges, Part II," 56. See a map of Camp Cooke, circa 1958, in appendix B.

7. Geiger, "Heritage of the 30th Space Wing and Vandenberg Air Force Base," 2; District Public Works Office, "Navy Facilities to Be Located at Cooke Air Force Base"; US Naval Missile Facility, "Introduction to Naval Missile Facility Point Arguello"; Bowen, *Threshold of Space*, 191–92; Naval Missile Facility Point Arguello (NMFPA), *Command History 1960: A Historical Report*, 2–6; and Stumpf, "Birth of the Test Ranges, Part II," 51–57. Stumpf notes that the transfer did not include Point Arguello itself because at that time it comprised part of the privately owned Sudden Ranch property. The Navy negotiated with the owner for long-term overflight permission.

8. Geiger, "Vandenberg AFB Launch Facility Status and History," 2, 5. Vandenberg North and Vandenberg South are also referred to as North Base and South Base, respectively.

9. Sturdevant, "Robert C. Truax and American Rocket Development," 5, 8–11; Truax, "Rocket Man," 302–3; Coolbaugh, "Genesis of the USAF's First Satellite Programme," 296; Vandenberg AFB, "Background of Vandenberg/Arguello Relationships," 1; and Stumpf, "Birth of the Test Ranges, Part III," 46. See an expanded biography of Robert C. Truax in in appendix A.

10. Sturdevant, "Robert C. Truax and American Rocket Development," 5, 8–11; Truax, "Rocket Man," 302–3; Coolbaugh, "Genesis of the USAF's First Satellite Programme," 296; Vandenberg AFB, "Background of Vandenberg/Arguello Relationships," 1; and Stumpf, "Birth of the Test Ranges, Part III," 46.

11. Sturdevant, "Robert C. Truax and American Rocket Development," 5, 8–11; Truax, "Rocket Man," 302–3; Coolbaugh, "Genesis of the USAF's First Satellite Programme," 296; Vandenberg AFB, "Background of Vandenberg/Arguello Relationships," 1; and Stumpf, "Birth of the Test Ranges, Part III," 46.

12. Truax to Hastings, memorandum; Hastings to Truax, memorandum.

13. "Navy Asked to Delay Air Station Decision."

14. Spires, *Beyond Horizons*, 57–60; and Stumpf, "Birth of the Test Ranges, Part II," 58–59. Stumpf notes that ARPA originally intended to construct as many as six Atlas launch sites on Point Arguello.

15. It is likely that Truax would have remained at WDD and responsible for Air Force satellite programs had he not been a naval officer. Sturdevant, "Robert C. Truax and American Rocket Development," 10–11; and Coolbaugh, "Genesis of the USAF's First Satellite Programme," 296–97.

16. Director, ARPA, to Commander, ARDC, "ARPA Order No. 41-59"; Director, ARPA to Commander, ARDC, "Location of the Missile Assembly Building for the Sentry Program"; Western Development Division (WDD), "WS 117L Support Requirements from the National Pacific Missile Test Range"; and Department of the Navy, Bureau of Aeronautics, "Examples of USAF Facility Establishment at VAFB Contrary to National Range Policy." Freitag remained special assistant to the commander, PMR, while assigned to the Bureau of Aeronautics.

17. Commander, ARDC to Chief of Staff, USAF. Despite continued lobbying for Atlas space launches from complex 65-1, Samos missions would be launched exclusively from Arguello's PALC-1 pads.

18. Berger, *History of the 1st Missile Division*, 126–27.

19. Berger, *History of the 1st Missile Division*, 126–28; White and Burke, "Agreement for the Coordinated Peacetime Operation of the Pacific Missile Range"; Bowen, *The Threshold of Space*, 193; NMFPA, *Command History 1960*, 7; and Stumpf, "Birth of the Test Ranges, Part III," 47.

20. Berger, *History of the 1st Missile Division*, 131–33; Bowen, *The Threshold of Space*, 193; Baar and Howard, "AF-Navy Space Range Fight Nears," 10–11; and Stumpf, "Birth of the Test Ranges, Part III," 47–48.

21. Wade and Monroe, "Bilateral Agreement between the 1st Missile Division-Pacific Missile Range," 8; NMFPA, *Command History 1960*, 10; and Berger, *History of the 1st Missile Division*, 128–29.

22. At that time Connolly was assistant chief of the Pacific Missile Range within the Bureau of Aeronautics. Truax served on the Connolly committee. Bowen, *The Threshold of Space*, 191–96; Navy Memo No 003P05G, "Review of Air Force Attitude in Connection with Pacific Missile Range Activities"; and Navy Memo from 05 to 00, "Air Force/Navy Relationship in PMR/VAFB area." This memo describes "The Navy's Concept and Position" and "The Air Force Concept and Position." "Background of Vandenberg/Arguello Relationships," 2–3; and Berger, *History of the 1st Missile Division*, 149–50.

23. Baar and Howard, "AF-Navy Space Range Fight Nears," 13; and Bowen, *The Threshold of Space*, 193–96; Geiger includes a chart depicting the revised launch azimuths in *Camp Cooke and Vandenberg Air Force Base, 1941–1966,* 156; Berger, *History of the 1st Missile Division*, 38–143; NMFPA, *Command History 1960*, 11; Stumpf, "Birth of the Test Ranges, Part II," 57; and Stumpf, "Birth of the Test Ranges, Part III," 4–49, 51.

24. The Sudden Ranch lease agreement was signed on 3 April 1959. Navy Memo from 05 to 00, "Air Force/Navy Relationship in PMR/VAFB area"; Berger, *History of the 1st Missile Division*, 149–50; and NMFPA, *Command History 1960*, 12. A portion of Sudden Ranch would be the site of the future Space Launch Complex 6 (SLC-6). Sudden Ranch, originally Rancho La Espada, was the western portion of a land grant awarded to Anastacio Carillo by the Governor of Alta California on 10 May 1847. After changing hands several times over the ensuing decades, Robert Sudden, a Scottish sea captain, purchased the property in 1883. Geiger, "The Heritage of the 30th

Space Wing and Vandenberg Air Force Base," 22; and Jenkins, *Space Shuttle: Developing an Icon*, II-467–II-468.

25. Director of Guided Missiles, OSD, to The Secretary of the Army, The Secretary of the Navy, The Secretary of the Air Force, "Peace Time Missile Firings at Cooke Air Force Base," 22 November 1957; Navy Memo from 05 to 00, "Air Force/Navy Relationship in PMR/VAFB Area"; Navy Memo No 003P05G, OP-05G to OP-05, "Review of Air Force Attitude in Connection with Pacific Missile Range Activities"; and Baar and Howard, "AF-Navy Space Range Fight Nears," 13–16.

26. For the Navy proposal, see Logsdon, Day, and Launius, "General Proposal for Organization for Command and Control of Military Operations in Space." Rosenberg, *The Air Force in Space*, 18–21; Schriever to Wilson, memorandum; and Bowen, *The Threshold of Space*, 198–201.

27. Deputy Chief of Staff, Operations, "Review of the Burke-White Agreement"; Navy OP-54, memorandum; and Special Assistant to Commander, Pacific Missile Range, "Renegotiation of the Burke-White Agreement."

28. Special Assistant to Commander, Pacific Missile Range, "Renegotiation of the Burke-White Agreement"; NMFPA, *Command History 1960*, 13; Bowen, *The Threshold of Space*, 196; and Geiger, *Camp Cooke and Vandenberg Air Force Base*, 160–61.

29. Rosenberg, *The Air Force in Space*, 18–21; Berger, *The Air Force in Space,* FY 61, 29–30; Futrell, *Ideas, Concepts, Doctrine: Basic Thinking in the United States Air Force*, 593, 601; AFBMD, Impact of the OSD 'Space Operations' Memorandum on the AFBMD Space Program, October 1959; "Background of Vandenberg/Arguello Relationships," 3; and Bowen, *The Threshold of Space*, 196–201.

30. Monroe to Cisler, "Presentation"; "Background of Vandenberg/Arguello Relationships" 3–4; NMF, PMR, *Command History 1963*, 13; Baar and Howard, "AF Attacks 'Secret' Navy Space Plan," 11; Baar and Howard, "Navy Denies Air Force's PMR Charges," 26; and Stumpf, "Birth of the Test Ranges, Part III," 51.

31. Walker L. Cisler, Chairman, The Advisory Group on Ranges and Space Ground Support, to Dr. Herbert F. York, DDR&E, "Report of The Advisory Group on Ranges and Space Ground Support," n.d. [Summer 1960]; Memo, Deputy, "Common Safety Criteria for All National Missile/Space Ranges"; and "Background of Vandenberg/Arguello Relationships," 3–4. The timing of the Cisler committee's activities is unclear. Cisler's report suggests that the group was not formed until the spring of 1960, yet documentation clearly describes his investigation having begun in August 1959.

32. "Background of Vandenberg/Arguello Relationships," 4; "Whole Town Takes Off Every Time a Missile Takes Off," *National Inquirer*, 27 October 1963, 27–28; and Thurneck, email, 1 November 2018 and 4 December 2018. Additionally, Thurneck and other veterans consulted for this study do not remember ever being evacuated from either launch complex when the Navy did so during Discoverer flights. One officer, Mirth, recalls going inside during the flights, and one other, Rosenberg, arrived at Vandenberg when an evacuation was underway. He and his wife had decided to go directly to Surf because it seemed romantic and a great location to rent a home. When they pulled into Surf, they encountered railroad repairmen being evacuated and were told to get out of town within 15 minutes to avoid the upcoming launch. "We jumped in our car and got out of there as fast as we could, but never saw any roadblocks reaching Lompoc." Rosenberg, email, 4 December 2018; Mirth, email, 4 December 2018; and Roy, email, 6 December 2018.

33. For this study, the Navy's PALC designation will be used chronologically until 1 July 1964, the date of the Arguello transfer to the Air Force. From that point forward, SLC will be used.

34. Roy, email, 29 August 2017 and 1 November 2018. I am indebted to Col Thomas E. Maultsby, USAF, retired, for providing additional information on the AFBMD Field Office. Maultsby, email, 6 August 2017. In October 1960 the AFBMD Field Office became the 6595th Test Wing.

35. Director, ARPA to Commander, ARDC, "ARPA Order No. 41–59"; Director, ARPA to Commander, ARDC, "Location of the Missile Assembly Building for the Sentry Program"; Western Development Division, "WS 117L Support Requirements from the National Pacific Missile Test Range"; HAER No. CA-133-1, 21; and Stumpf, "Birth of the Test Ranges, Part II," 58–59.

36. Roy, email, 1 November 2018. See an expanded biography of Robert W. "Rob" Roy in in appendix A.

37. Roy, email, 22 May 2017, 29 August 2017, and 1 November 2018.

38. Roy, email, 22 May 2017; and Thurneck, email, 28 October 2018.

39. NMFPA, *Command History 1960*, 7; HAER No. CA-133-1, 21; and Maultsby, email, 26 November 2018.

40. Roy, email, 1 November 2018; and HAER No. CA-133-1, 51–52, 67–103. See a map of Space Launch Complex 2 circa 1959 in appendix B.

41. Roy, email, 1 November 2018; and HAER No. CA-133-1, 51–52, 67–103.

42. Roy, email, 1 November 2018; and HAER No. CA-133-1, 51–52, 67–103.

43. Roy, email, 1 November 2018; and HAER No. CA-133-1, 51–52, 67–103.

44. Mirth, email, 8 February 2017, 30 October 2018, and 31 October 2018. See an expanded biography of Joseph D. "Don" Mirth in in appendix A.

45. Mirth, email, 30 October 2018.

46. Roy, email, 1 November 2018.

47. Rosenberg, email, 3 March 2017; and Mirth, email, 8 February 2017. The six systems referred to are Samos E-1, E-2, E-5, E-6, MIDAS, and Gambit. See an expanded biography of Robert A. "Rosie" Rosenberg in appendix A.

48. Spires, *Beyond Horizons*, 71; and Day, "A Sheep in Wolf's Clothing," 1. Samos had long been considered an acronym for Satellite and Missile Observation System. It seems that WS-117L Project Director Colonel Fritz Oder adopted the name only to signify the island home of MIDAS. For background on the reconnaissance program, see Richelson, *America's Secret Eyes in Space*, 44–64. In August 1959, Sentry's name was changed to Samos.

49. McDowell, "US Reconnaissance Satellites Programs, Part 1: Photoreconnaissance," 22–33; McDowell, "SAMOS," accessed 23 November 2018; GlobalSecurity.org, "SAMOS-A-Pioneer," accessed 20 December 2018; Day, "A Sheep in Wolf's Clothing," 1; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

50. See note 49.

51. Mirth, email, 30 October 2018 and 5 November 2018; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

52. Samos carried 250 lbs of film compared to the 16 lbs carried by the early Corona camera systems. Day, "A Sheep in Wolf's Clothing, 2 (The Need for Higher Resolution)"; McDowell, "U. S. Reconnaissance Satellites Programs, Part 1: Photoreconnaissance," 22–33; McDowell, "SAMOS," accessed 23 November 2018; Global Security.org, "SAMOS-A-Pioneer," accessed 20 December 2018; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

53. Day, "A Square Peg in a Cone-Shaped Hole: The Samos E-5 Recoverable Satellite, 1 (Clever Compromises), 2 (Slow Progress)"; and Coglitore, "Manuscript Review Comments."

54. Day, "From Cameras to Monkeys to Men: The Samos E-5 Recoverable Satellite, 1 (A Second Try)"; McDowell, "US Reconnaissance Satellites Programs, Part 1: Photoreconnaissance," 22–33; McDowell, "SAMOS," accessed 23 November 2018; GlobalSecurity.org, "SAMOS-A-Pioneer," accessed 20 December 2018; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

55. See note 54.

56. Day, "From Cameras to Monkeys to Men: The Samos E-5 Recoverable Satellite, Part 3, Terminated."

57. Day, "From Cameras to Monkeys to Men: The Samos E-5 Recoverable Satellite, Part 3, Terminated"; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

58. Day, "From Cameras to Monkeys to Men: The Samos E-5 Recoverable Satellite, Part 3, Terminated"; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018.

59. Day, "From Cameras to Monkeys to Men: The Samos E-5 Recoverable Satellite, Part 3, Terminated"; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018. The *Samos 5* capsule was pressurized to approximately 70 degrees Fahrenheit, with relative humidity of approximately 50 percent.

60. From 27 November 1963 to 25 May 1972, Air Force controllers launched 35 Thor-Agena Corona missions from SLC-3W with only 2 having failed. The Thor variants consisted of 1 SLV-2, 15 SLV-2A Thrust Augmented Thors, and 8 SLV-2G and 11 SLV-2H Long Tank Thrust Augmented Thorads. The Corona systems included 1 KH-4 Mural, 18 KH-4A, and 16 KH-4B camera systems. See chap. 2.

61. 1st Missile Division, memorandum.

62. Cantwell, *The Air Force in Space, Fiscal Year 1964*, 51; and Galloway, "A Decade of US Reconnaissance Satellites," 249–53.

63. Berger, *The Air Force in Space, Fiscal Year 1961*, 44–48; and Richelson, *America's Space Sentinels*, 17.

64. Berger, *The Air Force in Space, Fiscal Year 1961*, 44–48; and Richelson, *America's Space Sentinels*, 17. The Joint Chiefs of Staff and Secretary of Defense on 16 January 1961 approved the operational plan that assigned MIDAS responsibilities to NORAD and the Air Defense Command. In mid-March Air Defense Command authored a proposed operational plan calling for a constellation of eight satellites spaced in two orbital rings to ensure continual coverage of the Soviet landmass. Data from the sensors would be transmitted to Ballistic Missile Early Warning System (BMEWS) radar sites, then relayed to the NORAD command post. Richelson, *America's Space Sentinels*, 17–18. Joseph Charyk became the first director of the NRO in September 1961.

65. Berger, *The Air Force in Space, FY 1962*, 72–82; and Richelson, *America's Space Sentinels*, 18–22.

66. Berger, *The Air Force in Space, FY 1962*, 72–82; Richelson, *America's Space Sentinels*, 18–22; HAER No. CA-133-1, 23, 32–34; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; and Richelson, *America's Space Sentinels*, 18–22.

67. Berger, *The Air Force in Space, FY 1962*, 72–82; and Richelson, *America's Space Sentinels*, 22–25.

68. Berger, *The Air Force in Space, FY 1962*, 72–82; and Richelson, *America's Space Sentinels*, 18–22. The "other" available early warning system was the Over-the-Horizon-Backscatter (OTH-B) radar that, despite its potential, would experience considerable deployment delays because of technical challenges; Richelson, *America's Space Sentinels*, 25–30.

69. Cantwell, *The Air Force in Space, FY 1964*, 51–59; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; Mirth, email, 20 October 2018 and 30 October 2018; and Richelson, *America's Space Sentinels*, 30–36.

70. Cantwell, *The Air Force in Space, FY 1964*, 51–59; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; Roy, email, 5 November 2018; Mirth, email, 5 November 2018; and Richelson, *America's Space Sentinels*, 36–44.

71. Cantwell, *The Air Force in Space*, *FY 1964*, 51–59; and Richelson, *America's Space Sentinels*, 36–44.

72. Cantwell, *The Air Force in Space*, *FY 1964*, 51–59; and Richelson, *America's Space Sentinels*, 36–44.

73. Cantwell, *The Air Force in Space*, *FY 1964*, 51–59; and Richelson, *America's Space Sentinels*, 36–44.

74. Cantwell, *The Air Force in Space, FY 1964*, 36–39; Peebles, *High Frontier: The United States Air Force and the Military Space Program*, 34–36; Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; McDowell, "Satellite Catalog," accessed 8 September 2018; Historic American Engineering Record (HAER); and Richelson, *America's Space Sentinels*, 44–48.

75. Neufeld, *The Air Force in Space, 1970–1974*, 31–40.

76. Rosenberg, email, 30 January 2017 and 26 November 2018.

77. Encyclopedia Astronautica, "Atlas," accessed 20 June 2009; and McDowell, "Satellite Catalog," accessed 8 September 2018. See a map of Naval Missile Facilities at Point Arguello circa August 1961 in appendix B.

78. Mirth, email, 30 October 2018.

79. During the on-loading of liquid oxygen, the air hammer, a void of liquid oxygen in a section of the oxygen feed line, allowed a very quick rush of liquid oxygen to advance through the gaseous occupied section of the feed line and impact the pad/Atlas interface connect valve like a "hammer." With oxygen leaking from the Atlas, it could not maintain pressure. Roy, email, 5 November 2018; Mirth, email, 3 November 2018; and Thurneck, email, 4 November 2018. A video of the Atlas collapse is available online: What You Haven't Seen, "Atlas Agena Rocket Depressurizes on Pad, Collapses and Tears Itself to Pieces," 24 November 2017, https://www.youtube.com/.

80. McDowell, "Satellite Catalog," accessed 8 September 2018. For a discussion of the Gambit program, see Day, "Ike's Gambit, 1 (Hawkeye's Spies in the Sky), 2 (The Bang-Bang OCV)."

81. McDowell, "Satellite Catalog," accessed 8 September 2018; *TRW Space Log 1996*–90; Encyclopedia Astronautica, "Snapshot," accessed 21 December 2018; US Department of Energy, "SNAP Overview," accessed 21 December 2018; and Mirth, email, 8 February 2017.

82. McDowell, "Satellite Catalog," accessed 8 September 2018. For a discussion of the Gambit program, see Day, "Ike's Gambit, 1 (Hawkeye's Spies in the Sky), 2 (The Bang-Bang OCV)."

83. McDowell, "US Reconnaissance Satellite Programs, Part 1," 22–33; McDowell, "US Reconnaissance Satellite Programs, Part 2," 40–45; McDowell, "Satellite Cata-

log," accessed 8 September 2018; and Encyclopedia Astronautica, "Titan," accessed 20 June 2009.

84. Rosenberg, email, 9 February 2017; and Mirth, 8 February 2017, 12 February 2017.

85. Mirth, email, 3 November 2018.

86. Roy, email, 6 November 2018.

87. Roy, email, 1 November 2018; Rosenberg, email, 27 January 2017; Mirth, email, 11 March 2017; and Thurneck, email, 4 April 2017.

88. Geiger, "Heritage of the 30th Space Wing and Vandenberg Air Force Base," 22–25. Sudden Ranch was acquired by way of eminent domain proceedings. From the Navy, the Air Force acquired the following: Point Arguello, CA; Pillar Point (San Mateo County), CA; Kokee Park (Kauai County), Hawaii; South Point (Hawaii County), Hawaii; Canton, Midway, and Wake Islands; Eniwetok and Bikini Atolls in the Marshall Islands; and six range instrumented ships (*Huntsville*, *Longview*, *Range Tracker*, *Richfield*, *Sunnyvale*, and *Watertown*); Stumpf, "Birth of the Test Ranges, Part III," 53–54. Although normally referred to as the Sudden Ranch, the property in question consisted of Charles E. Sudden's 14,390 acres and the Lino Scolari Ranch's 500 acres. Stumpf describes the course of negotiations as well as the difficult decision to select Point Arguello rather than the Cape due to the Florida congressional delegation's determination to have the MOL launched from the Cape. The DOD made clear that safety and security remained primary considerations, citing the issue of overflight of civilian areas from the Florida site, and its so-called dogleg trajectory required for polar launches would not meet the MOL's trajectory requirements. Also see, Jenkins, *Space Shuttle*, II-467–II-468. See a view of the Western Test Range in appendix B.

89. Cleary, *The 6555th Missile and Space Launches*, 209–10.

90. Cleary, 24–25.

Chapter 4

East Coast Development

Cape Canaveral Air Force Station, Patrick AFB, and the Eastern Test Range, 1948–1972

Cape Canaveral, Florida, has been the major East Coast launch center of the nation's space program from its inception. Comprising the northernmost wedge of a barrier island 50 miles east of Orlando on the Florida coast, the Cape remained separated from the mainland to the west by the Banana River, Merritt Island, and the Indian River, which embraced a portion of the Intracoastal Waterway. The location proved ideal for testing cruise missiles and, later, launching ballistic missiles and spacecraft. Launches in a southeasterly direction avoided important shipping lanes and major population centers by passing over islands that served as tracking stations along a 10,000-mile course that would extend from the Bahamas to Ascension Island in the South Atlantic, to the coast of South Africa, and eventually into the Indian Ocean. As a result, burned-out missile stages and expendable boosters avoided densely populated land areas. Moreover, with an easterly launch the earth's rotation added greater velocity, which enabled boosters to orbit heavier loads. As the launch head of the Eastern Test Range, the Cape in the 1960s became the center for Air Force–supported instrumented nuclear detection, communications, and early warning satellite launches as well as NASA's Mercury, Gemini, and Apollo manned flights and all American spacecraft launched eastward into low-inclination equatorial orbits.[1]

From Naval Air Station to Long Range Proving Ground

The development of Cape Canaveral began on the eve of World War II with the establishment of the Banana River Naval Air Station, the predecessor of Patrick Air Force Base. With war clouds looming, the US government recognized the need to reinforce the Atlantic Coast Defense System by reducing Florida's exposure to sea attack and thereby helping to protect shipping lanes. Congress responded by passing the Naval Expansion Act of 17 May 1938, allowing the Secretary of the Navy to appoint the Hepburn Board to review potential sites along the Florida coast. After deciding to locate a major naval base at Jacksonville, the Board proposed siting an auxiliary base to the south in Brevard County. In June 1939, civic officials from Cocoa, Eau Gallie, and Melbourne met with Cdr W. M. Angus, the Public Works Officer for the Seventh Naval District, and settled on a site for the naval air station on the Banana River 20 miles south of the Cape Canaveral headland. That facility would become Patrick AFB and, as the administrative headquarters of the future Cape Canaveral Air Force Station, provide personnel and support for launch operations and maintain tracking stations of the Eastern Range. In 1939 and 1940, the Navy acquired 1,822 acres of property; initial land clearing started on 18 December 1939. Construction began five months later, and naval leaders formally commissioned the Banana River Naval Air Station on 1 October 1940.[2]

During the Second World War, the air station's primary mission was antisubmarine patrol operations along the Florida coast conducted by PBY Catalina and PBM Mariner seaplanes. Landing strips built in 1943 allowed land-based aircraft to join the patrol operation. The station also supported PBY seaplane pilot training and operated an advanced navigation school and major aircraft maintenance facility. For two years after the war, the Banana River Naval Air Station supported naval operations at a reduced level until 1 August 1947, when it was formally inactivated and placed in caretaker status rather than allowing the property to be returned to the local community.[3]

Meanwhile, in October 1946, the Joint Research and Development Board had established the Committee on the Long Range Proving Ground to examine potential locations for a joint long range proving ground. The proving ground's mission was to develop a range for testing long range guided missiles that would be operated jointly by the three services but under executive supervision of the Air Force. The committee focused on three potential locations. The first, a northern Washington coast site with its range into the Aleutian Islands, received little consideration because of its poor weather, isolation, and logistical challenges. Between the other two sites, El Centro, California, with its range over Baja, and the Banana River site, with launches from Cape Canaveral over the Atlantic, committee members initially favored El Centro because of its proximity to missile manufacturers. The newly established Department of Defense approved the committee's choice in the fall of 1947 and authorized creation of a joint long range proving ground group at El Centro. The next year, however, the

California site had to be abandoned when Mexico's president, Miguel Aleman Valdes, balked at the prospect of missile flights over the Baja peninsula. No doubt the president had been influenced by a wayward V-2 rocket launched from White Sands that mistakenly veered south over El Paso, Texas, and landed in a Juarez cemetery on 29 May 1947. A year later, faced with significant domestic opposition and criticism from Central American neighbors, President Aleman felt compelled to refuse permission for missile flights over Mexican territory.[4]

American officials quickly shifted their focus to the Cape Canaveral area when the British government offered to allow overflight of the Bahamas and later to lease island real estate to the US for downrange tracking stations. The Cape, indeed, offered many advantages as a potential center for missile launching operations. Although far from large urban areas, it could be accessed by water, rail, and road and had a generally warm and sunny climate most of the year. Moreover, the Banana River Naval Air Station, only 20 miles south, would be a superb support base for the Eastern Test Range. On 11 May 1949, with negotiations with the British ongoing, President Truman signed Public Law 60, which established the Joint Long Range Proving Ground at Cape Canaveral. The following year, on 21 July 1950, the British signed the Bahamian Agreement, which permitted the construction of range stations in the Bahamas.[5]

Both the range and the support base underwent a number of organizational changes in this early period. The Navy had anticipated these developments and, on 1 September 1948, had transferred the Banana Naval Air Station to the Air Force. The station was renamed the Joint Long Range Proving Ground (JLRPG) on 10 June 1949 and activated four months later, on 1 October 1949, along with the establishment of the Air Force Division, JLRPG. The latter was redesignated the Air Force Long Range Proving Ground Division on 16 May 1950, with responsibility for the JLRPG missile range. Then, on 1 August 1950, the base was renamed Patrick Air Force Base, to honor Maj Gen Mason M. Patrick, first Chief of the Air Service and Army Air Corps after World War I. Since April of that year, the JLRPG had been under the command of Air Force Maj Gen William L. Richardson, who also commanded the Long Range Proving Ground Division at Patrick AFB that later, on 30 June 1951, was renamed the Air Force Missile Test Center (AFMTC) and the range renamed the Florida Missile Test Range. That October, the Cape region of the LRPG missile range received a new official designation, when the Long Range

Proving Ground was renamed Cape Canaveral Auxiliary Air Force Base (CCAAFB).[6]

Under General Richardson's leadership, the AFMTC and the Cape experienced a period of rapid growth. Because the US government owned only property surrounding the Lighthouse and nearby Coast Guard stations, the Cape region's private property was acquired through purchase and condemnation. On 9 May 1950, under a contract between the Army Corps of Engineers and Duval Engineering Company of Jacksonville, Florida, Duval began construction of the initial permanent access road and LC-3 near the Lighthouse. The Air Force accepted the complex on 19 November 1951. Already, however, the Air Force had occupied the complex and supported the first major launch from the Cape when *Bumper 8*, consisting of a V-2 first stage rocket and a WAC Corporal second stage, lifted off on 24 July 1950. In the same area, the Air Force occupied launch complexes 1, 2, and 4 by the fall of 1952 and officially accepted them from the contractor a year later. By July 1954, in addition to the four launch complexes, the CCAAFB had in place missile assembly buildings and a central control station to support a variety of cruise missile flights. Richardson also oversaw the construction of Port Canaveral at the southern end of the Cape. Begun by the Army Corps of Engineers in July 1950, the deep water port initially allowed berthing of cargo and range instrumentation ships but would later be enlarged to support commercial shipping and ballistic missile submarines.[7]

Armed with the Bahama Agreement, the Air Force began building the first tracking stations on the islands, starting with Grand Bahama. At the same time, it also developed Jupiter Auxiliary Air Force Base 95 miles south of Patrick to support Matador cruise missile flights downrange. By the close of 1954, the Grand Bahama Island station was operational, while construction of additional tracking stations was underway on Eleuthera, San Salvador, and Mayaguana as well as in the Dominican Republic and Puerto Rico, nearly 1,000 miles southeast of the Cape. Air Force "blue suit" personnel operated the tracking stations until 31 December 1953. On that date, the Air Force, relying on a cost comparison study done in 1951 that favored contractor operations, signed a range contract with Pan American World Services. Pan American then subcontracted RCA to operate and maintain the range stations and tracking equipment once the AFMTC transferred property and equipment to the contractors. Pan American

World Services would retain the range contract under Air Force supervision until October 1988.[8]

The Era of Cruise Missile Testing and Operations

During the decade of the 1950s, aerodynamic winged missiles dominated launch activity at the Cape and provided important experience for future space launch operators. Flight testing began in 1951 with the Matador surface-to-surface missile. Under the supervision of AFMTC's 6555th Guided Missile Wing, contractors and Air Force personnel assembled the missile, launched R&D flights, and prepared two Matador pilotless bomber squadrons for operational deployment in Europe. Produced by the Glenn L. Martin Company, the Matador measured 39.6 feet in length and 28.7 feet from wing tip to wing tip and could launch a 40 kiloton warhead a distance of 600 miles with its solid rocket booster and liquid propellant turbojet engine. With more than 280 flights, the Matador established the record as the era's most launched missile. Although flight testing of the missile continued until 1961, the Martin Company in 1959 introduced the Mace, an upgraded version of the Matador that used an automatic terrain recognition and navigation system. The Mace totaled 44 R&D flights from October 1959 until July 1963, but the missile never achieved operational status.[9]

The Matador program provided valuable experience for future space launch operators. Newly commissioned 2nd Lt Rob Roy, for example, cites his work with the Matador as fundamental for his future operational role with space launch at Vandenberg AFB. Originally scheduled for overseas Matador deployment, he was reassigned to the 6555th Test Wing (Development), redesignated the 6555th Aerospace Test Wing (ATW) in 1961, and quickly involved himself in the launch area when the Martin Company, the system integrator, needed additional flight data to correct a horizontal stabilizer problem. During this period, he took part in an important change in which the military became a central part of the system development process. Until this time, the Air Force had contracted a prime integration company to be responsible for system concept, design, development, fabrication, test, and employment training. Military personnel served only as advisors and onlookers. Beginning with the hands-on involvement of Roy and other Air Force personnel with the Matador program, blue suit Air Force personnel became an integral element of the system development effort and "no longer just trainers for military deployment." The Matador's military team gained in-depth knowledge of propulsion, mechanical hardware capabilities, electronics, and design for field use. Lieutenant Roy, in fact, took part in developing the on alert readiness Matador launch console, an experience that would prove important later at Vandenberg. As he asserted, the type of training and experience he acquired at the Cape "proved to be a foreshadowing of the intricacies of space and missile weapons systems to come for the military."[10]

Because the Matador's terminal dive exposed it to attacking aircraft and ground fire, the Air Force decided a faster, more capable missile was needed. The proposed solution came with the Northrop Aircraft Company's subsonic, swept-wing Snark, the only intercontinental US cruise missile, capable of launching its 7,000-pound warhead up to 5,500 nautical miles. With a length of nearly 74 feet and a wingspan of 42.5 feet, the Snark's Allison turbojet engine provided power up to Mach 0.94, but an afterburner was expected to give it supersonic dash capability. The missile's ballistic nose separated from the vehicle and fell to its target in a supersonic trajectory. After serious engine malfunctions, however, Northrop replaced the Allison engine with the Pratt & Whitney J-57 engine, upgraded the solid rocket boosters that launched the vehicle, and shortened the missile's length to 67.2 feet. Even so, the Snark continued to experience problems, and a review of the missile's performance in 1959 gave it a one-in-six chance of hitting the target area. So many of the 97 downrange flights tallied between 29 August 1952 and 5 December 1960 failed that the Atlantic Ocean became known as "Snark infested waters." Nevertheless, the Air Force activated the 702nd Strategic Missile Wing, placed the first Snark on alert at Presque Isle, Maine, on 18 March 1960, and declared the blue suit unit operational the year after, on 28 February 1961. Its operational lifespan ended abruptly, however, when a month later President Kennedy described the Snark as "obsolete and of marginal military value" and Strategic Air Command inactivated the 702nd on 25 June 1961. In the words of the Patrick chief historian, the Snark was "an abysmal failure as a weapon system, but it gave SAC considerable experience in preparing, training, and deploying other strategic guided missile cadres in later years." The Snark also was responsible for the construction of the

Cape Canaveral Skid Strip landing site that would continue to serve as the Cape's "airfield" in support of missile and space operations.[11]

Another cruise missile even more unsuccessful than the Snark proved to be the Navaho. The ambitious program called for Northrop to produce three versions of a supersonic guided missile capable of achieving at least Mach 2.75 speed to deliver a W-41 nuclear warhead 5,500 nautical miles to within 1,500 feet of the target. A variety of guidance and engine problems during its 26 flights between August 1955 and January 1959 doomed both the X-10 and XSM-64 versions of the Navaho. It was referred to as "Never go, Navaho," and the Air Force Headquarters cancelled the program that July. Despite its failure, however, the Navaho program provided an important legacy for ballistic missile and space programs. As noted by Maj Gen Harry J. Sands Jr., former commander of the AFMTC at Patrick, "Out of the Navaho came the development of the accelerometers, the gyros, the guidance systems and the engines that are the basis for the ones we use today." Rocketdyne, for example, used the Navaho engine design in various versions of the Atlas and the Thor.[12]

At the same time, the increased range of winged missiles precipitated an expansion of downrange tracking sites. By 1957, with the addition of Ascension Island in the South Atlantic, the range extended 5,000 nautical miles from Cape Canaveral. Equipment included radio-based telemetry receiving stations, optical systems, radar tracking sites, timing systems, communications facilities, and command destruct equipment.[13]

Despite the failures and limitations of winged missiles, they provided their Air Force support personnel, like Lieutenant Roy, valuable experience for future ballistic missile and space launch operations. The winged missile era also left a legacy of rocket and missile components that would be used in future ICBMs, cruise missiles, and tactical air-to-air missiles. On the broader strategic stage as well, the cruise missile fleet provided a margin of safety during the early stages of the Cold War as ballistic missile development got underway.

The Era of Ballistic Missiles

Ballistic missile testing at the Cape had begun well before the end of the winged missile era. The Western Development Division had initially established only a small liaison office at AFMTC in August

1955. Anticipating ballistic missile tests in 1957, the division replaced the liaison office on 1 May 1956 with a field office that grew from 3 officers and 4 civilians at its opening to 49 officers, 8 Airmen, and 21 civilians by December 1959. The increase in personnel reflected ballistic missile testing's domination at the Cape and the expansion of the range after 1957. Indeed, by January 1960, the Atlantic Missile Range included 13 major stations, 91 outlying sites, a fleet of telemetry ships, and 3 marine support stations and extended nearly 9,000 miles from the Cape to the tip of South Africa and into the Indian Ocean.[14]

Initial ballistic missile testing at the Cape centered on three missiles, the Thor, Atlas, and Titan, that would soon be configured as space boosters for DOD and NASA missions. Generally, all missile test programs used instrumentation to measure the missile's position, velocity, acceleration, altitude, and attitude to assess stability and control characteristics as it rose off the pad. The requirement for a high degree of tracking accuracy continued during the important staging sequences when rocket engines shut off and booster segments fell away. The same degree of accuracy would characterize space launches as well.[15]

Thor Test Flights

Thor IRBMs launched from Launch Complex 17, located near the southern perimeter of the Cape close to the Lighthouse. The complex consisted of two launchpads that shared a common blockhouse. Construction began in April 1956 and proceeded rapidly. Air Force and contractor personnel occupied pad 17B that September and launched the first Thor test vehicle from that pad on 27 January 1957. Work on pad 17A finished sufficiently for Thor support personnel to occupy it in April 1957 and to launch its first test missile four months later, on 30 August. By that point, LC-17 had a number of the basic site facilities in place. In addition to the blockhouse, the complex included a mobile service tower, an umbilical mast, a guidance site, airborne guidance test equipment, fueling facilities, housing and messing facilities, and Hangar M, a 40,000-foot missile assembly building. The 450- x 10,000-foot paved skid strip constructed for cruise missile support continued to provide for the launch and recovery of drones and cruise missiles while accepting aircraft arriving with ballistic missile and space launch vehicles and equipment.[16]

On pad 17A, only two of the five Thor test launches between 30 August 1957 and 28 January 1958 were successful before the Air Force began Thor-Able flights. By contrast, controllers at pad 17B launched 26 Thor test flights from 25 January 1957 to 17 December 1959 before commencing space launches. Eight of the 26 launches failed, but only one of the last 15 was unsuccessful.[17]

Atlas Test Flights

Unlike the Thor IRBM experience at the Cape, the Air Force initially constructed four complexes for its larger Atlas ICBM test program. Paul Smith Construction Company of Tampa, Florida, began work building all four Atlas ICBM launch complexes in January 1956. The Air Force accepted LC-12 and LC-14 in August 1957 and January 1957, respectively, and the remaining two, LC-11 and LC-13, in April 1958. All four complexes possessed the same basic elements of mobile service tower, umbilical mast, launch stand, blockhouse, storage and transfer facilities, missile guidance facility, and a data collection equipment station. The Atlas arrived at the Cape by C-133 Cargomaster aircraft and was transported to the hangars for receipt and inspection. Atlas contractors used all or parts of hangars J, K, N, H, and F as missile assembly buildings for Atlas processing, yet most checkout procedures took place at the launchpad.[18]

It should not be surprising that the early versions of the Atlas experienced a relatively high failure rate at the Cape. At the same time, the A series failure rate of 63 percent and the B series figure of 40 percent were based on only 8 and 10 launches, respectively. The C version had 1 failure out of 6 launches, while the E series Atlas launched 18 times with a high failure rate of 33 percent, and 2 of the 10 F series failed. From the perspective of Cape Canaveral's space launch community, the Atlas D series drew particular attention. Although it compiled a respectable success figure of 88 percent, with 4 failures among the 33 test launches, it also experienced 5 partial failures. As the vehicle selected by NASA to launch its first astronauts under Project Mercury, the Atlas would require more reliability standards than normally accepted by the Air Force.[19]

The Air Force–NASA Relationship

From the beginning of space operations at Cape Canaveral, Air Force boosters and upper stages have primarily supported NASA objectives, first with instrumented satellite launches, then in support of the manned lunar landing program.

The Air Force relationship with NASA has reflected both cooperation and competition. Writing to his staff in April 1960, USAF Chief of Staff Gen Thomas D. White declared that the "Air Force must cooperate with NASA . . . to the very limit of our ability and even beyond it to the extent of some risk to our own programs." Born of the necessity to share resources while accommodating often conflicting operational goals, the Air Force–NASA partnership reflected both competition and mutual dependence. Before the launch of the first Sputnik on 4 October 1957, the military services dominated the country's infant space program. Apart from the International Geophysical Year satellite competition, civilian priorities remained secondary. Among the services, the Air Force believed that its responsibility for the development of the Atlas and Titan ICBM, the Thor IRBM, and the multifaceted military reconnaissance satellite system, WS-117L, gave it pride of place as the lead service for space. Its claim also reflected an extensive biomedical research program that viewed human spaceflight as an extension in the chain of operational development from aviation medicine to space medicine. The administration of President Dwight D. Eisenhower, however, refused to sanction the Air Force's quest to lead the national space program. This rejection left Air Force space proponents frustrated and contributed to early friction between the service and a NASA dependent on the Air Force for a wide array of support. Even though NASA's dependence on the military diminished during the Apollo era of the 1960s, the national, integrated space program directed the civil and military agencies to cooperate on common objectives. This policy would continue during the shuttle period to follow. While mutual interests, especially involving space launch and human spaceflight, and competition for scarce resources created a competitive atmosphere, a genuine cooperative spirit has characterized the Air Force–NASA association to the present day.[20]

Already in the Kennedy administration the Defense Department and NASA had established a pattern for future cooperative measures through an agreement reached on 23 February 1961, by which both parties decided to seek the consent of the other before developing new launch vehicles. According to several formal agreements signed in the fall, NASA would pursue development of large liquid propellant rockets, in tandem with the Air Force's work on large solid-propellant rockets until it became clear which would better support the lunar mission. At the same time, the panel approved Air Force plans to develop a large, standardized "workhorse" booster for potential future needs of both NASA and the Defense Department. By autumn of 1961, this proposed system had become the Titan III, a vehicle which would consist of a basic Titan II modified by the addition of two strap-on solid rockets. The Titan III would be capable of orbiting near-Earth payloads of 5,000 to 25,000 pounds.[21]

A second coordination effort involved facilities and resources needed to support the lunar landing program, which NASA had already designated Project Apollo back in the summer of 1960. Interest centered on a joint study of possible launch sites conducted by Maj Gen Leighton I. Davis, who had succeeded Maj Gen Donald N. Yates as commander of the AFMTC and the Defense Department's representative for coordinating range support for NASA, and NASA's Dr. Kurt H. Debus, chief of the agency's Cape Canaveral launch operations. In July they agreed on Cape Canaveral as the Apollo launch site, with the recommendation that NASA purchase approximately 80,000 acres on Merritt Island just north of the already overcrowded missile and space launch complex.[22]

On 24 August 1961, NASA Administrator James E. Webb and Deputy Secretary of Defense Roswell Gilpatric signed a launch site agreement, whereby NASA would acquire the large parcel of land needed for lunar operations and "the launch site will be operated as a Joint DOD/NASA venture under one manager to prevent duplication and promote efficiency." Additionally, "a single agency [the Air Force] . . . will manage and direct all range operations to include range safety, launch scheduling, and the provision of range operations service." Although the arrangement also made NASA responsible for all costs associated with the lunar project, this issue of cost reimbursement would become a contentious problem throughout the decade.[23]

Although NASA purchased its first parcel of land through the Corps of Engineers on 10 November 1961, it soon found itself in a dispute with the Air Force over the latter's proposal to place a Titan III facility on the southern part of NASA's land acquisition as well as acquire an additional 10,900 acres in the north "to protect the full launch potential of the Atlantic Missile Range." Dr. Debus objected and suggested that the Air Force locate its Titan operation on the mainland, or offshore, or even in Cumberland, Georgia. He worried that Titan III launchpads located north of LC-37 would infringe on NASA's use of that complex and that access roads from the industrial area to LC-34 and LC-37 could be impaired. In late April 1962 General Davis submitted a revised Air Force proposal requesting 14,800 acres for the Titan program. The additional land, Air Force officials argued, would permit the NASA launchpads to move further north and ensure safe distances between the Titan III pads, to be used for the proposed Dyna-Soar space plane, NASA's Saturn V pads, and any future Nova pads. In June 1962, after the Senate Armed Forces Committee had approved the 14,800 acre request, NASA agreed to having the Titan III site on the southern portion of the new land.[24]

Not unlike the experience at the Pacific Missile Range with Air Force-Navy jurisdictional issues, however, NASA and the Air Force at the Cape differed over control of various elements of range and launch activities. An agreement signed by Secretary of Defense Robert S. McNamara and Administrator Webb on 17 January 1963 resolved the major differences by delineating responsibilities for sharing range communications and other equipment and facilities. While the AFMTC would continue as executive agent and single manager of the AMR, NASA would have more direct control of developments on Merritt Island, and the Merritt Island Launch Area would be considered "a NASA installation, separate and distinct from the Atlantic Missile Range . . . and the host agency . . . for the providing of facilities and services to DoD, as DoD is host at Cape Canaveral and elsewhere on the AMR." The two agencies were to consult with each other on plans and requirements "to ensure a maximum of mutual assistance, and a minimum of duplication." The January 1963 agreement resolved the major points of contention apart from cost sharing responsibilities.[25]

As the 24 August 1961 arrangement suggested, NASA remained heavily dependent on DOD support, especially at the Cape. The civilian agency relied on the DOD's experience with the Navy Transit navigational satellite in planning its own commercial or civilian satellite system and looked to it for its procurement procedures, contract management services, and cost and work scheduling methods. From the civilian agency's inception, the DOD, largely through the Air Force, had supplied personnel, rocket boosters, launch and range facilities, and communications and tracking networks, as well as experience gained from the ballistic missile program. By 1962, the Air

Force and NASA had concluded 10 major agreements and a host of implementing arrangements.[26]

Instrumented Space Flight in Support of NASA

At Cape Canaveral Air Force operational support of NASA programs began with Thor and Atlas robotic scientific and lunar exploratory space missions.

Thor

The first Thor space launch flights took place on Pad 17A after only five missile test flights. Then, needing just four months to modify the site to support upper stages and payloads, controllers launched the maiden flight of the Thor-Able space launch test vehicle on 23 April 1958. Unfortunately, it failed when it experienced a turbopump failure at T+146 seconds. After two additional successful test flights, the first of three Thor-Able I Pioneer lunar probe missions in support of NASA launched on 17 August 1958. All three failed, one due to another turbopump malfunction and two others when the third stage failed to ignite. The failures prompted officials to fly six reentry nose cone test missions with the Thor-Able II. The Thor-Able combination then launched three successful flights supporting NASA missions and one in support of the Navy that failed. The NASA flights consisted of *Explorer 6*, *Pioneer 5*, and *TIROS 1*. *Explorer 6* launched on 7 August 1959 to assess trapped radiation of different energies in the upper atmosphere. *Pioneer 5*, launched on 11 March 1960 to perform a Venus flyby, experienced technical issues that meant foregoing the flyby in favor of investigating interplanetary space and confirming the existence of interplanetary magnetic fields. The Navy's Transit 1A navigation satellite was destroyed, however, when the flight on 17 September 1960 did not reach orbit after the third stage failed. After the TIROS launch, pad 17A supported NASA's Delta missions almost exclusively. The exceptions proved to be two antisatellite test flights and, on 31 October 1962, the successful launch of ANNA 1B, a multiservice geodetic spacecraft, on the final flight of the Thor-Able-Star combination. Pad 17A would continue supporting NASA's Delta launches into the next century.[27]

The Air Force also began launching Thor space launch vehicles on pad 17B nearly two years after the initial launch from pad 17A. After

26 test flights, controllers launched the initial space mission, a Navy Transit 1B navigation satellite designed to support Polaris submarines, on 13 April 1960. Nine more DOD-supported satellite launches with the Thor-Able-Star combination followed, including five Transit, two Courier satellites, one composite, and the first ANNA satellite. Four missions ended in failure. *Transit 3A*, launched 30 November 1960, failed when the Thor cut off prematurely and the resulting debris from the destroyed vehicle landed in Cuba. Earlier, on 18 August 1960, a premature cut off of the Thor engine had resulted in failure of the *Courier 1A*, the Army's high-volume communications satellite. On 24 January 1962, a naval composite payload consisting of geodesy, electronic intelligence, ionospheric, and calibration satellites failed when the second stage Able produced insufficient thrust. Finally, the initial ANNA geodesy mission on 5 October 1962 failed to achieve orbit when the second stage did not ignite. The ANNA flight proved to be the last DOD space launch from pad 17B. Except for six Thor suborbital flights to test reentry vehicles, the pad henceforward supported NASA-launched Delta missions.[28]

Even though Thor launch vehicles at the Cape would operate in the 1960s primarily as NASA assets, the Air Force continued its procurement role for both Thor and Atlas boosters used by the civilian agency. Indeed, on 9 August 1963, Lt Gen Howell M. Estes Jr., AFSC Vice Commander, and NASA Associate Administrator Robert C. Seamans Jr. signed an agreement describing the responsibilities of NASA and the Air Force regarding the space agency's use of Thor-Agena, Atlas, and Atlas-Agena systems. Superseding a February 1961 agreement on the Agena B, the new accord charged Space Systems Division to design, engineer, and test the basic Thor and Atlas boosters and Agena D stages. NASA would purchase these vehicles from the Air Force and conduct its own launchings from both its LC-39 on Merritt Island and LC-17, LC-34, and LC-36 at the Cape.[29]

Atlas

Air Force Atlas space launch operations initially involved LC-12, LC-13, and LC-14. Although Project SCORE, the first US communications satellite to orbit in space on 18 December 1958, flew from LC-11, its other non-test flight missions consisted of only five Advanced Ballistic Reentry System suborbital launches between 1 March 1963 and 2 April 1964 before being deactivated in August 1967.[30]

In the transition from ballistic missile to space booster site, the Atlas complexes had to be configured to support upper stages and payloads. This took the form of increasing the height of the A-frame mobile service tower and umbilical mast. At LC-12 and LC-14, for example, contractors extended the service tower to 154 feet 8 inches in height and the umbilical mast to 84 feet 6 inches above its launch stand that measured 60 feet wide by 78 feet long. A 57-foot by 20-foot launchpad building extended under the ramp, which was 24 feet wide and 92 feet long and gradually rose to 22 feet in height. The now trapezoidal-shaped service tower consisted of 14 movable steel framework decks, and for launch it moved by rail at least 300 feet back from the launch stand. Unlike the Atlas blockhouses at Vandenberg AFB, the blockhouses at the Cape's Atlas-Agena complexes were dome-shaped reinforced concrete structures, 10 feet 6 inches thick at the base and 5 feet 6 inches thick at the dome's apex. The floor measured 60 feet in diameter, with inside walls in a 12-sided configuration. A layer of sand insulation that measured 10 feet thick at the dome's top and 40 feet at its base was held in place over the blockhouse structure by a thin layer of concrete. Four periscopes in the control room provided visual coverage of the site. For safety, they were positioned about 750 feet from the launch stand. The sites also received different propellants, additional electrical cables at the launchpad and blockhouse, and new equipment in the blockhouse to handle the upper stages and payloads. Unlike LC-12 and LC-14, LC-13 received a new, mobile service tower that measured 179 feet in height, and an umbilical tower extended to 92 feet 6 inches above the launch deck. The configuration changes at LC-13 were made four years later than those at LC-12 and LC-14 to accommodate the larger, taller payloads to be launched by the Atlas D-Agena D combination.[31]

The Atlas arrived at the Cape in a C-133, while the Agena came in on a C-124 Globemaster. Once offloaded, both vehicles went into processing, the Atlas to hangars used in the ICBM test program, hangars J, K, N, H, and F, and the Agena to Hangar E. Additionally, Lockheed contractors used Hangar AA, a smaller, all-metal building behind Hangar E, for document storage. Contractors and Air Force personnel working on the Agena frequently visited the hangar for copies of procedures, drawings, and related material.[32]

Fig. 8. LC-12 with its Mobile Service Tower, 28 February 1963. (Photo courtesy of John Hilliard)

Fig. 9. Atlas 197D Agena at LC-13 with Mobile Service Tower, 8 October 1963. (Photo courtesy of John Hilliard)

At LC-12, Atlas missions in support of NASA's lunar objectives began inauspiciously with two unsuccessful Atlas-Able Pioneer lunar probe flights followed by various failures of the first six Ranger missions programmed to photograph the moon prior to impact. On the first two prototype flights, in August and November 1961, the Agena failed to restart, while on the next four problems with the spacecraft doomed the missions. *Ranger 3* experienced a guidance system failure, missed the moon by nearly 23,000 miles, then orbited the sun. *Ranger 4*'s spacecraft became disabled, *Ranger 5* also missed the moon, and the cameras failed on *Ranger 6*. The final three Ranger spacecraft, however, used a redesigned television instrument and were spectacularly successful. Each transmitted thousands of pictures, with *Ranger 9*, launched on 21 March 1965, sending back 5,800 images that confirmed crater-on-crater as the dominant feature of the moon's surface. Apart from the first two Ranger missions, the Atlas-Agena B combination had performed well.[33]

Likewise, the Atlas-Agena booster configuration successfully launched three of four interplanetary probes between 22 July 1962 and 15 June 1967. Unfortunately, *Mariner 1* experienced a guidance system failure at T+295 seconds and was destroyed by the range safety officer. *Mariner 2* performed *Mariner 1*'s Venus flyby mission five weeks later, becoming the first spacecraft to successfully fly by another planet. In another first, *Mariner 4*, launched on 28 November 1964, achieved the initial flyby of Mars, recording the first close-up images of the planet that, in fact, challenged proponents of life on Mars. Finally, *Mariner 5*, launched on 14 June 1967, performed the second Venus flyby and successfully assessed the Venusian atmosphere with a complement of experiments. Atlas-Agena D booster combinations also launched two of NASA's six Orbiting Geophysical Observatory satellites to study the magnetosphere, one Orbiting Astronomical Observatory to examine various objects in ultraviolet light, and three Applications Technology Satellites to conduct communications, meteorology, and scientific experiments. In December 1967, a month after the third Applications Technology Satellite mission, the Air Force deactivated LC-12.[34]

Launch Complex 13 supported both DOD missions and NASA's Lunar Orbiter Program. The first set of ARPA-sponsored Vela nuclear detection satellites inaugurated space launch at the complex. The initial Vela launch occurred on 16 October 1963, one week after the Partial Test Ban Treaty went into effect and marked the maiden voyage of the SLV-3 Atlas-Agena D. This booster combination launched diamond-shaped Vela Hotel satellites in pairs into a 50,000-mile circular orbit where they operated opposite one another. On 17 July 1964 and 20 July 1965, the Air Force successfully launched a second and third pair of Vela satellites to continue monitoring compliance with the 1963 test ban treaty by detecting nuclear tests in space. Future Vela satellites would be heavier and more complex, requiring them to be launched by the heavy-lift Titan IIIC booster.[35]

In 1966, the Air Force transferred LC-13 to NASA to enable the civilian agency, using Atlas-Agena D boosters, to launch five Lunar Orbital missions between 10 August 1966 and 1 August 1967 to help determine optimum Apollo landing sites. Using a Kodak camera system adapted from the Air Force's Samos E-1 reconnaissance camera, the five spacecraft photographed 99 percent of the near and far side of the moon's surface and achieved a resolution of 3 feet 3 inches. In addition to the lunar missions, NASA launched an Orbiting Geophysical Observatory mission on 4 March 1968 before LC-13 was reassigned to the Air Force. Beginning on 6 August 1968, Atlas-Agena D boosters would successfully launch 12 of 13 classified Canyon and Rhyolite electronic intelligence satellites on behalf of the National Reconnaissance Office, with the final launch occurring on 6 April 1978.[36]

Launch Complex 14, the third in the trio of former Atlas ICBM sites, achieved fame as the launch complex that supported NASA's Mercury and Gemini manned spaceflight missions. After the Mercury test capsule flight on 9 September 1959, LC-14 supported NASA's *Pioneer 3* lunar probe mission on 26 November 1959, and two ARPA-sponsored MIDAS test launches, on 26 February and 24 May 1960. Only the second MIDAS launch was successful. The Atlas-Able I–launched *Pioneer 3* failed when the payload shroud broke off at T+45 seconds, and *MIDAS 1* failed to orbit when the second stage Agena A remained attached to the Atlas booster. After the successful orbiting of the second MIDAS launch, Air Force officials relocated the MIDAS program to Vandenberg Air Force Base, where it would continue as a polar-orbiting infrared-sensor detection satellite program. After the second MIDAS launch and three additional Atlas D test flights, LC-14 would support 11 Mercury missions, including 4 manned flights, followed by 7 Atlas-Agena D Gemini missions, for which the Agena would serve as the target vehicle for the two-man Gemini spacecraft to practice its rendezvous and docking techniques. Although deactivated in February 1967, three months after the final

Gemini mission, LC-14 continued to function as a support facility for Atlas-Agena D launches on LC-13.[37]

Atlas-Agena Operations at Cape Canaveral AFB and Vandenberg AFB

The Atlas-Agena operations at the Atlantic Missile Range (AMR) and the Pacific Missile Range (PMR) became the subject of a 1962 Space Systems Division Space Launch Survey Team assessment to determine if standardization of operations at both ranges would be feasible and cost-effective. Because Air Force leaders would periodically return to the prospect of range standardization in the coming years, it is important to examine the initial assessment of the issue.

The survey team compared hardware, procedures, and organizational arrangements at both ranges. Beginning with their dissimilar origins, the survey noted that the AMR was created as an R&D missile test base and used R&D manual-type equipment to gain quantitative data for realistic testing and further development of the particular system. As for vehicle processing at the Cape, the Mission Assembly Building (MAB) hangars functioned mainly for receipt and inspection of the booster, and little checkout of Atlas occurred before its erection on the pad. The PMR, by contrast, originated as an operational site and functioned under the concept that the booster should be "pad ready" before it was erected. As a result, technicians conducted as many subsystem tests as possible in the MAB to check out the Atlas. The PMR, with an operational priority, also used automatic equipment not designed to collect data to address future development of the system.[38]

Regarding organization and management, the survey team found that the Cape's 6555 ATW operated with more clearly defined responsibility and authority. Vandenberg's 6595 ATW, by contrast, had to create project offices as counterparts to Space Systems Division (SSD) program offices, located in nearby Los Angeles, to keep SSD project officers "off the back" of the launch working element. Likewise, complex scheduling and coordination required at the PMR made range support at AMR much cleaner. Often SSD program offices bypassed 6595 ATW project offices and submitted requirement documentation directly to PMR without coordination. Despite having overall responsibility for Air Force PMR operations, the 6595th's challenge increased by having to coordinate with SAC officials, the 1369th Photographic Squadron, the 6594th ATW, and various Navy elements.[39]

As for Special Project classified Atlas-Agena missions, a Systems Test Complex handled integrated system checkout procedures with the Agena vehicle, payload vehicle, and payload at the PMR. For AMR Agena missions, the Agena served only as second boost stage vehicle and did not require an integrated system test complex. In a significant difference in equipment and procedures between the two launch sites, the AMR, unlike the PMR, used a gyro laboratory that gave the base the capability to check Atlas flight control systems. The survey team concluded that this gave AMR operations a somewhat greater probability of mission success.[40]

After focusing on differences between the two ranges, the survey team provided a number of recommendations. It strongly proposed that the PMR operation would benefit from a more streamlined management structure, and the team thought this likely once the Air Force replaced the Navy as range authority. The team also recommended that PMR officials examine flight control system tests and quality control procedures at the factory to determine if PMR operations would benefit from a gyro lab.[41]

Despite differences in equipment and procedures at the two ranges, the inspectors did not recommend standardized checkout procedures or replacing existing equipment to achieve commonality because, they argued, basically the same checks were successfully performed at both places. Differences in support equipment, mission requirements, and range requirements did not imperil operational success, and efforts to standardize these elements seemed impractical and uneconomical.[42]

With Vandenberg's continued focus on ICBM testing and classified reconnaissance missions and NASA's domination of operations at the Cape, Air Force leaders saw little to gain in any effort to standardize operations at the two sites. In any event, commanders would continue to coordinate with each other as appropriate, while space launch operators would perform the same functions and provide the same basic support for Atlas-Agena operations at both launch sites. Consequently, the survey team recommended no official standardization effort be undertaken, and this conclusion would be echoed after future assessments of standardization prospects at the two launch ranges.[43]

Meanwhile, the Atlas-Agena combination would continue to launch robotic spacecraft at the Cape, and the Agena would serve as the target vehicle for NASA's Gemini rendezvous and docking program. First, however, the Atlas would make history as the first booster to launch NASA astronauts into LEO.

Air Force Support for Project Mercury

For NASA's Project Mercury, the nation's first manned space program, the Air Force provided most of the astronauts, launch facilities and vehicles, range support, and, with the Navy, the necessary recovery forces. NASA designed Project Mercury to show that man could endure an accelerated rocket launch into LEO, perform a variety of functions, including enduring periods of weightlessness, and survive the challenge of reentering the atmosphere and landing safely.

Mercury, in fact, emerged from an Air Force project, Man-in-Space Soonest, the capstone of a lengthy postwar Air Force effort in biomedical research and interest in flying pilots in space. Despite mounting an aggressive campaign back in the spring and summer of 1958 to have its Man-in-Space Soonest development plan approved, the Air Force failed to convince Eisenhower administration officials to approve the plan. That August the president assigned the human spaceflight mission to NASA, and Man-in-Space Soonest, with its Air Force biomedical and related manned programs, became part of the new agency's Project Mercury. With human spaceflight now a NASA responsibility, Air Force leaders henceforth would pursue a role for military pilots in space largely in cooperation with NASA.[44]

Air Force support for the Mercury program at the Cape actually began with the appointment, on 10 August 1959, of General Yates, AFMTC commander, as the designated DOD representative for Mercury support operations. A month later, he established the Mercury Project Office (Range) to perform liaison functions between Center officials and Dr. Kurt Debus, the official in charge of NASA's field office at the Cape. Additionally, the Air Force provided a wide variety of support to NASA operations at the Cape. Hangar S, for example, served as the assembly building for capsule checkout and assembly and housed the biomedical and training facilities. To control Mercury operations, the Air Force provided its Space Flight Control Center Building 1385, near LC-14, to serve as the Mercury Control Center.

NASA flights also would use the data acquisition and reduction resources at Patrick Air Force Base and other test center locations as well as the existing land and island-based tracking and telemetry network and recovery ships. The Air Force had extended the range when the Atlas launch program compelled officials to arrange for a communications relay station near Johannesburg, South Africa, as well as use of Durban, South Africa, for instrumented aircraft, and dock space at Cape Town. To support NASA's Mercury flights, the Range was extended further to include Indian Ocean and African sites and areas to approximately 75 degrees east longitude.[45]

The Mercury program called for two types of boosters. The Redstone, the product of Wernher von Braun's rocketeers at the Army Ballistic Missile Agency, would be used for the suborbital portion of the program. To retrofit the Redstone for human spaceflight required lengthening the tanks and using alcohol instead of the more toxic Hydyne and making nearly 800 additional changes to the Redstone.[46]

Launched from dual-pad Launch Complex 5/6 on 21 November 1960, the first Mercury-Redstone (MR) test flight rose only 3.8 inches off the pad, while the second, flown the following month, showed significant improvement but landed the capsule 20 miles beyond the target area. The second official flight, *MR-2*, on 31 January 1961, lofted the chimp Ham on a parabolic trajectory and recovered him successfully. Because of a booster malfunction, however, the capsule landed 60 miles downrange from the nearest recovery ship. This prompted von Braun to demand an additional mission before flying an astronaut aboard the Redstone. To the chagrin of Navy lieutenant and astronaut Alan Shepard and many others, substituting the unmanned flight on 23 March 1961 meant that Soviet cosmonaut Yuri Gagarin and not an American astronaut became the first into space. On 5 May 1961, Alan Shepard achieved fame as the first American in space, if not into orbit, aboard *Freedom 7*, and on 21 July, Air Force Capt Virgil I. "Gus" Grissom followed him into space and back aboard *Liberty 7* on the last MR mission. The success of the two suborbital human flights convinced NASA to cancel a third scheduled flight and commence the orbital phase.[47]

NASA had chosen the Air Force's more powerful Atlas to launch the 2,464-pound Mercury capsule into a 150 x 100 mile orbit from LC-14. Man-rating the Atlas proved to be more difficult than expected. With traditional safety concerns of launchpad and range damage now overshadowed by apprehension about the potential loss of human life, the reliability of the Atlas missile became a major issue. Initially, the Convair Corporation had accepted a 20 percent failure rate, but even this was far exceeded by the failure of seven of eight launches in early 1959. It seemed that the missile either blew up on the launchpad or needed to be destroyed by the range safety officer when it deviated from its programmed flight path. Testifying before Congress, Robert R. Gilruth, NASA's Manned Spacecraft Center director, offered a major understatement in saying, "You don't want to put a man in a device unless it has a good chance of working every time."[48]

In response to NASA's concerns, Convair president J. V. Nash had an exhaustive investigation performed and presented a report to the NASA administrator on 21 December 1960 that attributed most Atlas-Agena failures to be the fault of the Agena. He argued that the "Atlas has been used as a space booster in ten attempts so far and in only one of these ten has the Atlas failed . . . and that failure was during a static test." Meanwhile, NASA and the Air Force continued to work on modifications to improve performance and reduce risks to the astronauts. To keep the engines from exploding, engineers developed a fiberglass shield to surround the liquid oxygen tanks, and every system considered suspect or unreliable was replaced. The most important addition was an abort sensing system for emergency ejection of the capsule that participants affectionately referred to as ASS. With *Mercury 7* astronauts becoming American icons representing the nation's technological and political aspirations, success of the Mercury program would mean the very continuation of NASA's human spaceflight endeavor.[49]

The Mercury orbital phase began inauspiciously on 29 July 1960 when the Mercury Control Center lost contact with the initial Mercury-Atlas (MA) 1 suborbital test flight less than a minute after liftoff. Investigators attributed the failure to compatibility problems between the booster and the Mercury capsule adaptor and spent the next six months making appropriate modifications to the adaptor. After a successful MA-2 suborbital flight on 21 February 1961 to test booster-payload compatibility and the abort system, the program experienced another failure with MA-3, the first Mercury orbital mission, launched on 25 April 1961. Investigators determined that a short circuit in the booster's programmer prevented the pitch and roll sequence to function, and the range safety officer destroyed the

Atlas at T+43 seconds. Recovery forces, however, retrieved the Mercury capsule.[50]

After extensive modifications to the Atlas booster, MA-4, launched on 13 September 1961 with a crew simulation instrument package, became the first successful orbital mission and verified the effectiveness of NASA's 20-station tracking system. The success of MA-4 also provided a needed morale boost after the Soviet Union had flown cosmonaut Gherman Titov in a daylong orbital flight in August.[51]

Before proceeding with the first human Mercury mission, however, NASA planned one last unmanned flight with Enos, a five-year old chimpanzee from Cameroon, Africa. MA-5 required 40 weeks of preparation that included modifying the autopilot to correct the 20 seconds of vibration that engineers detected with MA-4. Despite a malfunctioning attitude control system detected during the second orbit of the 29 November 1961 flight, both Enos and the spacecraft were recovered in good condition. NASA now considered the Atlas and Mercury spacecraft prepared to launch a human into orbit.[52]

Air Force personnel launched four manned Mercury missions for NASA. Only one of the four was without significant issues. The third flight, *Sigma 7*, launched on 3 October 1962, completed six orbits in a "textbook flight" that returned precisely to the recovery area and had astronaut Walter Schirra on board the USS *Kearsarge* recovery ship 40 minutes later. Understandably, the most celebrated flight was the first, with John Glenn's three-orbit *Friendship 7* mission on 20 February 1962. Despite the "wonderful trip—almost unbelievable" and President Kennedy's famous postflight comment declaring space "this new ocean," John Glenn experienced attitude control problems and the challenge of reentry with the retropack still attached to secure the heat shield. Perhaps most significant, Glenn demonstrated the importance of a human at the controls when he had to forgo the automatic control system for the manual-electrical fly-by-wire procedure. Especially controversial was Scott Carpenter's flight three months later in *Aurora 7*. His poor use of fuel and responses to ground control led to a reentry landing over 185 miles past the target point. Although Carpenter received the expected hero's welcome, especially in his hometown of Boulder, Colorado, he never again flew in NASA's astronaut program.[53]

Fig. 10. *Friendship 7* launches, Atlas 109D Mercury MA-6, from LC-14, 20 February 1962. (Photo courtesy of John Hilliard)

Air Force astronaut Col L. Gordon Cooper flew the long-duration, final Mercury MA-9 mission in *Faith 7* on 15 May 1963. After the Atlas booster initially failed inspection, Convair rolled out "their best bird yet," one that housed an upgraded propulsion system with a hypergolic igniter. After a one-day delay to repair the gantry engine and radar in Bermuda, *Faith 7* lifted off, reached orbit, and flew without incident until orbit 19 of the scheduled 22-orbit mission. Then, the spacecraft's systems began to fail, and by orbit 21 Cooper had lost all altitude readings and electrical power to operate the automatic stabilization and control system. Like John Glenn before him, he verified the importance of the pilot-astronaut by resorting to manual reentry procedures and guided his spacecraft to a pinpoint landing just four miles from the USS *Kearsarge*. When retrieved by naval helicopters, he followed proper procedures as an Air Force officer by requesting—and receiving—permission to come aboard.[54]

Although several NASA officials proposed continuing Project Mercury with a longer, three-day, 48-orbit mission with astronaut Alan Shepard sometime in October 1963, MA-10 never flew. Instead, NASA decided that Mercury's objectives had been met, and it was time to move on to Project Gemini.

Air Force Support for Project Gemini

When NASA determined that the Apollo program would use the concept of lunar orbit rendezvous, planners recognized the need for an interim program between Mercury and Apollo. On 7 December 1961, NASA announced a "two-man Mercury" program, soon to be named Project Gemini, for the twins of classical mythology. Gemini's objectives included rendezvousing and docking in LEO, enduring 14-day orbital flights to demonstrate that astronauts could survive a mission to and from the moon, and working outside the spacecraft with extravehicular walks in space.[55]

Air Force leaders enthusiastically supported NASA's new human spaceflight programs. Not only did Air Force participation fulfill its obligation to cooperate with the civilian agency, but it also provided an opportunity to advance its own human spaceflight objectives. Secretary of Defense McNamara had stated that Air Force space programs must "mesh" with NASA's wherever possible. Air Force leaders saw their support of NASA programs, and the civilian agency's support of service initiatives, as the wedge needed to maneuver a reluctant defense secretary into approving its programs for flying pilots in space: Dyna-Soar, Blue Gemini, and, later the Manned Orbiting Laboratory (MOL). By 1962, the Air Force concept focused on a Military Orbital Development System (MODS), including a permanent station test module, a Gemini spacecraft, and the Titan III building-block launcher. In August of 1962, the Air Force added an interim program named Blue Gemini, which centered specifically on rendezvous, docking, and personnel transfer functions. Air Force pilots would fly six Gemini missions to gain astronaut experience for the MODS missions. By December, however, Secretary McNamara had cancelled Blue Gemini, citing high costs, duplication, and the inability of Air Force leaders to justify the mission.[56]

Then, in January 1963, McNamara stunned NASA administrator James Webb by first proposing that DOD take over Project Gemini and, when that was declined, suggesting the program be managed jointly by DOD and NASA. Although an agreement reached by McNamara and Webb on 21 January 1963 largely settled the conflict in NASA's favor, it went far to address Department of Defense concerns. NASA would continue to manage Gemini while a joint Gemini Program Planning Board would avoid duplication and ensure objectives were met by determining the experimental program and delineating between DOD and NASA "requirements and program monitoring." Significantly, the parties agreed to "initiate major new programs or projects in the field of manned space flight aimed chiefly at the attainment of experimental or other capabilities in near-earth orbit only by mutual agreement." Ultimately, 16 of the 49 Gemini experiments represented Department of Defense projects that proved important for NASA, too. As for the Air Force's remaining military human spaceflight programs, McNamara would cancel the Dyna-Soar spaceplane in December 1963 but approve the MOL.[57]

Meanwhile, the Air Force proceeded to supply NASA with the vehicles needed for Gemini. Weighing 7,000 pounds, more than twice that of the Mercury spacecraft, Gemini required a booster more powerful than the Atlas. The new Air Force Titan II missile not only had two and a half times the thrust of the Atlas and would easily lift the heavier Gemini spacecraft, but it could also carry redundant systems and had the advantage of using self-igniting storable propellants. In December 1961, the same month NASA announced the interim program, the Air Force agreed to provide 15 Titan II boosters for Gemini as well as 6 upper stage Agena rockets, NASA's choice for the target vehicle. Air Force SSD acted as NASA's contractor for both vehicles, and Aerospace Corporation engineers provided technical support.[58]

Given the Agena's proven success, NASA officials expected nothing other than to simply fit the Agena with its specially designed docking adapter to dock the Gemini spacecraft. For the Gemini, however, Agena's Bell main engine needed to be able to restart five times rather than the standard two. Electing to switch from the standard solid-propellant starting system to a liquid propellant alternative, however, resulted in technical problems that led to cost overruns and schedule delays. Likewise, Bell encountered challenges modifying the secondary propulsion.[59]

By the spring of 1963, it became clear that man-rating the Titan II would also require more changes than originally anticipated. These included inertial rather than radio guidance, a new launch tracking system, backup circuits to the electrical systems, and a redundant malfunction detection system. Moreover, in two of its first four flights, the missile exhibited second stage combustion instability in failing to reach full thrust, while technicians also had to deal with oxidizer and fuel pump leaks and a variety of general engine imperfections. Most alarming, during its first flight on 16 March 1962, a 30-second longitudinal oscillation began two minutes after liftoff and while the first stage was still burning. Although Air Force officials declared the flight a success, NASA worried that what came to be termed the "pogo" effect could add an additional +/- 2.5 Gs of missile acceleration to the 2.5 Gs that the astronauts would already experience. This might very well prove incapacitating during an emergency. Ultimately, investigators determined the solution to be a combination of a surge-suppression standpipe, higher fuel tank pressure and aluminum oxidizer feed lines, and a fuel surge chamber added to the fuel lines. With these modifications, missile N-25 achieved a pogo level considerably below NASA's maximum on its 1 November 1963 flight. Subsequent test flights confirmed the success of the changes.[60]

By the spring of 1964, the Titan II had experienced only three test flight failures among the 23 launches at the Cape, and NASA could confidently judge the Titan II ready for human spaceflight. In retrospect, NASA officials lauded the Air Force and its contractors for their hard work making the Titan man-rated while also challenged to produce an operational missile. As George Mueller, head of NASA's Office of Manned Spaceflight, told Administrator James Webb in

December 1965, "Configuration management is not a new term but the detailed application of the Air Force to the GLV [Gemini Launch Vehicle] development is a model of its kind and a significant contribution toward improved management of all major programs, in DoD and in NASA."[61]

Delayed for several months by various hardware problems, *GLV-1* lifted off from LC-19 on 8 April 1964 on what Maj Gen Ben I. Funk, SSD commander, would call "just completely a storybook sort of flight." The flight plan called for testing the structural integrity of the new spacecraft and modified Titan, assessing the tracking and communications system, and providing training to the ground support crews for the upcoming manned missions. Although the flight achieved all objectives after three orbits, the unmanned Gemini remained in orbit for 64 revolutions over four days before reentering and burning up as programmed. Preparations for *GLV-2*, scheduled to test the Gemini heat shield in an unmanned suborbital flight, progressed without major issues until August 1963, when it had to weather a severe lightning storm and later two hurricanes. When the launch finally occurred, on 19 January 1965, the mission was a complete success.[62]

Gemini III, the first manned mission, with astronauts Gus Grissom and John Young aboard, launched on 23 March 1965 and completed its five-hour, three-orbit mission successfully. *Gemini IV* and *Gemini V*, launched on 3 June and 21 August 1965, respectively, also flew their planned missions without serious incident. *GLV-4* was especially notable for the first "spacewalk," by astronaut Ed White, that NASA reluctantly approved. Tethered to the Gemini spacecraft and using a portable thruster to maneuver, White spent an exhilarating 20 minutes "walking" in space before returning. When directed to come back inside, Mission Control had an open microphone and the world would hear him say, "It's the saddest day of my life."[63]

Although the eight missions that followed achieved their planned objectives, they experienced a variety of problems. In December 1965, the Agena target vehicle for *Gemini VI* failed, prompting NASA to achieve the first rendezvous with *Gemini VI-A* and *Gemini VII*, launched in rapid succession on 4 December 1965 and 15 December 1965, respectively. Astronaut Air Force Col Edwin "Buzz" Aldrin, who would fly on the final Gemini mission, was a key figure in NASA's development of rendezvous and docking procedures. Having written his PhD dissertation at the Massachusetts Institute of Technology on orbital rendezvous, Aldrin, referred to as "Dr. Rendezvous" by his fellow astronauts, was instrumental in determining the required trajectories and orbital maneuvers that would enable the Gemini spacecraft to intercept its target vehicle.[64]

NASA had scheduled *Gemini VIII*, crewed by astronauts Neil Armstrong and David Scott, to perform the initial rendezvous and docking mission and for Scott to make the first spacewalk since Ed White's foray. Launched on 16 March 1966, the flight proceeded normally until the Gemini had successfully docked with the Agena target vehicle. When the Agena began turning the combined spacecraft to the right as programmed, however, the astronauts experienced an uncontrolled roll and had to forcibly undock from the Agena. The Gemini, however, continued to roll, and only with difficulty was Armstrong able to steady the spacecraft, determine that a thruster had stuck in the on position, and successfully perform the reentry procedures. Investigators never conclusively determined the cause of the thruster malfunction.[65]

Although the last four Gemini missions experienced no emergencies, they nevertheless were not without challenges. Originally scheduled to fly on 17 May 1966, *GLV-IX* was renamed *Gemini IX-A* and launched on 3 June with a backup augmented target docking adapter after the original Agena target vehicle had been destroyed. Unfortunately, when the Gemini approached the target, the crew realized that the nose fairing had opened but remained attached to the adaptor. Unable to dock with the target vehicle, the crew concluded their mission with a two-hour extravehicular walk in space. *Gemini X* lifted off on 18 July 1966 and completed the first double rendezvous when the Gemini spacecraft first docked with the Agena target vehicle and later flew within 10 feet of the drifting Agena from the *Gemini VIII* mission. Astronaut Michael Collins then completed a spacewalk to inspect the dormant Agena.[66]

Titan II

When considering the performance of the two launch vehicles, the Titan II, with its entirely successful launch record, deserves special praise, especially considering its troubled outlook in 1963. In late July 1963, Lt Col John G. Albert took over the 6555 ATW Gemini Launch Vehicle Division that included an eight-person staff, LC-19, and portions of hangars T, U, and G. His Titan II contingent grew in number as the Gemini program took shape. During the next five months, the Division expanded to include 17 officers, 8 Airmen, and 5 civilians. By the end of 1964, the Gemini Launch Vehicle Division roster consisted of 20 officers, 19 Airmen, and 4 civilians.[67]

In August 1963 Air Force contractors, under Division supervision, finished an 18-month reconfiguration project on LC-19 to prepare for Project Gemini. Division personnel also supervised the Martin Company's checkout of the initial modified Titan II after it arrived from the company's Baltimore plant on 26 October 1963. Both Division and Martin personnel remained busy with the booster given the myriad problems they encountered before *Gemini I* launched on 8 April 1964. Although Colonel Albert's team maintained test control over the launch vehicle, Martin's Gemini-Titan II Launch Operations Division controllers erected the vehicle and conducted check out and launch.[68]

Although the Titan II appeared to achieve a flawless launch record, film analysis of Titan II ICBM launches had raised concerns about post-staging tank rupture. Investigators discovered the problem on at least eight occasions and attributed the cause to flying debris, structural bending, or second stage engine exhaust. In any case, NASA eventually decided that this issue represented no threat to astronaut safety and declined to take corrective action.[69]

Atlas-Agena

Unlike the Titan II, the Atlas-Agena D target vehicle operation at LC-14 could not boast of a perfect track record. Indeed, the Atlas-Agena exploded during the first Gemini target vehicle launch on 25 October 1965, and on the third flight, on 17 May 1966, the Agena failed to orbit.

1st Lt Victor W. Whitehead found himself the Agena Project Officer at the Cape for the first three Gemini target vehicle launches that included the two failures. He had arrived at the Cape as a second lieutenant in early September 1962, fresh out of college with an aeronautical engineering degree and no training on launch vehicles. Like his contemporaries at Vandenberg, he used contractor manuals and test-launch procedures and learned "on the job." As he progressed, he received mentoring from officers at the Cape and attended short courses on the Agena liquid rocket engine and the Atlas rocket. He had worked on the Atlas for the *Mercury Sigma 7* and *Faith 7* missions and served as Agena Project Officer for three Vela flights.[70]

By the time of *Gemini IV*, launched on 6 March 1965, NASA had transferred its launch control operations from the Cape's Mercury Control Center to its newly completed Mission Control Center in Houston, Texas. Lieutenant Whitehead remembers that "there was a good working relationship with the NASA folks on both Mercury and Gemini." He frequently traveled to the Manned Spaceflight Center to brief NASA officials on Agena issues and worked closely with NASA flight controllers who would control the Gemini Agena once it was on orbit. Working from his position in the Complex 14 blockhouse, he said, "I even had a direct communications line . . . to their console in NASA Mission Control in Houston."[71]

Vic Whitehead also participated in both accident investigations. The 25 October 1965 Agena launch failure, he recounted, was traced to a "decision to change the propellant lead at start of the Agena main engine . . ., which caused the engine to explode on ignition." Engineers adjusted the start sequence, and an extensive firing test program run at the Arnold Engineering Development Complex verified the fixes. On the 17 May 1966 flight, investigators determined that the Agena staged on schedule, but a flight control problem prevented the Agena from attaining enough velocity and altitude to activate its engine. While contractors addressed the target vehicle's issues, NASA turned to the augmented target docking adapter for the *Gemini IXA* mission.[72]

Shortly before his reassignment from the Cape, Vic Whitehead participated in the adapter mission on 1 June 1966. As he explained, the Lockheed fairing used with the Gemini Agena was improperly attached to the adapter by a non-Lockheed contractor. In doing so, the two sections of the fairing were prevented from splitting apart by a band surrounding the cylinder juncture on the fairing. When encountered by the astronauts, they—and the press—called it "the angry alligator." Whitehead noted that it was "not a pleasant time."[73]

When the program concluded with the launch of *Gemini XII* on 11 November 1966, NASA had flown 12 Gemini missions, 10 of them manned, in addition to the Agena flights. The following April, the Air Force deactivated LC-19. The NASA team had demonstrated that rendezvous and docking could become routine and that astronauts could perform spacewalks and live and work effectively for extended periods in space. The challenges of varying degrees of difficulty that the astronauts confronted also confirmed the critical importance of their role as pilots of the spacecraft. These achievements, together with the knowledge gained from their experience and the completed Gemini experiments, made Gemini an essential bridge from Project Mercury to the Apollo moon landing venture.[74]

The Air Force would continue to provide range support for NASA's Apollo effort, which included communications, telemetry, and tracking information. The space agency, however, would handle Saturn I operations at LC-34 and LC-37B and Saturn V launches at its LC-39 on Merritt Island primarily with NASA personnel. Meanwhile, much of the Air Force focus at the Cape turned to the heavy-lift Titan III, the first Air Force booster specifically designed and developed for space launch operations.

Fig. 11. A three-stage view of Titan II Gemini (GT-9A), "The Angry Alligator," launching from LC-19, 3 June 1966. (Photo courtesy of John Hilliard)

Advent of the Titan IIIC at the Cape

The agreement signed on 17 January 1963 between NASA administrator Webb and defense secretary McNamara accorded the Air

Force responsibility for all Titan III construction, even that within NASA's Merritt Island Launch Area at the north end of Cape Canaveral. LC-41, for example, was constructed in NASA territory, and the complex's property delineated by its security fence as well as the access road fell within the Titan III program's jurisdiction. The January 1963 accord also acknowledged that the Titan III site would be part of the AMR under Air Force administration.[75]

The Titan III construction program embraced two launch complexes, LC-40 and LC-41, and a unique integrate-transfer-launch (ITL) area at the north end of Cape Canaveral. C. H. Leavell, based in El Paso, Texas, and Peter Kiewit & Sons of Omaha, Nebraska, received the contract to build the launchpads on 13 June 1963, and they began construction that August on both sites. The 6555 ATW's Titan III Division, under Lt Col Marc M. Ducote, oversaw the construction effort with a contingent that had grown by mid-1964 to 39 officers, 31 Airmen, and 14 civilians. The contractors completed initial construction at both launch sites in 1964, LC-40 in January and LC-41 in April. Each completed launch site included a mobile service tower, umbilical tower, launchpad, aerospace ground equipment building, gas storage area, air conditioning shelter, propellant loading areas, and a variety of other service facilities. Instead of building blockhouses at the Titan III complexes, however, launch controllers operated from a Launch Operations Control Center in the industrial area. The first Titan IIIC launched from Pad 40 on 18 June 1965 and from Pad 41 on 21 December 1965.[76]

The ITL system provided an integrated approach to Titan IIIC launch preparations. Air Force space planners expected the new Titan IIIC facility to increase reaction time and launch rates, enhance booster configuration flexibility, and accommodate various payloads without having to tailor each payload-booster combination. In short, the Titan III would join the Thor and Atlas as a standard launch vehicle, SLV-5.

Technicians in the 23-story vertical integration building (VIB) received, inspected, erected, and checked out the core vehicle components before sending the booster to the 235-foot tall solid motor assembly building (SMAB), where the two solid rocket motors were attached to the booster. The Titan core assemblies arrived by air, while the solid motor segments arrived by rail. A warehouse, storage areas, and a variety of support buildings completed the system. A 19.9-mile double-track rail network provided transportation within the ITL area and connected the ITL to the two launch complexes. Payload mating took place either in the VIB or at the launchpad. A rail-mounted mobile transporter that also served as the launch platform brought the completed vehicle to the launchpad, where support personnel could have the Titan IIIC ready for launch as soon as five days later. With Titan III assembly and checkout performed at the nearby ITL facility, vehicles did not have to spend excessive time on the launchpad before launch.[77]

The area selected for the ITL system presented a major challenge to the construction crews. Shallow water from the Banana River covered the proposed rail access terrain from the launch complexes to the ITL site and much of the latter area as well. In February 1963, contractors began dredging operations to transfer landfill from the Banana River to the ITL site. When the impressive operation concluded in 1965, 6.5 million cubic yards of landfill had been removed to build three man-made islands for the site.[78]

Until the mid-1970s, Titan IIIC missions supported DOD objectives exclusively. Operations began with the first Titan IIIC launch from Pad 40 with a dummy payload on 18 June 1965. Launches from the Cape were usually directed easterly on an azimuth of 93 degrees, providing an orbital inclination of 28.5 degrees. A second experimental flight on 15 October 1965 launched successfully, but a Transtage malfunction prevented orbiting the experimental Lincoln calibration satellite and an optical sensor payload.[79]

The Air Force had designated LC-40 as the Titan III launch complex for the MOL program. California-based Akwa-Downey Construction Company began building the MOL Environmental Shelter in October 1965 and completed the project in June 1966. That October, McDonnell Aircraft delivered a Gemini capsule to the shelter to conduct a test of the heat shield that had been modified with a circular hatch for use by MOL astronauts. A month later, on 3 November, a Titan IIIC launched the only MOL Gemini mockup mission, in which the Gemini prototype separated for suborbital reentry while the MOL mockup orbited and successfully released three satellites. Although the MOL program continued until cancelled by the Nixon administration in 1969, no additional Titan IIIC launches took place at LC-40 for the next four years. In April 1970, the Air Force modified the environmental shelter to process new Titan IIIC fairings, and Titan launches resumed on 8 April 1970 with the flight of *Vela 11* and *Vela 12* nuclear detection spacecraft. Titan IIIC rockets would launch 22 additional DOD payloads from LC-40 until March of 1982. These payloads consisted primarily of Defense Support Program early warning satellites and Defense Satellite Communications System payloads. Of the 22 flights, only two DSCS missions failed to achieve geosynchronous orbit.[80]

At LC-41, the first Titan IIIC flight on 21 December 1965 successfully launched two Lincoln communications satellites along with an Oscar amateur radio satellite. After this initial experimental flight, Titan IIICs would launch only nine more payloads. The single mishap occurred on 26 August 1966, when the Titan IIIC's payload fairing failed at T+79 seconds, resulting in loss of the eight Initial Defense Communications Satellite Program (IDCSP) satellites. The remaining eight launches consisted of four more IDCSP payloads, two Vela flights of two satellites each, another Lincoln communications satellite mission, and a 1,600-pound Air Force tactical communications satellite mission. Most of the missions also included a variety of secondary payloads. With the second Vela flight, on 23 May 1969, the Air Force terminated Titan IIIC operations at LC-41. After remaining inactive for nearly five years, the complex was reconfigured for Titan IIIE-Centaur operations in support of NASA's planetary exploration initiative, which included two Viking missions to Mars in 1975 and the two Voyager flights to the outer planets in 1977.[81]

Fig. 12. Titan IIIC Gemini/Manned Orbiting Laboratory launch from the Integrate-Transfer-Launch complex at Cape Canaveral, 3 November 1966. (Photo courtesy of Space and Missile Systems Center)

Conclusion

As noted in the conclusion to chapter 3, by the early 1970s space launch activity at the Eastern Test Range had declined considerably compared to operations at Vandenberg Air Force Base. The shift began in 1964 in the personnel area. The 6555 ATW peaked in January 1964 with 144 officers, 573 Airmen, and 76 civilians. Its numbers fell almost immediately when the Atlas-Agena blue suit initiative ended in January, and the Titan II Weapons Division was discontinued that June. After cancellation of the Gemini mission in November 1966, the wing's roster totaled 70 officers, 204 Airmen, and 47 civilians. By 1970, with Minuteman launch operations concluded, the Titan Systems Division accounted for 78 of the remaining 154 personnel. The downturn was reflected that same year in the redesignation of the wing as the 6555th Aerospace Test Group and subordinated to Vandenberg's wing.[82]

Operationally, the launch data also reflects the decline in space launch activity at Cape Canaveral. While NASA flights represented the bulk of the launches, the space agency's numbers fell significantly during the last half of the decade. From a high of 24 launches in 1966, it had 16 in 1967, 9 the following year, 11 in 1969, but only 2 in 1970, and 5 in both 1971 and 1972. Air Force launches declined from seven in 1965 to three in 1966, 1967, and 1968, rose to four in each of the next three years, and then fell to two in 1972. To be sure, the decline can be attributed to more than cancellation of Gemini and several other programs. Because satellites had become increasingly complex and capable of extended life spans on orbit, they required fewer launches. The Vela nuclear detection satellites, for example, increased in weight from 520 pounds for each of the first two pairs launched in October 1963 by an Atlas-Agena to 730 pounds for the fourth pair, orbited by the heavy-lift Titan IIIC in April 1967. Their lifespan increased as well, from 5 years for the first pair to more than 10 years for the fourth. When comparing the Cape's launch record to Vandenberg's, however, clearly the greater launch tempo at the West Coast site reflected the expanding classified satellite reconnaissance program.[83]

Fewer space launches also resulted in fewer active launch complexes. In 1964, Air Force officials deactivated LC-11, while in 1967 they either deactivated or sold for salvage Atlas complexes 12 and 14, plus three Titan complexes (15, 19, and 20) and complex 18 for Vanguard and Blue Scout launches. While the Air Force lost complexes, NASA gained Complex 17's pad B in 1965 and controlled complexes 34, 36, and 37 to augment its Saturn V operations on Merritt Island. Launch Complex 13, which the Air Force transferred to NASA in 1966 for Lunar Orbiter missions, reverted to the Air Force two years later for several Atlas-Agena NRO launches. By that time, it had joined the Titan IIIC LC-40 and LC-41 as the only sites at the Cape solely dedicated to Air Force space launch operations, and LC-41 was inactive while being reconfigured for NASA's Viking missions. Looking back from the vantage point of the early 1970s, only 7 of the original 42 launchpads remained "mission critical," and one, LC-14, had no launch capability.[84]

Range operations also underwent significant changes over the course of the decade, as efforts to consolidate activities at the various range stations continued. By September 1963, the Eastern Test Range extended nearly 10,000 nautical miles from the Cape over the Atlantic Ocean to Ascension Island, then beyond Pretoria, South Africa, to Mahé in the Seychelles. By the end of the decade, the conglomerate of installations, stations, and sites had been reduced to 59 from a high of 104 in 1960. The range would undergo both equipment upgrades and further consolidation on the road to space-based tracking capabilities later in the century.[85]

By 1972, "Navy Blue" submarine-launched ballistic missile programs comprised more than half of all major launches at the Cape, and Navy requirements for range time would continue unabated. As for space operations, NASA remained the dominant agency for manned space and deep space missions. Despite the drawdown in facilities and the operational tempo at Cape Canaveral, however, the Air Force would continue to launch important NRO, nuclear detection, communications, and early warning satellites—all payloads requiring geosynchronous or near-geosynchronous orbits—and to provide essential support for NASA's Apollo and post-Apollo initiatives and its planetary exploration program. Above all, in the years ahead the Space Transportation System, or space shuttle, would transform space operations not only at the Kennedy Space Center but also at Patrick Air Force Base and the Eastern Range.

Notes

1. Aerospace Corporation, *The Aerospace Corporation. Its Work*, 117–19; Patrick AFB, FL/OI, memorandum; Hall, "The Air Force in Space," 21–22, information used is unclassified; 45th Space Wing (SW), "From Matadors to Delta IVs," n.p.; Lethbridge, "The History of Cape Canaveral Chapter 1," accessed 10 January 2019; Cleary, "Evolution of the Wing," 1; and Whipple, "History of Patrick Air Force Base," 1. The range extending from the Cape over the Atlantic had initially been designated the Florida Missile Test Range in 1951, the Atlantic Missile Range in 1958, the Eastern Test Range in 1964, and the Eastern Range in 1991. Cleary, "Development of the Eastern Range," 1–2.

2. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; and 45th SW, "From Matadors to Delta IVs."

3. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; and 45th SW, "From Matadors to Delta IVs."

4. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; 45th SW, "From Matadors to Delta IVs"; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 5; Lethbridge, "The History of Cape Canaveral, Chapter 2," accessed 10 January 2019; 45th SW, *From Sand to Moondust*, 9; Air Force Eastern Test Range, *Chronology of the Joint Long Range Proving Ground*, 1–124; and Stumpf, "Birth of the Test Ranges, Part I," 56. The Mexican president also asserted that he had no constitutional authority to grant the US request and declined to seek legislative approval. Stumpf provides a comprehensive assessment of the selection process based on Committee on Long-Range Proving Ground sources.

5. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; 45th SW, "From Matadors to Delta IVs"; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 5; Lethbridge, "The History of Cape Canaveral, Chapter 2," accessed 10 January 2019; 45th SW, *From Sand to Moondust*, 9; Air Force Eastern Test Range, *Chronology of the Joint Long Range Proving Ground*, 1–124; and Stumpf, "Birth of the Test Ranges, Part I," 56, 58–59.

6. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; 45th SW, "From Matadors to Delta IVs"; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 5; Lethbridge, "The History of Cape Canaveral, Chapter 2," accessed 10 January 2019; 45th SW, *From Sand to Moondust*, 9; Air Force Eastern Test Range, *Chronology of the Joint Long Range Proving Ground*, 1–124; and Stumpf, "Birth of the Test Ranges, Part I," 56. On 16 December 1955 the CCAAFB was redesignated Cape Canaveral Missile Test Annex. On 22 January 1964, following President Kennedy's death, the Cape installation was renamed Cape Kennedy Air Force Station. On 1 April 1974, the site was designated Cape Canaveral Air Force Station. See an expanded biography of Maj Gen William L. Richardson in appendix A. See an organizational chart of Cape Canaveral and Patrick AFB in appendix B.

7. Whipple, "History of Patrick Air Force Base," 1–4; Lethbridge, "The History of Cape Canaveral, Chapter 1"; Cleary, "Evolution of the Wing," 1; Peterson AFB, Fact Sheet; 45th SW, "From Matadors to Delta IVs"; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 5; Lethbridge, "The History of Cape Canaveral, Chapter 2," accessed 10 January 2019; 45th SW, *From Sand to Moondust*, 9; Air Force Eastern Test Range, *Chronology of the Joint Long Range Proving Ground*, 1–124; Stumpf,

"Birth of the Test Ranges, Part I," 56; and Eastern Space and Missile Center (ESMC)/HO, "Background Information on Patrick and the Eastern Test Range," 1991, 4–6. See a map of Cape Canaveral in appendix B.

8. Lethbridge, "The Missile Test Range Takes Shape (1949–1958)"; Cleary, "Development of the Eastern Range," 1; Sands, interview, 30–31; and Stumpf, "Birth of the Test Ranges, Part I, " 58–59.

9. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 27–48; 45th SW, *From Sand to Moondust*, 12–14; and Cleary, "Military & Civilian Roles in Range and Launch Operations," 1–2.

10. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 27–48; 45th SW, *From Sand to Moondust*, 12–14; Cleary, "Military & Civilian Roles in Range and Launch Operations," 1–2; and Roy, email, 1 November 2018.

11. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 56–66; 45th SW, *From Sand to Moondust*, 14; and Cleary, "Military & Civilian Roles in Range and Launch Operations," 2–3. The Snark skidded to a stop using skid plates for landing and thereby provided the nickname for the Cape landing strip. Lethbridge, "The Missile Test Range Takes Shape (1949–1958)."

12. Werrell, *Evolution of the Cruise Missile*, 97–108; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 67–75; 45th SW, *From Sand to Moondust*, 14; and ESMC/HO, "Background Information on Patrick and the Eastern Test Range," 8–9.

13. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 87; and Cleary, "Development of the Eastern Range," 1–2. See a map of the Air Force Missile Test Center, 5,000 mile range, in appendix B.

14. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 83–84; Cleary, "Development of the Eastern Range," 3; and Air Force Missile Test Center (AFMTC), *History of the Air Force Missile Test Center*, 7–8.

15. Although not discussed, it should be acknowledged that during this period the Army tested its Redstone, Jupiter C, and Juno launch vehicles, while the Navy tested its Polaris SLBM and Vanguard launch vehicle. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 90–91.

16. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 96, 101; 45 Space Wing, *Eastern Range Launch Site Summary*, 6; and AFMTC, *History of the Air Force Missile Test Center*, 9.

17. 45th SW, *Eastern Range Launch Site Summary,* 32, 34–35; see McDowell, "Satellite Catalog," accessed 20 January 2019. It should be noted that Thor test flights were launched from LC-18; however, since no Thor space missions were launched from that pad, the test flight record will not be discussed.

18. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 108–13; 45th SW, *Eastern Range Launch Site Summary,* 2–4; and Hilliard, email, 3 January 2019.

19. 45th SW, *Eastern Range Launch Site Summary,* 25–28; McDowell, "Satellite Catalog," accessed 20 January 2019; and Cleary, *The 6555th: Missile and Space Launches Through 1970*, 112–16. The following test launch failure figures are by launch complex: LC-11, 27 launches, with 4 failures and 4 partial failures; LC-12, 14 launches with 2 failures; LC-13, 10 failures and 2 partial failures among 30 launches; and LC-14, 12 launches with 6 failures.

20. Spires, *Orbital Futures,* vol. 2, 713–14.

21. Spires, *Beyond Horizons: A History of the Air Force in Space, 1947–2007*, 106–7.

22. Spires, 107. The initial land purchase totaled 72,644 acres. See expanded biographies of Maj Gen Leighton I. Davis and Maj Gen Donald N. Yates in appendix A.

23. Spires, *Orbital Futures*, vol. 2, 815–17; and Berger, *The Air Force in Space, Fiscal Year 1962*, 14–17.

24. Berger, *The Air Force in Space, Fiscal Year 1962*, 14–16; Cleary, *The 6555th: Missile and Space Launches Through 1970*, 184; AFMTC/HO, "Land Acquisition. Cape Canaveral," 26 July 1962; and ESMC/HO, "Salient Points Concerning Merritt Island Land Program," 25 June 1990. NASA had been developing a design for a large rocket, the Nova, which was replaced by the Saturn V. The 14,800 acres included the remaining north portion of Merritt Island and 53,000 feet of beach property east of Oak Hill in Volusia County.

25. Williamson, "Access to Space: Steps to the Saturn V," 149–53.

26. Spires, *Beyond Horizons*, 108.

27. NASA's Delta was designed using Thor as its first stage. *TRW Space Log*, vol. 32, 65–68; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; and 45th SW, *Eastern Range Launch Site Summary*, 6–7, 32–34; ANNA is an acronym for Army, Navy, NASA, Air Force.

28. *TRW Space Log*, 68–76; Encyclopedia Astronautica, "Thor," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 8 September 2018; and 45th SW, *Eastern Range Launch Site Summary*, 6–7, 34–37. The six Thor missiles were surplus Thors returned from the United Kingdom and used to launch Aerothermodynamic Elastic Structural Systems Test (ASSET) delta-winged reentry vehicles.

29. The Air Force launched all NASA missions at Vandenberg AFB. Cantwell, *The Air Force in Space, Fiscal Year 1964*, 11–12. It should also be noted that the Scout four-stage solid-propellent booster, while primarily a NASA resource, operated at the Cape as Blue Scout by a "blue suit" Air Force contingent from 1961 to 1965 from LC-18. 45th SW, *Eastern Range Launch Site Summary,* 8, 37–38; and 45th SW, *From Sand to Moondust*, 19–20.

30. SCORE was preceded by the launch, on 1 February 1958, of the Juno-launched Explorer I scientific satellite that first detected the Van Allen radiation belt. 45th SW, *Eastern Range Launch Site Summary*, 2, 25–26. Although Atlas flights occurred at LC-36, this was a NASA-operated Atlas-Centaur complex throughout the 1960s and into the 1970s and will not be discussed. The Air Force, however, would remain interested in the Centaur, both as the upper stage for NASA's Titan IIIE planetary missions and later for the Titan IV.

31. 45th SW, *Eastern Range Launch Site Summary*, 2-4; and Hilliard, email, 8 January 2019, 14 January 2019. Unlike the umbilical masts at Vandenberg, which can be retracted and lowered into the launch deck trench, those at the Cape are not retractable. Historic American Engineering Record, "Vandenberg Air Force Base, Space Launch Complex 3 (SLC-3)," 52.

32. Whitehead, email, 7 January 2019, 8 January 2019; and Hilliard, email, 3 January 2019.

33. 45th SW, *Eastern Range Launch Site Summary*, 2; *TRW Space Log*, 69–90; Encyclopedia Astronautica, "Atlas," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 20 June 2009.

34. 45th SW, *Eastern Range Launch Site Summary*, 2, 26; *TRW Space Log*, 75–109; Encyclopedia Astronautica, "Atlas," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 20 June 2009.

35. Spires, *Beyond Horizons*, 152–54; Berger, *The Air Force in Space, Fiscal Year 1962*, 14–16; and Neufeld, *The Air Force in Space, 1969–1970*, 38–39. The Air Force had started a blue suit launch program at LC-13, but abruptly cancelled it on 1 January 1964, without explanation. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 172.

36. For a comprehensive treatment of the Samos program, see Hall, *Samos to the Moon*. 45th SW, *Eastern Range Launch Site Summary,* 2, 26; *TRW Space Log*, 75-109;

Encyclopedia Astronautica, "Atlas," accessed 11 July 2017; McDowell, "US Reconnaissance Programs, Part 1," 22–33; McDowell, "US Reconnaissance Programs, Part 2," 40–45; and McDowell, "Satellite Catalog," accessed 20 June 2009.

37. 45th SW, *Eastern Range Launch Site Summary*, 4–5, 28; *TRW Space Log*, 67–104; Encyclopedia Astronautica, "Atlas," accessed 11 July 2017; and McDowell, "Satellite Catalog," accessed 20 June 2009.

38. Space Systems Division, *Report on Atlas/Agena Launch Operations*, 4-13 to 4-20.

39. Space Systems Division, 4-12, 4-23 to 4-25, 5-1 to 5-2, 6-1.

40. Space Systems Division, 4-21, 4-23 to 4-25, 5-1 to 5-2, 6-1.

41. Space Systems Division, 5-1 to 5-2, 6-1.

42. Space Systems Division.

43. Space Systems Division. The lack of standardization would eventually lead to large cost impacts. One of the future EELV program objectives was to standardize the launchpads on each coast. McKinney, "Manuscript Review Comments," 22 January 2020.

44. Spires, *Orbital Futures*, vol. 2, 715–16; and Launius, "First Steps into Space," 9–11. By the end of 1958, the Air Force had accepted NASA's suggestion that the service appoint liaison personnel to work with their NASA counterparts on Project Mercury at the Langley Research Center.

45. Spires, *Beyond Horizons*, 107; and AFMTC, *History of the Air Force Missile Test Center, January-June 1960,* 7–8, 71–73.

46. Launius, "First Steps into Space," 29.

47. Launius, "First Steps into Space," 30–33; Williamson, "Access to Space: Steps to the Saturn V," 14–15; and Swenson, Grimwood, and Alexander, *This New Ocean: A History of Project Mercury*, 310–77.

48. Williamson, "Access to Space: Steps to the Saturn V," 15; Launius, "First Steps into Space," 29; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 80. The Air Force had supplied NASA with nine Atlas D launchers, four of which launched Mercury astronauts.

49. Convair estimated that it cost the company 40 percent more to build the man-rated Atlas. Launius, "First Steps into Space," 29–30; Williamson, "Access to Space: Steps to the Saturn V," 15, 76–81, 84–85; Swenson, Grimwood, and Alexander, *This New Ocean*, 307–8; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 81–82.

50. Swenson, Grimwood, and Alexander, *This New Ocean*, 335–38; Encyclopedia Astronautica, "Atlas," accessed 11 July 2017; McDowell, "Satellite Catalog," accessed 20 June 2009.

51. Swenson, Grimwood, and Alexander, *This New Ocean*, 381–89.

52. Swenson, Grimwood, and Alexander, 402–7.

53. Swenson, Grimwood, and Alexander, 422–34, 446–60, 473–86; and Launius, "First Steps into Space," 33-34; Christopher C. Kraft, mission director for the Mercury missions, was so upset with Carpenter's performance that he "swore an oath that Scott Carpenter would never again fly in space. He didn't." Kraft, *Flight: My Life in Mission Control*, 170.

54. Swenson, Grimwood, and Alexander, *This New Ocean*, 494–503.

55. Launius, "First Steps into Space," 37–38; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 83.

56. Spires, *Beyond Horizons*, 121–22; Hacker and Grimwood, *On the Shoulders of Titans*, 117–18.

57. The number of experiments was later increased to 51. Hacker and Grimwood, *On the Shoulders of Titans,* 118–22; and Spires, *Orbital Futures*, vol. 2, 723–25.

58. Hacker and Grimwood, *On the Shoulders of Titans*, 41–42; Cantwell, *The Air Force in Space, Fiscal Year 1964*, 36–39; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 100.

59. Hacker and Grimwood, *On the Shoulders of Titans,* 157–62.

60. Spires, *On Alert: An Operational History of the United States Air Force Intercontinental Missile Program*, 66–67; and Hunley, *Preludes to U.S. Space-Launch Vehicle Technology: Goddard Rockets to Minuteman III*, 269–74. G refers to the gravitational force, or g-force, acting on a body under acceleration. It is defined as 9.80665 meters per second squared. Stumpf, *Titan II: A History of a Cold War Program*, 73–79; Hacker and Grimwood, *On the Shoulders of Titans,* 134–37, 141–44, 166–69; and Launius, "First Steps into Space," 39.

61. Hacker and Grimwood, *On the Shoulders of Titans,* 169–70.

62. Hacker and Grimwood, 194–200, 203–9; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 101–2.

63. Hacker and Grimwood, *On the Shoulders of Titans,* 249–50; and Launius, "First Steps into Space," 42–44.

64. Hacker and Grimwood, *On the Shoulders of Titans,* 265–291; and Launius, "First Steps into Space," 44–46.

65. Hacker and Grimwood, *On the Shoulders of Titans,* 308–21; and Launius, "First Steps into Space," 47.

66. Hacker and Grimwood, *On the Shoulders of Titans,* 332–41. NASA had Lockheed Missiles and Space Company develop the backup augmented target docking adapter (ATDA), a smaller spacecraft consisting of the docking target fitted with an attitude control propulsion system but lacking the Agena orbital change rocket. Encyclopedia Astronautica, "Atlas Target Docking Adapter," accessed 3 March 2019.

67. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 187–88.

68. Cleary, *The 6555th: Missile and Space Launches Through 1970.*

69. Hacker and Grimwood, *On the Shoulders of Titans,* 166–71.

70. Whitehead, email, 31 March 2018.

71. Whitehead, email, 2 January 2019.

72. Whitehead, email, 2 January 2019; and Hacker and Grimwood, *On the Shoulders of Titans,* 330–32.

73. Whitehead, email, 9 January 2019.

74. Hacker and Grimwood, *On the Shoulders of Titans,* 332–41. NASA had Lockheed Missiles and Space Company develop the backup ATDA, a smaller spacecraft consisting of the docking target fitted with an attitude control propulsion system but lacking the Agena orbital change rocket. Encyclopedia Astronautica, "Atlas Target Docking Adapter," accessed 3 March 2019; and McDowell, "Satellite Catalog," accessed 20 January 2019.

75. Williamson, "Access to Space: Steps to the Saturn V," 149–51.

76. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 194, 199–202; 45th SW, *Eastern Range Launch Site Summary,* 17; Isakowitz, *International Reference Guide to Space Launch Systems*, 276; and Air Force Space & Missile Museum, "Integrate-Transfer-Launch (ITL) Complex," accessed 24 February 2019.

77. Williamson, "Access to Space: Steps to the Saturn V," 149–51; and Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 119.

78. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 194; and Air Force Space & Missile Museum, "Integrate-Transfer-Launch (ITL) Complex," accessed 24 February 2019.

79. Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 119; and McDowell, "Satellite Catalog," accessed 20 June 2009. It should be noted

that Launch Complex 20 supported four Titan IIIA test launches in 1964 and 1965. 45 SW, *Eastern Range Launch Site Summary,* 9, 39; and Cleary, *The 6555th: Missile and Space Launches Through 1970*, 199.

80. See the declassified NRO files on MOL, including the 20 May 1964 "Agreement Between NASA & DoD Concerning Gemini Program and MOL." Cleary, *The 6555th: Missile and Space Launches Through 1970*, 204–5; 45th SW, *Eastern Range Launch Site Summary,* 53; McDowell, "Satellite Catalog," accessed 20 June 2009; and Air Force Space & Missile Museum, "Launch Complex 40," accessed 24 February 2019.

81. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 204–7; 45th SW, *Eastern Range Launch Site Summary,* 17, 53–54; McDowell, "Satellite Catalog," accessed 20 June 2009; and Air Force Space & Missile Museum, "Launch Complex 41," accessed 24 February 2019.

82. Cleary, *The 6555th: Missile and Space Launches Through 1970*, 208–9.

83. *TRW Space Log*, 96–151; Spires*, Beyond Horizons*, 153; Encyclopedia Astronautica, "Titan," accessed 20 June 2009; Encyclopedia Astronautica, "Vela," accessed 3 March 2019; and McDowell, "Satellite Catalog," accessed 20 June 2009.

84. 45th SW, *Eastern Range Launch Site Summary,* 21–29.

85. AFMTC, *History of the Air Force Missile Test Center, January–June 1960,* 6–8. AFETR, *History of the Air Force Eastern Test Range*, vol. 2, 6–7; AFETR, *History of the Air Force Eastern Test Range*, vol. 1, *Fiscal Year 1969*, 268; and AFETR, *History of the Air Force Eastern Test Range*, vol. 1, *Fiscal Year 1973*, 261–64.

Chapter 5

The Space Transportation System

Challenges of the Space Shuttle, 1969–1986

The advent of the Space Transportation System (STS), or space shuttle, as the successor to the Project Apollo lunar program in the 1970s offered tremendous potential with its promise of routine access to space for both civilian and military agencies. At the same time, it presented enormous challenges because of its technical complexity, high cost, and promise, as a joint civil-military program, to satisfy both NASA and Defense Department requirements. For the Air Force, the Defense Department's executive agent for the STS, the shuttle represented a possible new era of military manned spaceflight, an end to dependence on its fleet of costly, expendable launch vehicles (ELV), the reassertion of Air Force influence in the national space program, and greater prominence of space within the Air Force. Over the course of the 1970s and early 1980s, the shuttle prompted Air Force planners to increasingly reassess space policy, technological feasibility, and optimum organizational structures in preparation for what advocates confidently proclaimed to be the "age of the shuttle."

NASA expected the shuttle, once operational, to launch all civil and national security payloads. Yet for the Air Force the feasibility of exclusive reliance on the shuttle depended on the accuracy of NASA's predictions for the shuttle's capability, cost, and launch rate. By the end of the 1970s, the Air Force came to have serious reservations about the space agency's shuttle mission model that led to considerable tension between NASA and the Air Force and DOD. Moreover, as one perceptive Air Force space launch veteran has noted, "committing all DOD payloads to a civil, manned launch system was bound to lead to issues—and it did—in spades. An open culture like NASA's and a security-minded culture like the DOD's were fundamentally incompatible and required numerous compromises by both parties."[1] Ultimately, the Air Force would choose to pursue a balance between the space shuttle and ELVs, a balance that had not been entirely resolved by the time of the *Challenger* tragedy in January 1986.

The Air Force Commits to a Space Shuttle

When the Nixon administration canceled the Manned Orbiting Laboratory (MOL) program in June 1969, the field of manned space flight now was left almost exclusively for NASA to exploit. Although the Air Force would continue to cooperate closely with NASA, service leaders, especially the senior uniformed officers, would never again wholeheartedly embrace manned military spaceflight. Yet, while Secretary of the Air Force Robert C. Seamans and other civilian Air Force officials refused to pursue an Air Force manned space program, they were not averse to cooperating with NASA's post-Apollo venture to develop a reusable national STS to provide routine space access for both civilian and military agencies.[2]

Shortly after taking office in 1969, President Richard M. Nixon, as part of his initial program review, formed a Space Task Group to determine the best direction for the nation's post-Apollo space program in a future beset by declining interest in space and severe budget constraints. In September, shortly after *Apollo 11*'s historic July lunar landing, the group's report outlined three long-range possibilities. The first two comprised variations on an expensive, ambitious program to launch a manned mission to Mars in the 1980s. This would occur after first establishing a lunar base and a 50-person Earth-orbiting space station supported by a fully reusable STS to "shuttle" between Earth and the space station. The third alternative, which involved only the shuttle for use in LEO, appealed to a cost-conscious Nixon administration determined to pursue a less challenging space future.[3]

The Space Task Group's report forecast between 30 and 70 flights yearly during the period 1975–1985 and confidently predicted that the STS could reduce payload costs to LEO from a one-way figure of $800 per pound to "between $50 and $100 per pound for a round trip." The low costs would be achieved by designing the STS "for operations comparable to those of transport aircraft today yet retaining the high reliability that has been achieved with present manned spacecraft." Apart from low-cost, routine access to space, the report claimed that the STS would perform on-orbit repair of satellites, support a space station, launch high-energy missions, conduct short-duration orbital missions, and, consequently, contribute to the nation's international prestige. Finally, it would improve space operations as a cargo carrier and as a "mission-dedicated vehicle for vital needs of national defense or of specific civil operations."[4]

The STS report drew considerable interest from the DOD and NASA during the latter months of 1969. Before giving formal approval, however, they needed to assess the shuttle's technical feasibility, projected cost, and civil and military requirements more thoroughly. In February 1970, NASA Administrator Thomas Paine and Air Force Secretary Seamans signed an agreement that established an eight-member, joint NASA–Air Force Space Transportation System Committee that would review and advise on "program objectives, operational applications, and development plans." While NASA would manage development of the space shuttle, the committee would ensure that the STS was "designed and developed to fulfill the objectives of both the NASA and the Department of Defense in a manner that best serves the national interest." The agreement also designated the Air Force as Department of Defense executive agent for the shuttle. At this early juncture, DOD representatives cautioned that the shuttle needed to meet departmental requirements for it to transition completely from ELVs.[5]

For NASA, the shuttle represented the centerpiece of its future manned space program in the wake of the administration's cancelation of the final two Apollo lunar flights and reduction of the Apollo Applications program to the *Skylab* mini space station. For the Air Force, initial enthusiasm was tempered by NASA's central responsibility for shuttle design and development and by questions about the system's long-term benefits. Initially, Air Force interest centered on the project as a cost-effective replacement for launching future larger, heavier surveillance and reconnaissance satellites of the National Reconnaissance Office that would require lifting capacity greater than the Atlas and Titan expendable boosters could provide. Air Force leaders like Secretary Seamans also advanced the argument initially made in the Space Task Group report by emphasizing the variety of services they expected the shuttle to provide. "The shuttle," he said, "offers the potential of improving mission flexibility and capability by on-orbit checkout of payloads, recovery of malfunctioning satellites for repair and reuse, or resupply of payloads on orbit, thus extending their lifetime. Payloads would be retrieved and refurbished for reuse and improved sensors could be installed during refurbishment for added capability."[6]

Even before President Nixon formally approved the shuttle on 5 January 1972, the STS Committee had achieved considerable progress on design and performance specifications. From the start, it was clear to NASA, DOD, and Air Force officials that NASA needed Air Force support to "sell" the project to a budget-conscious administration and Congress. Characteristically, in the 1970s NASA would focus on its always uncomfortable budgetary battles with a parsimonious Congress while the Air Force remained in the background, uncompromising on military requirements. In exchange for its support, the Air Force demanded a vehicle capable of launching its largest, heaviest payloads into polar orbit from Vandenberg Air Force Base and, under emergency conditions, returning to the California launch site. This meant developing a shuttle with greater cross-range and payload capacity than NASA favored. To achieve this, the Air Force needed a cross-range capability of 1,100 miles rather than the 265 miles proposed by NASA officials. Accommodating the Air Force demand required the development of a delta-winged orbiter with larger wings for maneuverability that would be considerably more complex and costly than the smaller, straight-winged vehicle originally proposed by NASA.[7]

NASA and the Air Force also differed over payload weight and shuttle size. NASA favored a cargo compartment 12 feet in diameter and 40 feet long, but the Air Force insisted on dimensions of 15 feet by 60 feet that would accept its largest, heaviest payloads. This meant having the capacity to launch a payload of 65,000 pounds easterly into a low-inclination Earth orbit (38.5 degrees) and 40,000 pounds into a low Earth (100 nm) near-polar orbit (98 degrees) from Vandenberg. Without the larger cargo bay, the Air Force would have to use its Titan III and, thereby, negate the justification for the shuttle. The Air Force also estimated that fully half of its future launches would involve heavy payloads in geosynchronous orbit. To achieve this, the shuttle would need to accommodate these payloads as well as Lockheed's so-called orbit-to-orbit shuttle, or space tug, which would "shuttle" the spacecraft to higher orbits and return to the orbiter. Air Force requirements, evolving mission needs, and technological challenges involving this, the most complex spacecraft yet attempted, would add to the shuttle's checkered course of development. Design changes, in particular, contributed to cost increases, new launch-site requirements, and, ultimately, schedule delays—all of which would jeopardize NASA's initial projections of 60 flights per year at half the cost of expendable boosters.[8]

When President Nixon, with one eye on the ailing aerospace industry, gave formal approval to the space shuttle's $5.5 billion, six-year development program in 1972, he declared the future shuttle the "work-horse of our whole space effort." He said it would replace all expendable boosters except the smallest (Scout) and the largest (Saturn) and could lower operating costs by as much as one-tenth of those of ELVs. By March of that year, only two months after the president's announcement, NASA and the Air Force had reached agreement on the shuttle's design. A delta-winged orbiter would be launched into LEO by the force of its three 470,000-pound-thrust liquid rocket engines in the orbiter, and two water-recoverable, solid-fuel rocket motors on the booster, each capable of four million pounds of thrust. An expendable, external, liquid-fuel tank completed the basic design. After reentry, the orbiter would land on a conventional runway using a high-speed, unpowered approach. In effect, the orbiter and solid rocket boosters would be recovered, refurbished, and reused. Significantly, the 156-inch-diameter booster motors were the product of the Air Force's large solid rocket development program that dated back to 1960. Although the new booster concept resulted in a drop in overall development cost from $5.5 billion to $5.1 billion, projected operational costs rose to $10.5 million per mission, more than twice the original estimate. And from the beginning, congressional and administration officials would remain concerned about the cost of supporting both the shuttle and ELVs.[9]

In the future, cost-efficiency would be dependent on achieving the high launch rate of 60 flights per year projected for the 1980s. Specifically, the 1972 NASA-DOD mission model called for 445 flights in the initial 11 operational years, consisting of "6 in 1978, 15 in 1979, 24 in 1980, 32 in 1981, 40 in 1982, 60 annually from 1983 through 1987, and 28 in 1988." NASA's final economic plan also projected a fifth orbiter and a yearly launch rate of 40 flights from the John F. Kennedy Space Center (KSC) and 20 from Vandenberg AFB. The high launch rate would be achievable because of the projected turnaround time of only 160 hours, or approximately seven days. The development schedule called for the first "horizontal" flight test in 1976, to be followed by manned and orbital test flights in 1978, with full operations commencing in 1979.[10]

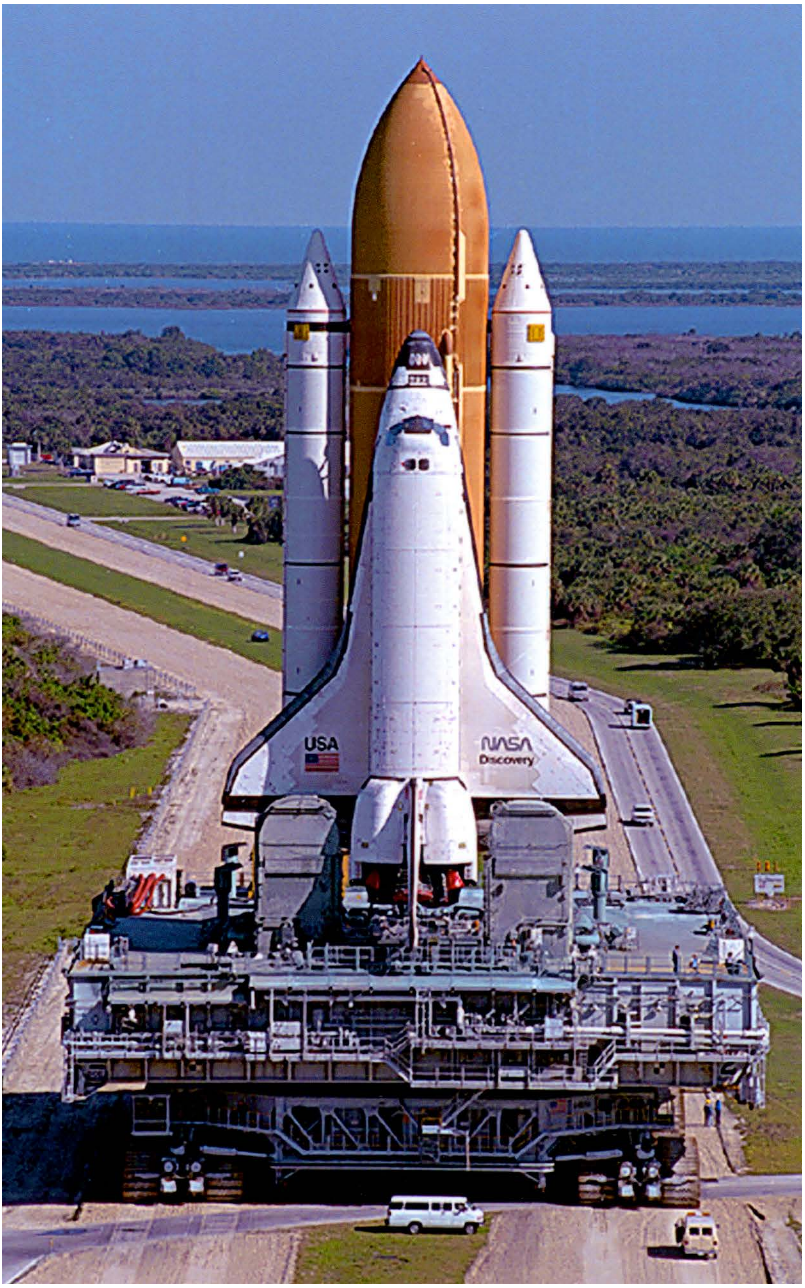


Fig. 13. Space shuttle *Discovery*, STS-63, at LC-39B, 10 January 1995. (Photo courtesy of John Hilliard)

In late 1973, the Department of Defense created a Space Shuttle User Committee, chaired by Brig Gen John E. Kulpa Jr., the Office of the Secretary of the Air Force's Director for Programs, Office of Space Systems, to focus on military responsibilities for shuttle support. By the end of that year, the Air Force and the DOD had agreed on a December 1982 operational date for Vandenberg based on refurbishing the old MOL space launch complex, SLC-6. They had agreed, also, to establish a schedule for phasing out its fleet of ELVs during the 1980–85 time frame. They intended to implement a phased transition schedule that would retain the most important programs until the shuttle demonstrated full operational capability. At the same time, an Upper Stage Committee appointed by the Space Transportation Committee examined space tug requirements and reaffirmed that a full-scale space tug, with retrieval capability, should be developed by NASA. To ease NASA's ever-present budget hurdles and provide the agency a more deliberate development schedule, however, the Upper Stage Committee suggested that the Air Force demonstrate its commitment to the shuttle by developing a less costly interim upper stage (IUS) vehicle based on modification of an existing upper stage vehicle. The Air Force agreed, and the IUS vehicle joined the Vandenberg launch site as the service's major responsibilities for shuttle development.[11]

Although the basic elements of the shuttle program had fallen into place by 1974, technical and political problems would continue to play havoc with developmental and operational milestones. Along with its responsibilities for constructing the Vandenberg launch site and producing an IUS vehicle in place of a space tug, Air Force concerns would focus on how best to protect and control classified military space missions from NASA's Johnson Space Center (JSC). Should they be handled by NASA's controllers alone or by an Air Force element colocated at the JSC? Or should the Air Force develop a new organization to replace or augment its overworked Satellite Control Facility in Sunnyvale, California? This organizational issue became one of many the Air Force confronted in the latter half of the decade.

The Shuttle Precipitates Air Force Organizational Challenges

While the focus in the 1970s remained on USAF-NASA cooperative efforts to realize their STS development commitments, the arrival of the shuttle also precipitated a major shift in Air Force thinking on space. Traditionally, the Air Force and the DOD had assigned space systems on a functional basis to the command or agency with the greatest need. But in the late 1970s, systems possessing multiple capabilities and serving a variety of defense users, like the DSCS, the shuttle, and the projected GPS, promised to blur the functional lines enormously. Moreover, the poorly defined line separating experimental from operational space systems meant that Air Force Systems Command retained "ownership" of on-orbit spacecraft well beyond what many in the operational arena considered the legitimate responsibility of a research and development command. Would AFSC also serve as the military's "operational" organization for the shuttle, or would Air Force space requirements be better served by creating a new, major command for space operations? The shuttle generated an intense competition for operational responsibility among four major Air Force commands, each considering itself the logical choice to assume the operational space mission.

In April 1974, Aerospace Defense Command (ADCOM) commander Gen Lucius D. Clay Jr. precipitated the bidding war by calling on the chief of staff immediately to award ADCOM operational responsibility for the shuttle. He argued that his command possessed the experience through serving as the operational command for the ground-based space surveillance system, the newly operational Defense Support Program infrared early warning satellite system, and as the command with the only "blue-suit" launch team in the Air Force. The command's 10th Aerospace Defense Squadron (AERODS) had been launching Defense Meteorological Support Program satellites atop Thor boosters since 1965. As General Clay argued, "The breadth and magnitude of ADCOM operational space activities is not equaled by other DOD agencies." Less direct in his argument was his motivation to justify the importance of his command's space role through award of the shuttle. With the decline of ADCOM once elaborate air defense structure, General Clay hoped that the shuttle could preserve the existence of the command itself. Shortly thereafter, the Military Airlift Command, as the Air Force "transportation" agent, along with Strategic Air Command and AFSC, entered the competition, each staking out its claim to the shuttle. In October, Chief of Staff Gen George S. Brown solicited formal arguments from the commands, and General Clay responded in November with a 10-page position paper, arguing that the STS be placed "in an operational environment where its flexibility can be exploited and translated in military benefits." He then outlined his rationale for Aerospace Defense Command as the logical operational command.[12]

In the spring of 1977, however, the DOD designated AFSC's Space and Missile Systems Organization (SAMSO) as the Department of Defense Manager for Space Shuttle Support Operations "to ensure effective and economical Department of Defense operational support of STS requirements during the development phase of the program." Under a 1964 Department of Defense memo, AFSC already had been acting in this capacity vis-à-vis NASA manned spaceflight missions. Aerospace Defense Command officers pointedly noted that this memorandum assigned support responsibilities only, leaving for the future a decision assigning an overall DOD shuttle operator. In the future, Aerospace Defense Command also would be directed to provide specific support for shuttle operations, but the Air Force would defer choosing a major operational command for the shuttle until after establishment of Space Command in 1982.[13]

Shuttle Development Problems Increasingly Concern the Air Force

Although NASA assumed that future DOD satellites would be launched on the shuttle, the Department of Defense and the Air Force never committed to the reusable space transportation vehicle as its exclusive launch system. By the mid-1970s, the attitude of both the Air Force's top brass and, especially, the middle-rank space enthusiasts had evolved from "resigned acceptance" to "cautious optimism." If the STS lived up to expectations, it could help achieve the long-sought institutional goal of normalizing space operations by means of standardized, reusable launch vehicles and, although hardly a priority at this point, perhaps preserve a military manned presence in space. From the start, NASA had assumed that all future DOD satellites would be launched on the shuttle. To meet the rising costs and shore up political support for the shuttle, NASA officials insisted that the DOD commit itself to a "shuttle-only" policy and phase out its fleet of expendable launch vehicles. The DOD and the Air Force, however, never formally agreed to NASA's entreaties. Department of Defense statements on shuttle use and ELV phaseout always included a caveat that the shuttle first needed to demonstrate its promised high launch rates and low-cost operations before the military would discontinue ELV production completely. As the decade wore on, NASA realized that a fifth orbiter was needed to achieve the rate of 60 flights annually and lobbied the Air Force to pay for it. The DOD and the Carter administration declined to authorize the request. Despite their cautious optimism, DOD and Air Force leaders grew increasingly concerned about the shuttle's high development costs, the growing pressure to phase out its ELV fleet, and the rising expense of supporting two launch programs.[14]

In a 14 January 1977 memorandum of understanding, NASA, the DOD, and the Air Force reaffirmed and more clearly defined their mutual responsibilities for shuttle development and operations. NASA would be responsible for shuttle development, flight planning, operations, and control, regardless of the user, as well as landing-site arrangements at the KSC and overall financial management. The Air Force, for its part, would develop a restricted access facility at the JSC for classified missions, construct a second launch facility at Vandenberg Air Force Base, and build the interim upper stage vehicle for transporting payloads from the shuttle to higher altitudes and inclinations. NASA also expected to use the IUS for its ambitious planetary missions. The Air Force would be responsible for the "mission integration of users involving Department of Defense programs . . . [and specifically act as] . . . the focal point for providing the necessary data to NASA for the STS integration of the integrated Department of Defense payload upper stage combination." Most significantly, "DoD will plan to use the STS as the *primary vehicle* for placing payloads in orbit" [emphasis added]. The shuttle would not be the military's exclusive launch vehicle.[15]

Despite the wording of the January 1977 agreement, many among the civilian Air Force leaders considered that military space launches would be accomplished exclusively by the space shuttle. That year, the shuttle gained perhaps its strongest advocate in Dr. Hans Mark, who, during the Carter administration, became undersecretary of the Air Force and, consequently, director of the NRO. He decided that all future NRO satellites should be configured exclusively for the shuttle. As undersecretary of the Air Force (1977–79) and as Secretary of the Air Force (1979–81), he led the effort to make the shuttle "cancelation-proof" and designate it the military's exclusive space launch vehicle. Although President Jimmy Carter nearly canceled the shuttle on two occasions, his Presidential Directive (PD) 37, *National Space Policy*, issued 11 May 1978, came close to achieving Secretary Mark's objective by stating, "the Shuttle-based Space Transportation System . . . [will] . . . service all authorized space users. . . . Military and intelligence programs may use the Shuttle Orbiters as dedicated mission vehicles."[16]

In pursuing his shuttle-only objective, the undersecretary worked diligently to make the shuttle cancelation-proof, first by promoting PD 37, and then having the Carter administration support payload integration efforts that compelled DOD satellite developers to make their satellites not just "shuttle compatible" but "shuttle optimized." Shuttle compatible meant, in effect, a payload designed for the shuttle, but not necessarily one compatible with ELVs, whereas a shuttle-optimized payload would take advantage of the shuttle's unique capabilities and likely only be compatible with the shuttle.[17]

Air Force Brig Gen Joseph D. "Don" Mirth, Space Division's deputy for space launch and control systems and shuttle program director during Mark's tenure, recalled that "Mark was absolutely convinced the shuttle was going to be able to live up to its promises" and that the Air Force had to show Congress that it was totally committed to the shuttle. Mark went so far as to direct the Air Force to prepare plans to terminate the Titan's ITL support facilities at the Cape and to shut down its Martin Marietta production lines.[18]

Maj Sebastian F. "Seb" Coglitore, who served as launch integration manager in the Los Angeles office of the Secretary of the Air Force Office of Special Projects (SAFSP) in the late 1970s, agreed on the role of Undersecretary Mark in promoting a full-fledged military commitment to the shuttle. "One way to get the Air Force further involved with the shuttle," Coglitore said, "was to have a DOD payload fly on an early shuttle mission." It would also help shut down the Delta, Atlas, and Titan program production lines. Major Coglitore served as the office's shuttle integration manager, focusing on a "new" program, code-named Damon, which Coglitore described as "a palletized Hexagon camera planned to fly as an attached payload on the Shuttle." Originally scheduled to fly aboard *Columbia* on a DOD placeholder flight, STS-18, the Damon project was accelerated in order to fly on Orbital Flight Test-4 when the shuttle program continued to slip its flight schedule.[19]

By early 1980, Damon had been approved, with Lockheed chosen as prime contractor and Perkin-Elmer as subcontractor. Yet mounting congressional opposition put the program in jeopardy. As described by historian Dwayne Day, "DAMON was part of a multi-party struggle . . . between different parts of the NRO as well as members and staff of the House Permanent Select Committee on Intelligence." Opposition centered on skepticism about the decision to fly all NRO payloads on the shuttle, the program's cost, and the shuttle itself as an effective reconnaissance platform. By December 1980, Congress declined to continue funding, and Damon was canceled.[20]

With Damon terminated, the pallet became available for other payloads, and Major Coglitore became the program manager of a restructured effort as part of a Space Division–SAFSP joint program to meet the 1982 launch date with the Air Force–NASA classified palletized Cryogenic Infrared Radiance Instrumentation for Shuttle (CIRRIS), which would be the first instrument to fly on the shuttle using the challenging cooling agent, liquid helium. Despite shuttle delays, Coglitore remains convinced that Hans Mark "greased the skids" to have payload DOD 82-1 manifested on STS-4, the fourth and final shuttle operational flight test. Launched on 27 June 1982, with the DOD payload described by shuttle astronaut Thomas K. Mattingly II as a "rinky-dink collection of minor stuff they wanted to fly," the central objective of the payload was to act as a pathfinder for DOD shuttle programs to follow. Unfortunately, the CIRRIS portion of the multi-element payload failed because the hatch refused to open. Even so, when the brief flight landed at Edwards Air Force Base on the Fourth of July, President and Mrs. Reagan were on hand to meet the orbiter and crew, and the president took the opportunity to pronounce the STS operational.[21]

Meanwhile, continued shuttle schedule slippages heightened Air Force concerns. The technical challenges associated with the shuttle's complex design and payload configuration proved more difficult to master than expected, and problems with the orbiter's main engine and the thermal protection tiles proved especially challenging. Critics increasingly faulted NASA's research and development mentality and called for more military involvement in shuttle management. Military concerns prompted Carter administration officials in 1978 and 1979 to conduct high-level policy reviews, which led in March 1980 to a modification of the 1977 NASA-DOD agreement. The revised accord sought to accommodate the military by assigning priority to the DOD in shuttle mission preparations and flight operations, and by integrating DOD personnel more directly into NASA's line functions. Even so, by the end of the decade, the various development and production issues affecting the shuttle program compelled NASA to postpone the initial test flight from 1979 to June 1980, then to April 1981, with the first operational flight expected no earlier than the spring of 1982, nearly two years behind schedule.[22]

Despite a tilt in DOD's favor, the Air Force remained uneasy about committing to a shuttle-only policy and phasing out its expendable launch fleet, even after the shuttle became fully operational. Especially for personnel directly involved in the shuttle program at Vandenberg, the project raised many red flags in their preparation to support a mission model of 20 launches annually.[23]

Preparing for Shuttle Operations at Vandenberg AFB

The major focus of shuttle planning at the West Coast site fell to the Los Angeles-based SAMSO, renamed Space Division on 1 October 1979. Leading up to the president's January 1972 decision, SAMSO, assisted by Aerospace Corporation, had conducted wide-ranging studies of issues affecting DOD's participation in the shuttle program. These included, among others, design changes required to fly an existing payload on the shuttle, cost savings from payload retrieval and refurbishment, a shuttle system impact assessment, and six analyses of DOD-oriented shuttle applications.[24]

After the president's decision, SAMSO's planning efforts embraced support for both the shuttle and the future of the current expendable launch vehicle fleet. In 1972, DOD planners concluded that the current fleet of ELVs would fulfill all anticipated mission requirements until the shuttle began operations, at that time scheduled for the late 1970s. "Even then," according to SAMSO planners, "compatibility of the Shuttle's operational concepts with DOD mission requirements would have to be demonstrated fully before the final retirement of an expendable booster like the Atlas." The Air Force would consistently reaffirm this requirement despite pressure from NASA to have the service declare the shuttle the exclusive launch vehicle for DOD missions.[25]

DOD's role in space shuttle planning in the early 1970s was the responsibility of SAMSO's Deputy for Launch Vehicles, Col Harry R. Vautherot, who oriented his efforts in two directions: procuring ELVs for current and future use and promoting development of the STS. In late 1973 his office issued a DOD Space Launch Vehicle Management Plan that provided its perspective on managing the ELV inventory for the 1975–85 period. After describing technological state-of-the-art advancements that could benefit the booster fleet, he argued that not only was funding unavailable for such improvements, but "no launch vehicle capabilities . . . [or new technologies] . . . beyond those planned by 1975 are required to support the present DOD mission model."[26]

Regarding the shuttle, Colonel Vautherot also confirmed that "complete compatibility of [the] STS operational concept with DOD mission requirements must be fully demonstrated prior to full retirement of the expendable booster inventory." Looking ahead to the transition phase, considered to begin in fiscal year 1980 (1 October 1979–30 September 1980), he foresaw the requirement for dual-capability payloads that would be compatible with both ELVs and the shuttle. Planning should focus on payload integration with a coordinated block-change spacecraft design followed by simultaneous phase out of the old spacecraft design and the expendable launch vehicle. The planners assumed that expendable boosters would not be available after fiscal year 1982. ELV phaseout would begin with hardware procurement decisions for the final flights, starting with payload programs because they required lead times greater than ELVs and launch services. Vautherot's directorate also recommended a backup capability for high-priority missions, both during the transition period and perhaps beyond, but recognized the challenge of funding an ELV capability while also supporting shuttle operations. The plan also suggested that SLC-6, the former MOL site, be selected as the Vandenberg shuttle launch site.[27]

SAMSO planners also understood the need for an orbit-to-orbit "propulsive stage" vehicle to launch DOD high-energy spacecraft from the shuttle to higher orbit. According to DOD projections, half of its missions had energy requirements that exceeded the shuttle's capability. The Air Force had agreed to provide what it referred to as a two-stage, solid-propellant IUS vehicle until NASA had developed a space tug with payload retrieval and on-orbit servicing capability that would be phased into the inventory beginning in 1984. The IUS was to be developed at minimum cost by modifying an existing ELV upper stage vehicle that could be reusable but would not be able to retrieve payloads.[28]

In the spring of 1972, the Air Force, with NASA's concurrence, had chosen Vandenberg for the shuttle's West Coast launch site and immediately began developing flight and ground support systems. Regarding the latter, DOD tested a set of DOD missions with preliminary NASA software and determined that the majority of the orbiter's guidance, navigation, and control software would support the requirements of both agencies. Ground support involved developing optimum concept and facility siting arrangements for the shuttle's recovery, turnaround, and launch operations. Based on studies done by Ralph M. Parsons Company in 1972 and Rockwell International in 1973, Air Force planners developed a planning baseline in February 1974 for shuttle operations and facilities at Vandenberg. The plan called for a four-year construction development project for the military's facilities, with "groundbreaking" to begin in fiscal year 1977, to support shuttle flight operations scheduled to start at Vandenberg in December 1982. Officials ruled out assigning some West Coast shuttle activities to Edwards Air Force Base but chose Cape Canaveral for IUS development to take advantage of the Titan's SMAB's facilities. Construction of the shuttle's ground facilities at Vandenberg would be the biggest and most expensive project ever undertaken by SAMSO.[29]

As for the type of facilities, planners chose those supporting an integrate-on-pad approach rather than the integrate-transfer-launch concept used by Titan operations at the Cape. While the latter would permit a higher launch rate, integrating the various elements of the STS on the pad meant lower construction and operating costs. Three possible launch sites at Vandenberg were under consideration. Planners eliminated the North Vandenberg and Bear Creek areas and chose SLC-6, the site for the canceled Manned Orbiting Laboratory, which had facilities that could be modified for an expected $150 million less than the expense of constructing new ones at either of the other two sites.[30]

After a comparison study, transporting the shuttle's external tanks to Vandenberg by barge rather than by air proved to be more cost effective. Consequently, plans called for building a harbor and port at the unused Point Arguello Coast Guard station. The project also required a series of environmental studies on the shuttle's potential impact on the area. These ran the gamut from archaeology and paleontology to marine biology and terrestrial ecology. Lastly, the baseline development plan addressed the issue of mission operations. Would DOD requirements be met by the system being developed by NASA, and how best to protect the classified information that would be transmitted by the telecommunications system of the STS? Eventually, the Air Force would construct its own controlled element within NASA's Johnson Space Center in Houston, Texas, to handle classified information.[31]

In December 1976, Air Force headquarters also approved SAMSO's final transition plan for transferring ELV payloads to the shuttle. An STS payload integration plan issued in 1975 established a timeline for transitioning satellites to the shuttle at projected block changes to minimize disruption. During the transition period, a new common core Titan that provided greater payload capacity and reliability would replace all other ELVs except the Scout. The next year the new configuration was designated the Titan III 34D, consisting of a first stage core that had been developed for the defunct Titan III MOL vehicle and stretched 68 inches longer. As Col Victor W. Whitehead, who served as SAMSO's Titan III program manager at the time, later explained, "As good luck would have it, we had to do two SRM [Solid Rocket Motor] qual[ification] firings to qualify new material in the SRM nozzle throat, so we filled the spacer with propellant, insulation, liner, et al to create a new half segment, and then qual fired the stack giving us a 5-1/2 segment SRM." Stage I's thrust increased to nearly 530,000 pounds, while total liftoff power improved to 2,800,000 pounds of thrust. The booster would use inertial guidance at the Cape and radio guidance at Vandenberg. Planners expected to use the Titan 34D during the transition phase with the Boeing Aerospace-manufactured IUS rather than the Transtage. The IUS had been designed with solid-propellant motors of two different sizes: a large motor carrying 21,600 pounds of propellant that produced an average thrust of 43,700 pounds and a much smaller, 6,000 pound motor capable of an average thrust of 17,170 pounds. Using the motors in different configurations would provide a whole family of vehicles capable of a variety of missions. At the end of 1977, NASA had canceled its plan to develop the space tug; accordingly, the IUS was now renamed the inertial upper stage vehicle.[32]

The enormous scope of the Vandenberg shuttle construction project that began in January 1979 is reflected in ground system requirements. Those included design criteria for 15 major facilities, with specifications for 1,500 separate items of ground support equipment and computer software. Among the major facility projects at Vandenberg, three drew the most attention: modification of the SLC-6 launchpad, extension of the original skid runway by 7,000 feet, and building facilities for orbiter checkout and for maintenance. At the SLC-6 site, for example, extensive modifications and new construction included extending the service tower transport rails 150 feet, major excavation of the hillside surrounding the launch mount, changes to the preexisting service tower and the launch mount, building a hazardous waste disposal facility to handle eight times the anticipated amount, and constructing a 4,000-ton, 300-foot-tall, moveable wind screen to provide year-round protection during the orbiter's mating with the external tank. At the Cape, NASA was responsible for all things shuttle, but the Titan's ITL SMAB, owned by the Air Force, would be used for processing the solid-propellant motors of both the IUS and the shuttle.[33]

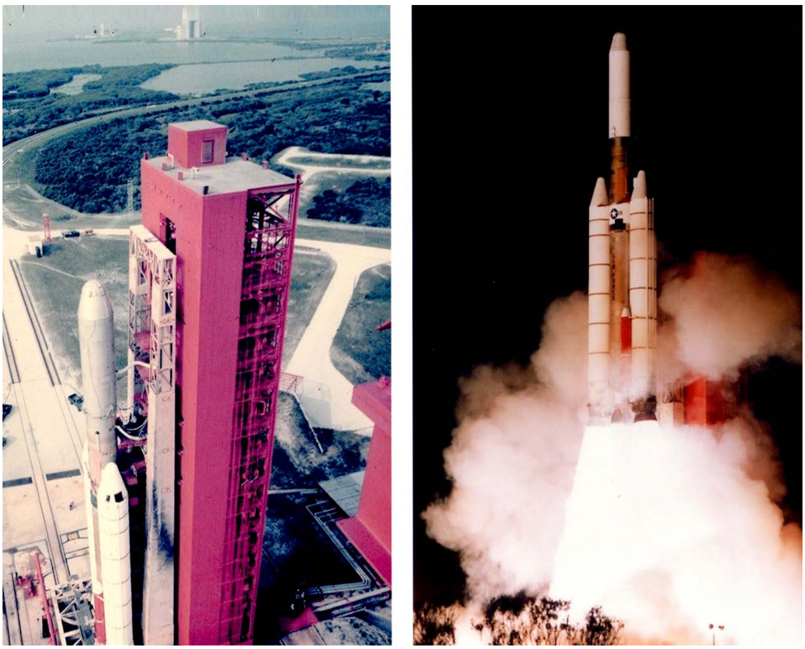


Fig. 14. The Titan 34D launch vehicle at LC-40, launching 30 October 1982. (Photo courtesy of John Hilliard)

By the end of the decade, however, nearly every element of the entire shuttle project—from orbiter to launch site—had experienced cost overruns and delays that not only resulted in lengthened schedules but also put the ELV transition program at risk. Tests of the orbiter's main engine, for example, revealed problems with the turbine blades in the high-pressure fuel pump and bearings and seals in the high-pressure oxidizer pump. The 34,000 silica glass fiber thermal protective tiles used for the underside of the shuttle as well as most of the fuselage sides and vertical stabilizer proved difficult to manufacture and time consuming to apply (or reapply), requiring Rockwell to initiate a round-the-clock work schedule with extra workers. Moreover, the weight of the orbiter and DOD's satellites had increased to the point that NASA had to investigate thrust augmentation options to be able to launch 32,000-pound photo reconnaissance spacecraft into low polar orbit from Vandenberg.[34]

With delays in the shuttle program, the Air Force, with approval from Secretary of Defense Harold Brown, contracted Martin Marietta to increase its initial production of 5 Titan 34Ds to 14 and later to 16. Air Force Secretary Hans Mark had wanted to cap the Titan 34Ds at 16 and close the production line to preclude satellite program managers from delaying or canceling transitioning to the shuttle. DOD expected the Titan 34D to provide critical backup capability for high-priority missions until the shuttle became operational. Although the Titan production line would remain open, Secretary Mark believed that production of large ELVs would end once Martin Marietta produced the final Titan 34D.[35]

The IUS vehicle also experienced a variety of developmental problems. Integrating the IUS guidance system with the Titan 34D proved more difficult than expected, and costs increased in the summer of 1980 when NASA canceled its order for the Titan 34D/IUS combination. At the same time, Boeing inspectors found cracks in the small rocket's nozzle, defective exit cones, and bad propellant. To complicate the production problems, redundant avionics added weight and the initial software proved to be too large for the computer's memory. With requirements continuing to shift and evolve, by 1979 Boeing faced a cost overrun of $15 million (nearly $56 million in 2019 currency) and at least a six-month initial operational capability (IOC) schedule delay. This led to a major confrontation between SAMSO and Boeing, which wanted the Air Force to pay for the entire overrun.[36]

At one point, Brigadier General Mirth, Space Division's Deputy for Space Launch and Control Systems, and his assessment team proposed canceling the IUS entirely. Ultimately, the IUS project would cost the Air Force three times the original award of $250 million ($771,243,932 in 2019 currency). As Mirth admitted, "Nobody really realized how . . . [complex] . . . and difficult that stage was." Ironically, when NASA canceled its IUS order in 1982, it selected the Centaur for the shuttle. Backing out of the IUS joint purchase arrangement with the Air Force also meant higher costs for the Air Force vehicle.

Worried that its two-stage and three-stage IUS vehicles would be underpowered for planetary missions, NASA expressed renewed interest in the liquid propellant Centaur G, the most powerful upper stage vehicle in the space arsenal. NASA's flip-flop on its commitment to the IUS also provided ammunition for critics of the civilian agency's competence and management practices.[37]

Ground facility construction at Vandenberg also faced significant schedule delays by the end of the decade even though construction had only begun in January 1979. Expected budget deficits compelled planners in 1978 to restructure the Vandenberg site's schedule by extending the original IOC of December 1982 to June 1983. By August of 1981, this date would be extended to October 1985. And, while the flight tempo of 20 shuttle launches per year remained the target, planners realistically expected only 6 flights in 1983 and a lower rate of 10 launches yearly by mid-1985.[38]

Although a number of factors accounted for the delays, NASA's penchant for repeated design changes and frequently unannounced modifications ranked at the top of the list. Mirth also served as shuttle program director during this period. Responsible for overseeing the entire Vandenberg shuttle construction program, he remembered that the original technical change forecast anticipated 200–300 per month. By 1979, however, NASA's design changes totaled 1,500 per month and "ran the gamut from just paperwork to launch mount design." He found the launch mount that the flight stack sat on before launch to be the most difficult and substantial change he faced. "NASA kept changing their estimates of the flexibility and stiffness of the entire flight stack," he said. That affected how stiff the mount needed to be and required repeated redesigns of the launch mount. In a meeting at NASA headquarters, Mirth announced a nine-month schedule slip and "pinned the cause on NASA. Several of them went ballistic" before one of the NASA officials acknowledged that, indeed, they were responsible for the delay.[39]

Mirth's experience with the Vandenberg shuttle project and his relationship with NASA officials confirmed the skepticism he expressed when he first heard that the Air Force planned to launch the shuttle from SLC-6. "I was astounded, amazed, incredulous. . . . I couldn't believe that someone in the Air Force had actually committed to do this." Two issues concerned him. One was the requirement for the shuttle to be able to return to Vandenberg in case of an abort. That meant having the runway cleared after launch for an extended period, with the ever-present danger of the infamous Vandenberg fog bank closing in and obscuring the landing site. "I couldn't even think about running a launch operation that way," he said. He also questioned the challenge of towing the shuttle orbiter from the main base to Vandenberg South over a suspect bridge to meet the schedule of 20 flights per year launched by 1,500 people from one pad. That meant, he said, "We'd have a manned launch from a single pad every eighteen days, all year long!" He calculated that an operational launch would cost $50 million, not the $15 million or $18 million projected in 1975 to attract future customers. The NASA figure could only be achieved by reducing manpower and conducting more flights per year. Mirth concluded the real cost per flight would total more than $1 billion were the expense of R&D included.[40]

Fig. 15. This aerial view shows Vandenberg AFB's Space Launch Complex (SLC) 6 from the south, with the shuttle *Enterprise* on the pad, October 1985. (Photo courtesy of John Hilliard)

Mirth's responsibilities also included the environmental requirements. The government required the submission of an environmental impact assessment for the construction program to proceed. Initially completed in 1977, SAMSO and later Space Division officials proceeded to investigate issues related to air quality, hazardous waste, marine biology at the proposed Point Arguello harbor, the status of the Coast Guard station boathouse as a historical site, and preservation of important Chumash Indian archaeological sites. Although construction schedules do not appear to have been seriously affected, it would not be until 1982 that the Air Force's mitigation proposals would satisfy government officials.[41]

NASA's design changes, together with substandard construction, unexpected technical problems, and weather issues kept the Vandenberg ground facilities program in flux and compelled the Air Force to extend the four-year construction program an additional year. Yet, while preparations for the shuttle era dominated much of the Air Force space launch arena in the 1970s, the service continued a vigorous if modest ELV operational flight schedule throughout the decade.

Expendable Launch Vehicle Planning and Operations in the Shadow of the Shuttle

While the major focus of Air Force shuttle planning involved preparing Vandenberg for shuttle and IUS operations, the responsibility of SAMSO's Deputy for Launch Vehicles, and later shuttle program director, also embraced the current and future expendable launch vehicle fleet and the transition of space launch from ELVs to the shuttle. In order of their payload lifting capacity, the ELV inventory in 1972 consisted of Thor (SLV-2) boosters, converted IRBMs from the deactivated United Kingdom force; Atlas E/F refurbished "Wheatfield" ICBMs; Atlas (SLV-3) launch vehicles often used by NASA with the Centaur upper stage; and a variety of Titan III (SLV-5) heavy-lift space launch boosters. The latter contingent included the Titan IIIB and Titan IIID launched from Vandenberg with classified payloads and the Titan IIIC and Titan IIIE flown from Cape Canaveral with both DOD and NASA payloads.[42]

As part of the Air Force commitment to the shuttle, it agreed in late 1971 to refrain from developing any new ELVs and only procure existing designs until the shuttle demonstrated its operational capability. SAMSO's planners evaluated the ELV force over the next two years and determined that the current fleet "had reached a level of maturity" and would fulfill all mission requirements until the shuttle became operational. Indeed, in late 1973, Deputy for Launch Vehicles Colonel Vautherot confirmed SAMSO's ELV policy in his directorate's DOD Space Launch Vehicle Management Plan. As a result, during the decade of the 1970s, the Air Force essentially stopped investing in major improvements to its expendable launch vehicles, facilities, infrastructure, and range systems not required to support the shuttle. With this "no change policy," upgrades to the ELV force would focus only on minimal, affordable measures to improve reliability, reduce costs, and increase mission flexibility.[43]

The assessment of the ELV force also addressed declining launch rates, decreased production, and diminished procurement and development activity. Vautherot's office worried that continuous booster production might no longer be possible, with the resulting negative effect on prime contractor personnel and skills, and availability of critical components and spare parts from vendors. This pessimistic production outlook reflected the arrival of larger, longer-lived, more reliable, and more sophisticated satellite systems that benefited from the solid-state electronics revolution. Some satellite programs, relying on their experience in the 1960s, found that by the early 1970s they needed only one to two launches annually, while by the end of the decade these same programs experienced a launch demand of just one every several years. The objective, then, became taking advantage of fewer standard launch vehicles and associated facilities to combine missions and add subsatellites to the manifest.[44]

To address the lower-launch-rate issue, SAMSO proposed attempting to maintain 100 percent launch vehicle reliability through a variety of policy, test, and motivational measures intended to stabilize design and production and to reduce the number of configurations. Indeed, a joint NASA-DOD policy statement, in 1973, directed the agencies to review any proposed launch vehicle or facility changes "with the specific objective of preventing proliferation of vehicle configurations." At one point, budget constraints and the decline of Air Force–DOD launches at the Cape led Vautherot's office to consider consolidating all launch activity at the Western Test Range to ensure a less costly and more effective use of launch facilities and boosters. An analysis determined that such a measure was technically feasible, would not compromise range safety, and would produce significant savings. Operationally, however, the study found "certain mission requirements (payloads requiring geosynchronous orbits) are adversely impacted by consolidation," and the issue was dropped.[45]

The Cape's relatively low launch rate for both NASA and Air Force–DOD missions in the late 1960s and the first years of the new decade, as described in chapter 4, remained at that modest level for most of the 1970s. Flying primarily Atlas-Centaur combinations and Titan IIIEs from 1973 through 1980, NASA's launch rate averaged between three and four flights per year, with a high of six in 1978 and lows of a single launch in 1979 and 1980. From 1981 through 1985, the year before the *Challenger* tragedy, NASA averaged just two ELV launches per year, with four of these the new Atlas G. The 1970s, however, witnessed several of NASA's most spectacular missions, including Titan IIIE launches of the two Viking flights to Mars in 1975 and the two Voyager flights in 1977 to the outer planets and beyond.[46]

At the Eastern Test Range, the Air Force compiled a total of 23 flights from 1973 through 1980 for an average of nearly three launches annually. During this period, the Air Force relied on the Atlas-Agena SLV-3A to successfully launch three Rhyolite and two Canyon classified electronic intelligence payloads for the National Reconnaissance Office. For heavier payloads requiring geosynchronous orbits, such as the DSP early warning satellites and the DSCS communications satellites, the Air Force preferred the Titan IIIC. For this eight-year period, the Titan IIIC launched five DSP and six DSCS satellites, as well as two Chalet signals intelligence spacecraft. Also, NASA's Atlas-Centaur SLV-3D launched four Fleet Satellite Communications System satellites for the Navy during this same time. For the period 1981–85, the Air Force launched only eight ELVs but used the new shuttle transition booster, the Titan 34D, for four of the flights. Configured with the IUS, the Titan 34D's maiden voyage took place at the Cape on 30 October 1982 when it launched a pair of DSCS satellites. Two years later, three Titan 34Ds using the Transtage successfully launched two DSP payloads and one Chalet signals intelligence satellite.[47]

At the Western Test Range, Air Force missions predominated during the 1973–80 period, with only five of the 62 launches being non-DOD missions. These included one TIROS and two National Oceanic and Atmospheric Administration (NOAA) weather satellites, a solar scientific payload, and Seasat, a satellite designed for remote sensing of Earth's oceans. For this eight-year period, the Air Force launched 20 KH-8A Gambit 3 reconnaissance satellites on Titan IIIBs and 15 of the heavier KH-9 Hexagon payloads on the more powerful Titan IIID. Atlas E/Fs launched a variety of DOD spacecraft, most notably six of the initial GPS satellites. Including the 13 Atlas E/F flights and 9 Thor SLV-2A launches, the Air Force compiled a launch rate of just over 7 per year. The rate fell to an average of five flights annually during the 1981–85 period, which saw the Titan 34D also enter the inventory at Vandenberg. The new booster launched two Gambit 3 and two Hexagon satellites, although the Hexagon flight on 28 August 1985 had to be destroyed at T+272 seconds when an oxidizer leak forced the turbopump to fail and led to a premature shutdown.[48]

Both ranges also experienced relatively low failure rates during the 1973–80 era. At the Cape, a Titan IIIE launching a Viking payload on its maiden mission, on 11 February 1974, suffered a Centaur liquid oxygen turbopump malfunction, and the range safety officer issued a destruct command at T+525 seconds. On 20 February 1975, NASA also lost an Atlas-Centaur and communications satellite when a lanyard separated improperly during booster jettison, producing a programming error and loss of control. The range safety officer then gave the destruct command at T+403 seconds. That same year, an Air Force Titan IIIC, launched on 20 May with a DSCS payload, failed after experiencing a Transtage gyroscope malfunction. Three years later, on 25 March 1978, the Air Force lost another Titan IIIC carrying DSCS satellites when the second stage hydraulic malfunction compelled the range safety officer to destroy the booster.[49]

At Vandenberg, on 13 April 1975, an Atlas F carrying two experimental infrared detectors failed when an explosion in the flame trench led to a sustainer engine malfunction during ascent and the booster and payload were destroyed at T+303 seconds. A second mission failed when a Thor-Burner 2A launching a Defense Meteorological Satellite Program weather payload on 19 February 1976 lacked sufficient kerosene fuel, compelling the satellite to reenter the atmosphere after only one orbit. Two more Atlas E/F missions, one with a weather satellite and another with an electronic intelligence payload, failed in 1980 when their B-1 engines suffered from turbopump problems that left the weather satellite in a useless orbit, breaking up the electronic intelligence satellite.[50]

AFSC Examines the Condition of Space Launch in the mid-1970s

From 1973 to 1985, the Cape experienced 4 failures out of 41 launches for a failure rate of 10 percent, while Vandenberg lost only 6 of its 113 flights for a launch failure rate of 5.3 percent. Although the overall failure rates might appear "acceptable," the Air Force became alarmed when three missions failed within a year, from April 1975 to February 1976. Immediately after the Thor failure in February 1976, Gen William J. Evans, AFSC commander, chartered an ad hoc study group whose membership reflected a broad spectrum of the Air Force and civilian space community. In assessing the three most recent launch failures and broadening their investigation to include all mishaps since 1965, the group focused on reliability, testing, and management issues.[51]

In their briefing that described the recent failures to General Evans on 12 April, group spokesmen noted that the Thor and Atlas were mature systems with outstanding reliability records. The problem, they emphasized, resulted from integration breakdowns, with the Thor receiving an insufficient fuel load and the Atlas F experiencing an incompatibility of launch stand and Atlas booster. Lt Col Frank E. Watkins, who was the Atlas Space Technology Branch chief at the time and a member of the anomaly investigation team, explained that liquid oxygen and RP-1 fuel had bled into a flame bucket that had lost its water through erosion. "We were all at fault," he admitted. Both mishaps were considered easy procedural and modification fixes: water in the Atlas flame bucket and sufficient kerosene fuel for the Thor.[52]

The Titan's Transtage electronic piece parts failure, however, deserved special attention because of the large number of single point failures in the upper stage's complex avionics system. The investigators also determined that design and procedural breakdowns accounted for most mission failures since 1965, and integration problems appeared to be increasing in recent years. As with the Transtage issue, the review found that the upper stages, with their complex electronic systems, provided the greatest risk for space launch vehicles. On a positive note, the ad hoc study found that, contrary to Colonel Vautherot's concerns, reliability had not deteriorated from aging and storage and that shelf limits on parts seemed adequate for both the older systems and the Titan III stages.[53]

The group's evaluation of acceptance and qualification test programs revealed that manpower reductions since 1972 exceeded 25 percent while the launch rate, which indicated work level, had remained relatively stable. Management assessments noted weaknesses in the launch vehicle integration area, with contractor integrators relying on approximately 20 people to validate up to 83 percent of required tasks. The SAMSO Special Projects Office-Aerospace Corporation team, on the other hand, was "manpower limited," and used only five people to validate just 35 percent of the required tasks. As for the remaining requirements for both integrator teams, they "would be satisfied by review."[54]

The study investigators identified funding restrictions as being responsible for hampering launch vehicle integration functions, compelling Titan III avionics to operate without redundancy, and forcing a reduction in personnel that adversely affected quality assurance. They also criticized the use of fixed-price contracts that encouraged the contractor to economize at the "expense of conservative design and performance," which "drives reliability down independent of quality assurance."[55]

After describing its findings, the study group made several major recommendations. For the launch vehicle integration function, it recommended SAMSO publish a baseline document defining a set of functions to be performed, then select a single contractor to conduct the integration function for each SAMSO payload-launch vehicle program. Regarding management, SAMSO should issue a formal management plan for each program that described organizations, assignment of responsibilities, and communication procedures. To compensate for the shortage of Air Force personnel ensuring contractor compliance with proper standards and specifications, contractors must be motivated to maintain high standards and accept a larger share of the risk. This could be done by writing incentive contracts structured to "compensate for tendencies to lower standards due to launch rate, vendor performance, complacency, and end of program." The study also recommended establishing a formal system to share failure information among the ranges, program offices, and contractors and continuing to use refurbished launch vehicles that had proven to be reliable and economical. The investigators argued that, because booster avionics were becoming more complex and payloads more sophisticated and costly, redundancy was absolutely essential to assure reliability.[56]

Finally, the study strongly recommended replacing the 10th AERODS blue-suit launch team with a contractor team and transferring their key personnel to the Space and Missile Test Center (SAMTEC). The 1975 Thor failure of the last DMSP Block 5C launch had brought new scrutiny to the ADCOM space unit, whose launch rate had dropped from six per year in the late 1960s to a single DMSP launch annually. The study group's assessment found that the 10th used a "radically different launch and check-out management arrangement" that excluded support from the launch vehicle systems program office, SAMTEC, and Aerospace Corporation and that had no integrating authority responsible for the entire flight vehicle and its supporting elements. It also performed no analysis of failed parts and did not have the means to trace components. While its practice of making modifications without environmental reacceptance testing had worked with the simple Block 5C spacecraft, "these practices must be viewed with alarm" if carried out with the more advanced Block 5D system because of its more complex upper stage and the spacecraft's inertial guidance for the booster's ascent trajectory. Moreover, with the launch rate reduction, the 10th AERODS's proposed manning level of 116 neared "critical mass," given the 5D's added sophistication and the more complicated coupling to the Thor booster.[57]

In recommending elimination of the AERODS, however, the study group admitted that it did not account for ADCOM's need to continue the command's blue-suit launch team, the only existing launch team composed entirely of Air Force military personnel. Indeed, SAMSO commander Lt Gen Thomas W. Morgan had this in mind in deciding to continue the Thor DMSP launches by the 10th AERODS, albeit with more management responsibility accorded SAMSO's Deputy for Launch Vehicles and the 6595th Aerospace Test Wing. With the larger, heavier DMSP Block D2 spacecraft programmed for fiscal year 1980–1981, however, the Atlas booster, rather than the Thor, would be required. Gen Daniel "Chappie" James Jr., ADCOM commander-in-chief, viewed this as a golden opportunity to enhance the role of the 10th AERODS and also help protect his command from possible disestablishment. ADCOM had already been downgraded from an active defense to a warning command in the early 1970s. In the wake of the Thor failure on 19 February 1976, General James had lobbied Lt Gen James A. Hill, the Air Force's deputy chief of staff for programs and resources, to accord ADCOM the Atlas space launch mission that embraced both DMSP and the new GPS satellites. Neither James nor his ADCOM successor, Gen James E. Hill, however, were able to acquire the Atlas mission or preserve their command. On 31 March 1980, the Air Force inactivated ADCOM as an Air Force major command, with its air defense systems and its missile and space defense systems parceled out to Tactical Air Command and Strategic Air Command, respectively, in 1979 and 1980. What remained was ADCOM as a specified command, with a sole purpose of supporting NORAD with a much smaller footprint. The 10th AERODS successfully launched DMSP Block 5D-1 spacecraft with long tank Thor LV-2Fs yearly after the 1975 failure until their final flight on 14 July 1980, when the third-stage motor exploded due to a faulty connection between the second and third stages. In December 1982, Atlas E/Fs would replace the Thors and begin launching the DMSP Block 5D-2 payloads. Of the seven recommendations made by the ad hoc study group, five had been implemented by the end of 1976, and action officers had completed steps to implement the remaining two in May 1977.[58]

Space Launch Veterans Assess Their Experience

Several accounts of veteran experiences at Vandenberg illustrate the high degree of professionalism that continued to characterize Air Force space launch. The Atlas F failure at Vandenberg's SLC-3W in April 1975 was the only failure during the eight-year tenure of Lieutenant Colonel Watkins. He supervised the conversion of SLC-3 East from a Thor to an Atlas launch site during his assignment as chief of the Space Technology Branch and went on to serve as chief of the Atlas Satellite Programs Division from the spring of 1977 to the fall of 1981. During Watkins's Vandenberg experience, SLC-3 supported 19 Atlas launches and 7 different programs, including GPS, Seasat, several NASA weather satellites, and naval signals intelligence satellites, plus scientific and technological payloads. His keys to successful launch base operations included, among others, "detailed knowledge of the systems—know it better than the designer; must feel total responsibility for making mission successful; environment must encourage getting problems/goofs out in the open; absolute honesty and frankness." He declared, "These are the kinds of things Rob Roy

. . . [the Vandenberg space pioneer described in Chapter III] . . . passed on to [us] young L[ieutenan]ts in 1961." Like his predecessors, Watkins did not attend formal courses at Maxwell Air Force Base but benefited from the effective mentoring program conducted by Capt Rob Roy and others. Likewise, the attention to detail is evident in locally produced checklists and documents, such as a 1974 space engineer's handbook, a SAMTEC description of launch operations responsibilities, a field test operations guide, and flight readiness test plans for GPS missions. Watkins "never wanted to be assigned to an operational command" and appreciated being able to remain in AFSC for his eight-year period at Vandenberg. Reflecting on his launch experience, he was particularly proud of the extensive involvement of his people in both operations and initial contracting activity to ensure contracts included his launch operations perspective. He asserted, "You have many problems doing these kinds of things when you move your Air Force people every two to three years." Watkins always favored people over process. "Over the years in the space business," he argued, "we've gone from getting the right people to prioritizing process." At SLC-3, he believed that his mentoring program and his unit's ongoing training program created the professionalism that accounted for the success of Atlas operations during his Vandenberg experience.[59]

Frank Watkins's counterpart, "next door" at SLC-4, was then-Maj Sebastian F. "Seb" Coglitore, who served as test manager for the Titan Booster Satellite Division in the 6595th Space Test Group from June 1973 to June 1977. During his four years at Vandenberg, all 22 classified satellites launched from SLC-4 were successful. Major Coglitore's responsibilities embraced KH-8A Gambit 3 flights on Titan IIIBs, KH-9 Hexagon launches on Titan IIIDs, and most likely the new KH-11 Kennen, the first of the NRO's digital imaging spacecraft, also launched by the Titan IIID. A new program like Kennen required nearly two years of intensive planning to install test equipment at SLC-4E and to develop the test plans, plus range and support base plans for successful launch processing and launch.[60]

Both Gambit and Hexagon illustrate the evolution in satellite size, weight, and performance by the 1970s. As Coglitore described, "We were transitioning to longer on-orbit lifetime with both Gambit and Hexagon . . . [and] . . . the contractors were incentivized for on-orbit performance." Gambit 3, for example, was 5 feet wide, nearly 29 feet long (not including the Agena upper stage), weighed nearly 4,100 pounds, and carried more than 12,000 feet of film. Hexagon, however, was appropriately named "Big Bird" and was the size of a bus, at 60 feet in length and 10 feet in diameter. It carried nearly 60 miles of film and weighed up to 30,000 pounds.[61]

Confirming Watkins's experience, Coglitore noted, "The space launch career field through the '70s and '80s did not have any of the formal training that the missile officers did." Training for him, too, involved on-the-job training at the factory and the launchpad. While guides and handbooks proved useful, he stated that most of his fellow satellite personnel would build an "assorted goodies" binder consisting, for example, of a readiness checklist, space launch engineer's handbook, safety orientation guide, and various other training documents. Both Watkins and Coglitore commented on the uniformly high morale throughout their tours at Vandenberg. So, too, did Capt Thomas D. "Tav" Taverney, who served as a field test force director at the Air Force Satellite Control Facility (AFSCF) in Sunnyvale, California, from September 1972 to August 1976. Both men knew one another and served in the Los Angeles AFB Special Projects arena after their Vandenberg assignments. As Seb Coglitore said to Tav Taverney, "So you were flying Hex[agon] out of the AFSCF while I was launching them." Taverney expressed their role in space launch best when he said, "While not the first generation of space people, I think in many ways we had more fun. They were just trying to find out if it was possible to build, launch, and operate space systems, and we got to stand on those giant shoulders and push the limits of what we could do from space." Coglitore agreed. Looking back, he said, "it has been a great ride."[62]

When Coglitore was reassigned to the Los Angeles Special Projects Office in June 1977, he likely continued to focus on Kennen as its launch vehicle integration manager for current operations and for its potential transition to the shuttle. In January, shortly before his reassignment, he had attended a meeting with Air Force and NASA officials at Vandenberg to discuss initial shuttle payload integration requirements for developing the Vandenberg facilities. He was astounded when the NASA contingent insisted the shuttle would launch 20 times a year from Vandenberg at $15 million per flight. Air Force requests for a breakdown of the missions repeatedly elicited the response of 4 or 5 DOD and 15 or 16 NASA or civil missions that invariably totaled 20. When asked for evidence of those missions in the budget, Air Force officials were told it was none of their business.

From Coglitore's experience, "NASA forced the Air Force to build the launchpad and other facilities to meet a bogus mission model." He had little respect for NASA's headquarters and shuttle program senior managers, who maintained an "unattainable story line," whereas the engineers and operators were "a joy to work with . . . professional and mission-oriented." Coglitore's criticism of NASA's shuttle mission model mirrored that of senior Air Force leaders, who by the end of the 1970s had become increasingly skeptical of committing all DOD space launches to the shuttle.[63]

The Air Force Pursues a Mixed-Fleet Strategy to Achieve Assured Access to Space

By the early 1980s, Air Force and DOD concerns about the shuttle approached alarm as the departments faced the prospect of the shuttle's continued high costs, production delays, and reduced flight schedules. That year, both the Air Force Scientific Advisory Board and the Defense Science Board addressed the space launch issue. Citing shuttle delays, the likely lack of an "on-call" launch capability, and the general austerity of space launch assets, the two boards proposed a "mixed-fleet" policy of using both the shuttle and expendable boosters for military payloads. Officials remained uncertain whether the mixed-fleet concept should become a permanent policy or only be pursued until the shuttle proved capable of fulfilling its early promise of routine spaceflight. In light of potential shuttle delays, mishaps, and traffic requirements, a number of other studies conducted within the DOD confirmed the need for ELVs to guarantee assured access to space for national security missions.[64]

By this point, long gone was NASA's rosy prediction of 60 flights annually. NASA had further reduced its already lowered STS flight schedule from a planned 14 launches in 1984 and 24 per year by 1986 to 5 in 1984 and 13 in 1986. A General Accounting Office investigation in 1982 noted that the earlier projected schedule in 1977 of 487 flights during the first 12 years of operations had been reduced by more than 50 percent to 234. Although the successful maiden flight of the shuttle in April 1981 eased some of the tension between NASA and the Defense Department, Air Force leaders remained leery of phasing out ELVs once the shuttle became operational.[65]

After recommendations by the two boards, Air Force Chief of Staff Gen Lew Allen formally identified the total reliance on the shuttle as a problem and called for study of a mixed-fleet strategy in October 1981. The following month, Undersecretary of the Air Force and NRO director Edward C. "Pete" Aldridge, who would become a central figure in the space launch arena throughout the decade, appeared before the National Space Club in Washington, DC, to give a "my views only" assessment of military space issues. Calling for a "new management structure for our space operations," he asserted that the Air Force "cannot continue to look to NASA as our country's Launch Service Organization in the Shuttle era." Although he cited as positive the appointment of Maj Gen James A. Abrahamson as NASA's Associate Administrator for Space Transportation Systems, he argued that the space agency should focus on "developing civilian space assets and transportation systems" and consider leaving operational responsibilities to others. The undersecretary also appeared to favor retention of ELVs even after the shuttle became fully operational. He observed, "It . . . seems illogical that our only 'truck' to deliver our goods to space be in the form of 3, or 4, or 5 highly complex launch vehicles. Fleet grounding, launch failures, or both could severely limit our access to space."[66]

As director of the NRO, Aldridge's concerns about shuttle launch reliability also embraced the future of his agency's reconnaissance satellites during this crucial transition period. In the early 1980s, the NRO confronted the imminent conclusion of KH-9 Hexagon, the NRO's most successful search program, with the launch of Hexagon 20. That payload, however, was originally scheduled for October 1985 but subsequently slipped to the summer of 1986 due to problems with Hexagon 19. By early 1980, NRO officials had decided to continue Hexagon launches atop the Titan 34D booster rather than have the shuttle fly the remaining KH-9s or additional Hexagon payloads that might be manufactured. The NRO also had considered the possibility of launching Hexagon on the shuttle. When a contract for such an analysis proved to be too expensive, the Special Projects Office called on highly respected engineer Captain Taverney, who had left the service in 1979, to assess the viability of flying the Hexagon camera on the shuttle. After the Special Projects Office facilitated his joining the Reserves, Taverney performed the analysis by constructing a simulator that showed the camera would not perform effectively at the shuttle's altitude. As he recalled, "Going up in altitude moved us from NIIRS (National Imagery Interpretability Rating Scale) 3-4 to NIIRS 2-3, and that was not very satisfactory."[67]

Hexagon, the last of the film retrieval satellite programs designed for searching large areas, was to be replaced by the KH-11 Kennen digital imaging system, which produced high-resolution images that could be read out almost immediately. Planners believed modifications to Kennen could deliver search imagery equivalent to Hexagon's. Even so, Secretary Aldridge's team worried that Kennen might not be able to accomplish both a search mission and its higher priority, high-resolution imaging of targets. This led to consideration of the extensive modifications needed to have the shuttle recover one of the final Hexagon payloads for refurbishment and reflight atop a Titan. Historian Dwayne Day has argued that a Hexagon 20 launched in 1986 could have been retrieved by the shuttle the following year, then refurbished and reflown by a Titan in 1988 or 1989. In the early 1980s, however, Secretary Aldridge had to confront those difficult issues in his effort to balance the need for a continued ELV capability for high-priority missions with an administration policy of shuttle launch primacy.[68]

Indeed, in his National Security Decision Directive 42 (NSDD-42) of 4 July 1982, President Reagan reaffirmed the shuttle as the nation's primary launch vehicle and directed that "spacecraft should be designed to take advantage of the unique capabilities of the STS." ELV operations were to continue "until the capabilities of the STS are sufficient to meet its needs and obligations," while "unique national security considerations may dictate developing special-purpose launch capabilities." Even though it essentially called for the "shuttle-optimization" of President Carter's PD-37, the Air Force and DOD continued to conduct studies and reviews in 1982 and 1983 that confirmed the importance of maintaining an ELV capability while recommending continued commitment to the shuttle. One of the most convincing arguments for the mixed-fleet approach came from Lt Gen Richard C. Henry, commander of Air Force Systems Command's Space Division, who also reflected the Air Force's disenchantment with manned spaceflight. Writing to Gen Robert T. Marsh, the AFSC commander, in March 1983, Henry worried about the imminent shutdown of Titan and Atlas production lines and reliance on a costly shuttle fleet with reduced operational schedules. After providing an extensive, comparative analysis of ELVs and the shuttle, he argued the shuttle was "better used for those missions where the utility of man is clear . . . [and that] . . . man is not needed on the transport mission to GEO [geosynchronous Earth orbit] and is . . . the more expensive alternative." He recommended "an investment strategy in a mixed fleet, preferably with commercialization."[69]

Air Force efforts to retain an ELV capability received additional support from the 16 May 1983 presidential directive, NSDD-94, on commercialization of ELVs. With the government now endorsing commercial ELVs, the Air Force realized that an ELV backup for the shuttle could be available at little or no cost to the government. Undersecretary Aldridge's call for commercial production of expendable launch vehicles as a means of providing the Defense Department more affordable backup boosters did not please NASA, because commercial ELV production would infringe on the space agency's shuttle marketing operation. In the early 1980s, when the European Space Agency's successful marketing of the Ariane rocket threatened to corner the launch market for commercial satellites, NASA received permission to promote the shuttle commercially at artificially low prices. The American ELV industry, meanwhile, had been blocked from commercial competition and, subsequently, had suspended production in light of the military's shuttle-only policy. NASA expected to recoup its costs later in the decade through cost-effective commercial operations, but it had based its planning on erroneous estimates of yearly flights, without accounting for such vagaries as mechanical difficulties, weather delays, and slow turnaround procedures. After four orbiters and six years of operation, *Challenger*'s January 1986 mission represented only the twenty-fifth orbiter flight. At the same time, the producers of satellites had proceeded on the assumption that future flights would be cheap and frequent. By 1984, the Reagan administration had become sufficiently concerned about the likely shortfall in NASA's commercial operations to pass the 1984 Commercial Space Launch Act, which sought to ease the cumbersome, bureaucratic launch process by centralizing all commercial launches under the Secretary of Transportation. At the same time, the act tended to move NASA out of the private launch business.[70]

During 1983, the problems affecting the shuttle became more worrisome. Real costs for shuttle launches were now becoming evident as large overhead expenses had to be spread over fewer flights. By this time, NASA had canceled plans for both the space tug and a fifth shuttle orbiter, which contributed to a drastic reduction in annual flights and an increase in operational costs. Moreover, all four orbiters performed nearly 20 percent below design specifications, requiring NASA to upgrade the shuttle's main engines to perform at 104-percent thrust and develop a lighter, filament-wound case for the solid rocket boosters. Additionally, designing payloads optimized for the shuttle usually required a complete redesign to position the satellite horizontally (attached on its side in a cradle with trunnion pins) to handle lateral loads along the space vehicle axis. For ELV launches that had satellites mated to the booster at their aft end, designers configured spacecraft for launch loads along the longitudinal axis. The horizontal configuration also took advantage of NASA's pricing policy that was based on linear feet of the payload. The shuttle-optimized payload thus tended to be wider and heavier than the current ELV fleet could launch—and more costly. Shuttle costs also increased when the workforce of 6,000 personnel, which was four times the expected figure, did not decline despite the lower launch rate. By contrast, the Titan program needed only about 600 people to manufacture and launch the booster. Moreover, instead of the projected turnaround time of seven days, the workforce required nearly 60 days to prepare for subsequent shuttle flights. Given this recycle time, an orbiter could fly no more than six times a year, which would result in a maximum of 24 flights annually for the fleet of four orbiters.[71]

These concerns about the shuttle's costs, performance, and launch rates reinforced the Air Force's determination to pursue its plans for a mixed fleet with ELVs to complement the shuttle. The Titan 34D, nearing the end of its scheduled availability, however, could provide only an interim solution, because it could not match the shuttle in launch weight and payload size. Moreover, NASA elected to modify only two of the four shuttles, *Atlantis* and *Discovery*, to handle heavy DOD payloads. By the end of 1983, Undersecretary Aldridge, proclaiming the need for "assured access to space," outlined growing Air Force support for the additional step of developing an upgraded Atlas, termed the Atlas II, refurbishing deactivated Titan II ICBMs, and procuring a more powerful Martin Marietta Titan. The latter vehicle would consist of a 200-inch payload fairing to handle a shuttle-configured Centaur upper stage and a shuttle-configured payload; it would possess the capability of launching 10,000 pounds into geostationary orbit. Initially referred to as the Titan 34D7 because of its 7 rather than 5½ segmented, solid rocket motors, it soon became known as the Complementary Expendable Launch Vehicle (CELV), and then, in August 1986, the Titan IV.[72]

As the Pentagon's Air Force Chief of the Space Launch and Control Division in the early 1980s, Col Victor W. Whitehead was responsible for all DOD expendable launch vehicles. He continued to work at Space Division as ELV program director. Working closely with Undersecretary Aldridge, he found himself at the center of the mixed-fleet strategy in the Air Force effort to preserve ELV production lines that had begun shutting down in 1983. Looking ahead, in addition to the Martin Marietta Titan IV, the Air Force would acquire the McDonnell-Douglas Aerospace Corporation (MDAC) Delta II (primarily for GPS launches) and the General Dynamics Atlas II (primarily for DSCS launches). Both were the winners of medium launch vehicle competitions. With the award to MDAC, the Air Force became responsible for the Delta program and, as Whitehead said, "This also completed the preservation and maintenance of production capability of the second US ELV manufacturer . . . [after the Martin Marietta Titan]." After the second medium launch vehicle award to General Dynamics for the Atlas II, Whitehead asserted, "With this award we had now successfully restored and maintained ELV production capability at all three US ELV manufacturers." Colonel Whitehead also served as Secretary Aldridge's key figure in developing the program to refurbish the deactivated Titan II ICBM (primarily for DMSP launches). All of those programs would come to fruition in the late 1980s or early 1990s.[73]

By early 1984, the Defense Department had accepted the Air Force mixed-fleet position. A "Defense Space Launch Strategy" statement, issued on 23 January, declared, "While affirming its commitment to the STS, DoD will ensure the availability of an adequate launch capability to provide flexible and operationally responsive access to space, as needed for all levels of conflict, to meet the requirements of national security missions." Secretary of Defense Caspar Weinberger explained that the new defense launch strategy would promote an "assured launch capability" by providing a complementary fleet of expendable commercial boosters. While the "STS will remain the primary launch system for routine DoD launch services," he said, "as Executive Agent for launch vehicles, the Air Force will take immediate action to acquire a commercial, unmanned, expendable launch vehicle" capable of launching shuttle-class spacecraft to geosynchronous orbits "to complement the STS." The defense secretary then approved the Air Force plan to procure 10 Titan 34D7s or CELVs capable of launching shuttle-class spacecraft to geosynchronous orbits. The Air Force expected to see the CELVs enter the inventory by 1988 to support a schedule of two launches per year.[74]

NASA did not respond well to DOD's action promoting the mixed-fleet strategy. Secretary Aldridge said that "NASA, especially its Administrator, was furious." In early 1984, NASA officials fervently lobbied against the CELV, asserting that "it was only a ploy of the Air Force to abandon the Shuttle" and would result in lower shuttle flight rates and higher costs. Over the next several months, NASA, supported by its congressional allies and the Office of Management and Budget, first lobbied hard to eliminate the Air Force's competition for an ELV then, in an unprecedented move, to compete with industry for the new ELV using government designs based on shuttle components. Under considerable pressure, the Air Force agreed to evaluate the NASA proposal but, to avoid direct government competition with industry, would select the industry winner and then compare it with the NASA entry. Meanwhile, NASA continued to oppose the Air Force plan and pressure contractors first not to bid at all and, failing that, to support the NASA proposal. At the same time, the civilian agency continued to undermine the Air Force selection by calling for additional study and attempting to block funding. These delaying tactics, if successful, would have meant closing down production lines with the prospect of potentially reopening them later at great cost. In May 1984, Undersecretary Aldridge had appealed to the Secretary of Defense to overcome the opposition raised by NASA, the Office of Management and Budget, and congressional critics. His appeal stressed the significance of the request. "With the dependence that we place on space systems to support our national security," he argued, "we cannot afford to have our access to space as 'fragile' as it will be without ELVs complementing the Shuttle." His options left little doubt that Secretary Weinberger would continue to support ELV production.[75]

By December 1984, Martin Marietta had won the industrial competition with its Titan 34D7 entry and received the contract, on 28 February 1985, to produce 10 CELVs after the second phase of the CELV source selection that eliminated the NASA entry. Secretary Aldridge declared that "the rest of the so-called 'competition' was a 'farce,' and should have been an embarrassment to NASA and its highly competent engineering team." Colonel Whitehead remarked, "NASA, working with the Congress, managed to force us into a second competition pitting the Titan IV against a NASA-contrived, nonexistent, 'Rube Goldberg' rocket composed of Shuttle SRMs and a second stage (which had its own shadowy origin)."[76]

Lt Col Thomas E. Maultsby also recalled the often bitter relationship between NASA and the DOD and Air Force. As assistant for space policy in the Office of the Secretary of Defense (Policy) from 1983 to 1986, he served as the daily DOD representative in interagency working groups that dealt with pricing policy, space station approval, and ELV issues. He noted that in considering shuttle pricing policy and the space station concurrently, negotiations "became very contentious and close to disingenuous." Citing one example, he explained that NASA representatives would arrive for a morning pricing meeting with an official STS manifest showing a high rate of STS space station flights in order to keep the cost per flight low. These same officials in the afternoon meeting that dealt with space station approval produced a different, yet "official" manifest depicting very few shuttle flights to support the space station, thereby keeping the cost of the station low. Maultsby recalled that he and other DOD officials attended both meetings and quickly realized NASA's efforts to bias both issues. When "NASA would not yield on this ambiguity," he said, "the Interagency group developed our own consistent manifest that we used in both discussions." Reflecting on his own experience and NASA's general reluctance to modify its positions on pricing, performance, and launch rates, he suggested that significant compromise on the space agency's part would have endangered its likelihood of receiving congressional approval for its budget and, thereby, imperil the shuttle program itself.[77]

Meanwhile, to end the "war" between the DOD and NASA, on 14 February 1985, the National Security Council hosted a meeting between Air Force Undersecretary Aldridge and NASA Administrator James Beggs. After much discussion, Aldridge convinced Beggs to accept a limited number of expendable boosters in exchange for Department of Defense commitment to the shuttle and a second-generation STS. That same month, the National Security Council confirmed this agreement in its *National Security Launch Strategy* directive, NSDD-164, which authorized the Air Force to procure 10 CELVs and declared, "DoD will rely on the STS as its primary launch vehicle and will commit to at least one-third of the STS flights available during the next ten years." NASA and the Department of Defense would also study a follow-on system that made "use of manned and unmanned systems to meet the requirements of all users." Indeed, the Air Force had already begun a technological initiative for developing a new expendable launch system, referred to as the Advanced Launch System (ALS), which would be restructured in the late 1980s to promote new booster technology for a variety of requirements.[78]

Conclusions

On the eve of the *Challenger* disaster, the shuttle remained the centerpiece of America's space launch program. Although the Air Force's commitment to the shuttle as its primary launch vehicle had been tempered by diminishing expectations, it hoped the addition of a limited number of mixed-fleet expendable boosters would help sustain the shuttle without delaying military launch schedules. In the wake of the *Challenger* tragedy, the often contentious debate over the requirement for complementary ELVs to launch crucial payloads disappeared. Henceforth, the assured access to space concept with the mixed-fleet strategy for government payloads became cornerstones of the national launch strategy as incorporated in *United States Space Launch Strategy*, NSDD-254, on 27 December 1986, which outlined the path forward to restore the nation's space launch capability. In retrospect, Air Force Secretary Aldridge, more than any single individual, possessed the vision, perseverance, and inspired leadership that made possible the mixed-fleet strategy and its centerpiece, the Titan IV.

Looking back on the shuttle experience, Air Force participation came at the behest of the service's civilian leadership. The blue-suit Air Force, in contrast to earlier NASA initiatives, reluctantly supported the shuttle. Air Force leaders were less than enthusiastic about human spaceflight and frequently ambivalent about space in general. Ironically, the shuttle helped provide support for an Air Force space focus by convincing Air Force leaders to centralize management responsibility for its increasingly effective unmanned space platforms in an operational space command. The central priority, however, became making space support essential to the war fighter, not flying pilots into space. Looking ahead from the *Challenger* tragedy, Air Force generals who had come of age through the shuttle years were less likely to support major new cooperative ventures with NASA in the near term. On the other hand, no one wanted to resort to business as usual, with its time-consuming practice of linking specific satellites to particular launch vehicles. The launch challenge for the 1990s would find NASA and the Air Force cooperating to develop an "assured launch strategy" based on lower costs and greater launch responsiveness.[79]

Notes

1. Maultsby, email, 11 March 2019.
2. Spires, *Orbital Futures*, vol. 2, 731.
3. The administration and Congress declined to support both the shuttle and a space station. Williamson, "Developing the Space Shuttle," 166–67; Jenkins, "Broken in Midstride: Space Shuttle as a Launch Vehicle," 362–63; and David, *Spies and Shuttles: NASA's Secret Relationships with the DoD and CIA*, 191–92; For coverage of the "selling" of the shuttle, see Temple, *Shades of Gray: National Security and the Evolution of Space Reconnaissance*, 475–80.
4. Department of Defense and National Aeronautics and Space Administration, "Joint DoD/NASA Study of Space Transportation Systems. Summary Report," 16 June 1969, in Spires, *Orbital Futures*, vol. 2, 863–69; and Neufeld, *The Air Force in Space, 1969–1970*, 6–7.
5. Paine and Seamans, "Agreement Between the National Aeronautics and Space Administration and the Department of the Air Force Concerning the Space Transportation System," NMI 1052.130, Attachment A, 17 February 1970, in Spires, *Orbital Futures*, vol. 2, 869–70; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, appendix 2, 246–48; and David, *Spies and Shuttles*, 193.
6. Quoted in Futrell, *Ideas, Concepts, Doctrine*, vol. 2, 685; and Spires, *Beyond Horizons: A History of the Air Force in Space, 1947–2007*, 180–81.
7. Crossrange is the "ability of the shuttle to travel to either side of its ground track during landing." Higher crossrange meant a larger, Delta-winged shuttle for greater maneuverability. Day, "Invitation to Struggle: The History of Civilian-Military Relations in Space," 264; Jenkins, "Broken in Midstride," 364–68; Williamson, "Developing the Space Shuttle," 166–70; and David, *Spies and Shuttles*, 193–95.
8. Day, "Invitation to Struggle: The History of Civilian-Military Relations in Space," 264; Jenkins, "Broken in Midstride," 364–68; Williamson, "Developing the Space Shuttle," 166–70; and David, *Spies and Shuttles*, 193–95. Neufeld asserts that current boosters could deliver payloads no greater than 30,000 pounds to LEO, and payloads were restricted to cargo bays 10 feet in diameter by 60 feet in length. Neufeld, *The Air Force in Space, 1970–1974*, 3–5; Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 89–90; Space and Missile Systems Organization (SAMSO), *History of Space and Missile Systems Organization, 1 July 1971–30 June 1972*, 84; David, *Spies and Shuttles*, 193–95; and Temple, *Shades of Gray*, 484–85.
9. Day, "Invitation to Struggle: The History of Civilian-Military Relations in Space," 264; Jenkins, "Broken in Midstride," 364–68; Williamson, "Developing the Space Shuttle," 166–70; Neufeld, *The Air Force in Space, 1970–1974*, 3–5; Aerospace Corporation, *The Aerospace Corporation. Its Work: 1960–1980*, 89–90; Space and Missile Systems Organization (SAMSO), *History of Space and Missile Systems Organization, 1 July 1971–30 June 1972*, 84; David, *Spies and Shuttles*, 193–95; and Temple, *Shades of Gray*, 484–85.
10. David, *Spies and Shuttles*, 196; Neufeld, *The Air Force in Space, 1970–1974*, 9–10; SAMSO, *History of Space and Missile Systems Organization, 1 July 1972–30 June 1973*, 201–6; and Jenkins, "Broken in Midstride," 374–76.

11. Spires, *Beyond Horizons*, 182–84; Neufeld, *The Air Force in Space,* 1970–1974, 11–13; SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 160–92; Spires, *Orbital Futures*, vol. 2, 732–33; and David, *Spies and Shuttles*, 200. David notes that an interagency group in 1976 asserted the need for backup ELVs, with production currently scheduled through 1982. Military, as distinct from intelligence, payloads would begin transitioning to the shuttle in 1980, with intelligence payloads to follow in 1982. Initially, all payloads were to be configured for both ELVs and the shuttle; Temple, *Shades of Gray*, 490.

12. For General Clay's correspondence and position paper, see Spires, *Orbital Futures*, vol. 2, 870–82.

13. C. W. Duncan Jr., Deputy Secretary of Defense, to the Secretaries of the Military Departments, et al, "Assignment of Responsibilities of the Department of Defense Manager for Space Shuttle Support Operations," 16 March 1977, in Spires, *Orbital Futures*, vol. 2, 887–89.

14. Also contributing to strained relations between the military and civilian agencies was the tendency of NASA officials to make program changes without notifying their Air Force counterparts. See the testimony of then-Col Joseph D. "Don" Mirth, email, 27 March 2017. Day, "Invitation to Struggle," 264–65; Williamson, "Developing the Space Shuttle," 176; Spires, *Orbital Futures*, vol. 2, 734–35; Government Accounting Office (GAO), *Implications of Joint NASA/DOD Participation in Space Shuttle Operations*, 3–21; Ulsamer, "Space. High-Flying Yankee Ingenuity," 98–104; and Temple, *Shades of Gray*, 493–96.

15. Yardley, Martin, Fletcher, and Clements, "NASA/DOD Memorandum of Understanding on Management and Operation of the Space Transportation System, 14 January 1977," in Spires, *Orbital Futures*, vol. 2, 882–87. Planning would later call for establishment of a Shuttle Operations and Planning Complex to join a new Satellite Operations Center in what planners would refer to as the Consolidated Space Operations Center (CSOC), to be constructed at Falcon Air Force Station near Colorado Springs, Colorado. After the *Challenger* accident, the Shuttle Operations and Planning Complex was canceled. Spires, *Beyond Horizons*, 197.

16. Presidential Directive 37, *National Space Policy*; Secretary of the Air Force Edward C. "Pete" Aldrich asserts that the directive declared the shuttle to be the "exclusive means for the United States to launch satellites into space." Aldridge, "Assured Access: 'The Bureaucratic Space War,'"; David, *Spies and Shuttles*, 207. See an expanded biography of Dr. Hans Mark in appendix A.

17. Temple, "Committing to the Shuttle Without Ever Having a National Policy," 43; Day, "Invitation to Struggle," 266; and Temple, *Shades of Gray*, 506–7.

18. Mirth, email, 27 March 2017. On 1 October 1979, the Air Force split the functions of Space and Missile Systems Organization (SAMSO), replacing it with the Ballistic Missile Office (BMO) and the Space Division (SD). For the late 1970s Air Force organizational changes, see Spires, *Beyond Horizons*, 196–97.

19. Coglitore, email, 11 April 2019, 22 October 2019.

20. Coglitore, email; Day, "Top Secret DAMON."

21. Coglitore, email, 11 April 2019; Cassutt, "Secret Space Shuttles"; and David, *Spies and Shuttles*, 223.

22. Space Division (SD), *History of Space Division, 1 October 1979–30 September 1980*, 75–76; Spires, *Beyond Horizons*, 223–24; Day, "Invitation to Struggle," 264–66; and Williamson, "Developing the Space Shuttle," 176. David examines a March 1979 "DoD Space Shuttle Transition Plan (FY 1977–1991)" that lists specific payloads and their scheduled transition time for shuttle operations. David, *Spies and Shuttles*, 209–11; and Temple, *Shades of Gray*, 528.

23. David, *Spies and Shuttles*, 214–17.

24. For a comprehensive discussion of the SLC-6 construction program, see Jenkins, *Space Shuttle: Developing an Icon*, II-470 to II-478; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1971–30 June 1972*, 84–85.

25. SAMSO, *History of Space and Missile Systems Organization, 1 July 1972–30 June 1973*, 64–65.

26. SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 47–49; and SAMSO, "DOD Space Launch Vehicle Management Plan, FY 1975–1985," 4-13, 5-1.

27. SAMSO, "DOD Space Launch Vehicle Management Plan, FY 1975–1985," 4-8, 5-1, 6-1 to 6-2; and SAMSO, "SAMSO Resources Plan, FY 1976–FY 1985," 5-23 to 5-24.

28. For a detailed list of projected Space Tug capabilities, see SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 163–64; SAMSO, "SAMSO Resources Plan, FY 1976–FY 1985," 5-119; SAMSO, "SAMSO Resources Plan, FY 1977–FY 1986," 5-112 to 5-113; and SAMSO "DOD Space Launch Vehicle Management Plan, FY 1975-1985," 6-1.

29. SAMSO, "SAMSO Resources Plan, FY 1976–FY 1985," 5-123; SAMSO, "SAMSO Resources Plan, FY 1977–FY 1986," 1 July 1975, 5-114; SAMSO, *History of Space and Missile Systems Organization, 1 July 1971–30 June 1972*, 86–87; SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 179–82; and SAMSO, *History of Space and Missile Systems Organization, January–31 December 1977*, 89–90.

30. SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 182–84; GlobalSecurity.org, "The SLC-6 Saga"; and Tomei, "The Air Force Space Shuttle Program," 22–25. Using the existing SLC-6 site would also avoid having to deal with environmental requirements and local Indian tribal concerns.

31. Spires, *Beyond Horizons*, 197, 223; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 182–84.

32. Whitehead, email, 18 March 2019; Taverney, email, 14 February 2017; SAMSO, *History of Space and Missile Systems Organization, 1 July 1975–December 1976,* 100; and SAMSO, *History of Space and Missile Systems Organization, January–31 December 1977*, 61–62.

33. SAMSO, *History of Space and Missile Systems Organization, 1 January–31 December 1978,* 118–19; and SAMSO, *History of Space and Missile Systems Organization, 1 January–31 September 1979,* 95–96. See table 1 in appendix B for STS construction projects.

34. Jenkins, "Broken in Midstride," 387–86; Williamson, "Developing the Space Shuttle," 174–76; SAMSO, *History of Space and Missile Systems Organization, 1 January–31 September 1979,* 74–75; and Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 3.

35. SD, *History of Space Division, 1 October 1979–30 September 1980*, 67–68; Temple, "Committing to the Shuttle Without Ever Having a National Policy," 43; and Temple, *Shades of Gray*, 504–6.

36. SAMSO, *History of Space and Missile Systems Organization, 1 January–31 December 1978,* 100–103; SAMSO, *History of Space and Missile Systems Organization, 1 January–31 September 1979,* 67–69; and SD, *History of Space Division, 1 October 1980–30 September 1981*, 113.

37. As Col Richard W. McKinney, USAF, retired, recalled, "I was the project officer in the Pentagon in the late 1980s to try to convince NASA that implementing a liquid fueled upper stage on the Shuttle posed unsupportable safety risks. The main

issue came if there was an abort or a return to landing for a shuttle launch. One scenario was the Centaur had to dump its fuel prior to landing. Putting highly flammable (hydrogen) overboard while the shuttle was trying to make an emergency landing proved to be too big of a hurdle to overcome. The Centaur version we were working with was Centaur G' (G-Prime)." McKinney, "Manuscript Review Comments," 24 January 2020; Dunn, "Evolution of the Inertial Upper Stage," 38–42; SD, *History of Space Division, 1 October 1979–30 September 1980*, 76–80; SD, *History of Space Division, 1 October 1980–30 September 1981*, 104–15; SD, *History of Space Division, 1 October 1982–30 September 1983*, 68–72; Ulsamer, "Space Shuttle Mired in Bureaucratic Feud," 72–77; ADCOM/NORAD, "Liquid Upper Stage (Centaur)"; and Mirth, interview.

38. SAMSO, *History of Space and Missile Systems Organization, January–31 December 1977*, 107; SAMSO, *History of Space and Missile Systems Organization, 1 January–31 December 1978*, 100–103; and SD, *History of Space Division, 1 October 1980–30 September 1981*, 138.

39. Mirth, interview; Mirth, email, 19 March 2019; SD, *History of Space Division, 1 October 1980–30 September 1981*, 105–13, 140–41.

40. Mirth, interview; Mirth, email, 27 March 2019; and Williamson, "Developing the Space Shuttle," 179.

41. SAMSO, *History of Space and Missile Systems Organization, 1 January–31 December 1978,* 116–18; SAMSO, *History of Space and Missile Systems Organization, 1 January–30 September 1979,* 93–95; and SD, *History of Space Division, 1 October 1980–30 September 1981*, 141–46.

42. SAMSO, *History of Space and Missile Systems Organization, 1 July 1972–30 June 1973*, 29, 69–73; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1973–30 June 1975*, 48. See table 2 in appendix B for the ELV family.

43. SAMSO, "DoD Space Launch Vehicle Management Plan, FY 1975–1985," 4-13, 5-1; and Jenkins, "Broken in Midstride," 365.

44. SAMSO, "DOD Space Launch Vehicle Management Plan, FY 1975–1985," 2-8 to 2-9; and Temple, "Committing to the Shuttle Without Ever Having a National Policy," 40.

45. SAMSO, "DOD Space Launch Vehicle Management Plan, FY 1975–1985," 2-7 to 2-9; and SAMSO (LVR), "SAMSO Historical Reports, 1 July–31 December 1971," 24 January 1972.

46. Delta and Saturn flights are not included in these figures. *TRW Space Log*, 151–246; McDowell, "Satellite Catalog," accessed 8 September 2018.

47. SAMSO, "DoD Space Launch Vehicle Management Plan, FY 1975–1985," 4-13, 5-1; Jenkins, "Broken in Midstride," 365; McDowell, "US Reconnaissance Programs," Part 1, 22–33; and McDowell, "US Reconnaissance Programs," Part 2, 40–45.

48. SAMSO, "DoD Space Launch Vehicle Management Plan, FY 1975–1985," 4-13, 5-1; and Jenkins, "Broken in Midstride," 365. See David, *Spies and Shuttles*, 245, for a description of the national security's interest in the satellite's Synthetic Aperture Radar.

49. SAMSO, "DoD Space Launch Vehicle Management Plan, FY 1975–1985," 4-13, 5-1; Jenkins, "Broken in Midstride," 365; and Air Force Systems Command (AFSC), "Ad Hoc Study Group on Space Launch Vehicles," 20–25.

50. *TRW Space Log*, 151–246; McDowell, "Satellite Catalog," accessed 8 September 2018.

51. *TRW Space Log*, 151–246; McDowell, "Satellite Catalog," accessed 8 September 2018; and AFSC, "Ad Hoc Study Group on Space Launch Vehicles," 21–25.

52. AFSC, "Ad Hoc Study Group on Space Launch Vehicles," 21-25; and Watkins, interview, 31 March 2017.

53. AFSC, "Ad Hoc Study Group on Space Launch Vehicles," 25, 29.

54. AFSC, 47, 66–67.

55. AFSC, 45, 51, 81, 83.

56. AFSC, 88–98; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1975–December 1976*, 93–95.

57. AFSC, “Ad Hoc Study Group on Space Launch Vehicles,” 71–75.

58. AFSC, 100–101; James to Hill, letter; Morgan to James, Commander, letter; James to Morgan, letter; SAMSO, *History of Space and Missile Systems Organization, 1 January–31 December 1977*, 50–53; SAMSO, *History of Space and Missile Systems Organization, 1 January-31–December 1978*, 58–60; SAMSO, *History of Space and Missile Systems Organization, 1 January–31 September 1979*, 57–58; McDowell, “Satellite Catalog,” accessed 8 September 2018; and SAMSO, *History of Space and Missile Systems Organization, 1 July 1975–December 1976*, 93–95. The major command was replaced by a direct reporting unit, the Aerospace Defense Center. ADCOM, the specified command that served as the US component of NORAD, remained until 16 December 1986. At that time it was inactivated and replaced by US Element NORAD. See Spires, *Beyond Horizons*, 195–96.

59. Watkins, interviews; and Watkins, “Launch Operations Data List.”

60. Coglitore, email, 7 February 2017. See an expanded biography of Brig Gen Sebastian F. “Seb” Coglitore in appendix A.

61. Coglitore, email; Taverney, email, 14 February 2017; Center for the Study of National Reconnaissance, “Gambit 3 (KH-8) Fact Sheet”; Center for the Study of National Reconnaissance, “Hexagon (KH-9) Fact Sheet”; and Taubman, *Secret Empire: Eisenhower, the CIA, and the Hidden Story of America’s Space Espionage*, 366. Taubman’s interesting comments on the KH-11 Hexagon are not referenced. Richelson, *America’s Secret Eyes in Space*, 105–8.

62. Coglitore, email, 7 March 2017; and Taverney, email, 15 February 2017, 17 February 2017.

63. Colonel Whitehead and Col Thomas E. Maultsby, who served as Assistant for Space Policy in OSD during the 1980s, agreed with Coglitore’s assessment of working relationships with NASA’s senior officials and its people at the operational level. Coglitore, email, 7 February 2017, 11 April 2019; Whitehead, email, 18 March 2019; Maultsby, email, 11 March 2019; and Maultsby, interview, 27 March 2019.

64. Spires, *Beyond Horizons*, 223–24; GAO Report, *Issues Concerning the Future Operation of the Space Transportation System*, GAO/MASAD-83-6, 28 December 1982, I, iii, 3,12; Whitehead, “The Complementary Expendable Launch Vehicle,” 1.

65. Coglitore, email, 7 February 2017; Taverney, email, 14 February 2017; Center for the Study of National Reconnaissance, “Gambit 3 (KH-8) Fact Sheet”; Center for the Study of National Reconnaissance, “Hexagon (KH-9) Fact Sheet”; and Taubman, *Secret Empire: Eisenhower, the CIA, and the Hidden Story of America’s Space Espionage*, 366. The 1977 total of 487 flights is for a 12-year period, whereas earlier, in 1972, NASA projected 445 flights for 11 years. See David, *Spies and Shuttles*, 196; Neufeld, *The Air Force in Space, 1970–1974*, 9–10; SAMSO, *History of Space and Missile Systems Organization, 1 July 1972–30 June 1973*, 201–6; and Jenkins, “Broken in Midstride,” 374–76. Jenkins asserts, “Nobody had ever believed the extremely high flight rates portrayed in many of the early mission models but, in the months before the *Challenger* accident, NASA was still expecting to ramp up to 24 missions per year.” Jenkins, *Space Shuttle*, III-97. Jenkins also provides details on NASA’s rising shuttle costs. See Jenkins, *Space Shuttle*, III-111 to III-112. NASA’s predictive flight schedules pre-*Challenger* did not normally distinguish between DOD military and NRO intelligence flights. Before the shuttle tragedy, the schedule projections also did not identify specific missions that would include payloads of the Strategic Defense

Initiative (SDI), proposed by President Ronald Reagan on 23 March 1983 to provide defense against ballistic missiles. In March 1984 DOD established the Strategic Defense Initiative Organization (SDIO) and appointed as its first director Lt Gen James Abrahamson, the experienced former NASA manager of the space shuttle program. As for future flight schedules, a NASA manifest circa 19 June 1985, for example, lists 38 missions from 17 July 1985 to 4 November 1987, only seven of which are DOD missions; none are shown dedicated to SDI primary or secondary experimental payloads. Nevertheless, the SDIO had already had one of its payloads flown on the shuttle. The manifest for *Discovery*'s 17 June 1985 mission included testing the SDI High Precision Tracking Experiment (HPTE) to determine whether a ground-based laser could remain pointed on a target in space. On flight day three, two mistakes in the crew activity plan initially put the orbiter in an incorrect position. The crew retested on day five, and this time the low-power laser based in Hawaii hit and reflected off the HPTE 8-inch-diameter mirror, successfully transmitting television images of the laser beam to ground control. Prior to the *Challenger* accident, on 28 January 1986, the SDIO intended to evaluate its SDI technologies for space-based defensive weapons on shuttle flights twice yearly beginning in 1987. Following *Challenger*, however, the SDIO, following DOD's example, decided to turn to ELVs rather than the shuttle for most missions while, at the same time, pursuing the feasibility of developing a heavy lift expendable launcher for future requirements. Available evidence indicates that none of the eight DOD payloads flown by the shuttle between 2 December 1988 and 2 December 1992 included SDI experiments. Jenkins, *Space Shuttle*, III-62, III-113; David, *Spies and Shuttles*, 240–43; Canan, "Coming Back in Space"; Rensberger, "Space Shuttle to Be Used in 'Star Wars' Laser Test"; Strategic Defense Initiative, "Lieutenant General James A. Abrahamson, USAF"; Broad, "Reverberations of the Space Crisis: A Troubled Future for 'Star Wars' "; and McDowell, "Satellite Catalog," accessed 16 April 2021.

66. USSPACECOM/J5SX, "Mixed Fleet"; Aldridge, "Address to the National Space Club, 18 November 1981"; and "NASA Shouldn't Operate Shuttle, AF Undersecretary Says," 105. Aldridge noted that new presidential science advisor Dr. George "Jay" Keyworth had studied the need for a mixed-fleet concept; David, *Spies and Shuttles*, 226. See an expanded biography of Edward C. "Pete" Aldridge Jr. in appendix A.

67. Day, "Black Ops and the Shuttle," 1–4; and Taverney, email, 27 February 2017, 22 April 2019. See an expanded biography of Maj Gen Thomas D. "Tav" Taverney in appendix A.

68. Day, "Black Ops and the Shuttle," 3–12. With Undersecretary of the Air Force Hans Mark so determined to have all satellites launched on the shuttle, it is not entirely clear why he authorized the final four Hexagon satellites to be launched atop the Titan if they were not in production until the early 1980s. Also, the Air Force faced huge costs in redesigning and reintegrating payloads originally designed for the Titan IIID, then for the shuttle, and then back to the Titan; McDowell, "US Reconnaissance Programs," Part 1, 22–33; and McDowell, "US Reconnaissance Programs," part 2, 40–45.

69. Spires, *Beyond Horizons*, 225; and Whitehead, "The Complementary Expendable Launch Vehicle," 1–2. For Lieutenant General Henry's letter to General Marsh, see Spires, *Orbital Futures*, vol. 2, 891–94; and David, *Spies and Shuttles*, 224.

70. Spires, *Beyond Horizons*, 226; Logsdon and Reed, "Commercialization Space Transportation," 406–13; Temple, "Committing to the Shuttle Without Ever Having a National Policy," 46–47; Space Division, *History of Space Division, 1 October 1982–30 September 1983*, 61–62; and Jenkins, *Space Shuttle*, III-111 to III-112.

71. Spires, *Beyond Horizons*, 182–83; Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 5; Coglitore, email, 7 February 2017; Whitehead, email, 18 March 2017; Mirth, email, 27 March 2017; Temple, "Committing to the Shuttle," 43–45; and Temple, *Shades of Gray*, 507–8. Temple asserts that "the shuttle represented an actual [cost] increase of more than an order of magnitude."

72. Compared to the shuttle's capability of flying payloads of 60,600 pounds and 8,400 pounds to LEO and GTO, respectively, the Titan 34D's comparable figures are 32,000 pounds and 11,000 pounds, respectively. The Atlas II would have the capability of launching 14,5000 pounds to a 100-nautical mile easterly orbit, and 6,100 pounds into a geosynchronous transfer orbit; David, *Spies and Shuttles*, 226–29; and Jenkins, *Space Shuttle*, II-541, II-454.

73. Whitehead, email, 18 March 2019; see also his briefing in response to Secretary Aldridge's request to reassess the use of Titan II as a space booster: "Use of the Titan II as Space Launch Vehicle"; Space Division, *History of Space Division, 1 October 1983–30 September 1984*, 88–95; AFSPACECOM/XPSS, "Space Transportation System"; and David, *Spies and Shuttles*, 219. See an expanded biography of Col Victor W. Whitehead in appendix A.

74. Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 5–6; and Spires, *Beyond Horizons*, 225–26. For Secretary Weinberger's memorandum, see Spires, *Orbital Futures*, vol II, 737, 894–97; and Jenkins, *Space Shuttle*, III-111 to III-112.

75. Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 6–12. For Secretary Aldridge's memorandum to Secretary Weinberger, see Spires, *Orbital Futures*, vol. 2, 737, 897–99; Space Division, *History of Space Division, 1 October 1983–30 September 1984*, 91–93; Space Division, *History of Space Division, 1 October 1984–30 September 1985*, 98–103; and Jenkins, *Space Shuttle*, III-111 to III-112.

76. Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 11–12; Whitehead, email, 18 March 2019; Space Division, *History of Space Division, 1 October 1984–30 September 1985*, 98–103; Space Division, *History of Space Division, 1 October 1983–30 September 1984*, 93–95. Initially, when the Air Force had proposed to fund the CELV with commercial resources, the proposed vehicle was termed the commercial expendable launch vehicle. Abandoning commercial funding, DOD now referred to the CELV as the complementary expendable launch vehicle "to underscore its benign relationship to the Space Shuttle." David, *Spies and Shuttles*, 228.

77. Maultsby, email, 11 March 2019; and Maultsby, interview. NASA Administrator James Beggs had sought Weinberger's support for NASA's prospective space station project. The secretary declined, arguing that it provided no national security benefits and funding a space station would divert NASA from its primary focus, the shuttle, which at this time still had the Department of Defense's firm commitment. See Spires, *Orbital Futures*, vol. 2, 737.

78. Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 12–15; For the document, NSDD 164, see Spires, *Orbital Futures*, vol. 2, 899–900; Spires, *Beyond Horizons*, 227; Space Division, *History of Space Division, 1 October 1983–30 September 1984*, 91–93; and Space Division, *History of Space Division, 1 October 1984–30 September 1985*, 106–7. The ALS and other proposed systems would founder on the inability to resolve Air Force and NASA requirements, as NASA always had a much larger lift requirement than the Air Force. Jenkins, *Space Shuttle*, III-112.

79. Aldridge, "Assured Access: 'The Bureaucratic Space War,' " 11–12; Whitehead, email, 18 March 2019; Space Division, *History of Space Division, 1 October 1984–30 September 1985*, 98–103; Space Division, *History of Space Division, 1 October 1983–30 September 1984*, 93–95; and David, *Spies and Shuttles*, 228.

Chapter 6

Tragedy and Response

The *Challenger* and the Road to the New Century, 1986–1999

NASA had expected a triumphant but routine mission of the orbiter *Challenger*, on 28 January 1986, in celebration of the space shuttle's twenty-fifth flight. Initiating use of the nation's second shuttle pad at the Kennedy Space Center, Mission 51-L was to launch the "first teacher in space," Christa McAuliffe; perform unprecedented observations of Halley's Comet; and deploy one of the space agency's Tracking and Data Relay System satellites. After cold weather delayed the flight for several days, the *Challenger* rose from its launch site that January day at 11:39 a.m. eastern standard time. Just 73 seconds after liftoff, a massive explosion destroyed the spacecraft, killing all seven crew members and plunging the nation's space program into the greatest crisis in its young history.[1]

While the nation justifiably focused on the *Challenger* tragedy, military space officials had additional worries. In early 1986, the Air Force had only begun to recover from the failure, in August 1985, of its Titan 34D rocket with a KH-9 Hexagon payload, which had to be destroyed when one of its engines shut down after liftoff and the rocket veered off course. Then, in April 1986, another Titan 34D, carrying the final KH-9 Hexagon satellite, exploded over its launchpad at Vandenberg, and in May NASA lost a Delta rocket. After those launch vehicle failures, space leaders effectively grounded the space program by prohibiting further flights of the shuttle and ELVs until the problems could be solved. The nation confronted an ailing space industry and a space program in disarray. President Reagan appointed a commission chaired by former Secretary of State William P. Rogers to investigate the *Challenger* accident. Among other findings, the commission's exhaustive report, issued on 6 June 1986, concluded that defective seals between two solid rocket motor sections sparked the chain of events that produced the explosion. NASA had much work to do before confidence in manned spaceflight could be restored.[2]

Without an assured heavy-lift launch capability, the military space program also found itself in crisis. The shuttle had been designated the primary launch vehicle for all future Defense Department payloads, and the Titan 34Ds had been scheduled only until the shuttle achieved its full flight schedule in the late 1980s. The Air Force expected to run out of expendable boosters sometime in 1988. Payloads previously manifested for the shuttle would remain in storage rather than replenish aging satellite constellations. There, while expensive investigations continued, they would generate a high cost while officials worried about potential atrophy and projected booster replacements.[3]

The *Challenger* accident proved to be a watershed in the nation's space program. The moratorium on shuttle flights, which extended for 31 months, forced civilian and military leaders to investigate both the future of space launch and the nation's entire space program. During the hiatus, Air Force officials led the way in reassessing the military space program. By the time the shuttle resumed operations on 29 September 1988, the DOD's relationship with NASA had been transformed and the Air Force had immersed itself in a searching self-examination of its commitment to space.

Reestablishing Space Launch Capabilities

During the moratorium on shuttle flights, NASA conducted political damage control and turned to the military for assistance. As part of its recovery plan, NASA appointed Adm Richard H. Truly as associate administrator for space flight and Space Division commander Lt Gen Forrest S. McCartney as director of the Kennedy Space Center and also sought advice from its former deputy director of the Apollo program, Gen Samuel C. Phillips. Not only did NASA specifically request help in a variety of areas, but it also agreed that military missions should take precedence on future space shuttle flights. NASA now endorsed a temporary mixed-fleet space launch policy and accepted the administration's decision to terminate its commercial launch endeavor, thereby opening the door to a resurgence of the expendable launch vehicle business.[4]

Moreover, when the Rogers Commission report appeared in June 1986, it advocated a space shuttle with lower weight and payload capabilities resulting from the addition of a redesigned joint on the solid rocket boosters and a launch abort and crew escape mechanism. It also proposed a conservative launch schedule to avoid "relentless pressure on NASA to increase the flight rate." The Air Force interpreted this as more reason to focus on dependable unmanned boosters and worked to find launch vehicles for its delayed inventory of satellites. As the shuttle launch schedule showed increasingly lengthy delays, the Air Force estimated that as many as 25 payloads would be affected and that the launch backload could not be overcome before 1992. As the situation unfolded, satellites currently in orbit would help by functioning well beyond their original design lifetimes. Nevertheless, the launch delay created a major challenge that would leave nearly a three-year gap without alternative launchers and would raise important questions about the future of the nation's space industrial base.[5]

Most seriously affected were the operational GPS satellite constellation, the early warning Defense Support Program, and the satellites controlled by the National Reconnaissance Office. DOD planners had programmed these payloads exclusively for shuttle launches and now needed them reconfigured for ELV compatibility. Others, too, would suffer from launch delays and the associated "ripple" effect. The Air Force moved swiftly to reinforce its expendable launch arsenal as part of its launch recovery program.

Before the *Challenger* accident, the Air Force mixed-fleet strategy had called for procuring 10 complementary expendable launch vehicles and 13 Titan IIs; flying the remaining Atlas E/Fs, Gs, and Hs and the Titan IIIBs; and building and flying the final contingent of Titan 34Ds. In the wake of the shuttle's diminished operational capabilities, the Air Force not only decided to fly the current ELVs but recommended, in July 1986, procuring an additional 13 Titan CELVs (renamed Titan IV on 25 July) and 12 new medium launch vehicles, Delta IIs, for GPS flights that would resume in 1989, two years behind schedule. Later, a second medium launch vehicle, the Atlas II, would be acquired to launch Defense Satellite Communications System satellites. The Air Force expected to launch Defense Meteorological Satellite Program payloads on Titan IIs and DSP satellites and the future Military Strategic and Tactical Relay System (Milstar) satellites on Titan IVs.[6]

The Air Force's decision to focus on expendable launch vehicles seemed more credible when NASA announced in May 1987 that shuttle flights would resume in June rather than February of 1988 and would be limited to 14 instead of 24 per year. Moreover, only lighter payloads would be flown, all of which meant fewer shuttle flights for the military. Acting Secretary of the Air Force Aldridge responded by calling for an additional 25 Titan IVs (adding to the 23 already approved by Congress), Titan IV launchpads, and 5 to 10 more Delta II medium-launch vehicles. Aldridge also defended his new space launch budget that would be doubled by the early 1990s. Although military missions would receive priority once the shuttle resumed flying, 18 of 36 payloads previously manifested for the shuttle would be reprogrammed for expendable launchers. After 1992, however, the Defense Department planned to use the shuttle only for Space Defense Initiative or Space Test Program (STP) research and development missions. In effect, the Air Force would abandon the standardized shuttle, the "airliner to space," for the diversification represented by expendable boosters. At the same time, although no one wanted to resort to business as usual and to the practice of linking specific satellites to particular launch vehicles, this practice seemed unavoidable for the four new ELVs. Even so, emphasis now would be on developing an "assured launch strategy" highlighted by lower costs and greater launch responsiveness.[7]

Developing the "New" Heritage ELV Fleet

While flying out the current inventory, the Air Force's Space Division supervised the development of four new expendables that were key to the success of the recovery effort. The Titan II and CELV/Titan IV programs had been initiated prior to *Challenger*, while the Delta II and Atlas II followed in its wake in response to the temporary shutdown of shuttle flights.[8]

Titan II. At Aldridge's direction, Col Victor W. Whitehead, Space Division's ELV Program director, had assessed the feasibility of using deactivated Titan II ICBMs as small to medium launch boosters in 1984. This led to a letter contract with Martin Marietta, signed on 6 January 1986 (and the "definitized" contract signed on 12 August), for 13 refurbished vehicles that would be earmarked for DMSP launches. Officially designated Titan II23G, the refurbished two-stage, liquid propellant rocket measured 70.7 feet in length and 10 feet in diameter. Launched only from Vandenberg, the Titan II could loft 4,200 pounds to a 100 nm polar orbit at an average cost per launch of $43 million (in 1986 dollars).[9]

Converting the Titan II to a space booster required adding payload fairings, adapter rings for mating payloads or upper stage adapters, and appropriate adjustments to the forward skirts. A remanufactured stage 2 oxidizer tank provided greater capacity, while an equipment truss secured telemetry and destruct systems and engineers installed umbilical connectors, electrical cables, and radio guidance equipment. Additional modifications included replacing the first stage engine rotor, applying a metal band to the stage II engine's corset to protect it against high loads, and a number of component upgrades to the propulsion system to address stress corrosion and improve reliability.[10]

Especially challenging for the program office was the difficulty of acquiring payloads, as it seemed that "no users were clamoring for the Titan II program's assets." NOAA had reduced its original requirement of four TIROS launches to one, while the Strategic Defense Initiative Office cancelled an experimental satellite commitment even after the Titan II program office agreed to use eight strap-on solid rocket motors for additional thrust.[11]

Originally scheduled for its initial flight on 1 April 1988, the Titan Initial Launch Capability (ILC) was postponed five months largely due to second stage guidance system problems. Launched from Vandenberg's SLC-4W, the Titan II first flew on 5 September 1988 with a classified electronic intelligence satellite, codenamed "Bernie." Although initially designated for DMSP launches, ironically, the Titan II continued to launch two more Bernie satellites and a Landsat Earth observation satellite before its initial DMSP mission in 1997. Air Force planners preferred to fly the DMSP satellites on the remaining Atlas E/F boosters because they were more cost effective and required less processing time.[12]

Titan IV. After *Challenger*, Titan IV, the largest and most powerful ELV since the Saturn family, moved from shuttle backup to mainstay of the nation's heavy-lift launch capability. In February 1985, Martin Marietta signed the initial CELV contract that remained in place after the vehicle was renamed Titan IV on 25 July 1986. Ultimately, the Air Force would procure 41 Titan IVs primarily to launch its DSP and Milstar satellites and the NRO's KH-12 Crystal payloads. Compared to the Titan 34D, the Titan IV (B) stood just four feet taller at 119.5 feet. Its strap-on solid motors were much longer (seven segments at 112.9 feet compared to five and a half segments measuring 90.4 feet), and its payload fairing was considerably wider (16.7 feet in diameter compared to 9.5 feet in diameter). The Alliant three-segment solid rocket motor upgrade (SRMU) gave it a 25 percent performance increase compared with the Titan IVA and its Chemical Systems Division seven-segment motors.[13]

The Air Force flew three different configurations of the Titan IV. From the Eastern Test Range Launch Complex 41 (later LC-40 as well), the Titan IV with no upper stage (NUS) could place 39,110 pounds (later upgraded to 49,000 pounds) into a LEO. The booster could loft 5,200 pounds into geosynchronous orbit using the IUS, and 10,000 pounds into GEO with the Centaur G-Prime. Once the Titan-Centaur used the more powerful motors produced by the SRMU program, it could place 12,700 pounds into GEO. After the last of four commercial Titan III flights on 25 September 1992, with NASA's Mars Observer payload, the Air Force would reconfigure LC-40 for Titan IV-NUS and Titan IV-Centaur launches while continuing to use LC-41 primarily for Titan IV-IUS missions. Considerably more expensive to fly than the other ELVs, the DOD Titan IV costs per launch (in FY 1986 dollars) were $142 million for the Titan IV-NUS, $191 million for the Titan IV-IUS, and $211 million for the Titan IV-Centaur.[14]

At the Western Test Range, the Air Force used SLC-4E to fly the Titan IV-NUS configuration that proved capable of lofting 31,100 pounds into a 100-nm polar orbit. To support the strategy of assured access to space, the Air Force proposed constructing a new, second Titan IV launch site at Vandenberg referred to as SLC-7. Congress, however, initially preferred modifying the shuttle-configured SLC-6 but then cancelled the second site option altogether, given the late 1980s climate of budget austerity and reduced launch rate. While SLC-4 would support both Titan II and Titan IV launches on separate pads, the launch control function would take place from the new remote launch control center 13 miles away in Building 8510 on North Vandenberg. An explosion during the Titan III 34D launch in April 1986 and ongoing concerns about safety led to abandoning the common blockhouse at the launch site.[15]

Initially, the Titan program office expected the Titan IV to achieve its ILC by the fall of 1988, but a variety of issues compelled schedulers to postpone the initial launch from the Cape until June 1989. Significant delays occurred after a Titan 34D failure in April 1986 when the solid rocket motor experienced a burn through and the vehicle exploded eight seconds after liftoff, and problems affecting the solid rocket motor program continued to contribute to schedule rollbacks. Additionally, a number of facility construction delays resulted when the program office realized that the launch base infrastructure at the Cape could not support the ambitious Titan IV manifest.[16]

The challenge of integrating diverse payloads also became a significant factor. Looking back on his experience as Titan IV program director, Coglitore recalled that "one area that we put a great deal of effort into was payload integration. . . . We had over 20 different spacecraft that were in various stages of integration planning . . . in those early days." Each Titan IV booster was to be custom fitted to the particular satellite for each of the programmed 41 launches. Complaints of integration complexity, cost, and limited flexibility when required to substitute missions prompted efforts to create a standardization booster modification kit. This proved difficult, because the payload fairing segments were too large to install in an off-pad facility. As a result, payload technicians integrated the payload to the rocket first at the pad, then installed the fairing around it. As retired Air Force Col John Stizza noted, "Some missions required months of processing on the pad so the payload could be assembled, integrated, tested, fueled and launched . . . [and] . . . if any hiccups occurred during this series, delays would mount." Although developing a standard booster-payload adapter would become a key recommendation in every space launch assessment during the post-*Challenger* recovery period, not until the arrival of the evolved expendable launch vehicles (EELV) fleet would a common interface become a reality.[17]

Finally, on 14 June 1989, the maiden flight of the Titan IV-IUS from the Cape successfully placed a DSP satellite into geosynchronous orbit, followed by the first Titan IV-NUS mission with a classified Naval Ocean Surveillance System signals intelligence satellite payload on 8 June 1990. It would be 1994, however, before the Titan IV-Centaur would overcome problems with the upper stage and first fly from the Cape. The maiden flight of the Titan IV/NUS from Vandenberg, with a Lacrosse radar imaging reconnaissance satellite, took place in March 1992, as numerous technical and logistical problems would continue to plague the Titan program's launch schedule.[18]

Delta II. The Delta II was the only new launch vehicle program that resulted directly from *Challenger*. After the accident, the Air Force required a new medium booster to launch the heavier GPS satellites that had been manifested for the shuttle. After McDonnell Douglas Aerospace Corporation (MDAC) won a medium launch vehicle I (MLV-I) competition in 1986, Colonel Whitehead, acting at Aldridge's direction, called MDAC's president, Sanford N. McDonnell, and "asked if they would like to rename the MLV-1 the Delta II . . . [and] . . . the president readily agreed." A key factor in the Delta II's selection was its viability as the right class of launcher for commercial payloads. The 21 January 1987 contract called for seven vehicles initially, with an option for 13 more, which the Air Force would exercise.[19]

Fig. 16. The Titan IVA/Interim Upper Stage 402A (K-1) with Defense Support Program satellite, launching from LC-41, 14 June 1989. (Photo courtesy of John Hilliard)

The Delta II came in two versions. The Delta II 6925 model measured 125 feet in height compared to 113 feet for the Delta I and used a wider 9.3-foot fairing rather than the Delta I's 8-foot fairing. With nine strap-on Castor IVA SRMs, this model could launch the 1,850-pound GPS II satellites into their operational orbit of 10,898 nm at 55 degrees inclination. The more capable Delta II 7925 version also stood 125 feet tall but used the lighter, more powerful graphite-epoxy motors and its upgraded RS-27A engine to loft the heavier, 2,100-pound GPS IIA satellites.[20]

MDAC developed the Delta II under the new "turn-key" contract procedure, whereby the contractor produced and launched the vehicle and the Air Force took acceptance on orbit. In short, the contractor delivered a launch service rather a government-owned vehicle.

Having the contractor provide a launch service would become common practice in the new century. As with the Titan vehicles, the Delta II failed to meet its initial IOC date of October 1988, in this case due to the slow start up of the production lines and a delayed transfer of the Cape's Launch Complex 17A and 17B resulting from NASA's final Delta missions for the SDIO. Rescheduled first for 8 December 1988, the initial Delta II 6925 launched from Vandenberg's SLC-2 with its GPS payload on 14 January 1989. The Delta II 6925 would fly the last of nine GPS satellites successfully on 30 October 1990 before Delta II 7925 became operational. The Delta II led the recovery of launch in 1988–1989 with three successful missions. At a relatively low cost of $40 million per flight, the Delta II would also become the most dependable of the new ELVs and the only one capable of providing a launch-on-need capability.[21]

Atlas II. The Atlas II represented the final link in the post-*Challenger* ELV launch recovery program. Previously, the Air Force had flown DSCS satellites in pairs on the Titan IIIC but now had decided to separate them into one per launch. As Colonel Whitehead explained, "This made more sense from a replenishment view and also provided the right performance requirements to orbit." This led to a second medium launch vehicle competition, won by General Dynamics Corporation. On 16 June 1988, that company received a contract to produce an initial complement of nine vehicles for an Atlas II fleet that eventually would increase to 62 launch vehicles. Although earmarked to launch DSCS satellites and STP payloads, the Atlas II would also launch the Navy's ultra high-frequency (UHF) satellites and SDI missions from Cape Canaveral and classified payloads from Vandenberg. Like MDAC with Delta, General Dynamics also focused on the commercial market and designed two commercial versions, the Atlas IIA, with an upgraded RL-10 engine, and the Atlas IIAS, with four Castor IVA SRMs added to the booster stage.[22]

The Atlas II was essentially an upgraded version of the Atlas-Centaur family. Compared to the commercial Atlas-Centaur (designated Atlas I), the new model extended the booster by 9 feet and the Centaur by 3 feet, increasing the total length to 156 feet. Among the new features, an improved MA-5A engine replaced the M5 engine; a roll control module fueled by hydrazine supplanted the vernier engines; and a thick layer of foam instead of fiberglass insulated the Centaur's tanks of cryogenic propellants. The Atlas II proved capable of launching 14,500 pounds to a 100 nm easterly orbit and 6,100 pounds to a geosynchronous transfer orbit from the Cape. Although initially projected to cost $45 million per flight, actual Atlas II flights, in fact, rose to nearly twice that figure.[23]

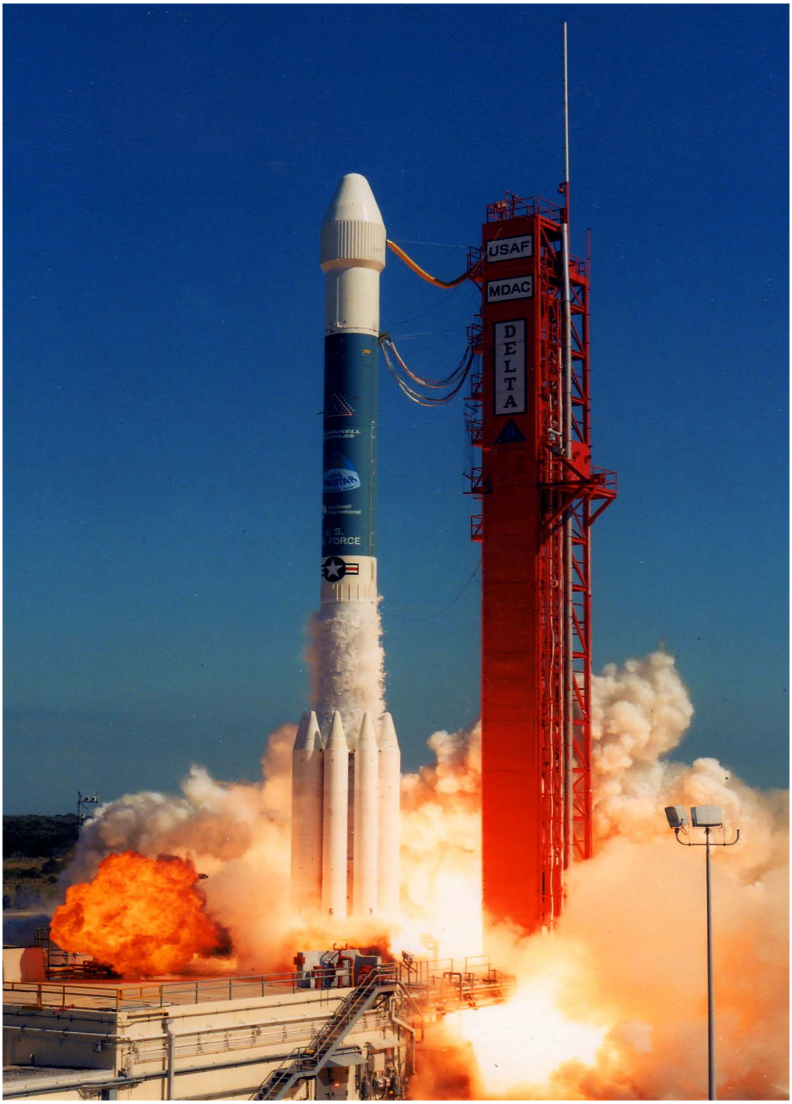


Fig. 17. Delta II 6925, D-184, with Global Positioning System (GPS) 14, launches from LC-17A, 14 February 1989. (Photo courtesy of John Hilliard)

Although the Atlas II development program also reflected the new "turn-key" approach, the Air Force considered it less successful than the Delta II program. Under its firm-fixed-price contract, General Dynamics was to provide all services to support the test, integration, and successful launch of the vehicle. It would apply a commercial launch service acquisition philosophy characterized, for example, by contractor-tailored quality provisions and reduced government oversight. To achieve its objectives, the company planned to take advantage of technology transfer from the ALS with a Preplanned Product Improvement (P3I) program, which was expected to reduce costs by minimizing so-called non-value overhead work by 30 percent. The Air Force Atlas II program office soon became concerned about the contractor's level of test and analysis and sought to alter the contract by including additional insight into the contractor's actions and more government control over launch processing. By the time of the first commercial Atlas II launch of a European telecommunications satellite on 7 December 1991, the Space and Missile Systems Center program managers had still not resolved all their differences with General Dynamics.[24]

A more positive development involved the innovative action of the Atlas II program office to define and produce a standard medium launch vehicle interface. The office involved all three major launch vehicle contractors in a joint study to achieve a common mechanical and electrical interface capability. Although the Space Systems Division historian asserted that the effort would succeed in producing a standard interface design for the Titan II, Delta II, and Atlas II, future developments proved this unnecessary for reasons of payload class and designated payload-booster combinations. Because payload size and class determined the rocket required, most missions flew on designated boosters that were optimized to place that size of satellite in the appropriate orbit.[25]

The initial DOD Atlas II launch had been scheduled for January 1991, but issues surrounding the inertial navigation unit, vehicle production start-up, site activation construction and repair at SLC-36A, and damage to the Centaur during testing contributed to an IOC delay of over a year. Finally, on 11 February 1992, Atlas-Centaur 101 launched from LC-36A during the last minute of the launch window and placed DSCS IIIB-14 into its correct geosynchronous transfer orbit. The Atlas II would launch seven more DSCS satellites in the course of compiling its impressive 100 percent successful launch record. With the IOC of the Atlas II, the Air Force had completed the ELV phase of the post-*Challenger* launch recovery program.[26]

Fig. 18. Atlas II, AC-101, carrying Defense Satellite Communications System (DSCS) 3, launches from LC-36A, 11 February 1992. (Photo courtesy of John Hilliard)

Advanced Launch System Program

While Congress fully supported the DOD–Air Force launch recovery program to expand and improve its expendable launch arsenal, it also endorsed planning for a more capable future space launch force under the aegis of the ALS program. Even before the *Challenger* accident, DOD and Air Force planners had begun to address future space launch requirements that centered on the requirement for a heavy-lift launch vehicle (HLLV or HLV; HLV used here except in quoted text) largely driven by the emerging requirements of the Strategic Defense Initiative Organization. National Security Decision Directive 261, signed by President Reagan on 25 February 1985, directed DOD and NASA to conduct a study of a future space transportation system that used both manned and unmanned launchers. The result of their efforts was a set of contractor studies, collectively referred to as the Space Transportation Architecture Study (STAS), that showed Air Force payload requirements in the late 1990s would exceed the capabilities of current and planned boosters—even the heavy-lift Titan IV. Both NASA and the SDIO, however, would need a heavy-lift booster capability in the early 1990s, when NASA expected to launch its space station components for on-orbit assembly and the SDIO intended to launch vast tonnages per year to deploy its space-based defense against ballistic missiles.[27]

In late December 1986, the Air Staff directed Air Force Systems Command and its Space Division to establish a development program for a heavy-lift cargo vehicle capable of launching 150,000 pounds into LEO. The initiative called for a near term ILC of approximately 400,000 pounds annually into LEO in 1992 or 1993 and a longer six-year development phase that would produce a vehicle capable of launching 5 million pounds per year in the late 1990s. Such a vehicle, some of the Air Staff argued, would "lower the cost per pound to LEO by a factor of ten compared to the Titan IV." Planners were to take advantage of ongoing STAS technology developments, especially launch and logistics improvements, and to "meet the assured access needs of all DoD users."[28]

In March of 1987, Secretary of the Air Force Aldridge expressed his support of acquiring the HLV in testimony to Congress that reflected widespread agreement in the space community on the need for a heavy-lift booster as the centerpiece of the program now referred to as the ALS. Even so, Air Force Space Command (or hereafter AFSPC) leaders questioned the appropriateness of the system given their concern, as expressed by Deputy Chief of Staff for Plans Maj Gen G. Wesley Clark, that "the HLLV program could possibly undermine initiatives seeking to decrease the size, weight, and complexity of satellites." He worried that the HLV might scuttle the command's plans for smaller boosters to provide "assured access to space" because payload developers tend to build heavier systems that would take full advantage of a more powerful booster. "We must ensure," he said, "that the HLV development will complement the AF need for flexible, responsive launch systems." Secretary Aldridge soon became concerned when NASA preferred Shuttle-C (Cargo), a "Shuttle-Derived Vehicle" based on shuttle components. Although this booster could be developed easily and rapidly, he believed it could not meet the goal of reducing the HLV payload cost per pound to orbit from $3,000 to $300.[29]

By the end of the year, considerable disagreement over the goals of the ALS had become apparent. The Air Force now favored gradual implementation of a family of vehicles, while supporting a technology program that would address SDI requirements but also benefit current systems and vehicles. The SDIO, however, needed a specific heavy-lift vehicle deployed in the late 1990s and wanted to retain fiscal control of the development process. It was not especially interested in the family of vehicles proposal or technological advances to be applied to other ELVs. NASA continued to favor its Shuttle-C proposal and viewed the ALS as a potential source of technology applicable to its shuttle derivative.[30]

The conflicting views on ALS prompted the Directorate of Space and SDI Programs in the Office of the Secretary of the Air Force to convene a meeting in early February 1988 to achieve a consolidated position on the ALS program. Attendees included officials from the secretary's office, the Air Staff, AFSC, Space Division, and AFSPC. After two days of deliberations, the participants agreed on a strategy that would expand the scope of the original ALS program beyond the HLV to include a family of vehicles and improvements to current systems. They decided on three objectives for the ALS program. First should be the focus on technology development and design work for SDI's heavy-lift launcher in the late 1990s. A second long-term goal would be to produce a family of vehicles to support both Air Force and national requirements. Finally, the ALS program should permit the transfer of ALS technology to current launch vehicle systems. The overarching objective of the ALS continued to be the development of a low-cost boost-to-orbit capability.[31]

As DOD Manager for ALS requirements, AFSPC prepared requirements documentation that spring calling for "a new family of launch vehicles that can provide responsive, reliable, flexible, low cost access to space for the broad range of expected payload sizes, orbits and launch rates." Fulfilling these requirements, the ALS program would differ significantly from current programs in terms of responsiveness, lifting capacity, and cost. Reflecting the early argument for the space shuttle, planners expected the ALS's large lift capacity and a high launch rate to enable the program to place as much as one million pounds into orbit in 2000, then by 2003 to 2005 be able to increase the figure to five million pounds. The system would also achieve a reliability rate greater than 98 percent, fulfill short-notice launch requirements of 30 days or fewer, and be able to accommodate a payload substitution within only five days of launch. Its launch rate would routinely reach at least 30 launches annually, achieving a 95 percent launch-on-schedule probability and providing a surge capability that would support seven missions within five days from an alert status.[32]

In August 1988, AFSPC commander Lt Gen Donald J. Kutyna validated the command's statement of operational need, which stated that "potential future threats to United States space assets made the development of an operationally responsive launch system necessary." Containing the first launch responsiveness requirement, AFSPC's document called for seven satellites to be launched in only five days as follows: two DSCS, two DMSP, two Milstar, and one Satellite Early Warning System (SEWS). Additionally, they proposed a payload changeout period of no more than five days. As the Space System Division historian declared, "These were staggering compressions of time by historic standards." The evolution of the ALS by this time to a more direct operationally oriented program reflected the efforts of United States Space Command and Air Force Space Command leaders to shift the focus of space launch from the research and development community to the operational elements.[33]

Operational Space

The appointment, on 6 February 1987, of Gen John L. Piotrowski to head US Space Command signaled the advent of three years of strong leadership in a variety of operational space areas. As commander-in-chief of the unified command, Piotrowski sought to bring an operational focus to the space mission, much of which was accomplished by involving AFSPC, the unified command's largest service component. General Piotrowski made it his mission to stress the needs of the warfighter and the importance of normalizing military space operations. As he explained, it was absolutely essential that the unified and specified commanders-in-chief, the Joint Chiefs of Staff, and Defense Department leaders develop an "operational mindset for the use of space." This would reflect the "natural process of maturing space operations from a research and development orientation to an operational mode for the employment of US space-based resources."[34]

General Piotrowski used as a springboard the new Defense Department Space Policy that Secretary of Defense Caspar Weinberger signed on 4 February 1987. The new policy affirmed that the shuttle would no longer be designated the primary launch vehicle for military missions. The nation must develop an assured space mission capability through balanced launch assets and more survivable systems. Moreover, the military should take advantage of civil and commercial space assets and promote advanced launch technology. Above all, the Defense Department must "provide operational capabilities to ensure the US can meet national security objectives." The Joint Chiefs of Staff called on the new commander of US Space Command to assess current programs and required actions. Although Piotrowski used his position to advocate a variety of improvements in space infrastructure, his attention centered on space launch and future operational payload requirements that would support theater and tactical commanders.[35]

General Piotrowski also spearheaded the effort of the operational space community to achieve a more responsive space launch capability. The problem with manifesting space payloads led him to reassess the issue of responsiveness in the context of deterrence and warfighting. Current policy, he argued, only guaranteed a return to a peacetime capability and a gradual recovery from the launch stand-down. This would mean a relatively rigid "launch-on-schedule" policy that often required as much as six months of preparation by contractor personnel before each launch. Such practices did not provide the responsive space infrastructure needed for warfighting. Moreover, "deliberate" on-orbit checkout procedures by Air Force Systems Command's Space Division meant that space systems remained under control of the research and development community too long before transfer to operational users. Piotrowski believed that the best way to ensure a launch system responsive to the warfighter would be a complete transfer of the launch mission from Space Division to Air Force Space Command. He formally proposed the transfer in a letter to Chief of Staff Gen Larry D. Welch on 28 September 1987. Launch transfer, he argued, would represent a natural evolution as AFSPC matured in its operational role and would enable the commander-in-chief of US Space Command to use his component directly for launch-related activity in wartime. He also advocated an Air Force "blue suit" launch operation managed by the operational commands. He proposed that AFSPC immediately assume operational responsibility for either the test ranges or upcoming Delta II/GPS launches.[36]

Piotrowski and his fellow space operators believed that developments in the wake of the *Challenger* tragedy supported their argument. For one, a special Defense Department commission on defense management practices, led by former Deputy Defense Secretary David Packard, called for acquisition commands to concentrate on research, development, and acquisition by divesting themselves of "operational" responsibilities. This led to the transfer, in 1987, of the Air Force Satellite Control Network, including the remote tracking stations, from Air Force Systems Command to AFSPC. Piotrowski hoped this transfer would provide sufficient incentive for reconsideration of the launch issue. At the same time, recent Defense Department policy relegating the shuttle to second priority behind expendable boosters effectively sealed the fate of AFSPC's expectation to control military space launch through its shuttle responsibilities. By February 1987, the Defense Department had decided to cancel funding and development of the Shuttle Operations and Planning Complex (SOPC) at Falcon Air Force Station, Colorado, and to mothball the shuttle launch complex at Vandenberg Air Force Base. As a General Accounting Office report suggested, cancellation of the SOPC also represented an end to dedicated military manned spaceflight efforts for the foreseeable future.[37]

Efforts to Develop a Responsive Launch Capability

With the return to expendable launchers and no provision for turning the new Titan IV and Delta II boosters over to AFSPC, the Defense Department's shift to expendable launch systems revitalized AFSC's central role in launch operations, which reinforced the status quo. Piotrowski's initial effort with the space launch issue proved unsuccessful. In denying his request in December of 1987, Air Force headquarters argued that the disruption involved in such a transition would adversely affect the launch recovery process. Moreover, it contended that every launch was unique and demanded considerable engineering and design work more suited to the research and development community. At the same time, an AFSPC study had raised questions about the lack of expertise within the command to handle a rapid rather than an evolutionary transition.[38]

From Piotrowski's perspective, the Air Force had to transition its force posture from one of remoteness to the concerns of the commanders-in-chief to one that ensured integration with warfighters' requirements. It should do this by emphasizing the interrelationship among survivable space systems and quick-reaction launch capabilities. These issues surfaced in early 1988, when Piotrowski surveyed the commanders-in-chief and theater commanders regarding their dependency on space systems. In response, the commanders declared they had found weather, intelligence, and communications satellite information increasingly necessary for their operations, but they bemoaned their inability to control these assets. Piotrowski's survey also revealed that without having access to weather and communications from satellites in a crisis situation, the commanders-in-chief did not conduct training to use this information. Piotrowski focused on the satellites themselves, particularly the trend toward multimission, multiuser satellites. They had proven cost effective and capable of satisfying a broad spectrum of requirements, but had they met user needs? Piotrowski and his counterparts thought not.[39]

General Piotrowski's "responsive" proposal called for developing many small, low-cost, single-mission satellites that could be launched on short notice and receive early on-orbit checkout. As such, they would be readily available for theater commanders. DARPA, which did not favor the practice of hardening satellites and producing more complex spacecraft, had long advocated cheaper, lighter satellites and a survivable launch capability through its Advanced Satellite Technology Program. In the early 1980s, however, an assessment by the Office of the Secretary of Defense recommended retaining high-altitude deployment of multimission satellites. Over the course of the decade theater commanders, SAC and the SDIO increasingly looked to so-called cheap satellites as the best means of satisfying theater weather, communications, reconnaissance, and intelligence requirements during a crisis.[40]

The Air Force became most interested in the possibility of lightweight communications satellites to complement existing networks in a "communications by the yard" approach to fulfill theater needs not met by current systems. Piotrowski and others saw small satellites as a key means to transition from the existing peacetime situation to a more responsive warfighting posture and, thus, to realize the objective of assured access to space. Moreover, a quick-reaction "on-call" launch response would meet operational needs and help institutionalize space inside and outside the Air Force. Such a capability would involve simpler, smaller, short-life payloads launched aboard a standardized bus by quick-reaction launchers from multiple launch sites across the country. Short-term tactical satellites from a mixed-fleet arsenal could meet important surge requirements of wartime commanders. The issue of launch responsiveness also would generate strong pressure to confront the central issue of who should control space launches.[41]

Launch Responsiveness Study Creates Momentum for Operational Space Launch

The concerns of the operational space community for a more flexible and responsive launch capability, in late 1987, convinced the Office of the Secretary of the Air Force and the chief of staff of the Air Force to support General Piotrowski's request for a study of potential improvements in launch responsiveness. When Gen Bernard P. Randolph, commander of AFSC, joined the initiative, the study became a joint effort by the Air Force development and user communities. Begun in early January 1988, the study addressed both near-term and far-term requirements and alternatives for improving launch processing timelines and was completed in April. Generals Randolph, Kutyna, Piotrowski, and Secretary Aldridge received briefings on the results in April and early May, and the written report, *Launch Responsiveness Study Final Report*, appeared on 23 September.[42]

In the area of requirements, a Launch Requirements Working Group assessed four basic strategy options to meet the goal of assured mission capability across the spectrum of conflict. Three of these—survivability and proliferation strategies and the use of alternative capabilities—involved sustained mission capability without directly dealing with launch responsiveness. The fourth alternative, however, a launch strategy itself, identified three alternatives. The first, launch on schedule (LOS), called for launching at predetermined times to maintain mission capability. The second strategy, launch on need, meant launching when necessary to replace satellites to regain capability. Finally, a surge strategy would involve deployment, under stress, of many space vehicles to achieve a wartime posture. After applying these strategies to particular vehicle and satellite programs, the group agreed that "LOS should be the fundamental strategy for all missions during peacetime." They noted that, because the defense community's conservative schedule for deploying replacement systems had not changed despite the presence of satellites routinely outliving their projected operational lifespan, proliferated constellations provided an unintended benefit. To support "small critical orbital force structures," a surge strategy would "flush critical satellites to orbit just prior to war…[and to]…respond to crisis situations short of war." The group determined that insufficient data prevented them from assessing requirements for survivable launch operations through a general conflict.[43]

The portion of the study that examined launch processing focused on the following existing satellite programs and their designated launch vehicles: Titan IV-IUS (SEWS), Titan IV-Centaur (Milstar); Delta II (GPS), Medium Launch Vehicle II (soon to be the Atlas II) (DSCS); Atlas E (DMSP); and Titan II (DMSP). The study team focused only on possible changes in launch processing and on-orbit checkout, even though these elements made up less than one percent of a space system's total life cycle from development through operations. To make launch support more responsive, only two choices were available: make evolutionary changes to existing system designs, or design new systems. The study team reviewed existing procedures and identified bottlenecks that slowed processing. Once a system proceeded through development to production, launch processing required 30 to 90 days, and on-orbit checkout took another 14 to 60 days, depending on the satellite. The team then offered solutions requiring either small or large investment of resources. In the first category were mainly procedural solutions which, if implemented, would accelerate launch processing in crisis situations or increase its efficiency at other times. These included increasing work shifts, performing nondestructive testing at the factory, reducing system testing, and building up a hardware inventory by expanding required facilities and using a dedicated launchpad. The team also recommended introducing standardized interfaces, automated launch checkout equipment, modular on-pad maintenance, and a reduction in launch base assembly. Although solutions in the second category promised major reductions in processing time, they would require a significant investment in resources. As the investigators admitted, "We are basically limited by both current complex satellites, outdated boosters and test equipment designs, and our processing techniques."[44]

A second area examined by the group embraced potential modifications of current launch systems and development of new hardware based on new requirements. After discussions with industry and government organizations, the team was optimistic about making evolutionary improvements to the existing ELV force. Most improvements, they found, could be provided by the technology applications under development as part of the ALS program and could be accomplished through a Preplanned Product Improvement (P3I) Program for the ELV fleet. P3I modifications included adaptive guidance, navigation, and communications, multipath redundant avionics, backups to solid rocket motor technology, improved ground operations, and low-cost flight operations. Space Systems Division was directed to produce a Launch Operations P3I Master Plan that planners hoped would take space support "a long way in finally 'operationalizing' our current ELV operations." Beginning with the Atlas II under development, the study team argued that not only would P3I increase launch responsiveness, overall performance and reliability, the initiative would also lower maintenance and operational costs, reduce launch turnaround times, and provide more flexibility for changing payloads.[45]

In the final area examined by the group, on-orbit checkout, they found opportunities for greater efficiency. With GPS, DMSP, and DSCS satellites, for example, nominal checkout times of from 24 to 60 days could be reduced to between 4 and 25 days. Specific suggestions involved the tension between the desire of the user to have the satellite as soon as possible and the necessity of a checkout process made longer by the complexity of current satellites. But did users believe rapid turnover worth acceptance of more risk? The group recommended that turnover agreements specify acceptable conditions of the satellite at an early satellite turnover.[46]

When the report came out in September, General Kutyna forwarded a copy to General Piotrowski. The AFSPC commander said the document would "be used throughout the space community as a baseline for further studies and actions which will move us toward more responsive launch systems. This is particularly important for making our case for operational launch systems in the R&D and contractor communities."[47]

The issue of launch responsiveness as highlighted in the Launch Responsiveness Study created strong pressures to confront the core issue of who should control launches. Indeed, by the time the Launch Responsiveness Study appeared, a fundamental shift in development philosophy affecting space launch was underway. The central question had become how AFSPC would acquire operational control of launches. The prevailing philosophy called for the operator to take control of the spacecraft after completion of on-orbit checkout. Accordingly, launch was and should remain an R&D responsibility because the development community best understood their complex systems, knew the way they should be integrated, knew the elements of the launch environment, and had the experience and knowledge to deal with on-orbit anomalies. Consequently, the development period extended from design of the booster and satellite through their testing and checkout, and it unavoidably included launch. The new development philosophy, as articulated initially by US Space Command's General Piotrowski and then AFSPC's General Kutyna called for transferring space launch vehicles to the operator before launch. Doing so would achieve the objective of aligning the space mission relationship between developer and operator in accordance with practices across the rest of the Air Force. Operators argued that such an alignment would produce a more responsive and operational space capability. The movement toward operationalizing space launch also received an important boost from the 1988 Blue Ribbon Panel. This panel proved to have the most far-reaching influence of the many post-*Challenger* space panels, studies, and plans until the watershed Space Modernization Plan of 1994.[48]

Blue Ribbon Panel Endorses ALS

In the spring of 1988, Air Force Chief of Staff General Welch formed a Blue Ribbon Panel on Space Roles and Missions, consisting of senior representatives from all Air Force major commands, to assess Air Force space issues. The vice chief of staff of the Air Force chaired an executive steering group that included General Kutyna and vice commanders from the other Air Force major commands. The main work would be done by the Panel Study team, headed by Maj Gen Robert Todd, vice commander of Air University.[49]

General Welch charged the panel to examine the role of space for the warfighter, the responsiveness of space systems, and organizational and institutional relationships. After deliberating over the summer, the panel briefed Welch in August and issued a report emphasizing the need to develop a space policy that reflected realistic warfighting capabilities and institutional pretensions to space leadership; a more rational strategy to achieve the space requirements subsumed under the four mission functions of space control, force application, force enhancement, and space support; and a broad corporate commitment to space. In February 1989, Air Force headquarters issued an implementation plan that identified 27 specific actions necessary to accomplish the changes recommended by the panel. The Blue Ribbon Panel report and the Air Staff's implementation plan provided necessary momentum on a number of important space issues, including space launch.[50]

Panel recommendations echoed the findings of the Launch Responsiveness Study in strongly supporting the major effort to develop effective new launch technology through the ALS program. The climate of fiscal austerity and strong opposition to the prospect of space-based missile defense systems had raised doubts about proceeding with an ALS program aimed only at producing a new large booster to support the Strategic Defense Initiative. As a result, by 1988 the ALS had evolved from a technological initiative to produce a heavy launch vehicle for the Strategic Defense Initiative and future space station to a multivehicle technology-oriented project to produce a family of vehicles. Not all participants approved of the restructured program's objectives, which eliminated production of the vehicle itself.[51]

Air Force officials, including Secretary Aldridge, expected ALS also to meet future Air Force requirements for large multiuser satellites that could not be handled by the shuttle or Titan IV, although General Piotrowski and AFSPC planners feared that ALS furthered peacetime rather than wartime objectives by undermining their initiatives to produce tactical satellites of smaller size, lower weight, and less complexity. AFSPC was leading the effort to restructure the program to support development of new vehicles that, by the late 1990s, could be expected to provide low-cost access to space for a variety of payloads. But with funding in short supply, might the launch dilemma be better addressed with a technology-only program directed toward improving the existing fleet of expendable boosters? Both the

1988 Launch Responsiveness Study and the Blue Ribbon Panel suggested this approach, and this recommendation emerged from a 1989 Defense Science Board study of space launch. Board members argued for limiting ALS to a study and to a propulsion-and-vehicle technology program without a full-scale development phase because, they argued, upgraded expendable launch vehicles would meet operational requirements for the foreseeable future. AFSPC still wanted ALS, renamed the Advanced Launch Development Program (ALDP) in December 1989, to address requirements for a future operational launch system rather than merely focus on upgrading existing launch vehicles. The larger issue had become the classic development dilemma of whether to continue investing in improvements to systems based largely on 30-year-old technology or, instead, to support promising but unproven technology that might result in a new family of launch vehicles that AFSPC believed would satisfy requirements into the late 1990s and even beyond. Given the austere financial climate, however, severe budget cuts by the Air Force and the SDIO in fiscal year 1990 reduced ALS to a technology-only initiative. Advocates of a family of vehicles would have to await the EELV program and its variety of launch vehicles and options.[52]

AFSPC Gains the Space Launch Mission

If the Blue Ribbon Panel's findings did not lead to clarification of the ALS program, they nevertheless helped produce major changes in the Air Force space launch mission. By the time the Blue Ribbon Panel's *Implementation Plan* appeared, on 3 February 1989, the country had just completed its "year of recovery" for "assured access to space." The Titan 34D had returned to service after two launch failures with an October 1987 launch of a KH-11 payload from Vandenberg, with a classified launch from Cape Canaveral to follow in May; the first of the refurbished Titan IIs began operations in September 1988 with an electronic intelligence satellite; and the new Titan IV would make its maiden flight of a DSP payload on 14 June 1989, with projections of three to five flights per year. Additionally, the new Delta II medium launch vehicle would make its first flight with Global Positioning System satellites in early 1989, and the Air Force had issued a contract for a second medium launch vehicle, a stretched version of the Atlas-Centaur for DSCS launches. The Blue Ribbon Panel had applauded the recovery of the expendable launch vehicle industry and mission.

It also created momentum for transfer of the space launch mission from Air Force Systems Command to AFSPC and led to a revised Air Force Space Policy in December 1988 that declared the Air Force would "consolidate space system requirements, advocacy, and operations, exclusive of developmental and, for the near term, launch systems, in Air Force Space Command." Although the policy stopped short of reassigning the launch function, it clearly reflected a central objective of the Blue Ribbon Panel, namely, to institutionalize the role of AFSPC as the focal point for operational space activity. Increasing awareness of AFSPC's responsibilities and the importance of space in the Air Force set the stage for action on the launch transfer issue.[53]

After General Piotrowski failed, in late 1987, to convince Air Force leaders to transfer the launch mission, he relinquished the burden of advocacy to General Kutyna. In February 1988, Kutyna provided Air Force Chief of Staff General Welch a lengthy rationale for transferring launch responsibility, which became the command's basic position in the months ahead. Space boosters, he argued, while complex and costly vehicles, represented operational rather than developmental systems, yet Air Force Systems Command's research and development personnel performed operational tasks involving range and launchpad operation, supervision of contractor personnel, and execution of launch countdown checklists. These could, and should, be handled by "operators" who could boast of considerable experience with current boosters over the years. General Kutyna favored a "clean stroke" transfer like that involving the Satellite Control Network rather than a piecemeal change. At the same time, Kutyna and his staff had always understood that such a transfer would require resolution of difficult budget, manpower, and contractor issues, as well as interface challenges with NASA and the classified national security programs, along with responsibilities for upper stage vehicles.[54]

General Welch, however, reaffirmed his earlier opposition, and the launch transfer issue joined several other concerns that would have to await Blue Ribbon Panel deliberations. In the new climate for change after publication of the implementation plan, Welch directed the Air Staff, in late May 1989, to review the responsibilities of Air Force Space Command and Air Force Systems Command to recommend "a more normal relationship between developers and operators." Subsequently, Air Force headquarters directed both commands to prepare and discuss with each other their positions on space launch. By the end of the year, the two sides continued to differ fundamentally on the nature and control of space systems. Air Force Systems Command proposed a lengthy, phased turnover of individual launch vehicles, but only after sufficient improvements had been made to make them "operational." Space Command, by contrast, favored immediate transfer of space launch, represented by the Space and Missile Test Organization, as well as all residual satellite control operations. In his presentation to General Welch in March 1990, General Kutyna declared that the transfer would enhance operational effectiveness in four ways. Making a single command responsible for the entire space support function would ensure unity of command, render systems more responsive to the warfighter, improve methods for the formulation of operational requirements, and assist the acquisition community by freeing it from performing operational functions. The AFSPC chief also countered the objections of Air Force Systems Command representatives, which centered on potential disruption to classified reconnaissance programs and contractor arrangements, and especially on what they considered the specialized, nonoperational nature of space systems.[55]

Although General Welch agreed with General Kutyna's basic position, he preferred to forego an immediate transfer and, instead, appointed a Launch Operations Transfer Steering Committee to examine various options for an effective transfer with minimal disruption. The goal would be to produce a plan "to bring launch operations into line with the normal division of roles and missions between operational commands and the acquisition command." Included among the committee members were Lt Gen Ronald W. Yates and Maj Gen Thomas S. Moorman Jr., who would soon assume command of Air Force Systems Command and AFSPC, respectively. In the spring of 1990, the committee examined 16 options that in one way or another compared AFSPC's position, which supported a direct transfer leaving launch systems to become more "operational" in the future, and Air Force Systems Command's argument, which favored an incremental transfer after first improving the launch systems to make them "operational." In mid-May, General Welch agreed to the committee's compromise recommendation, which clearly favored the operational command.[56]

On 1 October 1990, Air Force Systems Command would transfer to AFSPC its launch-related centers, ranges, bases, and the Delta II and Atlas E missions. The remaining Atlas II, Titan II, and Titan IV missions would be turned over later on a phased schedule. Combined task forces (CTF), consisting of AFSC and AFSPC personnel performing engineering and operational functions, respectively, would activate Titan IV and Atlas II operations at Cape Canaveral. After the second Atlas II DOD launch, the CTF would become an AFSPC squadron. The Titan IV CTF had a more difficult path to becoming an AFSPC squadron. The launch requirements included one Titan IV SRMU launch, two Titan IV-Centaur launches, and one launch from the newly modified Titan Launch Complex 40. Approving the transfer on 12 June 1990, Secretary of the Air Force Donald B. Rice declared that the "change in assignment of roles and missions further normalizes space operations and pursues our corporate commitment to integrate space power throughout the full spectrum of Air Force operational capabilities."[57]

It was left to General Moorman, in transfer ceremonies on 1 October at Patrick Air Force Base, Florida, marking the transfer, to best describe the "landmark event":

> I believe this transfer is part of the natural evolution of the Air Force space program. It is a testimony to how our thinking about space operations has matured. . . . The decision to transfer the launch mission was based on the beliefs that placing satellites into orbit has matured to a point where it should be considered an operational task, and that Air Force Space Command had sufficiently matured where it could assume the responsibility. . . . The transfer . . . is intended to be virtually transparent to both the users and operators. That transparency will help guarantee continued smooth operation of launch activities and will establish a foundation for moving forward toward normalizing our military access to space.[58]

The transfer of space launch represented not only the "most significant operational milestone" in the command's brief history, but also represented a major step on the road to an operational, warfighting perspective for space.[59]

Gulf War Tests Operational Space

The launch transfer arrangement received its baptismal fire in the first Gulf War. On 2 August 1990, two months before Air Force Space Command acquired the space launch mission, Iraqi leader Saddam Hussein shocked the world by invading and rapidly overrunning the small, oil-rich country of Kuwait, sending the Kuwaiti government into exile. On 7 August, under the operational name Desert Shield, allied forces began a five-month-long buildup in the Persian Gulf region. America now faced its first post–Cold War crisis.[60]

The Gulf War, fought under the operational name Desert Storm, represented the first major trial by fire for space forces, whereby military space systems could fulfill their promise as crucial "force multipliers." By all accounts, space forces provided the vital edge in ensuring the victory of the UN Coalition. Desert Storm involved the full arsenal of military space systems. Nearly 60 military and civilian satellites influenced the course of the war and helped save lives on the road to victory. Communications satellites established inter- and intratheater links to support command and control requirements for an army of nearly 500,000 troops. Weather satellites enabled mission planners to keep abreast of constantly changing atmospheric conditions, while early warning spacecraft supplied crucial data on enemy missile launches. Navigation satellites furnished precise positional information to all elements of the armed forces. Then, too, commercial satellites not only assisted in filling coverage and system gaps but broadcast the war over television to a worldwide audience. Desert Storm was, indeed, the first large-scale integration of space systems in support of warfighting.[61]

Yet Desert Shield and Desert Storm also had exposed the Achilles heel of the space program. When personnel from US Space Command and AFSPC reviewed US Central Command's request in the fall of 1990 to launch an additional DSCS III satellite, they quickly determined that the launch needed to await completion of the Atlas II's new Centaur upper stage, scheduled for July 1991. To be sure, from August 1990 to the end of Desert Shield, six military satellites joined the existing network, and all contributed to Desert Storm operations. All those spacecraft launches had been scheduled, however, well in advance of Desert Shield. In effect, the US space launch system continued to reflect a policy of launching on schedule, not on need. It simply could not respond to short-notice requests.[62]

From the ALS to the EELV

Space leaders like Generals Piotrowski and Kutyna had long been aware of the challenge a launch-on-need capability represented. The Air Force had been trying since the *Challenger* accident to solve the launch dilemma that the Gulf War had highlighted and to develop an effective, responsive space launch capability. Although ELV recovery had gotten the nation back to space, it did not provide long-term assured access to space. In the early 1990s, the Bush administration resumed the effort to move beyond the earlier ALS initiative. On 10 December 1990, on the eve of Desert Storm, the NASA-sponsored Advisory Committee on the Future of the United States Space Program, known as the Augustine Committee after its chair, Norman R. Augustine, breathed new life into the inconsistent planning for a replacement for existing boosters and the space shuttle. Among other recommendations, the committee's report called for deemphasizing shuttle operations and developing "an evolutionary, unmanned but man-ratable heavy-lift launch vehicle." At the time, the ALS had evolved from developing a heavy-lift booster to a family of launch vehicles into the ALDP, largely a technology study. AFSPC leaders and others in the operational space community, however, remained committed to the idea of producing a more responsive vehicle or family of vehicles.[63]

On 19 April 1991, after high-level meetings between NASA and DOD, the National Space Council modified the ALDP and redesignated the program the National Launch System (NLS), as called for by President George H. W. Bush in his 24 July 1991 National Space Policy Directive (NSPD) 4. According to the directive, the NLS was to "significantly improve the operational responsiveness of the entire spacelift process, while reducing all costs." Incorporating many suggestions offered by the Augustine Committee and outlined in the ALDP, the NLS was to launch medium to heavy payloads using "elements of existing launch systems and new technology." NSPD 4 directed DOD and NASA to work jointly to manage, develop, and fund the NLS equally.[64]

The NLS promoted standardization by including three launch vehicles that would use modular components, a standard engine, standardized interfaces, off-pad processing and encapsulation, and as many common components as possible. NLS-1, the heavy-lift workhorse of the booster fleet, would be able to launch a 300,000-pound payload for lunar and Mars missions. The medium-sized NLS-2, would be capable of 30,000- to 70,000-pound payloads, and NLS-3 would launch 20,000-pound spacecraft into LEO.[65]

The fate of the NLS, however, appeared troubled from its inception. NASA and the Air Force could never complete a formal memorandum of understanding, and this hampered every aspect of the program. Without an agreement on clearly defined and detailed roles and responsibilities, there could be no coordinated effort or agreement on funding, an acquisition strategy, or NLS derivative priorities and prelaunch concepts of operation. Although design and engineering work was proceeding satisfactorily, the Bush administration and Congress became increasingly concerned about the lack of direction and oversight and had budgeted funds sufficient only for the new initial work on the Space Transportation Main Engine program, not for full-scale development. After Congress directed termination in the fiscal year 1993 Defense Appropriations Bill, Vice President Dan Quayle called on former Air Force Secretary Aldridge to chair a newly established Space Policy Advisory Board to review the president's July 1991 Space Launch Strategy, examine the nation's space launch program, and recommend improvements.[66]

The Aldridge group completed its report, "The Future of US Space Launch Capability," in November 1992. The so-called Aldridge Report proposed the appointment of a single, executive-level manager, or launch "czar," to oversee the planning, coordinating, and implementing of the nation's space launch capability. The report also recommended cancelling the NLS and developing a new program called "Spacelifter." The new system would rely on "modular performance improvements . . . [that] . . . can meet all the medium and heavier lift requirements (20,000 to 50,000 pounds to low Earth orbit) of civil, DOD and commercial users" at half the cost of existing launch systems. Developed under Air Force leadership, the Spacelifter would use a single "core" vehicle to meet the lift requirements of all three sectors of the space community. This reflected AFSPC's continued interest in developing a family of vehicles leading to operational systems. When Congress effectively cancelled the NLS, the Aldridge group expressed its disappointment, but viewed the cancellation "as an opportunity to redirect the effort toward its program that they believed was based on well-defined performance and cost requirements and technical milestones."[67]

Although the Aldridge Report's assessment of the space program and its proposed Spacelifter was impressive, it came from a "lame duck" administration, and its proponents worried that it could suffer under new President William J. Clinton's administration when incoming vice president Albert A. Gore Jr., warning of funding challenges, promised to consider a completely new launch vehicle. Indeed, the Spacelifter remained in limbo for much of 1993, while Secretary of Defense Les Aspin had DOD conduct a bottom-up review of spending priorities for national defense. On 1 September 1993, OSD announced that Spacelifter would not be developed and, instead, DOD would pursue a program focused on the current varieties of launch vehicles.[68]

Indeed, the Clinton administration's Bottom-Up Review reflected a return to improved expendable launchers. Its analysis addressed the launch issue in terms of several options. One would be to extend the existing fleet to the year 2030; a second, to develop a new family of expendable launch vehicles to replace the current fleet beginning in 2004; a third, to promote a technological effort to develop a reusable vehicle; and finally, "austere" variations of the first two alternatives. The Defense Department decided on an austere approach, funding only required improvements to existing launch and range infrastructure.[69]

The Space Launch Modernization Plan May 1994 (Moorman Report)—and the Path Ahead

Like the studies that preceded it, the Bottom-Up Review helped lay the groundwork for the seminal plan completed in the spring of 1994 that would lead to a "modernized" family of EELVs that earlier planning efforts had favored. In November 1993, Congress, through the National Defense Authorization Act for fiscal year 1994, directed the secretary of defense to "develop a plan that establishes and clearly defines priorities, goals, and milestones regarding modernization of space launch capabilities for the Department of Defense or, if appropriate, for the Government as a whole." Defense Secretary Les Aspin responded by appointing General Moorman, vice commander of AFSPC, to chair a group of 30 individuals representing the defense, intelligence, civil, and commercial sectors to conduct a Space Launch Modernization Study, soon referred to as the Moorman Report. The study would assess requirements for a new launch capability, recommend measures to lower production costs for current systems, and provide a road map of options for spacelift into the twenty-first century.[70]

The Executive Summary that the Moorman team issued on 5 May 1994 provided a critical assessment of the "environment within which the national spacelift mission is conducted." For example, the Space Launch Modernization Plan's study team determined that, while DOD would be spending about 6 percent or $3 billion per year of its total budget on space programs in the 1990s, spacelift received only 20 percent of that figure. Of the rest, user equipment and control elements accounted for 50 percent of the space budget, while satellites garnered the remaining 20 percent. The plan forecasted an Air Force space budget that was expected to remain flat at best through 2010, and projected NASA prospects to be even worse.[71]

At the same time, spacelift hardware costs had risen for the Atlas II and Titan IV, and hardware problems affecting the boosters, upper stages, and payloads accounted for most of the launch delays that were afflicting the launch community. The study team singled out the Titan IV for having experienced a 60 percent increase, approaching $325 million for a Titan IV-Centaur launch, and blamed inefficient production rates for the escalation. Planners had originally expected the Titan IV production rate to be 10 annually instead of the current rate of 3 per year, a reduction largely attributable to the gradual decline of commercial competitiveness in the face of subsidized foreign launch vehicles. As for delays, the Titan IV was the worst offender, having experienced delays averaging 223 days for each of the initial eight Titan IVs launched, while among upper stages, the Centaur tallied 41 percent of all launch delays. The Moorman team also found Delta to be the most reliable booster because, compared to the Atlas and especially the Titan IV, it was less complex, had higher flight rates that provided better opportunities to find and fix problems, and correspondingly higher production rates and an easier learning curve. Moreover, at an average flight delay figure of 22 days, the Delta II was the only ELV system capable of meeting the launch-on-need requirement.[72]

The study team described four options for modernizing the nation's space launch capabilities. Under the first option, the government maintained the current fleet of Titan IVs, Titan IIs, Atlas IIs, Delta IIs, and the space shuttle "for the foreseeable future." Limited funding provided only for modest upgrades to enhance safety and reliability. This option had NASA continuing shuttle flights into the next century before replacing the shuttle. Option 1 predicted launch costs from $50-$125 million per flight for medium lift, $250-$320 million for heavy-lift flights, and $375 million per flight for shuttle missions. This option had the advantage of satisfying existing mission requirements with minimal long-term costs and using what the group considered an adequate technology base. On the other hand, it offered old and expensive labor-intensive procedures that could not compete in the long run and in effect ensured US competitive disadvantages in the commercial market.[73]

Option 2 offered more promise for the future by investing $1 billion to $2.5 billion in calendar year 1994 dollars in a family of EELVs.

The current fleet of ELVs already on contract would be flown out and the existing medium and heavy vehicles consolidated into a family of "right size" vehicles characterized by standardized components—cores, solids, upper stages, payload interfaces, and fairings. Simplified procedures and structures, along with increased production rates, would significantly reduce operational costs. The study team predicted recurring costs of $50-$80 million for medium ELV missions, saving as much as $45 million, and $100-$150 million for heavy flights, amounting to a savings of at least $150 million per flight. Although the shuttle costs would remain the same as for Option 1, the nation's commercial space launch industry would be more competitive internationally.[74]

Options 3 and 4 proposed the development of new launch systems. The third option favored a "clean sheet" approach to produce ELVs by using a "modular family composed of a common core vehicle and common major subsystems—strap-on stages, upper stage(s), payload fairings, and processing and launch facilities." The study team explained that the new system could be achieved either by replacing the current ELVs or by replacing both the current ELVs and the shuttle. Nonrecurring development costs for a new ELV system were estimated at $5 billion to $8 billion, while an additional $5–$6 billion would be required for a reusable Space Station crew carrier and a Space Station cargo carrier. Recurring mission costs would extend from a low of $40–$70 million per flight for medium lift to a high of $130–$230 million per flight for cargo transport. Although this option could benefit astronaut safety, commercial competitiveness and ELV operability and reliability, it required a large initial investment with the high risk of cost growth for the elements supporting the Space Station.[75]

Option 4, the most ambitious and expensive of the four options, proposed the development of a completely new, fully reusable space launch vehicle that would replace the shuttle, medium ELVs, and possibly heavy ELV payloads eventually. Major improvements in technology and engineering development would be required to make this system a reality, while the high cost estimates included the following: up to $900 million for technology demonstration; $6 billion to more than $20 billion for development; and between $2.5 and $10.5 billion to procure a four-vehicle fleet. Although recurring launch costs would be lower than the $6 billion annual cost of supporting the current ELV fleet and the space shuttle, the many unknowns associated with this omnibus vehicle made it a "moderate to high" risk project.[76]

The Executive Summary of the Space Launch Modernization Plan followed its four options with 15 findings and related recommendations. Several were especially notable. The study team assessed the need for a heavy-lift capability for the foreseeable future and determined that intelligence requirements and technology constraints limited the possibility of downsizing intelligence satellites for launching by medium lift boosters. Because Titan IV operating costs had risen from $34 million per launch in 1989 to $54 million in 1994 and were expected to increase to $72 million per launch by 1999, the group recommended measures to reduce expenses while recommending the NRO "continue to examine advanced spacecraft technologies that would provide major reductions in payload size and weight." Although the group focused on heavy-lift requirements, it also briefly addressed the potential for small launch vehicles that had been the focus of both US Space Command and Air Force Space Command. "Emerging distributed low-Earth-orbit constellation concepts for communications and . . . surveillance in DoD would revolutionize space missions," the Moorman Report asserted, but it favored allowing commercial market forces to function rather than having the government take a leading role "at this time."[77]

The study team determined that modernizing space launch capabilities required more funding for a core space launch technology program that had been "significantly underfunded and externally constrained." Noting that the technology work was largely achieved in now cancelled programs like the ALS and NLS, it recommended not only promoting work on reusable launch system technology and low-cost expendable rockets but also investigating Russian engine technology. Noting that "reliance on Russian engine technology has potential national security implications from a dependency point of view," the Group nevertheless suggested that the Air Force cooperate with NASA and industry to procure and test an RD-170 engine as a prime candidate for additional study.[78]

The Moorman Report also addressed operations at Cape Canaveral Air Force Station and Vandenberg Air Force Base and found them "constrained by antiquated and unsupportable ground systems and facilities." It noted that some range systems experienced an average of three failures per mission, and on 16 recent Delta II missions "Eastern Range equipment problems caused 22 delays." At the same time, the investigators lauded the Range Standardization and Automation (RSA) and launch base improvement efforts now in place to correct deficiencies.[79]

Data collection and standardization drew pointed criticism from the study team. Its investigation discovered that while substantial information on launch vehicles and supporting elements and processes existed, it proved difficult to obtain and use effectively. It recommended establishing a "standardized program for metrics, data collection, and supporting analysis." Beyond the data problem, there was "a lack of standardization within Air Force space launch systems and operations" across the board. Observing that the Eastern Range and the Western Range had developed their own procedures while under R&D management, the group found that unique procedures and systems remained in place despite the transfer of the launch bases to an operational command. To promote standardization, the group recommended that AFSPC cooperate with system program offices and NASA to "develop a standard set of procedures, systems, interfaces, processes, and infrastructure across all the launch bases."[80] The Executive Summary concluded by asserting that "space launch is the key enabling capability for the Nation to exploit and explore space . . . [and] . . . serious deficiencies in space launch, if left uncorrected, will have profound impacts on the Nation's future space program."[81]

At first glance, it might seem a rather simple, straightforward process to achieve consensus among the parties involved. Past experience with rocket replacement programs, however, had shown that meeting military requirements and civil space requirements at the same time with one rocket was simply not possible. NASA needed a big rocket, whereas the Air Force had a whole range of payloads, including loads as small as the DMSP satellite. General Moorman realized the dilemma of getting the national security, civil, and commercial sectors to speak with one voice about the future: "I find that when you have roles and missions kinds of issues and stakeholder kinds of issues, understanding the needs of your customers and their perspectives is absolutely essential. If you have understanding and consensus, lots of things are possible." He insisted on having significant representation from the NRO and from NASA on a team that would avoid parochialism and keep him "in the loop." "Serendipitously," he said, "the administrator of NASA, Dan Golden, was a good friend, and [retired Air Force Gen James E.] Jimmy Hill, one of my closest friends, was the deputy director." He kept both, as well as former Air Force

Secretary Aldridge, up to date on progress of the study. Aware that Golden's challenge was to replace the shuttle and wanting to have a policy that NASA would be responsible for reusable systems, Moorman proposed that NASA oversee reusable launch and the military oversee expendable launch. As he noted, getting NASA's agreement to focus on Option 4 and DOD's to focus on Option 2 was the key to persuading both to finally agree on a launch strategy going forward.[82]

Fulfilling that recommendation from the Moorman Report, President Clinton signed a new National Space Transportation Policy (PDD/NSTC-4) on 5 August 1994. It gave the DOD responsibility for "improvement and evolution of the current U.S. expendable launch vehicle (ELV) fleet" that would evolve from, and ultimately supersede, the so-called "heritage" systems—Atlas, Titan, and Delta. Since the Air Force was the DOD executive agent for space launch, the task of ELV development devolved upon it. Simultaneously, NASA received the nod to develop the "next generation reusable space transportation systems," a Reusable Launch Vehicle (RLV) that would eventually replace the shuttle. Improvements in reliability and operability were major policy goals, but the primary objective was to reduce dramatically the cost of launching payloads into LEO. Although ELV and RLV managerial lines were clearly spelled out in President Clinton's statement, room remained for the Air Force and NASA to coordinate and cooperate, especially regarding research and development of core technology. Furthermore, implementation of PDD/NSTC-4 compelled the Departments of Defense, Commerce, Transportation, NASA, and the CIA to agree on a common set of requirements and a coordinated technology plan addressing the needs of the national security, civilian, and commercial space launch sectors.[83]

Ultimately, the DOD, with expected approval from Congress, selected Option 2 of the Moorman Report and by the end of 1994 had in place a "road map" for the acquisition of the EELVs. Looking ahead to the new century, the EELV program office planned for demonstration flights of the medium EELV and heavy EELV in 2000 and 2004, respectively, with production models of the medium and heavy versions ready to fly in 2002 and 2006, respectively. Meanwhile, the Air Force would consider extending the Atlas II and Titan IV contracts, if necessary, focus on RSA measures to reduce range operating costs, and make only limited improvements to the existing ELV fleet to made it more responsive.[84]

Operational Commands Address Launch Responsiveness in the Early 1990s

Space launch responsiveness had been a major focus of US Space Command and Air Force Space Command during the post-*Challenger* recovery program and especially after AFSPC acquired the space launch mission from the R&D community. The Space Launch Modernization Panel, however, did not specifically address the issue of launch responsiveness and the need for a rapid response capability but instead focused on cost reduction in the near and far term. It found only the new expendable and RLV designs able to improve responsiveness but, given their costs of $5 billion to more than $20 billion, Deputy Secretary of Defense John M. Deutsch declared them "unaffordable." As a result, the study team decided that short-notice space launch was unachievable and did not assess it in the group's final report.[85]

From the perspective of the operational commands, improving the launch responsiveness of the current ELV fleet was also a key element in their effort to operationalize space launch. The immediate issue was the challenge presented by launch delays that affected the entire ELV fleet. When Gen Charles R. Horner assumed command of AFSPC in June 1992, he took an immediate interest in the launch delays at both Cape Canaveral and Vandenberg. Particularly troublesome was the extreme example of the Titan IV-Centaur combination that had been stacked on the Launch Complex 41 pad for more than two years because of problems with the Centaur upper stage. Although the Titan case received the most scrutiny, the problem of launch delays extended to all ELVs. General Horner wanted to "find out why we can't launch on time." Horner had been known to quip, "That Titan IV was on the pad so long we're going to paint it and put a building number on it." At his direction, a Launch Delay Study Team convened in August 1993 "to determine the causes of launch delays . . . [and] . . . compile a list of specific recommendations to correct the problem." Although hampered by the old issue of insufficient, inaccurate quantitative data being kept by the launch elements, the study team uncovered 50 causes of launch delays, grouped them into seven categories, and offered 15 major findings with 21 associated recommendations.[86]

In the category of launch philosophy, the study team found that only AFSPC considered mission success to consist of "both on-time launch and successful satellite insertion into orbit." Because of the high cost of spacelift missions, the space community exhibited a "perfection mentality" that produced a slow and methodical approach to spacelift that resulted in lengthy launch delays. The team recommended greater discipline in the launch process and contractor incentives for successful on-time launches.[87]

A second "philosophical" issue causing launch delays was continuation of research and development "beyond the factory and laboratory setting" to the launchpads. Because Martin Marietta, the Titan IV contractor, for example, had no facility at its Denver location to conduct a complete integration test, that testing took place at the Cape's launch site after the vehicle had been stacked on the pad. The systems integration problems that invariably occurred, therefore, produced delays and prevented additional use of the pad. "This is the primary reason the first Titan IV-Centaur mission at Cape Canaveral AFS has been sitting on the pad for over two years," the study team pointed out. It recommended contractors be required to finish hardware and software development before launch processing and keep modifications to vehicle configuration at the pad to a minimum.[88]

The team examined management of the launch mission and criticized the confusion over roles and responsibilities. Too often the space launch squadrons deferred to SMC because the program officers controlled the contracts; AFSPC had operational mission launch deployment authority, but the national community NRO controlled boosters with its own payloads. The solution, according to the team, was a single management authority at the national level with AFSPC, as the owner of the launch bases and ranges, the clear choice for leadership of the spacelift community.[89]

Addressing other long-term management issues, the study team called for the 30th and 45th Space Wings to improve the exchange of information and promote standardization of common procedures. The Air Force should also obtain access to maintenance data for boosters and spacecraft, and it should develop an improved reporting system for the wings to effectively evaluate performance through a comprehensive post-launch assessment process.[90]

As for the current booster fleet, the study team confirmed the oft-stated criticism of the ICBM-based technology that resulted in extensive modifications, "wringing out the last ounce of performance in order to accommodate ever-growing spacecraft weights." Moreover, hardware problems accounted for 36.8 percent of the Titan launch delays over the past 30 years, and the figure had jumped to 46.3

percent in the previous decade. The near absence of an industrial base to support the aging systems only worsened the problem. The team's only solution was for the Air Force to acquire "an entirely new booster system."[91]

Aging hardware also contributed to delays at the Eastern and Western ranges by requiring time-consuming reconfigurations before most launches. Overcrowded launch schedules added to the problem. Despite efforts to improve the equipment of the ranges over many years, more than 25 percent of the major systems faced obsolescence, with no sources for spare parts. The team favored continuing the implementation of the RSA initiative with its objective of lowering the time required to configure either range to just one hour by fiscal year 1999. As for delays due to weather, the study recommended incorporating improved technology into new systems to make them more weather-resistant and provided examples, such as adaptive guidance systems that could be used with timely wind data to enable launches in stronger wind conditions.[92]

Two of the team's key findings on spacecraft design addressed deficiencies long recognized by AFSPC. One was the definite connection between launch delays and the lack of standard interfaces between boosters and upper stages, due in large part to many current spacecraft having been designed to fly on the shuttle rather than ICBM-based boosters. Again, the team highlighted the Titan IV's complex set of problems stemming from operating five different configurations supporting a number of different payloads developed by the civil, military, and national communities. As expected, the group advocated standard booster-to-payload interfaces but admitted this was a solution for future launch systems.[93]

A second finding related to spacecraft design dealt with increasing payload size and weight that had occurred from greater mission capability, inclusion of secondary payloads, and often the addition of fuel to further a satellite's life. To keep pace with evolving spacecraft requirements, booster contractors needed to modify launch vehicles and support systems, for example by mating boosters to selected high-performance engines. To single out the Titan IV again, changing payloads also meant switching engines because booster-engine–upper stage configurations had been selected to accommodate the launch requirements of particular payloads. The team's solution focused on future systems by recommending that program management directives specify that spacecraft design growth must conform to the performance characteristics of the existing booster fleet.[94]

Recognizing that problems with spacecraft, because of their uniqueness, generally caused the longest delays, the study team suggested satellites be processed not on the pad but in their own payload processing and encapsulation facilities. This would free up the launchpad for other payloads to be launched. The team noted that the use of off-pad payload facilities enabled all four commercial Titan IIIs to launch within weeks of their scheduled launch dates. The Air Force Titan IV, by contrast, required many months at the launch site to deal with its payload problems.[95]

The team completed its work in November 1993 and, in December, issued its "Space Launch Delay Study," perhaps the most impressive of the many assessments of space launch deficiencies of the previous eight years. General Horner endorsed the study team's report and directed AFSPC's Directorate of Logistics to start implementing the report's recommendations the next year. Some could be addressed to help improve the current fleet immediately, while others would have to await the arrival of the EELV fleet.[96]

Missileers Join the Operational Space Launch Force

That same year AFSPC received another operational "boost" with the acquisition of the ICBM nuclear mission. The merger drew both positive and negative reaction at the time. Proponents of the merger, like Moorman, argued in a 1994 interview that "the addition of missileers greatly strengthened Space Command," giving it greater influence within the larger Air Force community. He also cited their "great operational . . . non-rated . . . culture" and their "superb commanders and great young officers." In retrospect, Moorman remained positive about the addition of missile officers. Their inclusion "was giving the command more structure, giving the command a little bit more discipline, and bit of an operational cache." At the time, General Moorman did not directly comment on the missileers' impact on space launch operations.[97]

Other veterans of space launch considered the addition of missileers a major mistake. Generally, the critics focused on the missile officers' effort to "missilize" space. Outspoken Maj Gen Robert A. "Rosie" Rosenberg, USAF, retired, for one, was quite critical of Air

Force Chief of Staff General Merrill A. McPeak's decision and believed the merger a "disaster . . . [that] . . . resulted in the Air Force losing its competence in the space business as Space Command, led by SAC missileers became a 'checklist mentality' business that failed to recognize space ain't like ICBMs!" According to Colonel Whitehead, he was in a conference with General McPeak, who apparently said that "you should be able to do space launches just like you did ICBM launches, which none of us who had been in the space business believed." Whitehead said that McPeak later admitted he was wrong.[98]

Recently retired Lt Col Stosh Kowalski agreed with General Rosenberg and explained, "ICBMs was very rigid and checklist-oriented, while many space missions required a lot of flexibility and on-the-spot decision making by the crew. There definitely were some areas where space needed some checklists because they were just winging it," but creating a checklist for every contingency for a rocket launch meant preparing for "thousands of possibilities and wasn't feasible (although they tried)." Looking back, another seasoned space launch veteran, Col John Stizza, concurred, asserting also that the ICBM officers lacked the technical credentials to excel in spacelift because of the field's emphasis on "multiple moves, job changes, and shortened assignments . . . developing technical depth was not part of this ethos." Retired Col Richard McKinney stressed the nuclear factor. Coming from SAC, "they all understood that mentality and there's a certain way you operate when you operate nuclear weapons . . . or bad things happen. . . . They brought the checklist mentality with them to space, but up until then space had been under the acquisition side, and . . . you learn to kind of think on your feet and deal with problems and assess things. There wasn't any room for that on the nuclear side." Although the ICBM officers would soon realize that launching space vehicles was not the same as launching missiles or aircraft, the merger remained controversial until 2009 when the ICBM force joined the newly activated Global Strike Command.[99]

The Operational ELV Fleet in the 1990s and the Broad Area Review of 1999

Whether the addition of missileers helped "operationalize" space in terms of improved space launch capabilities remains problematic. As the responsible space launch operational command, AFSPC argued that its operational focus would improve the space launch fleet's performance. Stizza questioned this possibility, however, asserting that "any schedule [e]ffects you find during this timeframe are completely unrelated to government efforts to operationalize. . . . While the government focused on checklists . . . contractors worked the day-to-day issues and schedules. These launch systems flew exactly as they were designed. Any effort to make them fly faster was a fool's errand." Moorman also remained skeptical of measuring operational effectiveness. "I'm also a big metric guy—you are what you measure. What are your criteria? How do you measure becoming more operational? How do I implement that? That sounds simple but it's anything but. I'm not sure I've ever seen it, you know."[100]

In terms of mission success, the command could point to a remarkable five-year record beginning after 2 August 1993, when a Titan IV carrying a KH-11 Kennen satellite blew up at T+100 due to an SRM burn through of the case wall. After this first-ever Titan IV failure, the heavy-lift vehicle flew 17 successful missions until the August 1998 mishap. The three medium launch vehicles also achieved an impressive record during that five-year period. After the only Titan II failure, on 5 October 1993, the booster successfully launched NASA's Clementine lunar orbiter, a NOAA payload, and a DMSP satellite. The three versions of the Atlas II flew 34 missions without a failure, while the Delta II experienced a single mishap among its total of 37 flights.[101]

The command's positive launch record ended abruptly on 12 August 1998. On that date, the last Titan IVA, carrying a classified Mercury electronic intelligence satellite, was destroyed at T+40 seconds following an electrical short that caused the guidance computer to produce a fatal pitch-down maneuver. This Titan IV failure was followed by two more Titan IV losses within the span of a year. On 9 April 1999, a Titan IVB's inertial upper stage did not separate; an investigation determined that an incorrectly taped umbilical did not allow the connector to disengage from the booster and resulted in placing its DSP payload into a useless orbit. Just three weeks later, on 30 April, a Titan's Centaur attitude control failure resulted in its Milstar satellite being left in an erroneous orbit due to a misplaced decimal point in the software code. Additionally, two commercial Delta III launches failed during the same time span.[102]

Responding to directions from the Department of Defense, Air Force Chief of Staff Gen Michael E. Ryan convened a panel to "analyze the causes of recent launch failures; recommend changes in practices, procedures and operations that might prevent such failures; and assure continued access to space for the Department of Defense." Chaired by former Chief of Staff Welch, a panel comprising key figures from both government and industry conducted what became known as the Space Launch Vehicles Broad Area Review (BAR). The BAR addressed two "overarching issues": the mission success of the $20 billion effort to complete the current Atlas, Delta, and Titan "fly-out" effort and the building of confidence among military, civil, and commercial customers in the launch success of the EELV family during transition to the future systems. The BAR team started at the beginning of May 1999 and completed its investigation early that November.[103]

Examining the current fly-out fleet's launch record, the panel observed that during the previous 12 years the Atlas, Delta, and Titan systems experienced just 12 failures out of 200 launches for an average of one failure annually. During the previous 10 months, however, the same systems suffered five failures during just 25 launches. Noting significant vehicle problems had also increased in the previous nine months, the panel concluded that the recent Titan IV and Delta III failures resulted from engineering and factory workmanship errors. The BAR panel attributed much of the problem to a "premature 'going out of business' mindset" in both government and industry that reflected anticipation of the EELV program and, especially with the "chronically understaffed" Titan and IUS programs, pressure to accomplish marginal cost savings by reducing engineering, quality assurance, and mission success personnel in the launch area. Moreover, the BAR team concluded, "actions have been initiated that begin to dismantle the government oversight capability with extensive fly-out to complete." Indeed, over the previous five years, in-house Air Force support had declined by nearly 66 percent, while Lockheed Martin had made significant reductions in Titan IV's quality and engineering functions.[104]

Among the BAR's 10 recommendations for the fly-out programs, management and accountability received special attention. The team asserted the Air Force must "rigorously track contractor actions to focus program management on disciplined systems engineering and processes and implementation of corrective actions resulting from failures and Contractor Independent Reviews." To further support this action, the Air Force and DOD should reverse the manpower reductions in engineering support, ensure an increase in technical support at contractor facilities, and provide more technical personnel at the launch bases.[105]

Given the fragmentation of authority, responsibility, and accountability for delivering operational spacecraft on orbit across several Air Force elements and industry, the BAR team recommended that Space and Missile Systems Center be responsible for all actions leading to certifying the launch vehicle and spacecraft ready for launch, with AFSPC launching the vehicle and having complete authority over safety and range issues. Addressing a long-standing issue, the BAR cited the need to formalize the risk management program that had been degraded over the past decade. Such a program would include a risk management plan for all fly-out systems, provide comprehensive post-flight analysis, and share data among all space launch elements.[106]

In mid-November, shortly after the BAR team delivered the final briefing on its findings and recommendations, General Ryan directed AFSPC and Air Force Materiel Command to address the recommendations. He provided a lengthy list of assignments and offices responsible for implementing them. The success of this effort clearly became evident in the 100 percent launch success record of the fly-out systems in the new century. The Atlas II launched 26 times, with its last delivery to orbit, a classified Naval Ocean Surveillance Satellite, occurring on 2 February 2005. Contractors launched the last of 68 Delta II missions in the new century from Vandenberg's SLC-2W on 15 September 2018. Carrying an Earth-science payload, it represented the one-hundredth successful Delta II in a row. Finally, the Titan could also boast a 100 percent success rate with both versions. The last Titan II flight, its fourth since 2000, launched on 18 October 2003 with a DMSP satellite. The Titan IV, experiencing no significant issues during its 11 flights in the new century, flew its final mission on 15 October 2005, carrying an NRO KH-12 Crystal reconnaissance satellite.[107]

By this point the Air Force had already begun the operational flights of its new generation of Delta IV and Atlas V EELVs. The BAR investigators had also assessed the state of the transition to the EELV program in light of the problems that plagued the fly-out systems. Their assessment provided a road map for government and contractors and, together with improvements identified for the heritage systems, helped ensure the successful roll out of the new EELV operational systems. The EELV family of space launch vehicles would reflect many of the improvements recommended by the various post-*Challenger* space launch assessments.[108]

Conclusions

In the 13-year period from *Challenger* to the end of the century, the space launch issue remained central to every aspect of the space program because without assured access to space there could be no space program. In the atmosphere of self-examination after the *Challenger* tragedy and the Titan booster failures in 1985 and 1986, the Air Force moved at the highest levels to reassess not only its investment in the shuttle but its entire commitment to space.

Looking back on the experience, the post-*Challenger* launch recovery program took two paths. One involved having the heavy-lift Titan IV and three medium-launch vehicles operational as soon as possible while relying on the current force to fly out their remaining vehicles. By 1989, both the Titan II and Titan IV and the Delta II had launched their initial payloads, and the Atlas II was to follow three years later. With the Atlas operational, the Air Force had completed the initial ELV recovery effort and had overcome the three-year shuttle delay. A second recovery path gained momentum soon after *Challenger*, as well. The *Challenger*'s shock waves generated a variety of space studies that attempted to understand the present and chart the future of space launch. They provided decision-makers a realistic assessment of the current state of space launch, recommendations to improve the current fleet, and potential launch systems for the new century. In a sense, the various studies and proposals charted a course that culminated in the Space Launch Modernization Plan of May 1994. With that plan's EELV option selected by Air Force leaders, the service now had a clear path to what promised to be a responsive, reliable, and affordable family of EELVs in the twenty-first century.

Notes

1. Williamson, "Developing the Space Shuttle," 183–85; Air Force Space Command (AFSPC), *History of Air Force Space Command, January–December 1986,* 128–32; and Space Division (SD), *History of Space Division, October 1985–September 1986,* xxxiii, 55–56, 60, 132. See also Logsdon and Williamson, "U.S. Access to Space," 34.

2. McDowell, "Satellite Catalog," accessed 20 January 2019; Williamson, "Developing the Space Shuttle," 184–85; SD, *History of Space Division, October 1985–September*

1986, 60–67; and McGinley, *"Challenger* Panel Is Seen Rebuking NASA Officials," 2. For literature focusing on the shuttle tragedy, see Launius, "Toward an Understanding of the Space Shuttle," 15–18.

3. Williamson, "Developing the Space Shuttle," 185–88; SD, *History of Space Division, October 1985–September 1986,* 60–67; AFSPC, *History of Air Force Space Command, January–December 1986,* 128–32; and Logsdon and Williamson, "U.S. Access to Space," 34–36.

4. The booster companies found it difficult to retool quickly for production. SD, *History of Space Division, October 1985–September 1986,* 60–67; and Dworetzky, "The Launch Gap," 54–62.

5. In discussions with DOD officials, however, NASA agreed that the shuttle manifest after resumption would be largely dedicated to national security missions. SD, *History of Space Division, October 1985–September 1986*, 60–67; AFSPC, *History of Air Force Space Command, January–December 1986,* 131; Dworetzky, "The Launch Gap," 54–62; Logsdon and Williamson, "U.S. Access to Space," 34–40; United States Air Force/XO, "DOD Space Launch Systems"; and Welling, "Questions Remain for Space Command," 26–30.

6. SD, *History of Space Division, October 1987–September 1988*, 49–51; SD, *History of Space Division, October 1985–September 1986*, 60–67; SD, *History of Space Division, October 1986–September 1987,* xli–xliii; AFSPC, *History of Air Force Space Command, January–December 1986,* 128–32; Eastern Space and Missile Center (ESMC), *History of the Eastern Space and Missile Center, 1 October 1988–30 September 1989*, 87, 91; Dworetzky, "The Launch Gap," 54–62; Logsdon and Williamson, "U.S. Access to Space," 34–40; United States Air Force/XO, "DOD Space Launch Systems"; and Welling, "Questions Remain for Space Command," 26–30; For descriptions of the Atlas E/Fs, Gs, and Hs, see ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present*, B-3.

7. SD, *History of Space Division, October 1987–September 1988,* 49–51; SD, *History of Space Division, October 1985–September 1986,* 60–67*;* SD, *History of Space Division, October 1986–September 1987,* xli–xliii; AFSPC, *History of Air Force Space Command, January–December 1986,* 128–32; Dworetzky, "The Launch Gap," 54–62; Logsdon and Williamson, "U.S. Access to Space," 34–40; United States Air Force/XO, "DOD Space Launch Systems"; Welling, "Questions Remain for Space Command," 26–30; and David, *Spies and Shuttles*, 234–43.

8. See Characteristics of US Launch Systems, circa 1994, in appendix B.

9. Whitehead, email, 18 March 2019; see also his briefing in response to Secretary Aldridge's request to reassess the use of Titan II as a space booster: "Use of the Titan II as Space Launch Vehicle," 17 January 1984; ESMC, *History of the Eastern Space and Missile Center, 1 October 1986–30 September 1987,* 97; Government Accounting Office (GAO), *Military Space Programs: An Unclassified Overview of Defense Satellite Programs and Launch Activities,* 60; SD, *History of Space Division, October 1985–September 1986,* 79–83; SD, *History of Space Division, October 1987–September 1988,* 57–59; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems,* 448, 464; and ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present,* C-4, C-9, C-10, C-19, C-22, C-30.

10. SD, *History of Space Division, October 1987–September 1988,* 57–59; and Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems,* 484.

11. SD, *History of Space Division, October 1987–September 1988,* 57–59; Space and Missile Systems Center (SMC), *History of the Space and Missile Systems Center, October 1991–September 1992,* 117–18. At one point, Air Force planners thought

that the remaining unrefurbished Titan IIs stored at Norton Air Force Base, California, could be used as government-supplied assets for the competitive procurement of the third medium launch vehicle (MLV III). Ultimately, the government selected an upgraded Delta II as its MLV III.

12. United States Space Command (USSC), *United States Space Command, Command History, 1995–1996,* 212; McDowell, "US Reconnaissance Programs," part 1, 22–33; McDowell, "US Reconnaissance Programs," part 2, 40–45; McDowell, "Satellite Catalog," accessed 8 September 2018; and *TRW Space Log 1996,* 260–333.

13. The Titan IVs were 10 feet in diameter. Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 449; ANSER, *United States Launch Vehicles,* C-4, C-8, C-11 to C-19; Whitehead, "Titan Launch Vehicle Program at Lockheed Martin Astronautics," 4; McDowell, "US Reconnaissance Programs," part 1, 22–33; and McDowell, "US Reconnaissance Programs," part 2, 40–45.

14. Space Systems Division (SSD), *History of the Space Systems Division, October 1990–September 1991,* 137–39; GAO, *Military Space Programs*, 48; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 449, 457; Whitehead, "Titan Launch Vehicle Program at Lockheed Martin Astronautics," 4–5; and *TRW Space Log 1996,* 260–333.

15. GAO, *Military Space Programs,* 48; SSD, *History of the Space Systems Division, October 1990–September 1991,* 117–18, 140–41; and SSD, *History of the Space Systems Division, October 1989-September 1990,* 216–17.

16. SD, *History of Space Division, October 1986–September 1987,* 65–66; and SSD, *History of the Space Systems Division, October 1989–September 1990,* 135.

17. Even with the EELV's Standard Interface Specification (SIS), payloads required individualized "tailoring." Although Isakowitz's *International Reference Guide to Space Launch Systems,* p. 449, asserts that the B model had a "standardized core configuration and interfaces," this is disputed by Colonel Whitehead and other Titan IV veterans. Whitehead, email, 12 June 2019; Coglitore, email, 11 April 2017; Stizza, email, 10 June 2019; and SSD, *History of the Space Systems Division, October 1989–September 1990,* 121–23.

18. As Col Richard W. McKinney, Program Element Monitor for the Titan IV, observed, the first flight of the Titan IV from the Cape experienced an anomaly when one of the two engine nozzles partially broke away and the other nozzle "gimballed strongly to help even out the thrust." The mission was a success, but "it was a close call." McKinney, "Manuscript Review Comments," 24 January 2020; McDowell, "US Reconnaissance Programs," part 1, 22–33; McDowell, "US Reconnaissance Programs," part 2, 40–45; and *TRW Space Log 1996*, 272–333.

19. SD, *History of Space Division, October 1987–September 1988,* 63–66; and Whitehead, email, 18 March 2019.

20. SD, *History of Space Division, October 1988–September 1989,* 101–2; SSD, *History of Space Systems Division, October 1989–September 1990,* 173–74; ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present,* A-7, A-9 to A-11, A-17; GAO, *Military Space Programs,* 58; and Isakowitz, Hopkins, and Hopkins, Inter*national Reference Guide to Space Launch Systems,* 96, 112, 115–18. The enhanced Delta II won the MLV-III competition to launch the heavier GPS IIR satellites.

21. SD, *History of Space Division, October 1987–September 1988,* 63–66, 71–72, 77–78; GAO, *Military Space Programs,* 58; SSD, *History of Space Systems Division, October 1987–September 1988,* 107–10; and *TRW Space Log 1996*, 269–333.

22. SSD, *History of Space Systems Division, October 1989–September 1990,* 182–83; SMC, *History of the Space and Missile Systems Center, October 1991-September 1992,* 106; and ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present,* B-5.

23. ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present,* B-1, B-5, B-8 to B-10, B-12, B-13; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems,* 54, 68–72; and GAO, *Military Space Programs,* 54. Retired General Dynamics Space Systems engineer John Silverstein commented, "The General Dynamics board agreed to fund the first ten commercial Atlas-Centaur launchers without a firm order in hand. Our then current work designing and building the wide-body Centaur for the Titan IV provided some base in both the engineering and manufacturing areas in our plant to keep the lights on." Silverstein, email, 22 March 2018.

24. SSD, *History of Space Systems Division, October 1989–September 1990,* 183-188; and SMC, *History of the Space and Missile Systems Center, October 1992-September 1993,* 74–76.

25. SSD, *History of Space Systems Division, October 1988–September 1989,* 116; and Stizza, email, 10 June 2019.

26. SSD, *History of Space Systems Division, October 1988–September 1989,* 111; SSD, *History of Space Systems Division, October 1989–September 1990,* 192–99; and Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems,* 65. At the Cape, LC 36A was designated for Air Force missions and LC 36B for commercial flights.

27. SD, *History of Space Division, October 1987–September 1988,* 112–19; and ESMC, *History of the Eastern Space and Missile Center, 1 October 1986–30 September 1987,* 128–35.

28. See note 26; AFSPC, *History of Air Force Space Command, January–December 1987,* 133–35.

29. AFSPC, *History of Air Force Space Command, January–December 1987,* 133–35; and SD, *History of Space Division, October 1986–1987,* 71–72.

30. AFSPC, *History of Air Force Space Command, January–December 1988,* 140–41; and SD, *History of Space Division, October 1987–September 1988,* 115–23.

31. AFSPC, *History of Air Force Space Command, January–December 1987*, 133–35; SD, *History of Space Division, October 1986–1987*, 71–72; ESMC, *History of the Eastern Space and Missile Center, 1 October 1987–30 September 1988,* 109–16; and ESMC, *History of the Eastern Space and Missile Center, 1 October 1989–30 September 1990,* 355–62.

32. AFSPC, *History of Air Force Space Command, January–December 1988,* 140–44.

33. AFSPC, *History of Air Force Space Command, January–December 1988,* 140–44; and SD, *History of Space Systems Division, October 1988–September 1989, 64,* 138–44. General Kutyna became the new three-star commander of Air Force Space Command on 19 October 1987. ALS also considered a "new" philosophy toward boosters by challenging the traditional assumption that "weight is bad." As argued by the ALS program manager, Col John Wormington, "If you start out with the idea that what you're after is low cost and not low weight, it turns out you can in fact spend weight and save money." This was possible because larger vehicles produced better cost per pound ratios, recurring costs did not increase with size, and higher reliability could be achieved with standardization of the core vehicle and tankage. This concept of the minimum-cost-design booster, commonly referred to as the Big Dumb Booster, had been under discussion in the 1960s and early 1970s before dismissed when the Air Force committed to the space shuttle. Although it resurfaced in the post-*Challenger* era, it never achieved serious consideration apart from a review under the ALS purview. See R. M. Allman, "Minimum-Cost-Design Space Launch Vehicle"; also see the comprehensive study, London, *LEO on the Cheap: Methods for Achieving Drastic Reductions in Space Launch Costs;* and Whitehead, USAF, email to the author, 11 June 2019. See an expanded biography of Gen John L. Piotrowski in appendix A.

34. On 23 September 1985, DOD created the United States Space Command, a unified command for space operations directly responsible to the Joint Chiefs of Staff. Spires, *Beyond Horizons*, 230–31.

35. US Space Command (USSC), *United States Space Command, Command History, January 1987–December 1988,* 56–60.

36. AFSPC, *History of Air Force Space Command, January–December 1987,* 135–36; USSC, *United States Space Command, Command History, January 1987–December 1988,* 242–49; and AFSPCACECOM, "Operational Space Launch." Also see the discussion of launch strategy in US Senate, *Air Force Space Launch Policy and Plans.*

37. AFSPACECOM, "Transfer of Space Launch Operations to AFSPACECOM"; and AFSPC, *History of Air Force Space Command, January–December 1990,* 81–84.

38. AFSPC, *History of Air Force Space Command, January–December 1990,* 81–85.

39. SD, *History of Space Division, October 1987–September 1988,* 547–54.

40. SD, *History of Space Division, October 1987–September 1988,* 547–54; and SD, *History of Space Division, October 1988–September 1989,* 588–91, 632–35. See also Piotrowski, "C3I for Space Control," 23–33; and Piotrowski, "The Right Space Tools," 46–48.

41. AFSPC, *History of Air Force Space Command, January–December 1990*, 81–85.

42. Air Force Systems Command (AFSC)-Air Force Space Command, *Launch Responsiveness Study Final Report,* April 1988, 1–2; AFSPC, *History of Air Force Space Command, January–December 1988,* 145–46; and SSD, *History of Space Systems Division, October 1988–September 1989,* 58–60.

43. AFSC-AFSPC, *Launch Responsiveness Study Final Report,* 2-1 to 2-7.

44. AFSC-AFSPC, 1-5 to 1-10.

45. AFSC-AFSPC, 1-10 to 1-12. The P3I initiative had been introduced in both the Delta II and Atlas II development programs.

46. AFSC-AFSPC, *Launch Responsiveness Study Final Report,* 1-12 to 1-13.

47. AFSPC, *History of Air Force Space Command, January–December 1988,* 146.

48. SD, *History of Space Division, October 1988–September 1989,* 57–58; and AFSPC, *History of Air Force Space Command, January–December 1990*, 84–87.

49. While the Air Force had modest success with small space launchers like Pegasus and Taurus, a more focused effort on launch-on-need capabilities would have to await the new century. For a discussion of the work of Space Systems Division's Small Launch Vehicle Program Office, see SSD, *History of Space Systems Division, October 1989–September 1990,* 237–42. See also Spires, *Beyond Horizons,* 323–27; on the Blue Ribbon Panel, see Spires, *Beyond Horizons,* 234–38; for the *Report on the Blue Ribbon Panel Study of the Future of the Air Force in Space,* May-August 1988, see Spires, *Orbital Futures*, vol. 1, 386–95.

50. Spires, *Orbital Futures*, vol. 1, 386–95.

51. SD, *History of Space Division, October 1987–September 1988,* 113–18; and AFSPC, *History of Air Force Space Command, January–December 1988,* 143–44.

52. Spires, *Beyond Horizons,* 237–38; AFSPC, *History of Air Force Space Command, January–December 1988,* 142; AFSPC, *History of Air Force Space Command, January–December 1989,* 157-159; and ESMC, *History of the Eastern Space and Missile Center, 1 October 1989-30 September 1990,* 356–62. ALS technology benefitted the current fleet of Atlas, Titan, and IUS vehicles with automated ground support systems, off-line processing, "paperless" management techniques, and the development of low-cost engines.

53. Spires, *Beyond Horizons,* 238; McDowell, "US Reconnaissance Programs," part 1, 22–33; and McDowell, "US Reconnaissance Programs," part 2, 40–45. See an expanded biography of Gen Donald K. Kutyna in appendix A.

54. Spires, *Beyond Horizons*, 239. The operational experience referenced by Kutyna refers to the 10th AERODS, the ADCOM blue suit unit which for many years flew Thor DMSP flights from Vandenberg.

55. Spires, *Beyond Horizons*.

56. Spires, *Beyond Horizons*, 240.

57. Spires, *Beyond Horizons*.

58. Spires, *Beyond Horizons*, 240-41.

59. For discussion of the additional organizational changes in the wake of the space launch transfer, including standing up the 30th and 45th Space Wings and developing memorandums of agreement between AFSPC and AF Materiel Command, see AFSPC, *History of Air Force Space Command, January–December 1990,* 93–107; and AFSPC, *History of Air Force Space Command, January–December 1991,* 137–46.

60. Spires, *Beyond Horizons,* 243.

61. Spires, 244–45.

62. Spires, 268. Part of the problem was the philosophy of Congress and the Air Force to avoid funding expensive spare satellites, a philosophy that has continued to the present day.

63. Spires, 267–69; AFSPC, *History of Air Force Space Command, January–December 1991,* 146–51; AFSPC, *History of Air Force Space Command, January 1992–December 1993,* 293–306; USSC, *History of United States Space Command, Command History, 1992,* 43–48; SMC, *History of the Space and Missile Systems Center, October 1991–September 1992,* 141–49; and SMC, *History of the Space and Missile Systems Center, October 1992–September 1993,* 102–9.

64. Spires, *Beyond Horizons*, 244–45.

65. Spires.

66. Spires. The instructions to terminate the NLS came from the Defense Appropriations Conference Committee meeting on 5 October 1992.

67. Spires.

68. Department of Defense, *Annual Report to the President and the Congress, "Space Forces,"* January 1994, 226; Spires, *Beyond Horizons*, 268–69; SMC, *History of the Space and Missile Systems Center, October 1992-September 1993*, 108–9; and USSC, *History of United States Space Command, Command History, 1992,* 48.

69. Spires, *Beyond Horizons*, 244–45. See an expanded biography of Gen Thomas S. Moorman Jr. in appendix A.

70. Department of Defense (DOD), "Space Launch Modernization Plan, Executive Summary," April 1994, 1–2. The document is found in Spires, *Orbital Futures,* vol. 2, 905–45; see also, AFSPC, *History of the Air Force Space Command, 1 January 1994-31 December 1998 and 1 January 1999-31 December 2003 Combined,* 341–53; 45th Space Wing (SW), *History of the 45th Space Wing, 1 January-31 December 1994,* 48–55. See "Characteristics of US Launch Systems" in appendix B.

71. DOD, "Space Launch Modernization Plan," 6–10.

72. DOD, "Space Launch Modernization Plan." The reduced Titan IV launch rate would require a "slow-down" of Titan production.

73. DOD, "Space Launch Modernization Plan," 15–17, 20.

74. DOD, 17–18, 21.

75. DOD, 18, 22.

76. DOD, 18–19, 23.

77. DOD, 25–28, 30.

78. DOD, 27–29.

79. DOD, 30–31.

80. DOD. Standardization continued to bedevil those involved. Brig Gen Glenn C. "Clint" Waltman, who commanded the 45th Operations Group at Patrick AFB from August 1993 to April 1995, remembered, "Gen Joe Ashy, then the AFSPC/CC, grabbed me and the 30 SW/OG (Col Gary Harmon) by the throats and told us to 'standardize' the ranges. Other than some cosmetic changes we failed. There was just too much bureaucratic and organizational inertia." Waltman, email, 13 May 2017.

81. DOD, "Space Launch Modernization Plan, Executive Summary," 32.

82. Richard McKinney, the initial program director of the Evolved Expendable Launch Vehicle (EELV) program, asserted "that was (Moorman's) initiative . . . his brilliance, and that's what made it work." McKinney, interview, 11 December 2019; Moorman, interview, 23 December 2019; and McKinney, "Manuscript Review Comments," 24 January 2020.

83. Cooperation between NASA and the Air Force continued. Four years later, in November 1998, the NRO joined the two agencies to form the Air Force-NRO-NASA Partnership Council to pursue common interests in reducing costs and, simultaneously, improving capabilities within four essential areas: launch, infrastructure, command and control, and industrial base. Spires, *Beyond Horizons*, 295; and Office of Science and Technology Policy, *"Fact Sheet—National Space Transportation Policy,"* see Spires, *Orbital Futures*, vol. 2, 946–52.

84. 45th SW, *History of the 45th Space Wing, 1 January–31 December 1994,* 55; and AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined,* 353–56.

85. AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined,* 353–53.

86. Moorman, interview, 23 December 2019; AFSPC, "Space Launch Delay Study"; AFSPC/LGML, "Launch Delay Study Draft Briefing," as of 15 October 1993; and AFSPC, *History of Air Force Space Command, January 1992–December 1993*, 315–17. The lengthy delay of the Titan IV at LC-41 was due to Centaur issues. A commercial Atlas I (Atlas-Centaur) failure, in April 1991, prompted contractors to redesign, replace, and retest the Centaur's separation ring and aft adapter. Given the delay, the classified program decided to substitute the next Centaur off the production line (TC-9) for TC-8, already mated to the Titan on LC-41. TC-8 was removed and TC-9 mated to the Titan on 7 January 1992, but test failures of the TC-9 components in April delayed the ILC until December 1992. Meanwhile, another Atlas I failure on 22 August 1992 meant further inspections, component replacements, and additional delays. The Titan IV-Centaur finally launched from LC-41 on 3 May 1994. After this embarrassing experience, the Air Force decided in June 1992 that a Titan-Centaur would be destacked if standing on the pad for more than a year. SMC, *History of the Space and Missile Systems Center, October 1991–September 1992,* 132–36.

87. AFSPC, "Space Launch Delay Study," 5–6.

88. AFSPC, 6–8.

89. AFSPC, 8–9.

90. AFSPC, 9–13.

91. AFSPC, 13–15.

92. AFSPC.

93. AFSPC, 16–17.

94. AFSPC.

95. AFSPC, 18.

96. AFSPC, *History of Air Force Space Command, January 1992–December 1993,* 324.

97. Moorman, interviews, 7 November 1994, 23 December 2019.

98. Rosenberg, email, 27 February 2017; and Whitehead, email, 18 October 2017.

99. Kowalski, email, 21 February 2017; Stizza, email, 27 February 2017; and McKinney, interview, 11 December 2019.

100. Stizza, email, 11 June 2019. It should be noted that AFSPC commanders also had to deal with space launch infrastructure badly in need of upgrading the deteriorating launch and range facilities and dated technology. As General Kutyna declared in April 1992, "Regrettably, years of neglect, underfunding, and deterioration due to age have brought us to the point of near crisis." For a discussion of the issue, see USSC, *United States Space Command, Command History 1992,* 40–42.

101. Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems,* 65–66, 108–10, 452–53.

102. AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 382–83; SMC, *History of the Space and Missile Systems Center, 1 January 1998–31 December 2001,* 51; and McKinney, "Manuscript Review Comments," 24 January 2020.

103. AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined,* 383–84; SMC, *History of the Space and Missile Systems Center, 1 January 1998–31 December 2001,* 51–52; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1999,* 44; and Institute for Defense Analyses (IDA), "Space Launch Vehicles Broad Area Review Report [BAR I]," November 1999, 5.

104. IDA, "BAR I," 7–18. It should be recognized that not everyone agreed with the BAR's assessment. Vic Whitehead, for example, who was vice president of Space Launch Systems at Lockheed Martin Aerospace at the time of the failures, declared them the result of "simple errors by experienced people with drastic results." He prepared a six-foot-long chart depicting the segment history timeline and the 20 to 30 separate reviews by the Titan team and government/Aerospace Corporation team that cleared the first Titan that failed for flight. Moreover, he did not believe lack of government oversight was a factor and knew "for a fact that as far as Titan went, there was no 'Going Out Of Business' attitude." Whitehead, emails, 11 June 2019, 12 June 2019.

105. IDA, "BAR I," 32–33.

106. IDA, "BAR I," 25, 29–30.

107. AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined,* 388; and McDowell, "Satellite Catalog," accessed 8 September 2018.

108. Key improvements would include modular components, standardized interfaces, common core vehicles, off-pad processing and encapsulation, and numerous common components.

Chapter 7

Evolved Expendable Launch Vehicles

1995–2019

At the end of the twentieth century, the Air Force looked to the EELV program to represent the nation's response to the challenge of achieving and maintaining assured access to space in the new century. The National Space Transportation Policy, issued by the Clinton administration on 4 August 1994, declared that "assuring reliable and affordable access to space through U.S. space transportation capabilities is a fundamental goal of the U.S. space program." To realize this objective, the policy directed the Department of Defense to serve as the "lead agency for improvement and evolution of the current expendable launch vehicle fleet, including appropriate technology development." In effect, it had chosen the Moorman Report's EELV concept option as the best approach to manage cost and risk. As the DOD executive agent for space launch, the Air Force, working through Air Force Space Command and the Space and Missile Systems Center's (SMC) EELV program office, was to "improve and evolve current ELVs" with the objective of reducing costs, "while improving reliability, operability, responsiveness, and safety." The EELV fleet of space launchers would compile a perfect launch record from its initial launch in 2002 to the end of the program in 2019 when, at congressional direction, DOD renamed the program the National Security Space Launch program to reflect the advent of reusable and partially reusable rockets and their components.[1]

An Innovative Approach to EELV Acquisition

The acquisition portion of the EELV program went through three phases on the road to operational capability. After several months developing medium- and heavy-lift launch requirements for the defense, intelligence, and civil sectors, the SMC issued a request for proposal (RFP) on 17 May 1995 for the first phase, termed Low Cost Concept Validation. That August SMC awarded four competitive, 15-month, $30 million contracts to Alliant Techsystems Inc., The Boeing Company's Defense and Space Group, Lockheed Martin Corporation's Astronautics Division, and McDonnell Douglas Aerospace to produce design concepts for EELV and methods to reduce the risks associated with EELV development. OSD established an EELV development cost target of $2 billion (in then-year dollars) and initially projected a fleet of 193 (177 national security and 16 NASA) EELV launches from FY 2002 to FY 2020.[2]

The Air Force and DOD expected to reduce the cost of military space missions by purchasing commercial launch services, as had been partially done with the Delta II and Atlas II programs. Vehicle hardware, associated infrastructure, and operational support would remain the responsibility of the providers. The EELV program envisioned a family of vehicles that were contractor-owned and -operated that could achieve a 25 percent reduction in production and launch costs. Planners also had "an objective of 50 percent reduction in the annual cost of spacelift" that, by 1995, had reached an estimated $22.5 billion for the current generation of ELV heritage launch vehicles. The program also called for a 45-day processing time for medium launchers and 90 days for heavy-lift vehicles and a more efficient launch system capable of lofting payloads weighing from 2,500 pounds to 45,000 pounds into LEO. The EELV program objectives were to be achieved while maintaining, as a minimum, the reliability and capability levels of the current programs.[3]

In June 1995, one month after SMC issued the initial RFP, Col Richard W. McKinney arrived at SMC headquarters to lead the EELV effort as System Program Director, a position he would hold for the next four years. Like the unique arrangement made for Gen Bernard A. Schriever to rapidly develop the Atlas ICBM in the 1950s, McKinney had a very short reporting chain that authorized him to bypass the SMC commander and report directly to the Pentagon's Program Executive Office, which, in turn, reported to the secretary of the Air Force for Acquisition.[4]

On 20 December 1996, Lockheed Martin and McDonnell Douglas received 18-month, $60 million contracts for phase two, known as Pre-Engineering and Manufacturing Development. Scheduled to end in the spring of 1998 with selection of one of the competitors, this phase required the two contractors to refine system specifications, verify production process capabilities and risk-reduction measures, and describe cost improvements. Lockheed Martin decided to streamline rather than replace its current launch operations practices and based its family of launchers on its Atlas IIAR-Centaur. McDonnell

Douglas, which Boeing acquired in 1997, chose to evolve its new family of spacelifters from Delta II and Delta III launch vehicle designs. According to McKinney, however, "it turned out really the evolved was kind of a misnomer." In fact, relying on design simplicity and new applications of existing technology, the contractors used very little of these older Delta and Atlas systems other than their names. As McKinney explained, "the Delta rocket was all new, and the Atlas program was essentially all new, too." They had different engines, different avionics, and bigger stages. Only the Centaur upper stage was common to both vehicle families, with its RL-10 engine modified for the Delta and less so for the Atlas.[5]

The strategy of selecting one company for phase three, known as Engineering and Manufacturing Development (EMD), reflected the conventional wisdom that the commercial market could not support two launch systems. Changes had occurred, however, in the launch market since the 1994 Moorman Report; by 1996, all four competitors argued that the market could sustain more than a single provider, and McKinney responded by contracting the Commercial Space Transportation Advisory Council to assess market trends. Its report concluded that the commercial sector had overtaken the government's portion and demonstrated increasing growth potential. Indeed, the international commercial demand for geosynchronous transfer orbit (GTO) flights was expected to reach as many as 40 launches annually. Given the positive forecasts of a strong commercial satellite market, especially for communication satellites, in November 1997 the Office of the Secretary of the Air Force for Acquisition responded to McKinney's recommendation by deciding on the innovative strategy of awarding two EMD contracts for development of two EELV systems, which would more effectively support the Air Force strategy of assured access to space. Two contractors also could be expected to provide more effective competition for future government launches and, with both vehicle families using standard payload interfaces, to better ensure that DOD payloads could be flown should one contractor's fleet of vehicles be grounded. In October 1998, the Air Force competitively awarded Boeing a $500 million contract to develop the Delta IV, together with a $1.36 billion Initial Launch Services (ILS) contract for 19 launches. Lockheed Martin also received a $500 million Atlas V development contract and a $650 million ILS contract for nine launches. The contracts called for demonstration flights in the year 2000, with production versions of the medium

EELVs to begin flying in 2002. The next year, each contractor's heavy-lift vehicle would fly a demonstration flight, with production models prepared to launch from Vandenberg in 2005 and the Cape in 2006. Planners expected to achieve a 20-year life cycle cost savings of $6.2 billion, or nearly 31 percent, over current heritage systems.[6]

In what was a cost-sharing arrangement between the government and the two contractors, the latter received only partial funding to develop the two EELV systems. The contractors would provide the remainder, in return for retaining ownership of flight hardware, launch operations, and system designs that allowed them to determine development plans for their long-term corporate objectives. The new acquisition strategy, which gave the EELV contractor total system responsibility, required the Air Force to function more as a commercial customer and to forego its traditional approach toward mission assurance, risk management, and general program control—to replace its oversight role with an approach called "insight." Because the Air Force expected the commercial providers to be launching for more customers than the military, there was no need to take delivery. The Air Force expected that sufficient insight would be available for its Air Force Materiel Command to ensure flight-worthy vehicles and for AFSPC, once the vehicle reached the launch base, to conduct government mission assurance activities and confirm EELV safety in ground and flight operations.[7]

The adoption of insight also reflected the effort of Darleen Druyun, acting Secretary of the Air Force for Acquisition, to manage programs faster and cheaper with fewer people. As a result, McKinney had to conduct the entire EELV program with an initial contingent of only 50 people. His "insight crowd" had to ensure the contractors fulfilled three requirements: first, ability to launch mass to orbit with 10 to 12 different orbits and payloads; second, design systems to 98 percent designer liability; and third, provide the two vehicle families a standard interface. If they met those three requirements, the contractors could do "whatever the heck they wanted to." Indeed, the process allowed a great deal of innovation because the contractors did not have huge government overhead to deal with.[8]

Colonel McKinney cited two factors that made his insight effort successful. First and foremost, he said "you need technically very sharp people" to effectively monitor the contractors' design and identify problems meeting one or more of the criteria without telling them how to solve the problem. Second, in a "revolutionary" measure for the mid-1990s, his program office had access to all contractor technical and programmatic data. "We had access to their computer systems," he explained. "We set up separate rooms . . . in the program office for those working on Atlas and on Delta" without each having access to the other's data, and just logged into their system." He also sent small teams to the contractor plants three weeks out of four, and they were able to sit in on any meeting they chose to attend. At the same time, improvements in computers and the internet made it easier to provide insight remotely. McKinney would later assert that much of the EELV program's remarkable success "goes back to the rigor and the insight that we had at the very beginning in the design because once the design is done . . . the main decisions are done."[9]

On the contractors' side, standardization—through the use of standard boosters, payload interfaces, modular design to accommodate the various payloads, launch platforms, and common infrastructure to support all EELV configurations—played a key role in meeting the program goals. Col Robert K. Saxer, who succeeded McKinney as EELV program director, described the dramatic reduction in development time. "What used to take weeks and months is now accomplished in hours or days," he explained, "thanks to simpler producible designs, automated focused factories, dedicated transportation systems, off-pad vehicle and payload processing, and integrated training centers and data enterprise networks."[10]

One of the most important accomplishments of the EELV program was the creation of a standard interface for all payloads. Termed the Standard Interface Specification (SIS), this joint government-industry team document contained over 100 requirements for every element of the launch vehicle–spacecraft interface. In addition to mechanical and electrical interfaces, the SIS included "mission design requirements, flight environments, and ground interfaces and services." The SIS promoted the dual integration of payloads to fly on both vehicle families and also facilitated shifting a payload from one spacecraft class to another, because 90 percent of the interface requirements applied to all medium, intermediate, and heavy-lift versions. As Aerospace Corporation's Randy Kendall observed, "The fact that both Delta IV and Atlas V provide the same standard interface is a significant improvement over the heritage systems, where moving from a Delta II to an Atlas II or from an Atlas II to a Titan IV was highly complex, if at all possible." Standardization in the development of the Delta IV and the Atlas V also made them more cost effective and enabled contractors to use the systems for commercial missions to benefit from the projected robust commercial space launch market.[11]

Colonel McKinney took pride in his office's innovative source selection procedures. He noted that he had supervised three source selections in less than three and a half years and developed a number of cutting-edge ways to do source selection rapidly. He said that, previously, companies would literally drive up to the program office door with a large truck full of binders of proposals. His office, instead, asked for two copies and a disk. As he argued, "We pioneered electronic source selection . . . we had a lot of innovations on just how to do a source selection, how to do it quickly." Invariably, he also included operators from AFSPC in the source selection process to ensure that the operator's viewpoint received consideration. Citing current practices that often might take more than a year, he said his office conducted source selections in 120 days. "You can do it quickly," he added, "if you have very clear requirements, good leadership from above, and then understanding what you're trying to get done." Reflecting on his experience as EELV program director, McKinney declared, "I think we lived up to the Moorman legacy on creating the EELV. It was evolved but it was mainly new evolved."[12]

The Delta IV and Atlas V EELVs

Boeing's plan called for developing five variants of the Delta IV with "dial-a-ride" designs to permit additional on-orbit capability for marginal cost. All five would use a 16.4-foot diameter common booster core (CBC) powered by an Aerojet Rocketdyne RS-68 main engine, the first American liquid oxygen–liquid hydrogen engine developed and flown since the space shuttle. Rocketdyne designed the RS-68 engine to be environmentally friendly, manufactured with fewer parts, and 30 percent more efficient than Delta's earlier liquid oxygen–kerosene engines. The standard Delta IV Medium-Lift configuration included a CBC, a Delta III cryogenic second stage, and a Delta III 13.1-foot diameter payload fairing. Slightly heavier payloads could be lofted into orbit by three Delta IV Medium-Plus variants using Alliant Techsystems solid Graphite-Epoxy Motors (GEM). To supplement liftoff, one variant used two GEMs with a 4-meter diameter fairing (designated Delta IV Medium-Plus 4,2), another with a 16.4-foot diameter fairing (designated Delta IV Medium-Plus 5,2), and a third variant used four GEMs with a 16.4-foot diameter fairing (designated Delta IV Medium-Plus 5,4). The Delta IV Heavy, the fifth version of Boeing's EELV family, consisted of three CBCs strapped together, an expanded Delta III cryogenic upper stage with enlarged tanks, and a 16.4-foot fairing. The standard Delta IV was projected to loft 10,000 pounds to GTO, while the three Delta "pluses" were expected to carry GTO payloads of approximately 10,700 pounds, 12,700 pounds, and 14,700 pounds, respectively.[13]

The Delta IV Heavy, the world's first all-cryogenic (LOX-LH2) heavy-lift space launch vehicle, was intended to boost up to 33,000 pounds to GTO. To reduce weight and parts count for the Delta IV, composite materials were used to build all principal structures. Boeing elected to build the CBC in a $400 million production facility underway by 1998 in Decatur, Alabama, while Halter Marine of Pascagoula, Mississippi, received a contract to produce a vessel capable of transporting up to three CBCs at once from Decatur to Vandenberg or Cape Canaveral. Both Boeing and Lockheed Martin had standardized launchpads on each coast. At Vandenberg, the Delta IV would use Space Launch Complex 6, the site once programmed for the space shuttle, and at the Cape Complex 37, once the launch site of NASA's Saturn I and Saturn IB launch vehicles. To avoid launchpad delays, contractor personnel would assemble the vehicle horizontally off-pad, erect it, roll it out to the pad, then mate it to the encapsulated payload on the launch pad. After integrated system testing, the vehicle would be fueled approximately eight hours prior to launching. Planners predicted total launch vehicle time at the base not to exceed a month, with just eight to 11 days on the launchpad, depending on vehicle configuration.[14]

Lockheed Martin's Atlas EELV family, offering the same "dial-a-ride" design as the Delta IV, comprised three vehicles based on a non-pressurized aluminum 12.5-foot diameter common core booster (CCB) first stage that was slightly wider than the initial stage of the Atlas IIAS. A unique feature of the Atlas V CCB was its use of the Russian RD-180 liquid oxygen–kerosene engine. Not only did this decision promote cooperative efforts with the Russian space community, but it also recognized the RD-180 for its exceptional capability. Initially used on the Atlas III, the two-thrust-chambered engine, providing continuous throttle between 47 percent and 100 percent of nominal thrust, became the first throttleable main engine used by any US launcher and produced little environmental contamination. All variants used the CCB, a stretched common Centaur upper stage configured with one or two engines, and Centaur avionics integrating the first stage for guidance, flight control, and event sequencing. For Lockheed Martin's 400 series medium-lift vehicle, its smallest EELV, the Centaur used either one or two Pratt & Whitney RL-10A-4-2 cryogenic liquid oxygen–liquid hydrogen engines, and various configurations of the Atlas 400 series could be tailored to the payload with the addition of one to three solid rocket boosters (SRB). The 400 series variants could loft payloads from approximately 11,000 to 13,200 pounds to GTO, and its larger 13.7-foot diameter fairing could enclose payloads up to 13.2 feet in diameter and 17.7 feet in length.[15]

Fig. 19. The Delta IV vehicle family. (Photo courtesy of United Launch Alliance)

The Intermediate EELV configuration, referred to as the Atlas V 500 series, consisted of the CCB with the Centaur upper stage and up to five newly designed Aerojet SRB. Manufactured in Zurich, Switzerland, the 500 series payload fairings measured 16.4 feet in diameter and 68 or 77 feet in length and enclosed both Centaur and payload.

The Atlas V 500 series with three SRBs could place payloads weighing about 15,200 pounds into GTO, while a variant using five SRBs would loft 18,000-pound payloads to GTO. The Atlas V 500 series also became the first Atlas capable of injecting payloads directly into geostationary orbit.[16]

Fig. 20. Atlas 551 launches from LC-41, 8 August 2019. (Photo courtesy of John Hilliard)

Lockheed produced design and test plans for the Atlas V Heavy Lift vehicle that measured 196 feet in length and, like the Delta IV Heavy, used three CCBs strapped together for its first stage. The largest Atlas V, the HLV, strapped three CCBs together, mated to the dual-engine Centaur upper stage. Measuring 17.7 feet in diameter and 86.6 feet in length, its longer Swiss fairing enclosed both the Centaur and its payload. Planners expected the Atlas V Heavy to launch payloads to GTO weighing 28,600 pounds. In a 2000 program restructuring, however, the Air Force acceded to Lockheed Martin's request and chose not to have the heavy version built.[17]

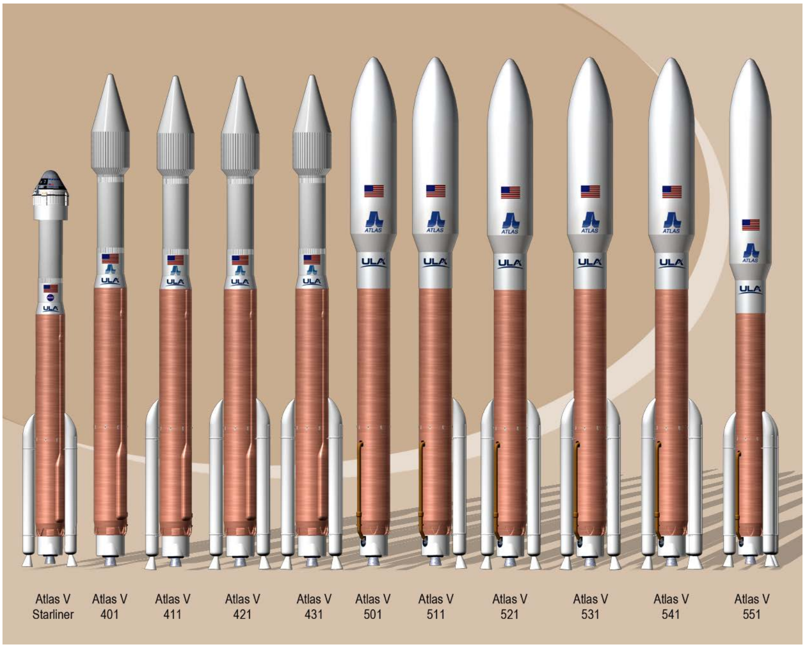


Fig. 21. The Atlas V vehicle family. (Photo courtesy of United Launch Alliance)

Lockheed Martin also had a single launch complex at each range. The company planned to launch the Atlas V from Space Launch Complex 3 East at Vandenberg and from the Cape's Launch Complex 41, currently the Titan IV site. Final assembly and testing of the Atlas took place at Lockheed Martin's Waterton Canyon facility in Littleton, southwest of Denver. After acceptance testing on the assembled stages, a C-5 aircraft flew them to the launch site. With Lockheed's "clean pad" approach, payloads would undergo processing and encapsulation before being mated to the new launch vehicles in a vertical processing building rather than being lifted on to the launch vehicle on the pad and exposed to the elements. Then the stacked Atlas V would be transported to the launchpad where launch personnel could fuel and launch the Atlas within 24 hours. Because both contractors practiced off-pad payload encapsulation and efficient stacking procedures, launch delays that had affected the legacy systems could be avoided. Col Robert P. Bongiovi, SMC's director of the Launch Enterprise Systems Directorate, considered payload encapsulation in the processing facility more important than standardization. Remaining in the "environmentally controlled fairing through mating and launch," he said, "was a game changer."[18]

1999 BAR Assesses the EELV Program

As luck would have it, by the time the Air Force adopted the acquisition strategy of dual sourcing the EELV program, the space launch environment had changed once again. First came the Delta III and Titan IV failures in 1998 and 1999 that led to formation of the BAR panel, which investigated and assessed potential systemic launch failures for all systems, including the EELVs. The commercial launch market also shrank at the end of the decade. New commercial market forecasts in 2000 indicated a dramatic reduction in commercial launch demand, making it likely that the Air Force would become the majority customer for both EELV companies. Furthermore, with fewer commercial launches preceding the initial government missions, the anticipated risk-reduction benefits declined substantially, particularly with the Delta IV Heavy, which was now unable to establish a track record with commercial flights before launching defense payloads.[19]

Concerned that problems reflected in the Titan IV failures could affect the emerging EELV program, the BAR investigators offered recommendations to build confidence "on the front end" of the EELV program. First, they urged the Air Force to produce a transition plan that described in detail the management and confidence-building approach that included lessons learned from the heritage programs. Specifically, under the direction of the Secretary of the Air Force, there should be a "value-added" government role as an involved customer providing technical participation during development, a formal EELV launch risk management program, an improved mission assurance process, and "robust engineering support until launch reliability is demonstrated." In short, in the Air Force–industry partnership, the Air Force should avoid the pitfalls of the Titan program and provide more oversight, with an expanded mission assurance component.[20]

The EELV program office believed its insight procedures had worked very well during the three-phase development process and for the critical design reviews for both rockets. The reviews had been completed in early 1999, largely on schedule, and well before the BAR occurred. With the design completed, Boeing and Lockheed Martin, by 2000 to 2001, had well underway the manufacturing of the engines and booster cores as well as all the integration testing. Given the Titan IV problems and the first launches of both Atlas V and Delta IV scheduled for 2002, the BAR examiners favored more rigor, more oversight, and an additional layer of mission assurance to enhance mission processing and execution.[21]

The 1999 BAR report (referred to as BAR I) also recommended performance of additional government Independent Reviews. Two BAR follow-up reports, both conducted by AFSPC's Independent Strategic Assessment Group (ISAG) appeared in September 2000 and April 2001. By November 2000, SMC had completed the requested EELV transition plan that described a transition period for conducting old and new operations concurrently under close scrutiny from launch squadrons, SMC detachments, and CTFs. The plan also called for greater government "participation and insight," emphasizing that launch service providers retained responsibility for launch performance, but for the first EELV government missions there would be "extensive government participation in system engineering, product assurance, mission integration, readiness review, surveillance of assembly, test and security as well as launch and recovery operations." By the time of the April 2001 report, the review panel would find that, while there might be skepticism about whether the Air Force had or intended to commit the required resources to execute the recommendations, much planning had been done, especially on providing more mission assurance and oversight. Though the additional oversight activities would substantially increase EELV costs, they would also lead to major advances in launch successes. Looking back from the perspective of 2006, Gen Thomas S. Moorman Jr. had nothing but praise for the BAR I report. "In hindsight," he said, "the BAR was one of the most useful study efforts ever as the US has not experienced a launch failure since the BAR recommendations were implemented."[22] The unprecedented record of success would continue throughout the course of the EELV program.

The BAR I recommendations included a call for early verification flights of the various EELV configurations. This suggestion became a high-priority issue in view of the launch market's contraction and the reduced commercial manifests. DOD responded by allocating funds for a Delta IV Heavy demonstration flight to take place in the summer of 2004, but not for an Atlas V Heavy-Lift vehicle. In late 1997, with the dual-acquisition strategy under review, Lockheed Martin had requested relief from its requirement for a West Coast Atlas V Heavy launch presence. It also received permission to have its Heavy design and test plans certified with a three-year call up capability. In the 2000 program restructure, given reduced commercial market demand and only two Atlas V DMSP flights expected from Vandenberg, Lockheed requested complete relief from its West Coast obligations. Even though granting Lockheed's request meant compromising the assured access to space strategy, the Air Force agreed that two launch providers were not required at that time and shifted the DMSP missions to Boeing's Delta IV. Acquisition officers also argued that the heavy version of the Atlas had been taken through the critical design review stage and could be resurrected if the Delta IV Heavy encountered development or launch problems. After contract modifications had been approved in the fall of 2000, Boeing's development contract increased from $500 million to $641 million. Its ILS contract increased to $1.525 billion, and it gained two additional launches for a total of 21. Lockheed Martin retained the same $500 million development contract, but its mission reduction from nine to seven resulted in an ILS contract decrease from $649 million to $505.8 million.[23]

The 2000 contract modifications did not endure. In February 2003, the Air Force opened a formal inquiry into charges that Boeing had in its possession Lockheed Martin proprietary information that gave it an unfair advantage during the October 1998 ILS contract competition. The investigation lasted more than two years and involved not only Boeing and former Lockheed employees but also Darleen Druyun, former principal deputy assistant secretary of the Air Force for Acquisition and Management. She admitted to providing Boeing with inflated contracts and confidential pricing information in return for employment at Boeing for herself and two relatives. She received a nine-month prison sentence. Investigators found that Boeing had in its possession nearly 25,000 pages of proprietary Lockheed Martin documents and had committed serious violations of federal law. In response, the Air Force suspended three Boeing divisions from receiving government contracts. It also revoked seven Delta IV launches and transferred them to Lockheed Martin. Despite Boeing's violations, Air Force undersecretary Peter B. Teets remained determined to have two EELV providers for assured access to space, and, citing national security requirements, he sanctioned several exceptions to the Boeing launch suspension so that Delta IIs could launch GPS satellites. Finally, on 4 March 2005, now Acting Secretary of the Air Force Teets ended the 20-month suspension, the longest ever imposed on a major defense contractor. In return for not facing criminal charges, Boeing paid a record $615 million to settle the criminal and civil fraud accusations it faced.[24]

The Air Force judgment against Boeing had also eliminated Boeing's exclusive use of West Coast launch facilities. Lockheed Martin received authorization to upgrade and use Vandenberg's Space Launch Complex 3 pad to launch everything up through the large Atlas V 551 version. Colonel Bongiovi concluded, "For the nation, from a launch perspective, getting that second West Coast capability was a huge deal. We have launched really important [payloads] using an Atlas out of Vandenberg."[25]

A New Acquisition Strategy and the Establishment of the United Launch Alliance

Faced with the prospect of a commercial market not providing sufficient business to support both Atlas V and Delta IV launch families, on 15 May 2002 Undersecretary Teets convened a meeting at the Pentagon to determine whether the government should contribute more funding for EELV launches to ensure that both launch vehicles remained viable for assured access to space. While considering this possibility that fall, the Air Force also had to address cost deviations and a 13 percent increase over the original October 1998 acquisition baseline contract largely due to enhanced mission assurance and risk-reduction activities and a cost breach that resulted from new satellite weight growth requiring a larger class of launch vehicles. By December 2003, the EELV Systems Program Office had to report a breach of both the 15 percent and 25 percent Nunn-McCurdy cost thresholds, and DOD's EELV program cost estimate that year rose by 77 percent over the prior year. Attributed primarily to the collapse of the commercial market, the government now needed to pay 50 percent more to acquire future launch missions to protect the space industry and maintain assured access to space. In April 2004, as required by statute, Michael Wynne, acting undersecretary of defense for acquisition, technology, and logistics, officially certified the EELV program as essential to national security, revised acquisition cost estimates, and established more effective management controls.[26]

Nunn-McCurdy cost deviations notwithstanding, the EELV System Program Office could report in May 2004 that the EELV program had bettered the original cost objective of reducing recurring launch costs by at least 25 percent to 50 percent by achieving "launch cost savings of 51.4 percent over heritage systems." Nevertheless, the recent cost increases alarmed defense department officials who, despite certifying the EELV program, had to confront questions about the affordability of maintaining two EELV services. That same year, DOD conducted a contractor-government study—led, appropriately, by retired Gen Thomas S. Moorman—to determine how best to provide assured space access in the future. The Moorman team weighed the advantages and disadvantages of selecting one EELV provider, remaining with two providers, combining EELV operations, or developing a completely new launch system that would also include NASA's evolving requirements. In their analysis, the investigators focused on various categories of uncertainty with launch policy, acquisition strategies, and operational plans. Although the Moorman group's 2004 "Assured Access to Space Study" recommended no particular option, it nevertheless discussed measures to make the various choices more credible and reduce the uncertainty that invariably affects all spacelift possibilities. As General Moorman cautioned, "Assured access is not a destination, but rather a journey. As a nation, we need to continue to adequately fund space launch operations and develop the next generation technologies that will increase responsiveness, improve reliability, and reduce costs."[27]

On 21 March 2005, just after lifting the Boeing suspension, Undersecretary Teets authorized a new EELV acquisition strategy. Alarmed by the prospect of one or both EELV companies being forced out of business because of the launch market collapse and the potential erosion of the space industrial base, he elected to ensure their survival by making the government the primary customer for the two EELV contractors and having DOD fund the yearly fixed costs of both Lockheed Martin and Boeing. Each company would receive two negotiated contracts, one for launch services, including vehicle production, and the other for infrastructure and labor. Announced in March 2006 by the Air Force and the NRO, the new "cost-plus" contracts guaranteed full DOD oversight and enabled the program office to acquire previously unavailable cost data. Together with options, the government would purchase 22 missions during the four-year period from 2006 through 2009. The contracts also could be amended rapidly if, as predicted, the two companies merged. As with the earlier acquisition strategy, the contractors continued to retain ownership of hardware and facilities and to provide the Air Force launch services, thereby relieving the government of ownership costs and logistics responsibilities.[28]

For their part, Boeing and Lockheed Martin, in May 2005, announced their plan to form United Launch Alliance (ULA). The new acquisition contracts were revised accordingly when ULA began operations in December 2006 as the sole-source contractor for EELV. Compelled by the collapse of the worldwide commercial launch market to establish ULA, Lockheed Martin and Boeing sought to pattern the merger after their joint operating agreement for the space shuttle program. The two companies would consolidate their launch vehicle facilities, equipment, processes, and personnel and expected that greater efficiency would reduce launch costs by between $100 million and $150 million annually. Under the new arrangement, Lockheed Martin's Atlas V production would move from Littleton, Colorado, to Boeing's Delta IV plant in Alabama. Engineering and administrative responsibilities would be consolidated at Lockheed Martin's Denver headquarters. The two companies would continue to handle commercial and nongovernment space launches. The Air Force approved the proposal, because it would guarantee the survival of two providers and assure military access to space. The US Federal Trade Commission then certified the joint arrangement, on 3 October 2006, with several restrictions: "1) the ULA must cooperate on equal terms with all other providers of government space launch vehicles, 2) the ULA must provide equal consideration to all launch service providers when seeking U.S. Government 'delivery-on-orbit' contracts, and 3) the ULA must safeguard any competitively sensitive information it received from other space vehicle and launch service providers." Meanwhile, DOD would remain the primary EELV patron. The congressionally mandated RAND *National Security Space Launch Report*, published in 2006, predicted development of a minimal commercial market, asserting that the US government as the only likely customer "must be prepared to bear virtually the entire financial burden of retaining either or both of these rocket families."[29]

The EELV Families Become Operational (2002–2011)

By this point, the operational phase of the EELV program was well underway. Examining the period from 2002 to 2011, at which time the Air Force adopted another new acquisition strategy, ULA compiled a perfect record of Delta IV and Atlas V flights.

The EELV program had to achieve an initial operational capability milestone for both Atlas and Delta medium launch vehicles and for the Delta IV Heavy. IOC requirements included functioning launch operation facilities, available contractor EELV data and technical manuals, insight training to assess operations and maintenance, and evidence of effective system production. In addition, the medium launch vehicles needed three launches of commercial or military payloads from the Cape within a year and one launch from Vandenberg. IOC for the heavy variant would occur when it successfully launched from either the Cape or Vandenberg. Full operational capability (FOC) required completion of the IOC milestone and finishing corrective actions for Delta IV Heavy launch, plus confirming the capability of Vandenberg's facilities and pads to launch the Heavy variant. On 12 December 2006, AFSPC commander Gen Kevin P. Chilton announced that the EELV launch vehicles had completed all necessary requirements and attained FOC status.[30]

On 21 August 2002 the initial Lockheed Martin Atlas V, series 401, successfully launched from Cape Canaveral's SLC-41. Three months later, Boeing followed with the inaugural launch of its Delta IV Medium-Plus (4,2) 400 series configuration from SLC-37B. Payloads for both flights were commercial telecommunications satellites. The first Delta IV military flight occurred just four months later when, on 11 March 2003, a Delta IV Medium carried out the first of two DSCS III missions at the Cape. The first Atlas V military mission did not occur until 9 March 2007, when a series 401 lofted six military research satellites into LEO. Not until 28 June 2006 did the first Delta IV launch from Vandenberg's refurbished SLC-6. Although the booster had been assembled on the launchpad in 2003, the launch date continued to slip due to issues preparing the NRO's improved Trumpet signals intelligence satellite. With this first EELV launch from Vandenberg, the Air Force now had fully operational launch sites on both coasts and reached a milestone on the road to assured access to space.[31]

The Delta IV Heavy, however, did not make its maiden operational flight until 10 November 2007, when it lofted the final DSP satellite into orbit. Back in 2000, considering the commercial market forecast, the Air Force had been especially concerned that too few Delta Heavy commercial missions would be flown before having to fly critical national security payloads. Consequently, the Air Force chose to fly a Delta IV Heavy test flight on 21 December 2004 with a 14,000-pound cylindrical demonstration satellite as well as a secondary payload of three nano satellites students had built to test technologies for small satellite constellations. Although the spacecraft failed to reach geosynchronous orbit after engine cutoff and booster separation occurred eight seconds early, Boeing declared that the mission provided enough data to launch a DSP mission "with great confidence" the following summer. Problems with Delta batteries and a Boeing technician and machinist union workers' strike, however, postponed the mission from October 2005 to April 2007, then further after a dress rehearsal on 28 February 2007 damaged the SLC-37B launch mount. The first operational Delta IV Heavy—the first Delta IV contracted by ULA—finally launched from the Cape with its DSP satellite payload on 10 November 2007. The Delta IV Heavy did not launch from Vandenberg's SLC-6, with its NRO payload, until 20 January 2011.[32]

The Atlas V, after eight commercial launches, flew its first Air Force mission from the Cape's SLC-41 on 8 March 2007. Among the additional Atlas V 401 "firsts," the mission flew to two different orbits and included the first Space Test Program mission with six experimental scientific and technology demonstration satellites. The four smallest satellites were attached using the EELV Secondary Payload Adapter (ESPA) ring for the first time, and all four satellites separated from the ring into their correct orbits. The Atlas V EELV launched from Vandenberg Air Force Base for the first time on 13 March 2008, when an Atlas V 411 lofted an NRO signals intelligence satellite from newly completed SLC-3E into a Molniya orbit.[33]

By 2011, when the next revision of acquisition launch strategy occurred, both ULA companies could cite an unblemished launch record. Boeing could point to 13 successful Delta IV operational missions, consisting of three Medium, seven Medium-Plus flights of both commercial and national security payloads, and three Heavy launches with national security satellites. Even more impressive, by 2011, Lockheed Martin's more cost effective Atlas V had launched 23 successful missions, comprising 17 of the 400 series and 6 of the 500 series. National security missions totaled 11 of the 23, with all but 3 flown from the Cape.[34]

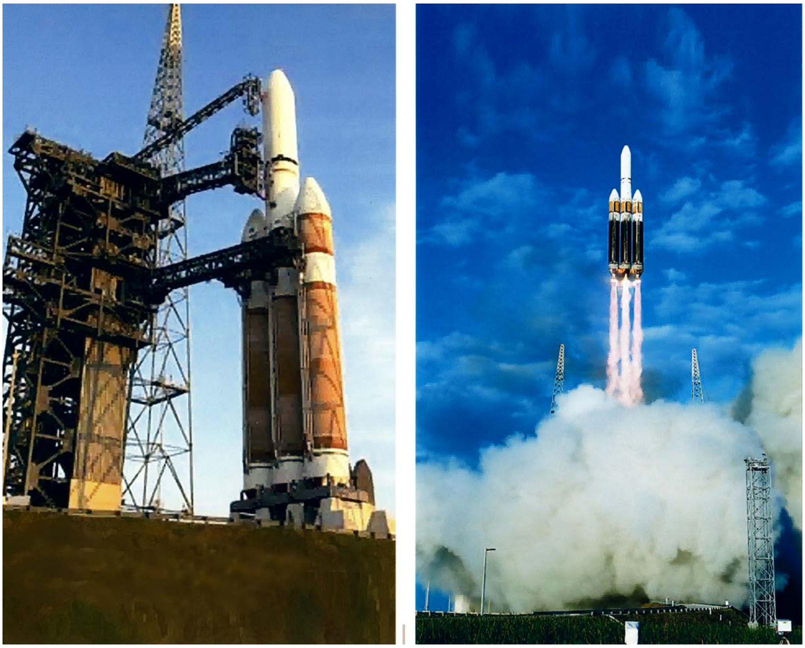


Fig. 22. The Delta IV Heavy on pad 37, left, and lifting off for its test flight, 21 December 2004. (Photo courtesy of John Hilliard)

The Air Force Modernizes Range Operations

Meanwhile, during ULA's initial 10-year launch period, the Air Force moved increasingly toward a "predominantly space-based range architecture" with special focus on developing Global Positioning System Metric Tracking (GPS MT) and the Autonomous Flight Safety System (AFSS). By the end of the first decade of the new century, the Air Force had achieved major upgrades to what it termed the Launch and Test Range System (LTRS), with more improvements on the way. With equipment developed, acquired, and maintained by SMC, the LTRS embraced the infrastructure, systems, and operational capabilities that supported launches for DOD, NASA, and commercial customers, primarily at Vandenberg's Western Range and the Eastern Range at Cape Canaveral Air Force Station, as well as manned missions from the Kennedy Space Center.[35]

Each of the ranges consisted of instrumentation, network, and control and display segments. The instrumentation segment observed the launch environment, followed vehicles in flight, and communicated flight termination orders when necessary. In addition to collecting weather information within a 15.5-mile radius of the launch, it moved to rely on metric tracking optics for safety during the initial 50,000 feet of flight and maintained a view of the vehicle for 31 miles. Both ranges relied on sensors, transmitters, and supporting facilities located at the launch head and downrange to monitor and track launch vehicles. The network segment used high-frequency radio, microwave, landline, fiber optic, satellite communications, and distributed networks to support range operations and connect to a variety of civil and defense elements. With data collected from the instrumentation assets, the control and display segment enabled operators to plan, schedule, and monitor and control range operations.[36]

Most LTRS equipment dated back to the 1960s and 1970s. A significant portion had become obsolete, inefficient, and needed standardization. Launch range modernization had been a priority from the early 1990s, shortly after AFSPC acquired the launch mission from Air Force Systems Command. In 1993, SMC awarded the first phase of the ambitious range standardization and automation (RSA) contract to the Harris Corporation of Melbourne, Florida, to overhaul and modernize elements of the ranges using new software and instrumentation systems. Concentrating primarily on the Eastern Range, this first phase reduced launch turnaround times, improved the range's reliability, and lowered maintenance and operations costs. Unfortunately, by the time Harris completed the contract in March 2000, it had experienced major cost overruns and often failed to meet scheduled requirements; consequently, the contractor was not awarded the second-phase RSA contract. Instead, in 1995, Loral Systems Company (acquired by Lockheed Martin in 1996) received a 10-year second-phase contract to upgrade and modernize the network, control, and display segments of the LTRS with automated and standardized systems. Unhappy with the progress and performance of the RSA contractors in the 1990s, however, SMC chose to award its first Spacelift Range System Contract on 3 November 2000 to ITT

Industries with responsibility for "fixing and improving" the Eastern Range. Its work centered on surveillance radar, command and destruct and metric tracking performance, and weather system upgrades. In its *National Security Space Launch Report,* RAND investigators complimented the ranges for maintaining "a commendable record for launch and test support, despite the advancing age of the equipment and facilities" and strongly supported the planned improvement programs.[37]

In January 2008, Gen C. Robert Kehler, AFSPC commander, called for a fundamental change in the conduct of launch and range operations in what became the Launch and Range Enterprise Transformation (LET). His proposal for "a new Launch and Range way ahead" proposed improving range capabilities by decreasing the "terrestrial footprint" of the LTRS instrumentation segment on the road to a space-based range architecture. His premise was that all range customers would eventually rely on GPS MT rather than C-band ground radars, followed by use of an advanced AFSS. Global Positioning System Metric Tracking represented the essential first step in achieving a space-based range that supported operationally responsive launch systems. If successful, the Eastern Range and Western Range would no longer need most of their radars and command systems. Although in 2006 Undersecretary of the Air Force Dr. Ronald M. Sega had set 2011 as the deadline for all launch providers to use GPS MT at both ranges, full implementation would not come until 2015.[38]

Under ULA's planned use of GPS MT on its Atlas V and Delta IV vehicles, signals from two L-band antennas mounted 180 degrees apart on the second-stage airframe skin were routed through low-noise amplifiers, then combined in a radio frequency multiplexer before being received by the GPS Tracking Unit. From there a GPS S-band transmitter telemetered velocity and position vectors to ground-based S-band receivers for processing by ULA Mission Control safety organizations at the two ranges. To provide initial redundancy for GPS metric tracking data, the range safety officer used two additional independent range tracking sources: telemetered inertial guidance information and tracking data from a launch head skin track radar.[39]

During the years after General Kehler's initiative, GPS MT passed through several bureaucratic and development hurdles, along with aging equipment breakdowns, before its first use on a Delta IV MPlus 4,2 launcher with a GPS IIF-6 payload on 17 May 2014. Later that year, Atlas V vehicles also began relying solely on GPS MT, which signaled the end of dependence on the aging C-band radars at both Vandenberg and the Cape. In February 2015, the 17-year process of transitioning to GPS metric tracking came to fruition when AFSPC announced that GPS MT had achieved FOC.[40]

The second major element of the LET initiative, the AFSS, used redundant on-board flight processers with inertial measurement unit navigation sensors and GPS data to provide greater flight control with an over-the-horizon surveillance capability and to destroy the vehicle if necessary. The AFSS eliminated the man-in-the-loop safety officer, who sent manual destruct commands to wayward rockets from his position at the range. The Air Force envisioned AFSS to be the cornerstone of a more responsive launch range. It promised better operational flexibility, greater launch site availability, and launch schedule predictability, plus overall space enterprise cost savings. In late 2016, Brig Gen Wayne R. Monteith, the Eastern Range director and 45th Space Wing commander, clearly had in mind the increased launch tempo expected from the AFSS when he predicted a higher launch rate in the coming years. Already, he declared, "we launch more vehicles today then we did in 1991, and we do it with 35 percent fewer people."[41]

An Orbital Sciences Corporation (OSC) Minotaur I performed the first flight test of the AFSS on its ORS-3 mission launched from Wallops Island, Virginia, on 20 November 2013. Working closely with OSC, Alliant Techsystems (ATK) had received nearly $10 million in federal funding to develop the system, and OSC had been the first launch provider to accept the AFSS. Until certain of government funding support, most range users initially resisted the costly AFSS investment. The innovative Space Exploration Technologies Corporation (SpaceX) received approval of its own tailored system that provided data for both the range safety tracking system and AFSS by incorporating GPS MT in a blended GPS/Inertial Measurement Unit.[42]

The first use of the AFSS at the Cape occurred on 28 April 2015, when a SpaceX Falcon 9 successfully launched a 10,377-pound Turkmenistan communication satellite into GTO. More importantly, launching from the Kennedy Space Center's historic Launch Complex 39A for the first time, a SpaceX Falcon 9's resupply mission to the *International Space Station (ISS)*, on 19 February 2017, marked the first sole use of the AFSS to guarantee public safety. Moreover, the mission demonstrated GPS MT's capability of supporting multiple objects simultaneously when the Falcon 9's first stage booster successfully flew back to Cape Canaveral's Landing Zone 1, the former Launch Complex 13. The first AFSS-supported flight at Vandenberg came four months later when, on 25 June, a Falcon 9 launched 10 Iridium communications satellites into LEO.[43]

The Air Force had planned to have launch service providers transition to the space vehicle–based flight safety system by FY 2018, but the process proved much more difficult than expected. The February 2017 SpaceX AFSS flight prompted the AFSC commander, Gen John W. "Jay" Raymond, to anticipate "all range users operating existing launch vehicles on the [Eastern Range] and [Western Range] to migrate those vehicles to AFSS within the next ten years (by 30 September 2027)." Others, including Air Force Secretary Heather A. Wilson, expected the transition to occur earlier in that decade.[44] Both might very well have been correct, given that AFSPC's Range of the Future 2028 project, then under way, depended on the full implementation of AFSS by the end of 2023 and by the DOD test community, thereafter, as rapidly as possible. The entire endeavor, however, was not expected to be completed until 2028.[45]

In the FY 2016 National Defense Authorization Act, Congress directed DOD to expand federal range access to meet the growing demand from a US commercial space launch industry whose share of the global commercial space market had increased from 10 percent to 64 percent between 2012 and 2017. As described in the AFSPC Commander's Strategic Intent, the Range of the Future 2028 intended to build on the work of the LTRS architecture by implementing AFSS and "plug-and-play" technology. The Eastern and Western Range architecture would evolve into national spaceports, capable of providing "flexible, right-sized launch services and infrastructure" that would enable on-demand space access and test operations at decreased cost.[46]

To realize globally competitive national spaceports, the range transformation project established several priorities. First, both ranges would convert to a common services-based plug-and-play architecture that simultaneously would support multiple users and a variety of operations. Implementing a more mobile, modular architecture would be simpler to operate, defend, and maintain and upgrade, while AFSS would enhance operational flexibility and agility. Second, the Air Force would enhance public services and infrastructure to provide more efficient and equitable access to range resources by relying especially on public-private partnerships. Public-private partnerships would also anchor the third priority, a new business model that would safeguard DOD and commercial space interests by promoting shared government and commercial financial investment together with innovative acquisition strategies.[47]

This ambitious Range of the Future 2028 construct sought to transform the Eastern and Western Ranges into agile and resilient national spaceports by 2028. As part of a consolidated, federally operated system of launch facilities, the spaceports would benefit from this structure, which would provide "consistent policy and regulation across the spaceports and allocation of resources and funding of the system rather than a site-centric approach." In short, the Range of the Future 2028 promised to realize the decades-long objective of range standardization, along with responsive space launch through its capability of supporting launch and test operations on demand.[48]

The New Block-Buy Launch Strategy and the Introduction of Launch Competition

In February 2010, Secretary of the Air Force Michael B. Donley directed AFSPC to conduct a 10-year update of the 1999 Broad Area Review (BAR I) of space launch performance. Led, once again, by Gen Larry D. Welch (USAF, retired, former Air Force chief of staff) and the Institute for Defense Analyses, a major focus of the three-month study involved launch acquisition practices. The study, BAR X, began by praising the Air Force for paying attention to mission assurance in the EELV program after BAR I, which clearly deserved a large share of the credit for no EELV mission failures. Also receiving kudos were AFSPC and the intelligence community for confronting the problem of launch schedules that proved less than credible. As part of his LET strategy, General Kehler tried to improve the launch scheduling process by modifying the procedures of the Current Launch Schedule Review Board (CLSRB) to ensure use of scheduled launch slots. The CLSRB allotted launch slots quarterly according to mission priorities, status of the constellation receiving the satellite, and confidence in the initial launch capability date. Before BAR X, launch slots had been reserved up to two years in advance. As of February 2010, the launch assignment would remain in flux from six to 12 months before scheduled liftoff, and the CLSRB would overbook the launch missions against the booster. Each launch slot in the current launch schedule now received one primary and at least one backup space payload, and the CLSRB decided at least six months prior to the launch whether the primary or alternate payload would be assigned the launch slot. This new strategy promised to produce greater launch confidence and additional flexibility in the launch schedule. Planners also expected the new CLSRB procedures to prevent unused launch opportunities and, thereby, to help overcome the backlog of EELV missions. Indeed, the number of national security launches increased, with four in 2010, seven in 2011, and eight in 2012.[49]

Unlike mission assurance and launch scheduling, space acquisition received a scathing critique from the 2010 BAR X assessment. Under the revised acquisition strategy adopted in 2006, the Air Force had contracted for each launch vehicle as required and had relied on separate contracts for overhead and facilities costs. This meant the Air Force could not guarantee an exact number of vehicle orders per year, resulting in varying numbers required—an issue exacerbated by multiyear delays in satellite deliveries—and resulted in low launch rates. Although the Air Force appreciated the flexibility of this acquisition practice, which enabled it to buy launch vehicles as needed, this strategy had proven expensive and jeopardized the stability of the launch industry because it could not establish a consistent, cost-effective supply chain. The government remained the main ULA customer, with commercial launch providing less than 20 percent of ULA's business since it began operations in 2006. As the BAR study declared, "The current practice for buying launch services threatens the future viability of the industrial base essential to assured access to space [for National Security Needs]." Citing the need to stabilize the industry and control costs, the study called for a fundamental change in the Air Force approach to space transportation by adopting "predictable multiyear contracting" with block buys to support eight launches per year and 10 booster cores.[50]

Prompted by projected increases in EELV program costs, DOD conducted five additional studies of space launch in 2009–2010, all concurring with the BAR X findings and recommendations. Indeed, the EELV program had focused on reliability and mission success rather than cost controls, and "DoD officials predicted EELV program costs would increase at an unsustainable rate," given launch industrial base instability and the current practice of buying launch vehicles one at a time. In March 2011, the Air Force responded by declaring its intention to buy an initial block of eight core vehicles annually over the next five years, from FY 2013 to FY 2017, at a cost of $15 billion. Testifying before the Senate Armed Services Committee that autumn, Gen William L. Shelton, AFSPC commander, predicted the EELV block-buy strategy "will provide predictability, economic order quantity opportunities, and a more stable industrial base, thereby lowering overall costs." The Air Force expected to save about $4.4 billion over the previous estimated launch cost for this period, with ULA being able to create a supplier structure that allowed them to "drive out cost." After undergoing several DOD reviews, addressing GAO criticisms of ULA's research on the number of cores required, and confronting another Nunn-McCurdy cost threshold breach, the Air Force finally received authorization in November 2012 to negotiate with ULA on a sole-source basis. It would obtain 35 cores for launch operations over a five-year period, from 2013 to 2017, for the purchases of launch services that subsequently were extended to 2019. ULA received the final sole-source contract award on 18 December 2013. By this time, however, ULA's national security space launch monopoly had become imperiled by an Air Force decision to reduce launch costs by introducing competition to the EELV program.[51]

New Launch Competitors and the New Entrant Certification Process

In the spring of 2011, when the Air Force decided to pursue a block-buy strategy, it also called for the availability of as many as 14 additional competitively procured cores beginning in FY 2015. If no new launch entrants qualified, the launches would be made available for noncompetitive acquisition by ULA. In the fall of 2011, the Air Force, NRO, and NASA signed the *Launch Vehicle New Entrant Certification Guide*, which required participants to achieve three successful launches and provide extensive performance data for assessment. New competitors had to use designated Air Force launch sites to be able to launch a minimum of 20,000 pounds to LEO, the low end of EELV lift requirements. All requirements had to be completed before applying for an EELV-class launch. Competitors would launch certification missions under the Air Force Orbital/Suborbital Program-3 (OSP-3) small and medium launch vehicle program that was viewed as "EELV on-ramp" to gain the necessary experience to compete for

EELV-class launches around the year 2018. ULA was excluded from competing. In 2012, two companies submitted required documentation to undergo the certification process. OSC of Chandler, Arizona, entered its Antares launch vehicle, and SpaceX of Hawthorne, California, submitted its Falcon 9 v1.1 rocket for certification. SpaceX proved to be the most promising new entrant to pursue certification for EELV-class government service contracts. Under the OSP-3 contract, SpaceX received two mission awards, the civilian Deep Space Climate Observatory payload and DOD's Space Test Program-2 satellite.[52]

Founded in 2002 by entrepreneur Elon Musk, SpaceX had launched its initial Falcon 1 rocket in March 2006 and its first Falcon 9 rocket, together with a Dragon spacecraft, in December 2010. Measuring 224 feet high and 12 feet in diameter, the two-stage Falcon 9 v1.1 rocket could launch 28,990 pounds to LEO and 10,690 pounds to GTO. SpaceX asserted it could offer EELV-class launches at much lower prices than ULA, citing, for example, a launch cost of $54 million for its Falcon 9 v1.1. versus $150–$180 million for a comparable Atlas V flight. On 7 June 2013, SpaceX signed a data sharing agreement with SMC, expecting to have its Falcon 9 v1.1 launcher certified by 2015, in time to compete for the 14 national security missions. To do so, it would need to provide evaluators access to eight reference orbits, along with strict requirements for capacity, accuracy of orbit insertion, and performance margins for every payload capability for every orbit. By the end of 2013, SpaceX had successfully completed two of the three required certification flights with communication payloads. It anticipated a final successful mission, scheduled for 6 January 2014, then winning competitive contracts for the upcoming national security launches.[53]

Musk expressed displeasure, however, with the ULA block-buy arrangement and the prospect of failing to attain certification in time for the initial EELV launch competition. He contested the Air Force cost-saving figure for the block buy and criticized the Air Force's decision of 4 March 2014 to reduce the planned purchase of 14 competitive launches to just seven, with none scheduled before 2016. The 14 missions had been set aside for competitive acquisition as part of a larger block buy that originally numbered 50 rather than 36 cores. In fact, the decision to reduce the number of competitive launches reflected reassessment of budget year requests given current five-year plan launch manifest priorities and satellite constellation requirements. That year the analysis convinced planners to spread GPS launches further downstream. Bongiovi explained that the first-year reduction from 14 to seven missions actually was from five to one. "If you're building a business case on that five and you get one," he said, "rightly so, there's a lot of consternation . . [and] "one of our industry partners, SpaceX . . . wasn't familiar with working with us, and it caused consternation." His directorate decided to extend the new entrant contracts, or phase 1A, by two years to learn how to conduct small head-to-head competitions and make awards that would get the government the best value. In the end, SMC ended up awarding six RFPs and 15 missions, with nine going to SpaceX and six to ULA. Bongiovi declared, "I think we were true to what we said we were going to do."[54]

Musk also claimed SpaceX could qualify to launch missions included in ULA's phase 1 block buy and should not be excluded from competing, despite not being certified when the block-buy decision was made. Frustrated by what he considered favoritism toward ULA and the status quo, the SpaceX chief appeared before a Senate subcommittee in March and declared, "Although the aggressive reintroduction of competition into the EELV Program is now the established policy of the Defense Department, the details related to creating a fair, full, and open competitive acquisition environment remain unresolved." With competition now seemingly restricted, influential senators, such as Dianne Feinstein and Barbara L. Boxer from SpaceX's home state of California and John S. McCain from Arizona, raised concerns about the cutback in available launches and the fairness of the EELV program as a whole.[55]

Increasingly convinced that ULA would retain its monopoly on launch services and continue to receive $1 billion annually to support its national launch infrastructure and technology development, on 28 April 2014 Musk filed a bid complaint against ULA and the United States in the US Court of Federal Claims. He questioned the legality of the phase one award to ULA on 18 December 2013. As part of the lawsuit, SpaceX argued that by using the Russian RD-180 engine for Atlas V launches, ULA and the United States were violating sanctions imposed in March 2014 to punish Russia for invading Crimea. Two days after the court filing, Judge Susan G. Braden lifted the temporary ban she had placed on additional purchases of RD-180s from Russia's NPO Energomash, because the government convinced her that it could do business with the Russian company without violating an executive order sanctioning the company's overseer, Russian Deputy Prime Minister Dmitry Rogozin.[56]

For the next nine months, the entangled issues of SpaceX certification and RD-180 acquisition remained contentious. Elon Musk continued to assert SpaceX could build American-made replacements for the RD-180 and end dependence on Russian engines. Senator McCain and others called for an end to using Russian engines. Congressional pressure mounted to improve competitive launch contracting practices and to build an American alternative to the RD-180. Meanwhile, Air Force leaders defended the block-buy strategy, arguing that canceling the contract would be too costly, and they refused to give SpaceX special consideration for certification. Asserting that certification processes had to be thorough and run their course, AFSPC commander General Shelton declared, "When you're spending $60 million and putting 100 people against the problem to get somebody certified, it's hard to say you're excluding them."[57]

At the end of October 2014, SMC announced that the Falcon 9 had passed the last of its required engineering review boards and moved "into its final phases, including close out of open items and parallel audits/analysis and reviews." Seeking to capitalize on improved relations between SpaceX and the Air Force at year's end, former US Attorney General John Ashcroft brokered a settlement—announced on 23 January 2015—by which SpaceX dropped its lawsuit in return for an Air Force commitment to increase competitive launch opportunities and work expediently with the company to complete its certification process.[58]

That spring, while SpaceX awaited final assessment that focused on qualifying the second-stage engine and structure, AFSPC tasked Gen Larry Welch, former chief of staff, to convene a BAR panel to examine the certification process for new entrants applying to launch national security space payloads. Identified as BAR XV, it was the sixth review conducted by General Welch and his ISAG from the Institute for Defense Analyses. The Welch panel acknowledged a new launch landscape, where multiple new entrant launch vehicles provided by companies dependent on being competitive in the commercial market would appear over the next decade.[59]

The panel members agreed that assured access to space for purposes of national security continued to require at least two launch providers to reduce the risk from single-point failure and to benefit economically from the competitive environment. While a viable commercial market was not assured, the national security space community should support "policies and practices compatible with launch service providers that are competitive in the commercial market" in order to retain two families of launch vehicles. This would make "faster, more efficient, more competition friendly certification processes essential to assured access to space for NSS [National Security Space] payloads." At the same time, the high costs of complex payloads and their importance to national security required that comprehensive flight readiness verification continued to ensure high reliability for those launches. To facilitate contractor success in the commercial market, the panel recommended the Air Force end the practice of requiring providers to complete all certification requirements before becoming eligible for a launch contract award. Instead, the prospective provider should be allowed to compete for a launch contract once the certifying official was confident the provider could deliver the required launch service.[60]

The BAR XV assessment, completed in April, likely helped convince the Air Force to revise its certification requirements. That month, the Air Force modified the requirement to enable a provider to make enough progress to convince the certifying official that the provider had the commitment and ability to complete the certification process in time for the scheduled launch. On 26 May 2015, shortly after the BAR panel issued its report, SpaceX finally received certification of the Falcon 9 v1.1 for national security space missions. Specifically, the Falcon 9 v1.1 received approval for four of eight orbits, but SpaceX planned to use its Falcon Heavy, after achieving certification, for missions involving those other four orbits. Indeed, the previous month the company had applied to begin the national security launch certification process for its Falcon Heavy to launch national security missions. For the Falcon Heavy, SpaceX used a strengthened Falcon 9 core and two additional Falcon 9 strap-on boosters for the first stage. Powered by 27 Merlin 1D first stage engines and a single second-stage Merlin 1D engine, the Falcon Heavy, with more lift capability that any current rocket, could launch 140,660 pounds to LEO, 58,860 pounds to GTO, and a 37,000-pound payload to trans-Mars injection.[61]

Certification also included approval of the agreements SpaceX had already made to develop launch sites at the Cape and Vandenberg. At the latter, SpaceX received permission to lease Vandenberg's SLC-3 East, although its proximity to Atlas V launches at SLC-3

West convinced the Air Force to move the SpaceX operation to SLC-4. At the Cape, SpaceX arranged a 20-year lease to refurbish LC-39A, the former shuttle pad, that included constructing a new horizontal integration facility. At Cape Canaveral Air Force Station, it received permission to use SLC-40, one of the deactivated Titan IV pads, and the integrate-transfer-launch complex. The new launch competitor also planned to reduce spaceflight costs by reusing its core boosters, and it acquired a five-year lease of the mothballed LC-13 on the Cape to accept controlled landings of its Falcon cores.[62]

Shortly after the Air Force certified the Falcon 9 v1.1, SpaceX decided to cease its production and develop an improved version, referred to as the Falcon 9 Upgrade (Falcon 9 v.1.2), or Falcon 9 Full Thrust. The Falcon 9 Upgrade improved on the Falcon 9 v1.1 by using engines with 30 percent greater thrust, larger tanks, and super-chilled propellants. In June 2015, SpaceX began working with the New Entrant Certification Team to prepare the extensive mission assurance work plans required for validating the Falcon 9 Upgrade. Using guidelines recommended by the BAR XV panel, the team anticipated that only certification of the modifications to the Falcon 9 would be required. Space X expected to receive Air Force certification of the Falcon 9 Upgrade for national security flights in January 2016.[63]

On 28 June 2015, just about a month after being certified, a Falcon 9 carrying over 4,000 pounds of food and supplies in a Dragon capsule bound for the *ISS* experienced fuel-pressure problems and was destroyed at T+79 seconds. A six-month accident investigation involved the Federal Aviation Administration (FAA), the Air Force, and Space X. Finally, on 1 December 2015, 45th Space Wing commander Monteith authorized the Falcon's return to flight, and on 21 December, SpaceX launched 11 communication satellites into LEO with its first Falcon 9 Upgrade mission. The FAA had granted SpaceX a permit to land the booster on solid ground, which the company did for the first time nine minutes after liftoff. Monteith, who served as launch decision authority for the flight, could hardly contain his enthusiasm, declaring, "I can't even begin to describe the excitement the team feels right now having been part of this historic first stage rocket landing."[64]

The Air Force Confronts the RD-180 Challenge

Despite SpaceX's success, its first failure the previous June had raised questions about the company's certification and future launch prospects and, given ULA's challenges, the long-term viability of launch vehicle competitors providing assured access to space. ULA, with its two launcher families, had achieved almost perfect reliability in the delivery of NSS payloads to the intended orbit with its two launch families. The BAR XV study had described ULA's business plan now that its 10-year monopoly on NSS launches was about to end. It noted that Atlas V offered the lowest cost, while the Delta IV could launch the heaviest payloads. Despite ULA's proven record of successfully launching complex NSS payloads, neither of its launcher families would be financially competitive with SpaceX and, most likely, other new entrants. Consequently, ULA needed to enter the commercial market with a vehicle and launch services less expensive than the Atlas V. It publicly declared its plan to develop a next-generation launch system (NGLS), soon termed the Vulcan. Accordingly, ULA intended to end production of the Atlas V and Delta IV in 2017, except for the Delta IV Heavy. It would produce the latter until DOD no longer needed it for heavy national security payloads.[65]

Meanwhile, the continued use of the Atlas V depended on decisions regarding availability of the Russian-designed and -produced RD-180 engine. In 1996, Lockheed Martin had selected the RD-180 to power its Atlas IIAR vehicle that was renamed the Atlas III in 1998. Concerns about reliance on a Russian engine receded in the face of the RD-180's low cost and superior performance compared to any heavy-lift US engine then available. With US government approval, Lockheed contracted with RD AMROSS, a limited-liability company based in Florida and owned equally by Pratt & Whitney and Russia's NPO Energomash. RD AMROSS would acquire, process, and coproduce the RD-180 engines that NPO Energomash built in Russia, then sell and deliver them to Lockheed Martin for integration. Production was to begin in 2008, but Pratt & Whitney canceled the project when efforts to replicate Russian processes proved more difficult than expected and cost estimates reached $1 billion over a five-year period to commence manufacturing the engine.[66]

The situation changed abruptly after Russia invaded and annexed Crimea in February 2014. The economic sanctions imposed by the Obama administration included an executive order blocking the

United States from receiving property from officials of the Russian Federation, and Elon Musk filed his lawsuit in April, claiming that the contract for acquiring RD-180 rocket engines was illegal. A DOD-directed RD-180 risk mitigation study issued in May concluded that eliminating the RD-180 would seriously endanger the "assured access to space" strategy. With the national launch manifest listing 38 Atlas V missions, and ULA having only 16 RD-180 engines stockpiled, the Atlas V could not fly after May 2016 unless RD-180 procurement continued. Moreover, neither SpaceX's boosters nor the Delta IV could replace the Atlas V through FY 2017. The study recommended that the United States obtain a manufacturing licensing agreement to coproduce the Russian engine but, most importantly, develop its own hydrocarbon-fueled replacement, no matter what the RD-180's fate.[67]

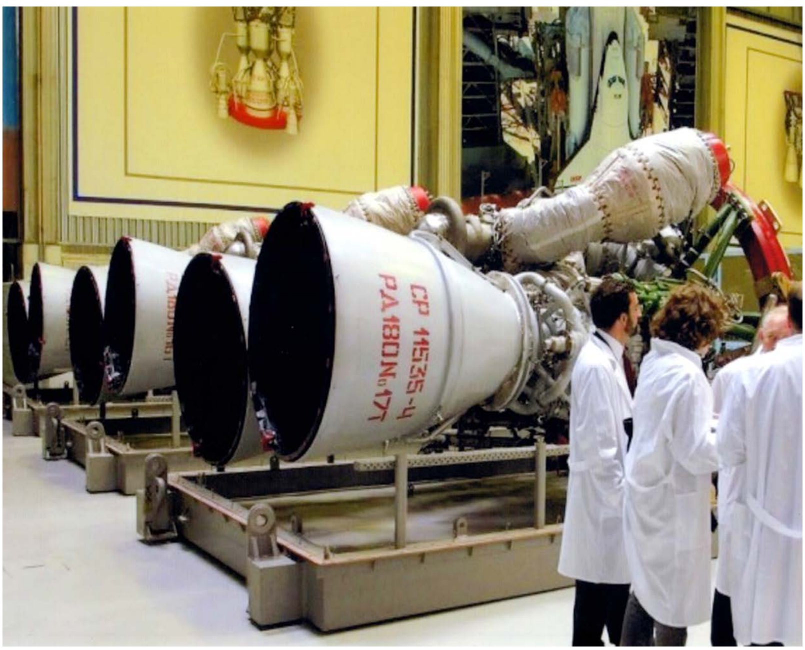


Fig. 23. Twin-nozzle RD-180 engines, manufactured by NPO Energomash in Khimki, Russia, are shown ready for shipment to United Launch Alliance (ULA) for the Atlas V, 6 June 2002. (Photo courtesy of John Hilliard)

The level of concern rose that spring when the Air Force chose not to coproduce the RD-180 in the United States for reasons of cost and continued dependence on the Russians for system engineering and components. Despite strained relations between Russia and the United States, Russia delivered five previously contracted engines by October 2015, and ULA continued to expect delivery of eight engines per year. Meanwhile, the Air Force, through the Defense Space Council and the DOD's Deputy's Management Action Group, decided to work with industry to determine the best path forward to produce an American alternative to the RD-180. In the past, because the Air Force bought commercial launch services, it had been less inclined to fund promising engine technology programs. Now, by engaging with the propulsion industry, Air Force planners believed that they could pursue a strategy like the one that produced the original EELV. This meant investing in engine designs to ensure that they met the more "stressing" Air Force launch requirements, then using those systems for their future national security launches. The Russian engine would no longer be used; DOD and ULA would acknowledge that the Delta IV Heavy was not the long-term solution, given its high cost and difficulty acquiring spare parts. Studies in the fall of 2014 led the Air Force to award 10 Broad Agency Announcement contracts with industry and academia to examine oxygen-rich, staged-combustion-cycle rocket technology and manufacturing techniques.[68]

By 2016, improvements in propulsion technologies convinced the Air Force to sign cost-sharing partnership agreements with four US companies to design and develop new rocket propulsion system prototypes. Blue Origin and Aerojet Rocketdyne, for example, received government funding for work on the Blue Engine (BE)-4 and Aerojet Rocketdyne (AR)-1 engines for the Vulcan. Blue Origin also planned to use the BE-4 in its New Glenn orbital launcher and hoped to have its initial launch in the fourth quarter of 2022. ULA had responded by forming a partnership with Blue Origin in September 2014 for developing the rocket company's BE-4 rocket engine fueled with liquid oxygen and liquified natural gas. The company estimated that it would require four years to produce an operational BE-4 engine, but Tory Bruno, ULA's president, later revised the completion date to 2022 or 2023.[69] Orbital ATK also accepted funding for its effort to move into the intermediate- and heavy-lift launch competition arena with its own NGLS, the OmegA, which it intended to launch in 2021. SpaceX, too, received money to develop the Raptor engine for use in its projected Big Falcon Rocket (redesignated Super Heavy in November 2018). By the end of 2014, congressional opposition to continued use of the RD-180 resulted in a provision in the FY 2015 National Defense Authorization Act (NDAA) that prohibited further purchases of RD-180s for DOD use, directed the secretary of defense to develop a next-generation rocket engine by 2019, and authorized $220 million for the project.[70]

Throughout 2015, efforts to develop an RD-180 alternative engine continued, while DOD officials chafed at the RD-180 restriction that, from their perspective, threatened assured access to space. In February Secretary of the Air Force Deborah Lee James warned of the technical challenges in meeting the 2019 date and the likelihood of "trading one monopoly for another." With the demise of the Atlas V and the high cost of the Delta IV compared to the Falcon 9, competition might cease, leaving SpaceX as the sole launch provider for national security launches. In March, ULA's Bruno explained that the Delta IV Medium would be phased out by 2018–2019, because its cost was 30 percent more than its Atlas V equivalent and it could not compete with SpaceX. He also argued against the ban on the RD-180 until the domestic replacement became operational. Gen John E. Hyten, AFSPC commander, agreed and favored a waiver to the FY 2015 NDAA to avoid dependence on a single provider (SpaceX), that had yet to launch a single NSS mission. Should there be a launch failure under that circumstance, he said, "A lengthy interruption in our ability to launch Air Force satellites would be catastrophic."[71]

Given the possibility of "trading one monopoly for another," congressional support grew for granting ULA access to additional RD-180 engines on a limited basis. Even so, opponents in the Senate remained unconvinced. They were led by McCain, now chairman of the Senate Armed Services Committee, who declared in the spring of 2015, "If the Air Force is unwilling to do what is necessary to meet the 2019 deadline, they are going to have to figure out how to meet our space needs without the RD-180." Meanwhile, SMC went ahead with formal proposals for developing prototypes of new launch systems. It also issued a broad agency announcement that described six to eight awards for $32 million to conduct advanced research on next generation boosters and propellants.[72]

Despite the political controversy surrounding reliance on the RD-180, the work of the US team performing mission assurance reviews on the engines in Russia remained unaffected. Composed of representatives from ULA, Pratt & Whitney, the Air Force, and Aerospace Corporation, the US team traveled to the Energomash facility at Khimki, outside Moscow, two or three times a year for mission assurance reviews. As team member SMSgt William P. Mayo, the Air Force quality engineer assigned to SMC, explained, "We reviewed changes to the baseline design and manufacturing processes [and] would perform a physical inspection of the hardware prior to shipment." Mayo also joined the team for the annual ULA Quality Audit of the NPO Energomash manufacturing site, where "we walked from shop-to-shop reviewing the quality metrics in each work center," and Russian officials also highlighted improvements made or "corrective actions" taken since the last audit.[73]

Mayo said the US contingent did not speak directly to their Russian counterparts on technical subjects. He and others in the US party had to be careful not to talk openly among themselves; they resorted to passing notes, whispering, or using another room to discuss questions with ULA representatives. Then, the ULA representatives would discuss the questions with the Russians through a Russian national interpreter employed by the United States. Mayo admitted that he had "zero expectations of privacy any place in Russia." Normally, when needing a US caucus, the US team would request the Russians leave the designated conference room. But, recalled Mayo, when the Russians installed video teleconferencing equipment in the conference room, "We would excuse ourselves from the room and use a room controlled by United Technologies." Back in the United States, Mayo visited the ULA site for more in-depth reviews of RD-180 engines assigned to specific Air Force NRO missions and to the Pratt & Whitney facility in West Palm Beach, Florida, to examine everything "off-baseline" (i.e., examine items that had not been built according to the agreed upon "baseline" procedures or specifications) for the engines he would be inspecting on his next visit to Khimki. As for the RD-180 political controversy, Mayo said, "It was never discussed with or by the Russians [and] never had an impact on our work. The Russians I worked with were very proud of their work and their engine; they concentrated on the task at hand."[74]

Regarding the RD-180 controversy, AFSPC historian Rick W. Sturdevant observed that "three interwoven strands of the RD-180 issue had become identifiable" by the spring of 2015. He listed those strands as "the DoD strategy for replacing the RD-180; USAF and ULA campaigning for near-term acquisition of more RD-180s; and language pertaining to RD-180 engines in what would become the Consolidated Appropriations Act for Fiscal Year 2016." As all three elements played out over the course of the year, DOD and Air Force leaders focused on acquiring additional RD-180s to keep the Atlas V operational until 2022, when the new US engine was expected to be operational. In testimony to the House Armed Services Committee that spring, Hyten warned, "We severely limit assured access [to space], undermine the competition we have worked so diligently to enable, and will have traded one monopoly for another in the medium and intermediate vehicle classes." Deliberations in the House and Senate continued throughout the year as the Consolidated Appropriations Act for Fiscal Year 2016 took shape. In the fall, ULA declined to bid on the launch services contract for a 2018 GPS III satellite mission, the first competitive launch contract in a decade. ULA cited RD-180 restrictions and no consideration for reliability or past performance as its rationale, but the lower cost of a Falcon 9 launch also played a role. This left SpaceX the sole bidder and gave credence to the prediction of "trading one monopoly for another." Some observers saw in ULA's nonsubmission its way of pressuring the government to waive the RD-180 ban.[75]

In the fall, Senator Richard C. Shelby (R-AL), an influential member of the Senate Appropriations Committee, entered the fray on behalf of ULA. Its Decatur, Alabama, work force could lose up to 800 workers if ULA was unable to compete for national security launches. In December, prospects for having the ban lifted improved when Undersecretary of Defense Frank Kendall III confirmed that guaranteeing competition for national security launches from Fiscal Year 2016 to Fiscal Year 2022 required at least 18 RD-180 engines. Although Senator McCain railed against "pork-barrel parochialism," Shelby succeeded in adding a single paragraph in the 2,200-page FY 2016 omnibus federal spending bill that overturned the ban by stating that space launch providers could compete for launches "regardless of the country of origin of the rocket engine." On 18 December 2015, the Consolidated Appropriations Act for Fiscal Year 2016 became public law.[76]

Nonetheless, lawmakers continued to argue well into the spring of 2016 over further use of the Russian engine and support for an American-made alternative. By May, a bipartisan group of senators offered an amendment to the FY 2017 NDAA that specifically permitted use of 18 RD-180 "rocket engines designed or manufactured in the Russian Federation" until 31 December 2022. Because of its firm cutoff date, Senator McCain supported the amendment, saying it provided a "sustainable path to achieve the broadly shared goal of assured access to space, competition in national security space launch, and ending our dependence on Russian engines." Signed into law in December 2016, the FY 2017 NDAA also approved more funding for development of the new rocket propulsion systems and future launch vehicles.[77]

SpaceX Ascends and ULA Responds

Meanwhile, SpaceX continued to lead the contingent of new entrant launch competitors for national security missions. The triumphant maiden flight of SpaceX's Falcon 9 upgrade on 21 December 2015 convinced SMC to certify the Falcon 9 upgrade launch vehicle on 25 January 2016 for national security space missions. After the last launch of the Falcon 9 v1.1 launch vehicle that carried a Jason-3 oceanographic satellite on 17 January 2016, the Falcon 9 Upgrade compiled an impressive run of eight successful missions launched from the Cape's LC-40 pad that year. All eight supported NASA and commercial customers. Only one of the eight first stage landing attempts failed when, on the 15 June flight, low thrust on one of the three landing engines resulted in the first stage running out of propellant close to the deck of the landing ship. The string of successful launches came to an end on 1 September 2016, when a launchpad explosion during propellant filling destroyed the Falcon 9 with its Israeli communications payload and severely damaged the LC-40 pad. The incident remained under investigation the rest of the year. Meanwhile, SpaceX continued to work on its Falcon Heavy, the "world's most powerful rocket," that would attempt to land all three first stage cores for reuse on its initial flight, originally scheduled for 2015 but subsequently postponed to 2017.[78]

Although ULA remained the dominant force in the US space launch vehicle market, it found itself seriously challenged by SpaceX. Faced with the rapid rise of a worthy competitor, in the spring of 2016 Bruno implemented a restructuring and cost-cutting effort to make the company more competitive for DOD launch contracts. He slashed his executive contingent by 30 percent and planned to reduce ULA's number of launch sites from five to two, with corresponding workforce layoffs. ULA also announced its intention to lower the Atlas V base launch price from $180 million to $109 million, but still far above the Falcon 9's base price of $62 million (actually $90 million for DOD missions). By comparison, ULA charged a minimum of $350 million to launch its Delta IV Heavy, while SpaceX signed a contract with the Air Force to launch the Falcon 9 Heavy, when certified, for $130 million. The SpaceX Heavy would also outperform the Delta IV by carrying 125 percent more weight to LEO and 93 percent more to GTO or, as SpaceX asserted, the Falcon Heavy could "lift more than twice the payload . . . at one-third the cost." In response, ULA argued that it sold reliability and "schedule certainty."[79]

Tory Bruno staked his company's future success on the Vulcan rocket, its EELV replacement. He expected the base version to sell for under $100 million. Standing 228 feet tall, the Vulcan's first stage would be powered by two BE-4 engines that burned methane and liquid oxygen or two AR-1 engines with the more familiar combination of liquid oxygen and refined kerosene. ULA's Vulcan would be partially reusable, with the two engines detaching from the first stage and gliding to Earth via parafoils using an inflatable heat shield for reentry protection, and then being retrieved by helicopters. Bruno considered this option more cost effective than SpaceX's recovery of the entire rocket stage because larger payloads and GTO payloads would leave insufficient fuel for propulsive landing. As he queried, "Is it better to recover 100 percent of the value of the booster some of the time or only two-thirds of the value of the booster all of the time?"

Critics countered by noting the speed and ease of Falcon turnaround practices compared to Vulcan's potentially error-prone recovery procedures and lengthy refurbishment requirement. As for launch costs, the Vulcan, with reusability of its first stage engines, would cost about $60 million per flight. The Falcon 9 would likely cost from $15 to $25 million per launch if, as projected, it achieved full reusability of its first stage cores and its payload fairings, then benefited from more than 10 launches of its first stage cores before needing refurbishment. Additionally, ULA did not plan to implement engine reusability until 2024, four years after the planned first launch of the Vulcan and well after SpaceX would have demonstrated the success of propulsive landing and full reusability. The year 2024 would also be the year ULA planned to introduce its second stage Advanced Cryogenic Evolved Stage that ULA CEO Bruno claimed was "on the scale of inventing the airplane. That's how revolutionary this upper stage is."[80]

SpaceX continued its exceptional growth and success with 18 flights in 2017 and 21 flights in 2018. The 2017 flights included several "firsts": On 30 March, an SES communications satellite became the first payload to fly on a reused first stage and the first to have its payload fairing remain intact after splashdown and recovery. On 1 May, SpaceX successfully carried out its initial national security mission with the launch of an NRO satellite on a Falcon 9 Upgrade, thereby ending the monopoly ULA had held on classified missions since 2006. SpaceX performed its initial mission for the Air Force on 7 September, when its second Falcon 9 Block 4 upgrade launched Boeing's X-37B, representing its fifth Orbital Test Vehicle flight, into LEO. In another "first" on 15 December 2017, a Falcon 9 Upgrade launched a Dragon capsule to the *ISS* from LC-40, the pad's first use since the explosion the preceding December. All previous Falcon 9 Upgrade missions in 2017 had flown from the historic LC-39A at the Kennedy Space Center. The 15 December flight also witnessed the twentieth successful booster landing, the second reuse of a Dragon capsule, the fourth reuse of a first stage, and the first flight using both reusable components.[81]

In 2018, SpaceX, after considerable delay, finally unveiled its highly anticipated Falcon Heavy launch vehicle. SpaceX fully expected to recover and reuse all three cores, plus the payload fairing and second stage after placement of the payload into its heliocentric Mars–Earth orbit. The widely publicized flight on 6 February 2018 proved incredibly popular, with over 2.3 million concurrent views of the live webcast showing the launch of Elon Musk's red Tesla roadster and its mannequin dressed in SpaceX's latest spacesuit. Although the two side boosters landed simultaneously at adjacent Cape pads, the central core failed to land on the drone ship when two of its engines did not restart and it landed in the Atlantic Ocean, damaging the landing ship. Next, Space X, under the OSP-3 contract awarded by the Air Force in 2012, prepared to launch the Air Force's Space Test Program-2 (STP-2) payload. That Falcon Heavy launch, on 24 June 2019, successfully placed 24 satellites into various orbits and orbital inclinations. In addition to the Falcon Heavy mission in February, the Falcon 9 Upgrade flew 20 successful flights in 2018 and concluded its impressive total on 23 December with its initial EELV-class launch of the GPS IIIA-01 payload on which ULA had declined to bid in 2016.[82]

During SpaceX's impressive run of launch achievements, ULA had been far from idle. Indeed, its unbroken series of successful launches continued with 57 flights in the eight years since the new Air Force acquisition strategy of the block-buy award to Bruno's company in 2013. From 2013 through March 2019, the Atlas V workhorse flew a total of 47 times, consisting of 37 flights from the Cape's LC-41 and 10 from Vandenberg's SLC-3E. Of the latter, the 17 October 2018 Atlas V flight, which launched a Mars lander and two Mars cube satellites, was the first Mars mission from Vandenberg AFB. ULA planned to fly the Atlas V 18 more times from 2020 to 2024 before the Vulcan supplanted it. For the same eight-year period, the Delta IV Medium flew 13 times, with its final mission, a GPS payload, rescheduled from July to August 2019 before being withdrawn from EELV competition. The Delta IV Heavy's launch manifest during the eight-year period totaled only five missions, consisting of three classified flights for the NRO and two unclassified flights for NASA. For the first time, NASA chose to use the heavy-lift Delta for its test of the Orion Multi-Purpose Crew Vehicle. The two-hour, two-orbit flight took place on 5 December 2014. Four years later, on 12 August 2018, a Delta IV lofted the space agency's Parker Solar Probe into a heliocentric orbit. ULA planned to fly an additional five Delta IV Heavy flights until 2024 when it was to be replaced by the Vulcan—scheduled for its initial flight in late 2022.[83]

Fig. 24. SpaceX's Falcon Heavy lifts off from LC-39A, 6 February 2018. (Photo courtesy of John Hilliard)

Conclusions

On 1 March 2019, the Air Force responded to congressional direction in the 2019 NDAA by renaming the EELV program the National Security Space Launch (NSSL) program. The new designation sought to reflect efforts to leverage the US commercial launch industry, which had grown significantly in the previous six years, and to recognize the arrival of reusable launch vehicles. As Bongiovi stated, the objective of the renamed program was to make launch services "more agile and effective for the warfighter."[84]

This was also a time to reflect on an incredibly successful space launch program. Over the previous 17 years, the EELV legacy included a perfect launch record of 79 successful national security launches of satellites worth $50 billion. Moreover, the innovations and efficiencies that characterized the program resulted in cost savings of at least 50 percent compared to the fly-out Delta, Atlas, and Titan launch vehicles. Perhaps the most significant cost factor involved the ability of the EELVs to cover the capability range without the coverage gaps that were present when moving from Delta II or Atlas III to Titan IV.[85]

Much of the EELV program's success could be attributed to oversight procedures pioneered by Colonel McKinney's EELV program office and expanded after the BAR on the eve of the first Delta IV and Atlas V launches. Colonel Bongiovi credited the original and subsequent BARs with contributing to the EELV success record in two ways. One involved the need for additional oversight, reflected in government mission assurance practices. "We consider ourselves part of the team to launch," Bongiovi noted, "and consider our government mission assurance efforts value added." He said his launch contracts were structured with clauses that required contractors to provide government access to their data, but the Air Force paid for this requirement. In that way, contractors were not forced to absorb the additional costs that could result in higher costs for commercial missions. Mission assurance activities commence early "in the flow." This allowed the Air Force team to identify problems and industry to address them immediately instead of later, when the cost impact would be greater. The Broad Area Review had strongly advocated for value-added government mission assurance.[86]

The launch enterprise director also cited the BAR recommendation that called for clear accountability through a more rigorous process to determine launch readiness, or spaceflight worthiness, that centered on integrated certification up to the SMC commander in a flight readiness review meeting. At that point, launch authority was delegated to the launch site mission director, who kept the commander informed throughout the launch process. While the launch site authorities would tell the mission director on the day of launch that he was cleared to launch from a safety and range perspective, it was the SMC commander and the mission director who made the final decision to launch. Assessing the success of the EELV program, Bongiovi added an additional factor: industry performance. He said Boeing, Lockheed Martin, and ULA "took mission success seriously every step of the way . . . . They are not interested in speeding into failure."[87]

By all measures, the EELV program met its original objective to "improve and evolve current ELVs" to reduce costs "while improving reliability, operability, responsiveness, and safety." Under the new designation, NSSL-class missions would continue the record of successful launches established by the EELV Delta and Atlas rockets. Indeed, in the year after the EELV program redesignation, NSSL launches maintained a perfect flight record, with three Atlas V and two Delta IV Heavy flights, along with 17 successful SpaceX launches. One article that described the new program designation asserted that "EELV is no more." Bongiovi, however, chose to emphasize that the new NSSL designation really did not reflect a change in the national security launch mission. Rather than getting upset about the name change, he remarked, "We decided to host a big party and had all the ex-SPO directors in for that ceremony."[88]

Notes

1. For the Clinton transportation policy and the Moorman Report, see Spires, *Orbital Futures*, vol. 2, 906–52.

2. GAO, *Access to Space*, 19–20; and Air Force Space Command (AFSPC), *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined,* 353–59.

3. Saxer et al., "Evolved Expendable Launch Vehicle System," 2; AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 360–64; Kendall, "EELV: The Next Stage of Space Launch," 42; AFSPC/DRSV, "The Evolved Expendable Launch Vehicle," issue paper; AFSPC/DRSV, "Evolved Expendable Launch Vehicle," point paper; AFSPC/Det1, "Change in EELV Acquisition Strategy," point paper; and RAND, *National Security Launch Report*, 29–32.

4. McKinney, interview. McKinney explained that he tried to keep the three-star SMC commander informed. The commander's job "was to organize, train, equip,

and give me the people and I had no responsibility to report to him." See an expanded biography of Col Richard W. McKinney in appendix A.

5. Saxer et al., "Evolved Expendable Vehicle Launch System," 5; AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 365–70; and 45th SW, *History of the 45th Space Wing, 1 January–31 December 1997*, 46–49.

6. 45th SW, *History of the 45th Space Wing, 1 January–31 December 1997*, 46–49; 45th SW, *History of the 45th Space Wing, 1 January–31 December 199*8, 41–42; and Space and Missile Systems Center (SMC), *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 92–93. Other Transaction Agreement (OTA) contracts covered development of launch vehicles, along with new or refurbished launchpads, payload interfaces, and other support infrastructure. GAO, *Evolved Expendable Launch Vehicle: DOD Guidance Needed*, 2, 10, 16; GAO, *Space Acquisitions: Uncertainties*, 7; GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 3; and McKinney, interview. McKinney believed that the maiden flight failure of the Ariane 5 on 4 June 1996 helped convince the contractors to accept two providers instead of one. The Commercial Space Transportation Advisory Committee, an advisory board within the FAA, provided advice and recommendations to the Department of Transportation and the FAA on the commercial space transportation industry. Saxer et al., "Evolved Expendable Vehicle Launch System," 5–7.

7. Kendall, "EELV: The Next Stage of Space Launch," 42; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1997*, 49; and 45th SW, *History of the 45th Space Wing, 1 January–31 December 2000*, 48. The relevant Operational Requirements Document II defined insight as "an operation risk management approach requiring minimum governmental involvement into contractor processes and operations. It relies heavily on government trust and confidence in contractor performance. At the launch base, insight is implemented through actions necessary to ensure public safety for all space launches and integrate the launch team to achieve successful space access for government missions."

8. Saxer et al., "Evolved Expendable Launch System," 4; and McKinney, interview. Over the course of his four-year assignment, Colonel McKinney's program office roster grew to approximately 90 personnel.

9. McKinney, interview.

10. Saxer et al., "Evolved Expendable Launch System," 9; AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 360–64; Kendall, "EELV: The Next Stage of Space Launch," 42; AFSPC/DRSV, "The Evolved Expendable Launch Vehicle," issue paper; AFSPC/DRSV, "Evolved Expendable Launch Vehicle," point paper; AFSPC/Det1, "Change in EELV Acquisition Strategy," point paper; and RAND, *National Security Launch Report*, 29–32.

11. Kendall, "EELV: The Next Stage of Space Launch," 43–44; and Space and Missile Systems Center, Launch Enterprise (SMC/LE), "Launch Systems Enterprise Directorate."

12. McKinney, interview.

13. Boeing's streamlined manufacturing processes were exemplified by the RS-68 engine, which had 95 percent fewer parts than the space shuttle main engine and needed only 8,000 hours to assemble compared to 171,000 hours for the shuttle engine. Saxer et al., "Evolved Expendable Launch System," 12–13; SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 88-90; Kendall, "EELV: The Next Stage of Space Launch," 42–44; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1998*, 42–43; Isakowitz, Hopkins, and

Hopkins, *International Reference Guide to Space Launch Systems,* 115–25, 128; and RAND, *National Security Space Launch Report*, 17–18, 22–23.

14. McKinney, interview. Boeing delivered its CBCs to the launch site by a dedicated transport vessel. This resulted in CBCs with 5-meter diameters, 160 feet long, which simplified their overall design. Lockheed Martin, by contrast, had to limit the size of its booster core to be transported by C-5 and Antonov aircraft. Saxer et al., "Evolved Expendable Launch System," 12–13; SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 88-90; Kendall, "EELV: The Next Stage of Space Launch," 42–44; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1998*, 42–43; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 97–99, 115–25, 128; and RAND, *National Security Space Launch Report*, 17–18, 22–23.

15. Lockheed Martin's efficiencies are illustrated by a Titan IV and Atlas V comparison. The provider reduced launch site processing facilities from 36 for the Titan IV to 3 for the Atlas V; launch site personnel from 1,200 to under 200; and number of days on the pad from 180 to just a single day for the Atlas V. Depending on configuration, off-pad processing time dropped to 18–26 days. Saxer et al., "Evolved Expendable Launch System," 9–11; SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 90–92; Kendall, "EELV: The Next Stage of Space Launch," 39–41; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1998*, 43–46; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 55–57, 68–77, 84; and RAND, *National Security Space Launch Report*, 14–17.

16. Saxer et al., "Evolved Expendable Launch System," 9–11; SMC, *History of the Space and Missile Systems Center*, 1 January 2002–31 December 2004, 90–92; Kendall, "EELV: The Next Stage of Space Launch," 39–41; 45th SW, *History of the 45th Space Wing, 1 January-31 December 1998*, 43–46; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 55–57, 68–77, 84; and RAND, *National Security Space Launch Report*, 14–17.

17. Saxer et al., "Evolved Expendable Launch System," 9–11; SMC, *History of the Space and Missile Systems Center*, 1 January 2002–31 December 2004, 90–92; Kendall, "EELV: The Next Stage of Space Launch," 39–41; 45th SW, *History of the 45th Space Wing, 1 January-31 December 1998*, 43–46; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 55–57, 68–77, 84; and RAND, *National Security Space Launch Report*, 14–17.

18. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 96; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1998*, 43–50; Isakowitz, Hopkins, and Hopkins, *International Reference Guide to Space Launch Systems*, 76–77; RAND, *National Security Space Launch Report*, 20–22; and Bongiovi, "Manuscript Review Comments." See an expanded biography of Col Robert P. Bongiovi in appendix A.

19. GAO, *Space Acquisitions: Uncertainties*, 1, 7; GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 3; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 3; and RAND, *National Security Space Launch Report*, 28–29.

20. Referred to as BAR I, the 1999 report was the first of six BAR reports. Institute for Defense Analyses (IDA), "Space Launch Vehicles Broad Area Review Report," 37–55; AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 387–88; SMC, *History of the Space and Missile Systems Center, 1 January 1998–31 December 2001*, 53–55; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1999*, 45–46; and 45th SW, *History of the 45th Space Wing, 1 January–31 December 2000*, 48–49.

21. GAO, *Space Acquisitions: Uncertainties*, 1, 7; GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 3; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 3; RAND, *National Security Space Launch Report*, 28–29; and McKinney, interview.

22. GAO, *Space Acquisitions: Uncertainties*, 1, 7; GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 3; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 3; RAND, *National Security Space Launch Report*, 28–29; IDA, "Space Launch Vehicles Broad Area Follow-up Review Report," September 2000, 53–67; IDA, "Space Launch Vehicles Broad Area Follow-up Review Report," April 2001, 4–12, 16; and Hildreth, *National Security Space Launch at a Crossroads*, 3–4. SMC revised the contracts to include a cost-plus feature for reliability confidence-building, incentives for mission success, and mission assurance add-ons; Moorman, "Framing the Assured Access Debate," 8.

23. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 93–95; and McKinney, interview.

24. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 96–101, 103–5; and SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 80.

25. Bongiovi, interview, 19 November 2019.

26. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 99–101; GAO, *Air Force Launch Services New Entrant Certification Guide*, 10; and GAO, *Space Acquisitions: Uncertainties*, 7.

27. Hildreth, *National Security Space Launch at a Crossroads*, 34; and Moorman, "Framing the Assured Access Debate," 8–12. One of the EELV options described in Moorman's 2004 "Assured Access to Space Study" was to combine EELV operations by having "the two contractors combining their engineering, production and launch capabilities into a joint venture." Boeing and Lockheed Martin adopted this option in 2006; AFSPC, *History of the Air Force Space Command, 1 January 2004–31 December 2005,* 170–73.

28. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 81–82; Hildreth, *National Security Space Launch at a Crossroads*, 4; GAO, *Space Acquisitions: Uncertainties*, 7–9; GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 3–4; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 3-5; and RAND, *National Security Space Launch Report, 2006*, 34.

29. IDA, "Space Launch Vehicles Broad Area Review Report," 37–55; AFSPC, *History of the Air Force Space Command, 1 January 1994–31 December 1998 and 1 January 1999–31 December 2003 Combined*, 387–88; SMC, *History of the Space and Missile Systems Center, 1 January 1998–31 December 2001*, 53–55; 45th SW, *History of the 45th Space Wing, 1 January–31 December 1999*, 45–46; and 45th SW, *History of the 45th Space Wing, 1 January–31 December 2000*, 48–49; 45th SW, *History of the 45th Space Wing, 1 January–31 December 2006*, 39–40; and Spires, *Beyond Horizons,* 322–23.

30. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 93; and AFSPC, "Operational Requirements Document (ORD) II," sec. 7.2, 7.3.

31. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 109–12; AFSPC, *History of the Air Force Space Command, 1 January 2004–31 December 2005*, 169–70; McDowell, "Satellite Catalog," accessed 8 September 2018; Encyclopedia Astronautica, "Delta IV," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 20 October 2021.

32. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 93–95; McKinney, interview; and Boeing, "The DemoSat Payload," accessed 20 July 2019.

33. Col John Stizza, the launch director for the Vandenberg Atlas V launch, remembers this first DOD mission to use the 411 configuration as being "a smooth flow" launch. He was especially impressed with the refurbished SLC-3E launchpad: "Even though it was a repurposed pad, it looked brand new." Stizza, email, 7 August 2019; SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 89–92; McDowell, "Satellite Catalog," accessed 8 September 2018; Encyclopedia Astronautica, "Atlas," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 29 October 2021.

34. McDowell, "Satellite Catalog," accessed 8 September 2018; Encyclopedia Astronautica, "Atlas" and "Delta IV," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 29 October 2021.

35. Specifically, the LTRS provided command and control, flight safety, meteorological information, telemetry data, ground-based surveillance, and communications. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 96; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 42.

36. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 97–99; For a comprehensive listing and description of range capabilities, see 45th SW/XP, "45 SW Eastern Range Customers' Handbook"; and 30th SW, "30th Space Wing Capabilities Handbook." See a map of LTRS Eastern and Western Ranges, 2005, in appendix B.

37. SMC, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008*, 100–101; 45th SW, *History of the 45th Space Wing, 1 January–31 December 2002*, 31, 33; RAND, *National Security Space Launch Report*, 23-25; and AFSPC/DRS, "Spacelift Ranges Modernization."

38. 45th SW, *History of the 45th Space Wing, 1 January–31 December 2009*, 46–50; SMC, *History of the Space and Missile Systems Center, 1 January 2009–31 December 2010*, 48–49; AFSPC/A3R, "Launch and Range Enterprise Way Ahead"; and Booz Allen Hamilton, "Launch Enterprise Transformation Study." See an expanded biography of Gen C. Robert Kehler in appendix A.

39. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 43; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 49–50; AFSPC/SEK, "Global Positioning System Metric Tracking (GPS MT)," point paper; Moore, Carr, and Friesen, "Launch Vehicle Mission Capability Enhancement"; and Abott, "GPS IIF-8 Launch To Be First with GPS Metric Tracking."

40. SMC, *History of the Space and Missile Systems Center, 1 January 2002–31 December 2004*, 109–12; AFSPC, *History of the Air Force Space Command, 1 January 2004–31 December 2005*, 169–70; Encyclopedia Astronautica, "Delta IV," accessed 29 October 2021; McDowell, "Master Orbital List," accessed 29 October 2021; Clark, "Rockets Leap into the 21st Century"; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 49.

41. AFSPC/SE, "Future Flight Safety Strategy (FFSS)," point paper; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 51–52; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 50–51.

42. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 50–51; and Gruss, "ORS-3 Launch Tested New ATK-developed Flight Safety System," accessed 23 August 2019. In 2014, Orbital Sciences Corporation merged with Alliant Techsystems to become Orbital ATK.

43. AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 151–52, 162; Herman, "Air Force Eastern Range Innovates," accessed 1 March 2018; Clark, "Auto-Destruct System Seen as a Key," accessed 1 March 2018; Jacobson, "VAFB to Host First West Coast Launch"; Encyclopedia Astronautica, "Falcon," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 29 October 2021.

44. AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 151.

45. AFSPC, "Commander's Strategic Intent, Range of the Future 2028," 2–3.

46. AFSPC, "Commander's Strategic Intent, Range of the Future 2028."

47. AFSPC, "Commander's Strategic Intent, Range of the Future 2028," 4–9.

48. AFSPC, "Commander's Strategic Intent, Range of the Future 2028," 9–10.

49. SMC, *History of the Space and Missile Systems Center, 1 January 2011–31 December 2012,* 31–32; IDA, "Launch Broad Area Review –2010 (BAR X)," 16–24; AFSPC/A3R, "AFSPC/CC's Vision for EELV Launch Manifesting"; and AFSPC Instruction 13-1213, "Launch Scheduling and Forecasting Procedures," 3–7.

50. IDA, "Launch Broad Area Review–2010 (BAR X)," 5, 56–62; AFSPC, *History of the Air Force Space Command, 1 January 2009–31 December 2010*, 45–46; and GAO, *Evolved Expendable Launch Vehicle: DOD Needs to Ensure*, 5–6.

51. The block buy contract, referred to as phase I, concluded on 30 September 2019. Bongiovi, interview, 19 November 2019; SMC, *History of the Space and Missile Systems Center, 1 January 2011–31 December 2012*, 43–44; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 5; GAO, *Evolved Expendable Launch Vehicle: Introducing Competition*, 5 March 2014, 4; CRS, *National Security Space Launch at a Crossroads*, 4–5; and SAF/AQS, "Evolved Expendable Launch Vehicle (EELV) Talking Points."

52. GAO, *U.S. Launch Enterprise: Acquisition Best Practices Can Benefit Future Efforts*, 4–5; GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 6; SMC, *History of the Space and Missile Systems Center, 1 January 2011–31 December 2012*, 44–45; CRS, *National Security Space Launch at a Crossroads*, 5–6; SAF/AQS, "Evolved Expendable Launch Vehicle (EELV) Talking Points"; Gruss, "US. Air Force Considers Extending OSP-3 Launch Contracting Vehicle"; and Riddle, "Manuscript Review Comments."

53. IDA, "Broad Area Review XV," May 2015, 6–7; GAO, *Air Force Launch Services New Entrant Certification Guide*, 10–12, 16–19, 23; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 67–69. See an expanded biography of Elon Musk in appendix A.

54. Bongiovi, interview, 19 November 2019; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 27–29; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 67–69; and GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 6.

55. Bongiovi, interview, 19 November 2019; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 27–29; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 67–69; and GAO, *Evolved Expendable Launch Vehicle: The Air Force Needs to Adopt*, 6.

56. GAO, *Air Force Launch Services New Entrant Certification Guide*, 22; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 29–30; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 69–70.

57. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 29–30.

58. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 32; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 32–33; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 70–71.

59. IDA, "Broad Area Review XV," 1–2.

60. IDA, "Broad Area Review XV," 12–13, 22–23.

61. IDA, "Broad Area Review XV," 18, 25–26; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 71–72; SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 134; Encyclopedia Astronautica, "Falcon," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 29 October 2021.

62. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 34.

63. SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 72.

64. SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 72–73; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 36–37.

65. Both vehicles, however, continued in service beyond 2017. IDA, "Broad Area Review XV," May 2015, 2–3; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 39; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 86.

66. Bongiovi, interview, 19 November 2019; Butler, "U.S. RD-180 Coproduction Would Cost $1 Billion"; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 75–76; and CRS, *National Security Space Launch at a Crossroads*, 7–8.

67. SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 77, 79–81; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 33–35; and CRS, *National Security Space Launch at a Crossroads*, 7–8.

68. The study's conclusions served as the genesis of the rocket propulsion system contracts awarded to four providers in 2016. Bongiovi, interview, 19 November 2019; and AFSPC, "Acquisition Strategy for Evolved Expendable Launch Vehicle," 13–14. A Broad Agency Announcement (BAA) (FAR 35.016) is a notice from the government that requests scientific or research proposals from private firms concerning certain areas of interest to the government. The proposals submitted by the private firms may lead to contracts.

69. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 34–36; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 81–83; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 38–39.

70. Bongiovi, interview, 19 November 2019; AFSPC, "Acquisition Strategy for Evolved Expendable Launch Vehicle (EELV) Program," 13–14; SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 137–40; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 43–47; Harwood, "ULA Touts New Vulcan Rocket"; Brissett, "Space Launch Competition"; Batto, "What Will Be the Response?"; and Ferster, "ULA to Invest in Blue Origin Engine as RD-180 Replacement."

71. Harwood, "ULA Touts New Vulcan Rocket"; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 85–89; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 39–44; and Bongiovi, interview, 19 November 2019.

72. Harwood, "ULA Touts New Vulcan Rocket"; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 85–89; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 39–44; and Bongiovi, interview, 19 November 2019.

73. Mayo, email, 23 June 2017, 31 July 2019; and Mayo, interview.

74. Mayo, email, 23 June 2017, 31 July 2019; Mayo, interview; and Bongiovi, interview, 19 November 2019.

75. AFSPC, *History of the Air Force Space Command, 1 January-31 December 2015*, 40–44; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 88–92.

76. AFSPC, *History of the Air Force Space Command, 1 January-31 December 2015*, 40–44; and SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 88–92.

77. The Air Force could submit a request to Congress for more than the 18 RD-180 engines authorized. An additional amendment authorized 25 percent of the funds to be spent on a new launch vehicle, upper stage, strap-on motor, or related infrastructure. Smith, "House Passes FY2017 NDAA-Update"; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 38–42; and SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 136–37.

78. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 35–37; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 34–38; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 71–73; SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 132–36; Encyclopedia Astronautica, "Falcon," accessed 29 October 2021; and McDowell, "Master Orbital List," accessed 29 October 2021.

79. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 38; Harwood, "ULA Touts New Vulcan Rocket"; Brissett, "Space Launch Competition," accessed 21 January 2018; and Batto, "What Will Be the Response?," accessed 25 July 2019.

80. SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 72–73; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 36–37; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015,* 46–47; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 73–74; and SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 135–36.

81. AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 140; and McDowell, "Master Orbital List," accessed 29 October 2021.

82. AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 140; and McDowell, "Master Orbital List," accessed 29 October 2021.

83. The final Delta IV Medium mission launched on 22 August 2019. Critics of the acquisition strategy argued that not only did the commercial market projections seem overly optimistic, but also other solutions to the launch dilemma seemed more promising. One observer, for example, thought it made more sense to continue to use the Delta IV Heavy rather than develop a new heavy-lifter for the few missions projected. Colonel Bongiovi dismissed this argument, citing high costs, problems obtaining parts, and the prospect of more efficient carriers in the near future. Bongiovi, interview, 19 November 2019; Harwood, "ULA Touts New Vulcan Rocket," 1–14; Batto, "What Will Be the Response?"; Brissett, "Space Launch Competition"; and McDowell, "Master Orbital List," accessed 29 October 2021.

84. Bongiovi, interview, 19 November 2019; McKinney, interview; Erwin, "EELV Is No More"; and McDowell, "Satellite Catalog," accessed 20 January 2019.

85. Bongiovi, interview, 19 November 2019; McKinney, interview; Erwin, "EELV Is No More"; and McDowell, "Satellite Catalog," accessed 20 January 2019.

86. Bongiovi, interview, 19 November 2019; McKinney, interview; Erwin, "EELV Is No More"; and McDowell, "Satellite Catalog," accessed 20 January 2019.

87. Bongiovi, interview, 19 November 2019.

88. Erwin, "EELV Is No More"; and Bongiovi, interview, 19 November 2019. Also see Spires, *Orbital Futures*, vol. 2, 906–52.

Chapter 8

The Twenty-First Century

A Responsive Space Launch Enterprise and Assured Access to Space

Surveying the space launch landscape in the spring of 2020, Col Robert P. Bongiovi, SMC Launch Enterprise Systems director, expressed optimism about DOD launch prospects for the coming year. "This year is going to be historic," he said, "because we have 11 of the big National Security Space Launch missions on the manifest." In addition, NASA planned to launch two interplanetary missions on Atlas Vs, and those would take precedence if their fixed windows conflicted with the NSSL launch schedule. NASA's commercial crew program was underway as well, and unmanned test flights could occur late in the year. Bongiovi's responsibilities also included the Small Launch and Targets Division at Kirtland AFB, New Mexico, which looked forward to a busy 2020 with at least 9 to 11 small to medium rocket launches on the manifest. Bongiovi declared, "Actually, I'm pretty impressed with where we've gone and where we've gotten to." A key factor in the Air Force launch program's effectiveness was the reorganizational initiative that took place five years earlier.[1]

On 14 October 2015, SMC established a new directorate to provide more effective space launch leadership in the new era of multiple space launch competitors. This new Launch Systems Enterprise Directorate (SMC/LE) brought together the Launch Systems Directorate, located at Los Angeles AFB, California, and the Rocket Systems Launch Program (RSLP), based at Kirtland AFB. The latter formerly had been subordinated to SMC's Advanced Systems and Development Directorate at Kirtland. Now, with the RSLP removed from development, launch was centralized under SMC/LE. As then–SMC commander Lt Gen Samuel A. Greaves declared, "Today, we unify Air Force space launch capabilities under one directorate to synchronize our acquisition activities."[2]

While SMC/LE exercised direction over the entire Air Force space launch enterprise, its focus remained largely on the acquisition and operation of EELV-class medium and heavy-lift vehicles and on range capabilities at Vandenberg AFB and Cape Canaveral AFS. In 2015, these systems included the Delta II, the EELV Delta IV and Atlas V launch vehicles, and new entrants like SpaceX's Falcon 9. Subordinated to SMC/LE, Kirtland AFB's RSLP executed small to medium launches, provided target vehicles primarily to the Missile Defense Agency's test program, and maintained Minuteman and Peacekeeper rocket motors for use as target vehicles. Most significantly, Kirtland's small launch vehicle program had made impressive progress with its various initiatives to provide an operationally responsive launch capability.[3]

The Air Force Adopts a Responsive Launch Initiative

From the late 1980s, Air Force space leaders had sought to develop a responsive launch capability to provide theater warfighters timely space support. This weakness became apparent during the first Gulf War, when AFSPC could not launch "on demand" a needed DSCS III communications satellite system. Despite this recognized problem, emphasis remained on developing an ELV replacement to launch medium and heavy classified satellites to LEO and GTO. The EELV family of Atlas V and Delta IV launch vehicles provided the desired NSSL capability for the twenty-first century. Although the EELV program might have assured access to space, an Air Force study in 2003 determined it could not satisfy the requirement for a more responsive space launch capability.[4]

In the late 1990s, Air Force Space Command became concerned about defending against adversaries' space systems in any future conflict, and it began studying the potential for launch systems to provide a rapid-response capability. The vulnerability of the nation's space assets drew the attention of the high-level, congressionally chartered Commission to Assess United States National Security Space Management and Organization (hereafter referred to as the Space Commission), which consisted of 12 space and national security veterans under the chairmanship of former Secretary of Defense Donald H. Rumsfeld. In its 11 January 2001 report, it took a broad view of the role of space in the nation's defense. "The U.S. is more dependent on space than any other nation," the Space Commission declared as it focused on the heightened vulnerability of the nation's orbiting satellites and ground-based space systems. "With the growing commercial and national security use of space," its report pointedly asserted, "the U.S. is an attractive candidate for a 'Space Pearl Harbor.'"[5]

These efforts laid the groundwork for the Mission Need Statement for Operationally Responsive Spacelift (ORS) that AFSPC issued on 31 October 2001. The Joint Requirements Oversight Council approved the Mission Need Statement in April 2002, and Air Force leaders expected ORS, once developed, to ensure the Air Force could "rapidly put payloads into orbit and maneuver spacecraft to any point in earth-centered space, and to logistically support them on orbit or return them to earth." In short, ORS meant a rapid spacelift capability to provide "on-demand satellite deployment [and] on-demand execution of space operations." Previously, only the Delta II, with its 60-day call-up, had been able to provide at least a partial on-demand capability. Now, planners expected to develop systems able to launch within hours of call-up and "conduct military operations within hours of reaching orbit." Moreover, the Mission Need Statement asserted, "ORS systems must provide a cost-effective means of executing DoD missions." This initial ORS concept envisioned a reusable launch vehicle program, and the Joint Requirements Oversight Council approved the Mission Need Statement in April 2002.[6]

In early 2003, AFSPC began investigating the best means of achieving the ORS requirements. As it did so, ORS was renamed Operationally Responsive Space, and the definition was broadened to include not just the launch vehicle but also research and development initiatives involving space vehicles, ranges, and near space systems. Commenting on the importance of ORS for responding to opposing space and counterspace systems, AFSPC commander Gen Lance W. Lord asserted that ORS "will provide an affordable capability to promptly, accurately, and decisively position and operate national and military assets in and through space and near space. ORS is a vision for transforming future space and near space operations, integration, and acquisition." Because AFSPC planners expected to implement ORS over a 20-year period beginning in 2004, there seemed to be little sense of urgency. Yet, in the wake of the Space Commission's criticism of the nation's launch deficiencies along with the experience of operations in Afghanistan and Iraq, DOD's Office of Force Transformation adopted ORS as a major initiative to rapidly provide joint tactical warfighters with a variety of affordable capabilities, and Congress followed with ORS funding in the FY 2005 defense budget. On 6 January 2005, ORS received a boost when President George W. Bush issued US Space Transportation Policy Directive 40, which called for the secretary of defense to "demonstrate an initial capability for operationally responsive access to and use of space."[7]

The need for an ORS capability became increasingly apparent over the next two years. In late 2006, for example, the Air Force's space operations doctrine document could still bluntly assert that "the US does not have the capability to perform multiple launches in rapid succession, or make rapid changes to a planned launch's payload" and, as recent combat experience had shown, "military planners are limited to on-orbit assets when responding to contingencies." With the ORS concept continuing to gain momentum, Congress, in the FY 2007 NDAA, required the secretary of defense to develop a comprehensive ORS plan and establish a joint ORS program office to implement the plan. On 17 April 2007, DOD issued an ORS plan that described a three-tiered, evolutionary approach to development. Under Tier 1, ORS officials would determine whether existing satellites could satisfy an urgent requirement within a few days. Were that not possible, Tier 2 envisioned launching a satellite within days or weeks using "plug-and-play" technologies. When Tier 1 and Tier 2 alternatives could not meet the need, planners would resort to Tier 3, which called for developing and operating the spacecraft within a year of the request. A month after issuing its plan, on 21 May, DOD "stood up" the Operationally Responsive Space Office at Kirtland AFB, with its first director, Col James K. "Kevin" McLaughlin, reporting directly to the DOD Executive Agent for Space.[8]

Developing Operationally Responsive Payloads and Launch Vehicles

Reviewing the ORS concept in 2006, Aerospace Corporation senior project engineer Les Doggrell observed, "The challenge for the Air Force lies in responding to [President Bush's policy] direction within the constraints of austere budgets." The Air Force had been addressing the satellite challenge of responsive space for several years with the use of TacSats, experimental tactical satellites that could be designed to respond directly to the needs of combatant commanders. Weighing under 1,000 pounds, TacSat ORS Tier 1 spacecraft provided a low-risk and relatively inexpensive means of exploring responsive capability concepts. This effort to develop responsive payloads represented a major departure from the nation's traditional approach of developing large, costly, multipurpose space systems that took many years to produce. Using modularity and "off-the-shelf" subsystems, ORS officials hoped to have these test-bed satellites launched within 12 to 18 months. Sponsored by AFSPC and the Air Force Research Laboratory (AFRL), the TacSat program included participation from the Defense Advanced Research Program Agency (DARPA), the NRO, and the Office of Naval Research.[9]

The initial satellite, *TacSat-1*, a 291-pound spacecraft developed by the Naval Research Laboratory, included low-resolution imaging and infrared cameras, data access through the Secret Internet Protocol Routing Network (SIPRNET), and a UHF cross-platform link that would permit direct control by operators in the United States Pacific Command. *TacSat-1*'s odyssey, however, helps explain the challenge of developing a low-cost launcher and the need for responsive ranges to support the ORS initiative. Costing $9.3 million, *TacSat-1* had met the objectives of cost and delivery within a year. Originally scheduled to launch in 2004 from Vandenberg Air Force Base on a SpaceX Falcon 1, officials postponed the mission when a Titan IV with a classified payload on a nearby launchpad experienced a six-month delay. By the summer of 2005, Kwajalein Atoll in the Marshall Islands had been selected as the launch site, but additional problems with the launcher pushed the scheduled launch date to late 2007 and, subsequently, into early 2008. Although the *TacSat-1* launch vehicle had development problems, the flexibility to reschedule rapidly proved impossible. By 2009, the *TacSat-1* launch was overtaken by events when SpaceX cancelled the Falcon 1 launcher and the program office determined that *TacSat-2* had fulfilled the initial satellite's mission requirements.[10]

Five additional TacSats followed *TacSat-1*. The 600-pound *TacSat-2* carried a "Roadrunner" payload, consisting of a color-imaging camera capable of achieving resolution of three feet in diameter, payload scheduling and data access through the SIPRNET, and a common data link X-band radio for direct transmission to the theater. On 16 December 2006, after only nine months of development, an Orbital Sciences Minotaur I successfully launched *TacSat-2* from NASA's Wallops Island, Virginia, facility. Designed to operate for one to two years, *TacSat-2* did not decay until 5 February 2011. *TacSat-3*, an 880 lb spacecraft, was configured with a hyperspectral imager and an onboard processor designed to provide data to the theater commander within 10 minutes of its collection. Launched on 19 May 2009 by a Minotaur I from Wallops Island, *TacSat-3* was the first to test the initial generation of modular bus technologies as part of the ORS plug-and-play approach to produce affordable, responsive payloads. *TacSat-4*, or *Com-X*, designed in conjunction with the NRO, tested beyond line-of-sight communications connectivity to evaluate the Blue Force Tracking augmentation system. Launched on a Minotaur IV from the Alaska Aerospace Corporation's Kodiak Air Station on Kodiak Island, Alaska, on 27 September 2011, the spacecraft's highly elliptical orbit enabled longer coverage of areas of interest. *TacSat-5* remained a conceptual project, but *TacSat-6*, the last in the series, successfully launched a three-unit cube satellite bus on 6 December 2013.[11]

By the time of the *TacSat-4* launch in 2011, the ORS office already had begun launching another series of small payload satellites to support theater commanders that, in effect, superseded the TacSat series. On 30 June 2011, a Minotaur I launched *ORS-1*, a satellite with a Senior Year Electro-Optical Reconnaissance System–2 sensor that produced visible and infrared imagery for US Central Command forces. Impressively, constructing *ORS-1* cost under $100 million and the Minotaur placed it on orbit in under 30 months. This mission also served as the trailblazer for the category 1 mission assurance approach, the first Air Force launch licensed by the Federal Aviation Administration (FAA). The ORS office launched three additional ORS missions. On 19 November 2013, *ORS-3* successfully launched from Wallops Flight Facility, Virginia, with a payload of 29 small ORS and Space Test Program (STP) satellites designed to demonstrate a variety of launch and range improvements. *ORS-4*, a rail-launched Super Strypi rocket carrying 13 experimental cubesats failed, however, due to a first stage motor malfunction in mid-flight after liftoff from the Pacific Missile Range facility off Barking Sands, Kauai, Hawaii, on 3 November 2015. The most recent mission, *ORS-5*, successfully launched by a Minotaur IV on 26 August 2017, placed a small surveillance satellite into a low-inclination orbit. The ORS office expected the satellite to produce more cost-effective situational awareness from GEO compared to larger, more complex satellites.[12]

While both GAO and RAND reports commented favorably on the TacSat program's progress, they criticized DOD's continuing inability to meet the challenge of developing a small, low-cost launch capability.[13] The ORS effort to develop responsive, low-cost launchers centered initially on the Force Application and Launch from the Continental United States Small Launch Vehicle (FALCON SLV) program. Begun in 2003, FALCON involved private industry in partnership with

DARPA, AFRL, and SMC. DARPA sought to produce a launch vehicle capable of lofting 1,000 pounds into LEO for no more than $5 million. Operational costs would be based on 20 flights per year over a 10-year period. The Air Force and DARPA initially pursued two options for its FALCON launcher: one, an Air Launch Quick Reach rocket to be released from the rear of an unmodified C-17 transport aircraft; the other, a SpaceX two-stage rocket capable of lofting a 1,000-pound satellite into LEO for an estimated cost of approximately $5 million. The Air Force disagreed with DARPA's decision to go forward with the Quick Reach rocket after an independent review team cited numerous safety risks, and the program ended after one air drop demonstration. Eventually, research would center on the technology for hypersonic vehicles. The Air Force also chose to develop the partially reusable Affordable Responsive Spacelift vehicle for payloads of 10,000–15,000 pounds, but DOD cancelled that program in 2006 after Congress refused funding on grounds it was "not considered a responsive space program."[14]

Fig. 25. Minotaur IV/Operationally Responsive Spacelift (ORS) 5 launches from LC-46, 26 August 2017. (Photo courtesy of John Hilliard)

During the previous decade, private industry and the Defense Department had developed Pegasus and Taurus, two other quick-launch vehicles. When the expected boom from the commercial marketplace did not occur, however, these vehicles could not provide a low-cost option. In response, Kirtland AFB's RSLP, using Orbital/Suborbital Program (OSP) contracts, worked with Orbital Sciences Corporation to produce the Minotaur I and Minotaur IV boosters that incorporated Minuteman and Peacekeeper ICBM technology, from 450 of the dismantled missiles it maintained. The Kirtland-based RSLP traced its origins to 1963 and the Advanced Ballistic Missile Reentry Systems program that used deactivated ICBM assets for reentry vehicle research. In 1972, the secretary of defense formally established the RSLP, giving it responsibility for the maintenance and safety of retired Minuteman and later Peacekeeper motors and to provide suborbital launch capability for various government agencies. When it could acquire sufficient funding, the RSLP also provided a modest space launch capability, too. All RSLP-supported launches were to be customer-funded, and the Minotaur launch vehicles could only be used for government payloads. The OSP-1 contract, awarded in 1997, had funded the use of surplus Minuteman II solid rocket motors, together with commercial upper stages for the first two configurations of the Minotaur booster. Under the OSP-2 contract, Orbital Sciences developed the heavier-lift Minotaur IV, consisting of three Peacekeeper solid rocket stages and a fourth commercial Orion 38 stage motor. The Minotaur IV had its first launch on 25 September 2010, when it successfully carried the Space Based Space Surveillance pathfinder satellite to orbit. With development of a new small rocket launcher proving especially troublesome, Minotaur I and Minotaur IV remained the key launch vehicles for the ORS program.[15]

In 2011, with the emphasis on new launch competitors, SMC's Space Development and Test Directorate focused on Orbital/Suborbital Program-3 (OSP-3), the third iteration of the program directed by the RSLP in its mission "to provide an enhanced capability and flexibility in the development of small and medium launch vehicles and launch services while providing an on-ramp for emerging capability." The following year, on 30 November 2012, SMC awarded four, five-year indefinite delivery, indefinite quantity (IDIQ) contracts, two to each of two "lanes," with recipients competing on a "lowest-price-technically-acceptable basis." The flexible IDIQ contracts allowed ordering products without having to redo the original contracts. The "lane 1" contracts, requiring a performance capability of lofting from 400 to 4,000 pounds to LEO, went to Orbital Sciences Corporation for its Minotaur I and IV and to Lockheed Martin Space Systems Corporation, which used its Athena Ic and IIc launch vehicles. For "lane 2," with a launch performance requirement above 4,000 pounds to LEO, the awardees were Orbital Sciences for its Minotaur VI and Antares vehicles, and SpaceX, with its Falcon 9 Upgrade and Falcon Heavy launchers.[16]

Over the next several years, RSLP continued its technology demonstration and launch efforts to develop small and medium responsive launch capabilities through a variety of programs, including SMC's Small Rocket Program that offered contracts for suborbital flights. The broader OSP-3 orbital initiative's performance period was extended from 2017 to 2019. In 2016 and 2017, interest in small-launch candidates raised the prospect of using RSLP's surplus ICBM motors, heretofore prohibited, for launching commercial payloads. Studies by the Institute for Defense Analyses and the GAO concluded that, if the law changed, only agreeing on a fair price to both the commercial buyer and the government stood in the way of commercial use. The surplus motors had little potential for impact on the commercial market, however, because Hill AFB, Utah, could only process three flight sets per year. Moreover, as RSLP chief engineer Randall L. Riddle noted, "I don't really see us ever buying another Minotaur 1 because the price you can get for that amount of performance—they're just not competitive." As of early 2019, the ban on using retired ICBM motors for commercial launches remained in place, and the growing demand for smaller, more responsive, low-cost launch vehicles continued into 2019.[17]

In 2015, the Air Force had submitted an "Operationally Responsive Low-Cost Launch (ORLCL) Congressional Report" in response to a legislative directive to review existing and past efforts, identify DOD requirements, provide a technology assessment, and discuss measures to better use innovative methods to provide a "consolidated plan for developing an operationally responsive, low-cost launch capability within DoD." The report began by cautioning that, in addition to responsive launch requiring a "launch-on-demand" capability, a genuinely effective operationally responsive space capability included responsive payloads, responsive ground resources, and responsive on-orbit checkout. The exhaustive report praised "recent DoD space launch program efficiencies and emerging true competition within the commercial sector" and asserted that "small launch vehicles—currently under research and development—hold promise for fulfilling the most urgent combatant command and responsive launch needs at affordable cost." It recommended continuing with small launch vehicle research and development, implementing range upgrades for responsiveness, investing where necessary throughout the launch enterprise where required for responsive launch, and adopting "rideshare" secondary payloads to reduce costs. At the same time, in each area assessed, the report concluded, "There are no clearly articulated and validated requirements for operationally responsive launch today [and] no payload mission needs for responsive launch have been identified." A GAO review of DOD's responsive launch report confirmed that "DoD currently lacks formal requirements for responsive launch but plans to validate future responsive launch requirements as it gains knowledge about emerging threats."[18]

Nearly three years later, when the Air Force provided a House of Representatives–directed briefing on responsive launch, validated operationally responsive launch requirements had yet to be developed. Submitted in the summer of 2018, the printed "Responsive Launch" briefing acknowledged progress in the responsive launch program and the need to responsively reconstitute on-orbit space capabilities and deploy on-orbit capability "on operationally relevant timelines." The briefing began by acknowledging that responsive launch had been extensively studied in the 2015 ORLCL report and its conclusions remained correct. The National Security Space program still had neither validated responsive launch requirements nor identified payload mission needs. Instead, the briefing advised, the Air Force and DOD were making progress "developing warfighting strategies that may lead to validated responsive launch requirements." In doing so, the Air Force continued to leverage industrial innovation and rapid advances in technology and to make limited research and development investments. In the FY 2018 NDAA, Congress, concluding the ORS had focused too little on developing innovative operational systems, renamed the ORS office the Space Rapid Capabilities Office (SpRCO). It was to "pursue innovative approaches to rapid fielding of space critical capabilities" by accelerating acquisition of new space technologies with emphasis on special access programs and other classified venues. Unlike the original ORS office, SpRCO had no launch component.[19]

The Rocket Systems Launch Program and Small Rocket Launch Initiatives

More comprehensive efforts to develop a responsive small rocket capability were led by Kirtland AFB's Small Launch and Targets Division under its RSLP. As division chief Lt Col Ryan A. Rose explained, "Our division is responsible for all of the small launch operations within the Air Force." Providing suborbital and orbital launch services, "our [RSLP] contracts have a large breadth of availability and flexibility to pretty much do any of the missions," consisting largely of experimental payloads, in contrast to the NSSL's operational focus.[20]

In a major change, the Air Force FY 2019 budget established a small-launch program with a dedicated funding line of $192.5 million for a five-year period. Until this time, RSLP had received funding only to store and maintain ICBM motors. Its space launches for the NRO, DARPA, and targets supplied to the Missile Defense Agency (and others) had been funded by the customers. Now, for the first time, the division had its own annual funding line to buy launch vehicle services as part of Air Force Space Command's manifesting process. Referring to the small-launch program in February 2018, Secretary of the Air Force Heather Wilson asserted that the goal was to "have a variety of launch capabilities in order to have assured access to space." From the vantage point of spring 2020, the Small Launch and Targets Division pursued a "variety of launch capabilities," with five major contract initiatives in place: Orbital Support Program-4 (OSP-4); Rapid Agile Launch Initiative (RALI); Sounding Rocket Program-4 (SRP-4); Small Rocket Program Orbital (SRPO); and Tactically Responsive Space Launch (TRSL).[21]

Orbital Support Program-4

OSP-4 provided support primarily for STP experimental payloads to LEO greater than 400 pounds. Responding to the demand for smaller satellites, the STP secured launches, primarily through the RSLP, for small and less expensive experimental spacecraft from a list provided each year by the DOD Space Experiments Review Board. As noted by Small Launch and Targets Division senior engineer Randall L. Riddle, despite literature stating an upper limit of 8,000 pounds, "There is no top end on it. We always end up with a plus or nothing on top of it." Having received $986 million in production line money to procure launch services over nine years under the OSP-4 IDIQ contract, the Small Launch and Targets Division in October 2019 awarded eight different companies a $50,000 minimum guarantee to compete for up to 20 missions. Federal government customers could order and expect the payload to orbit 12 to 24 months after the contract award. Riddle also explained, “We’re doing annual on-ramps to keep companies coming in . . . so that we’ve got the latest and greatest launch providers and prices and capabilities.” Colonel Bongiovi publicly commented, “The program balances technology, mission, risk, and schedule while leveraging rapidly evolving market forces.” In early 2020, mission source selection was underway for STP satellite 28, the initial OSP-4 mission, that could loft a mix of up to 44 microsatellites and nanosatellites.[22]

Rapid Agile Launch Initiative

Rose’s division also worked closely with the Space Test Division on the RALI, created by Congress in 2017 to “competitively and rapidly award DoD launch service agreements with non-traditional, venture-class companies.” Managed by the Defense Innovation Unit, the RALI contract called for three providers to send 21 satellites into space on five launchers in 2019 for a cost of $25.6 million. New innovative providers, such as Rocket Lab, were expected to launch within 18 months. On 5 May 2019, for the first RALI mission, a Rocket Lab Electron rocket successfully launched STP-27RD with three other R&D satellites from its Mahia Peninsula launch site in New Zealand. Although Rocket Lab did not meet the 18-month target, it did launch within 24 months, which the Air Force deemed acceptable for the company’s initial mission. Planners expected to launch three more RALI missions in 2020, including one by Vox Space, using Virgin Orbit’s *Cosmic Girl*, a modified Boeing 747 aircraft carrying LauncherOne, to launch a MiniCarb cubesat from Guam for monitoring greenhouse gases in the atmosphere. Postponed until the spring of 2021, the Vox Space RALI mission was successfully launched on 30 June 2021, and Vox planned a second mission for early December. Rose expected the RALI program to transition eventually to her division’s RSLP.[23]

Sounding Rocket Program-4

A third RSLP initiative, SRP-4, aimed exclusively at purchasing suborbital targets and supporting elements. For this program, the

Small Launch and Targets Division conducted a prescreening to select a pool of contractors with whom the Air Force could do business for a specific number of years. The division then did a source selection and chose two companies, Space Vector Corporation and Orbital ATK Inc. In November 2019, those two awardees received a multiple-award, IDIQ seven-year contract with a potential value of $424 million. The contract tasked the companies to develop and supply suborbital launch services to support prototype weapon systems development and missile defense system target tests. As with OSP-4, SRP-4's IDIQ contract provided an on-ramp to accommodate providers with new capabilities to become part of a pool to bid on future missions. The RSLP also used the SRP-4 contract to prepare targets for the Navy, perform R&D work for the AFRL, and support launches such as the 12 December 2019 test flight of a prototype conventionally configured, ground-launched ballistic missile from Vandenberg AFB for the Strategic Capabilities Office.[24]

Small Rocket Program Orbital

The RSLP used a fourth new small rocket launch contract to support small rocket launches of up to 400 pounds to LEO. The SRPO division did a market survey and determined the availability of interested small businesses. Deciding against having a standing IDIQ contract, the SRPO used what amounted to a preapproved business clearance to do a small business set-aside contract for the Agile Small Launch Operational Normalizer (ASLON)-45 mission. On 7 August 2019, SMC selected Vector Launch Inc. for the award, but the company formally withdrew its proposal on 26 August 2019. In just 14 days, the Small Launch and Targets Division re-awarded the $4.9 million contract to Aevum Inc. Scheduled to launch from Cecil Air and Space Port in Jacksonville, Florida, during the third quarter of 2021, the ASLON-45 payload consisted of three experimental cube satellites designed to improve real-time threat warnings. However, an engine supplier problem has delayed the mission until mid-2023. Commenting on the selection process, Bongiovi asserted the SRPO framework was "a shining example of SMC's drive to provide innovation and partnership across the Enterprise faster than ever before" for missions that could "directly support the warfighter and demonstrate new weapon system technologies and concepts."[25]

Tactically Responsive Space Launch

Finally, the Small Launch and Targets Division addressed the high-priority, congressionally mandated TRSL budget line in the 2020 NDAA. It provided $19 million for demonstration of a "tactically responsive launch for venture class" vehicles. As Lieutenant Colonel Rose explained, "This is Congress pushing for us to have that tactically responsive capability should we need it." She expected her division to demonstrate that capability over the next few years. Currently, RSLP small rocket launches required from 12 to 24 months to prepare for a launch. Rose explained that her team was still in the planning phase, but they understood the TRSL initiative required a much faster launch pace. "We would have some sort of call up," she said, "and tell them we need to launch . . . with a limited amount of preparation time." Dr. Will Roper, then assistant secretary of the Air Force for Acquisition, Technology and Logistics, established the challenging goal of 24 hours for the TRSL.[26]

The challenge of fielding operationally responsive satellites with a responsive, launch-on-demand capability remained formidable. Bongiovi explained, "There's this trap we fall into; we look at this operational responsive problem and treat it like a launch problem but to me what we've never gotten to the point is, how do we create a responsive architecture?" Such a framework would need to embrace infrastructure and personnel requirements and have in place preapprovals, such as launch authority, trajectories, and procedures with the FAA. Fundamentally, achieving responsive launch remained largely payload driven. Even in a responsive environment, Bongiovi asserted, "we're still going to have payloads that take 12 months or more to integrate and launch and get to their final orbit." Rose agreed, noting, "Just because we have a launch vehicle ready to go doesn't necessarily mean that there's a satellite ready to go." The problem was getting assets in place. Although prepositioning and stockpiling equipment was proposed, each had its own drawbacks and probably were prohibitively expensive. In reviewing the responsive architecture requirements, Bongiovi pointedly said, "I need money. I don't have the funding to do that, but it's a funding problem, not a technical problem right now." Meanwhile, the high-priority TRSL initiative had Rose's division focused on developing such a capability to respond quickly to threats by working toward the 24-hour objective established by Dr. Roper.[27]

Unfortunately, the Rocket Systems Launch Program's ambitious manifest for 2020 fell victim to the COVID pandemic. Hampered by supply chain issues, delays obtaining space and launch vehicles, and range quarantine restrictions, only one mission flew in 2020. On 15 July 2020, an NRO mission successfully launched from Wallops Island on a Northrop Grumman Minotaur IV. The other missions manifested for 2020 were pushed to 2021 and later. During the first eight months of 2021, RSLP launched four missions, including *Monolith*, a small R&D satellite aboard a Rocket Lab Electron rocket launched from New Zealand's Mahia Peninsula on 28 July 2021. Originally scheduled for a 2019 launch from Wallops Island, the mission, entitled "It's a Little Chile Up Here," had been delayed by software issues then the pandemic. RSLP planned at least another launch in 2021 and a busy, but as yet undetermined, manifest for 2022.[28]

New Competitors and the Future of the National Security Space Launch Program

While the small rocket launch community pursued a variety of responsive space efforts, the EELV-class program embraced new competitors for its future EELV-class launches. With competition between ULA and SpaceX intensifying in the second decade of the new century, two more heavy-lift competitors had entered the national security space acquisition arena. By the end of 2017, entrepreneur Jeffrey P. Bezos's Blue Origin had lined up three customers for New Glenn, its two-stage orbital launch vehicle named for astronaut John H. Glenn Jr. Measuring 270 feet tall with a 23-foot diameter, the first stage, powered by seven BE-4 engines burning liquid oxygen and liquid methane, was designed for use up to 100 times. The second stage used two BE-3U engines and the optional third stage used one. By 2018, Blue Origin had opened its 750,000-square-foot assembly plant at the Kennedy Space Center's Exploration Park and continued extensive refurbishment of Launch Complex 36, which it had leased from Spaceport Florida in 2015.[29]

Northrop Grumman acquired Orbital ATK on 26 June 2018 and entered the competition for EELV-class launches with its expendable, three-stage Next Generation Launcher, now renamed the OmegA. Standing 196 feet tall, the OmegA intermediate launch vehicle's first stage consisted of a Castor 600 SRM with up to six strap-on GEM-63

SRMs. Together with its second stage Castor 300 SRM and third stage, powered by two Aerojet RL-10C liquid-fuel cryogenic engines, the company expected OmegA to be capable of lofting 22,300 pounds to GTO and 17,200 pounds to GEO. The company also planned to develop a heavy version of the OmegA. Relying extensively on carbon composite materials, metal tanks for its cryogenic upper stages, and avionics from the Minotaur family, Northrop Grumman believed it could reduce production time by 46 percent and be competitive against the new generation of reusable and partially reusable rockets. Beginning motor and engine testing in 2019, it planned to fly its intermediate-lift OmegA in 2021. In August 2020, however, Northrop Grumman cancelled the OmegA when it failed to receive an additional contract award.[30]

On 10 October 2017, after its rocket propulsion contract awards the previous year, the Air Force opened phase 2 of its acquisition strategy next-generation, EELV-class rocket. The service issued a formal launch service agreement RFP for development of an EELV-class launch vehicle and stated its intention to select three EELV-class competitors in 2018. On 10 October of that year, SMC awarded shared public-private investment Other Transaction Agreement (OTA) launch service contracts totaling nearly $2 billion through 2024 to Blue Origin, Northrop Grumman, and ULA to develop launch system prototypes. The Air Force provided each company an initial award of $181 million and total OTA contract funds of $500 million to Blue Origin, $792 million to Northrup Grumman, and $967 million to ULA for development of its Vulcan Centaur. Although not receiving a launch service contract, SpaceX remained eligible to bid on future national security launch prototype contracts in the next phase of the OTA program.[31]

In February 2019, SMC issued a draft RFP for prospective competitors to review and determine whether to offer bids. It published the final RFP solicitation in May, giving competitors 60 days to submit their bids. The RFP encouraged emphasis on technical performance and the capability to carry national security payloads into nine reference orbits. In a selection process that, admittedly, included "subjective" elements, the Air Force planned to choose two of the competitors in 2020. Drawing on regular market research, it argued that the market could not support more than two providers who relied on government and commercial launch markets. The launch service procurement contracts would consolidate requirements into a block buy over a five-year ordering period. The 25 launches between 2022 and 2026 would be split between the two winners, with one winner receiving 60 percent of the contracts and the other 40 percent. The two providers were expected to launch a medium-lift prototype in fiscal year 2022 and a heavy prototype by 10 October 2024. Colonel Bongiovi explained that the phase 2 contract had "explicit funded efforts to make sure that our involvement is paid for and our access to data is paid for, and that they're not having to raise the price of their commercial systems in order to accommodate us."[32]

Meanwhile, until the new launch vehicles became operational in the 2020s, the Air Force expected NSSL-class launches by ULA's Atlas V and Delta IV Heavy or SpaceX's Falcon 9 Upgrade and Falcon 9 Heavy would provide assured access to space. In another procurement initiative, on 1 October 2019, SMC's Launch Enterprise Systems Directorate awarded United Launch Alliance launch support contracts to ULA for five Delta IV Heavy launches of NRO payloads and three Atlas V missions for the Advanced Extremely High Frequency (AEHF)-6 satellite, the X-37B spaceplane, and an NRO payload. Those contracts completed the original phase 1 block-buy contract that ended on 30 September. The 1 October award also ended the EELV Launch Capability arrangement that began in 2013. Critics had long viewed it as a billion dollar subsidy that unfairly supported ULA's launch monopoly. With the six additional Atlas V missions awarded to ULA under the phase 1A follow-on procurement, the nine Atlas V launches would likely be the final Atlas V missions the Air Force would conduct before transitioning to the two yet-to-be-selected providers, ULA and SpaceX, selected under the ongoing phase 2 launch service procurement program.[33]

A Space Enterprise Vision to Defend US Space Assets

Efforts to guarantee assured access to space and develop a more responsive launch capability, with both EELV-class and small launch vehicles, received a major assist from the Space Enterprise Vision (SEV) and associated Space Warfighting Construct (SWC) initiatives. On 11 April 2016, Gen John E. Hyten, AFSPC commander, announced the SEV that his command had developed jointly with the NRO the previous year. The SEV sought to provide a resilient space force by 2030, one capable of deterring aggression in the space arena and, if necessary, prevailing in any conflict that involved space. "In the recent past," Hyten said, "the United States enjoyed unchallenged freedom of action in the space domain. Most U.S. military space systems were not designed with threats in mind, and were built for long-term functionality and efficiency, with systems operating for decades in some cases." But the environment had changed, and potential adversaries were attempting to exploit US vulnerability and reliance on space capabilities. "The future space enterprise," Hyten predicted, "will be built by changing how we architect, develop, acquire, and operate our space systems." Such changes would also ensure that the bedrock strategy of assured access to space would remain viable. Space had become a potential warfighting domain.[34]

The SEV would replace the traditional "functional availability" metric with the concept of "resilience capacity" as the means to measure how well space forces could respond and adapt to future threats and rapidly counter them. To improve overall responsiveness, the SEV—harnessing industry's innovation—envisioned smaller satellites, rapidly acquired and launched and with a design life of three to five years. Routine space traffic management would be turned over to industry partners, and international partnerships would provide additional communications and weather support. New capabilities would enhance situational awareness, thereby improving performance of battle management command and control. The congressionally mandated TRSL requirement being handled by SMC's Small Launch and Targets Division reflected the SEV's interest in promoting responsive space operations.[35]

The SEV embraced all elements of space launch, but especially DOD assets. As for responsiveness, the SEV specifically called for accelerated launch operations by evolving a "freight train to space" approach that included more frequent, regularly scheduled launches to specific orbits and an "if it fits, it ships" capability, like railroad boxcars, for spacecraft. The difficulty of reaching agreement on making accelerated, low-cost launch a reality was illustrated, however, by a draft memorandum circulated by Maj Gen Nina M. Armagno, AFSPC chief architect for SEV, in October 2016. She explained it was imperative that AFSPC "reduce the cost of launch and the time associated with spacecraft to launch vehicle integration." As she explained, it took 60 to 90 days (if not longer) to integrate satellites and launch vehicles. To provide near-immediate replacements to reconstitute satellite constellations, integration time had to be shortened to weeks or possibly days. Armagno's memorandum proposed that every future medium-class Air Force commercial space mission would be sized to cost no more than $100 million for injection into standard LEO or GTO. National security space missions did not fall within the $100 million limitation but would have an 8,000-pound mass limitation. Emphasizing standardization, Air Force missions would use the EELV Standard Interface Specification to ensure full integration of mission and launch service provider. Furthermore, to improve responsiveness, missions would be interchangeable among launch providers up to a year before launch, and "recurring primary spacecraft integration will be accomplished in less than 6 months." Finally, all missions would include auxiliary "rideshare" payloads, and those that met authorized interface requirements could be chosen just 30 days before launch. SEV planners would also investigate the potential for disaggregating space constellations by separating tactical and strategic satellites. Given conflicting views about the requirements described in the proposal, however, the draft memorandum remained unsigned. Nevertheless, AFSPC continued to focus on accelerating integration timelines and improving affordability, while simultaneously meeting critical national security launch demands.[36]

The SEV "freight train to space" concept clearly promoted a more responsive launch capability by maintaining a launch-on-schedule strategy with an open manifest to reduce integration timelines. A viable launch-on-demand, or launch-on-need, capability, however, would have to await a validated requirement for a responsive spacecraft and sufficient funding. As experienced space launch operator SMSgt William P. Mayo noted, "There aren't any spacecraft ready to be launched that quickly, so we don't need a rapid launch capability yet. As for developing the capability before we need it, we don't have the money to pay for all the things we need right now, much less the 'nice to haves.'" Meanwhile, through its Kirtland division SMC's Launch Enterprise Systems Directorate had the authority to offer IDIQ contracts to launch service providers who could, for example, build and launch their rockets weekly. In this case, the Air Force could pay to ensure the rocket's availability when needed and, in effect, maintain a modest launch-on-need option.[37]

The SEV was primarily an integrated-architecture blueprint for deterring space threats and, if required, prevailing during a war in space. As AFSPC's core architecting team stated, "In almost all cases, SEV does NOT represent new requirements. SEV is a reallocation of existing requirements across an Enterprise Architecture." To implement that new blueprint and make SEV an operational reality, Gen John W. "Jay" Raymond, AFSPC commander, announced the Space Warfighting Construct in April 2017. Developed by the Air Force and the NRO, the SWC embraced space warfighting operational concepts, a well-prepared space mission force, resilient architecture, enterprise agility in the face of new and changing threats, and partnerships with both allies and the dynamic commercial space sector to support joint space operations.[38]

In the context of the SWC, SMC's Launch Enterprise Systems Directorate had introduced several important measures to improve launch efficiency and responsiveness. One was the Mission Manifest Office (MMO), an organization designed to centralize launch for both NSSL-class and small-launch operations involving multi-mission payloads. According to Bongiovi, the new organization resulted from the need to effectively incorporate new entrant and small launch manifesting. "We've created a clearing house," he said. "MMO is like a front door to launch. Operational customers can come in whether [they] . . . need a big launch vehicle or a small cubesat that could ride on the back of one of those launch vehicles." Since 2006, his directorate had operated a ULA-based program for Atlas V and Delta IV launches. The additional launch systems required a more centralized mission management structure. A major focus of the new MMO, working closely with Kirtland's Small Launch and Targets Division, involved supporting small payload vendors by identifying available DOD or other government launch missions for rideshare opportunities. Supported by a rideshare working group that it convened twice a year, the MMO's approach largely reflected the SEV "freight train to space" concept.[39]

Colonel Bongiovi highlighted the success of the MMO's arranging for a secondary rideshare payload to accompany the launch of the AEHF-5 communication satellite. Launched at 6:13 AM EST on 8 August 2019 from Space Launch Complex 41 at Cape Canaveral Air Force Station, the AEHF-5 payload separated from the Atlas V rocket and was successfully deployed into its geostationary transfer orbit. The hosted payload, an experimental cubesat designed to test orbital debris tracking capabilities, separated before the main payload. Procedures previously would have prohibited ejection of the secondary payload first to avoid endangering the primary AEHF satellite. Bongiovi declared, "That hasn't been done before and that was driven by the

Mission Management Office. If we're going to get more payloads responsibly to orbit we need to demonstrate that this is something we can do."[40]

In its focus on multi-mission rideshare opportunities, the MMO took advantage of the EELV Secondary Payload Adapter ring, with six ports, that became available for NSSL-class launches. Earlier attempts to program the ESPA ring for EELV launches in the 2005–2006 time frame did not survive constrained budgets at that decade's end. By the close of 2015, however, all three EELV-class rockets—Atlas V, Delta IV, and Falcon 9—had used the ESPA ring; by 2018, both DOD and NASA had made the ESPA ring and rideshare a top priority. Bongiovi said, "We need to be able to take cubesats up with our big satellites and deploy them where they need to be deployed. We need to be able to use multi-payload adapters, or rings, to put multiple payloads into orbits, sometimes different orbits, do multiple orbits." He pointed out that this had been done with the experimental Falcon Heavy deployments in three different orbits during its maiden flight on 6 February 2018. Small Launch and Targets Division chief engineer Riddle also emphasized the importance of mission flexibility in the rideshare program. "If I have a last-minute requirement I [have] a place to put it," he explained; the addition of the ESPA ring "came out of the SEV in the Space Warfighting Construct and that was a real change of [the] way of thinking for all of us." The work of the MMO and the use of the ESPA ring promised an end to stovepiping launch and an increase in responsive launch capabilities.[41]

Considering the overall impact of SEV on Air Force space launch, Colonel Bongiovi stated that his broad requirements remained much the same. "We're still buying commercial launch services that are tailored. We still have a broad need of capability. We still need to have small launch capability for experiment" and affordable, low-risk payloads. On the other hand, "I think the genesis of things [like the Mission Manifest Office] that we're doing today was SEV." It was not as if SEV provided a list of requirements that demanded action. Rather, "SEV had a set of concepts." Although the architecture was not yet in place, "what SEV did was put enough concepts out there that we know we need these capabilities to start being used in order to get to that 2030 construct." By September 2018, the SEV/SWC initiative had transitioned to the Enterprise Strategy and Architecture Office (ESAO). Under the ESAO, capability area teams worked on establishing launch requirements for mission areas in a future architecture to be deployed for the newly created US Space Force.[42]

Fig. 26. This rendering shows an EELV Secondary Payload Adapter (ESPA) ring. (Image courtesy of Moog Inc.)

A Space Force to Focus National Security Space Activity

It is unclear how much the SEV and its ESAO successor precipitated interest in or the establishment of the US Space Force, which the 2020 NDAA sanctioned and which activated on 19 December 2019. In this transition period, it was also uncertain precisely how the new organization might affect the future of space launch.

Although the idea of a space corps or space force had circulated in defense circles both during and after the Cold War, it had received special attention from the Commission to Assess United States National Security Space Management and Organization, or Space Commission, at the dawn of the twenty-first century. The Space Commission's report, on 11 January 2001, not only provided the most comprehensive analysis of the nation's space activities undertaken to date but also reflected Air Force views on how best to organize and lead the nation's space effort dating back to the administration of President Dwight D. Eisenhower.[43]

The commissioners directly addressed the feasibility of creating a more focused organizational structure for space activities. For the present, however, they did not favor establishing a new military department or space service or an Air Force space corps. The Space

Commission declared, however, "The use of space in defense of U.S. interests may require the creation of a military department for space at some future date. There is not yet a critical mass of qualified personnel, budget, requirements or missions." At the same time, any organizational changes should be made "so as not to preclude eventual evolution toward a Space Department if that proves desirable." The commission seemed more sympathetic toward establishing a space corps within the Air Force, rather than a space force, as "an appropriate model in its own right or a useful way station in the evolution toward a Space Department."[44]

The Space Commission examined several possible functions for a space corps, together with different organizational models, such as the Navy–Marine Corps relationship. Proponents of a space corps argued that a separate organization for military space would facilitate development of spacepower theory unencumbered by airpower constraints, thus maximizing the country's military space prospects. Indeed, the alternative of a space service would "improve the visibility of space programs, increase the space budget, eliminate redundancy, and [better] promote the development of space professionals." Space had no budget focus. Not only did space compete with air elements for resources in the R&D and procurement portions of the budget, the Air Force budget funded most of the military space programs for the other services.[45]

Many Air Force space professionals supported their argument for a separate space organization with analogies to the pre–World War II Army Air Corps experience. Seeking autonomy, then independence, from the Army, leaders of the Air Corps stressed the new, offensive role of strategic bombing rather than support to ground elements. In the Air Force, space—as reflected in the aerospace concept—had always been considered a medium in which to perform *defensive* support missions in support of ground and air operations. Were that role to change by placing weapons in space, a new, offensive role for space might suggest a more direct comparison to the quest of the Army Air Corps for independence.[46]

In considering a space corps and a military department for the future, the commission recommended the near-term goal of "a realigned, rechartered Air Force as best suited to organize, train and equip space forces." The commission designated Air Force Space Command as the organization that should spearhead the new space focus. It would be responsible "for providing the resources to execute space research, development, acquisition and operations" and would be commanded by a four-star general who no longer would be dual-hatted in a unified combatant commander or NORAD commander-in-chief role. Air Force Space Command's R&D mission would be enhanced by the transfer of SMC from the Air Force Materiel Command to AFSPC. "Consolidating space functions into a single organization [AFSPC]," the commission asserted, "would create a strong center of advocacy for space and an environment in which to develop a cadre of space professionals." On 1 October 2001, the Air Force formally transferred SMC to AFSPC.[47]

Reflecting on his experience as a member of the Space Commission, Gen Thomas S. Moorman declared, "To me that is the most thoughtful piece of work on space organization that has been done." In view of the recent establishment of the Space Force, he remembered the commission's warning: "If you [the Air Force] don't deal with these recommendations [from the Space Commission] you will be dealing with a Space Force." Despite the implementation of several of the commission's recommendations, military space responsibilities and requirements remained divided among various agencies, and critics continued to question the Air Force commitment to space and its space stewardship responsibilities.[48]

If the United States had faced a potential "Pearl Harbor" in 2001, the threat environment became more worrisome in the years after the Space Commission's report, because increasingly capable adversaries had improved their ability to take advantage of US space vulnerabilities. With space becoming a potential warfighting arena, the threat to American space dominance had compelled General Hyten, in 2016, to counter with the SEV, followed by General Raymond with the Space Warfighting Construct. At the same time, influential members of Congress had become critical of Air Force stewardship of space and what they perceived as the secondary role of space in a service dominated by air interests. Although a House of Representatives bipartisan 2017 proposal to create a space corps within the Department of the Air Force failed, momentum for establishment of a space corps or space force grew. The next year President Donald J. Trump publicly supported establishment of an independent space force and, in June 2018, called for the Defense Department to begin the formal process. Eight months later, on 19 February 2019, the administration issued White House Space Policy Directive-4, officially directing the secretary of defense to prepare and submit a legislative proposal to establish a United States Space Force as the sixth branch of the US Armed Forces within the Department of the Air Force. The policy directive explained the rationale for the new branch:

> It is imperative that the United States adapt its national security organizations, policies, doctrine, and capabilities to deter aggression and protect our interests. Toward that end, the Department of Defense shall take actions under existing authority to marshal its space resources to deter and counter threats in space, and to develop a legislative proposal to establish a United States Space Force as a sixth branch of the United States Armed Forces within the Department of the Air Force. This is an important step toward a future military department for space[49]

The 2020 NDAA, signed into law on 20 December 2020, officially established the US Space Force within the Department of the Air Force. On that date, Air Force Space Command was redesignated the US Space Force, and AFSPC commander Raymond was appointed Chief of Space Operations. He remained dual-hatted as commander of United States Space Command, an assignment he was expected to fulfill for another year. Over time, officials expected the Department of Defense to consolidate personnel and space missions from across the military services into the Space Force, as appropriate and consistent with law, and to move it, eventually, from under the Department of the Air Force to become the Department of the Space Force.[50]

Initially, key Air Force and Pentagon officials had opposed the Space Force proposal. They argued it was unnecessary and would simply add to bureaucracy and the cost of government. Momentum for the Space Force increased, however, once the president voiced his support. Air Force space veterans have hailed the new Space Force as needed for a variety of reasons. Richard McKinney, the first EELV program director, spoke for many when he noted space was no longer an uncontested domain. Now, he cautioned, "you need people who think about space 24/7," he said, and "the Space Force will do that." He and other space veterans focused on the space budget, the issue that had prompted congressional action to create a space corps or space force in the first place. Now, an independent Space Force would not have to compete with other Air Force budgetary priorities but instead have its own service acquisition executive. Moreover, the same argument the Space Commission had made on behalf of Air Force Space Command 18 years earlier applied in 2020: "Consolidating space functions into a single organization would create a strong center of advocacy for space and an environment in which to develop a cadre of space professionals." In the larger context, centralizing military space responsibilities within the Space Force would also promote the long-sought Air Force goal of the institutionalization of space throughout the military community.[51]

Clearly, military space found itself in a transitional period, with a newly established Space Force facing many unresolved issues. It remained to be seen what impact the evolving organization would have on space launch. As currently structured, SMC's Launch Enterprise seemed to provide the required organizational focus for NSSL and small rocket space launch acquisition and operations.[52]

A Space Launch Enterprise Vision for Preserving Assured Access to Space

Looking back over the 75-year history of Air Force space launch, the Air Force had made remarkable progress in its quest to develop a responsive, reliable, affordable space launch enterprise that guaranteed assured access to space. Among the many milestones on this long journey, none proved more significant than the advent of the Evolved Expendable Launch Vehicle program.

The Space Commission's 2001 report, issued on the eve of the initial EELV operational launches, had asserted the United States would not "remain the world's leading space-faring nation by relying on yesterday's technology to meet today's requirements at tomorrow's prices." The report noted that the nation's space booster technology dated from the Eisenhower presidency; the country continued, at the dawn of the new century, to rely on its so-called heritage space boosters —Atlas, Titan, and Delta—only modestly improved. Although the Air Force had developed a standardized booster and upper stage scheme in the 1960s to cut costs, space boosters remained expensive to operate and required several months of launch preparation time.[53]

The Space Commission's report appeared in the wake of the Titan IV launch failures in the late 1990s and subsequent Broad Area Review of NSSL. Significantly, the commission investigators did not assess the innovative EELV program whose practices, procedures, and boosters were about to transform space launch. Reflecting on the achievements of the EELV program, McKinney stated, "I think we lived up to the Moorman legacy on creating the EELV. Moorman put all this process in place and the whole EELV team all the way along has just done remarkable things."[54]

Over 50 percent more affordable than the legacy vehicle fleet, EELV boosters achieved an unmatched reliability record with 18 years of consecutive successful launches. Innovations in launch processing, including off-pad integration, payload encapsulation, standardized interfaces, and the added EELV Secondary Payload Adapter for rideshare opportunities, contributed to improved EELV-class launch responsiveness. Moreover, the EELV Delta IV and Atlas V booster families could cover gaps in launch capability that legacy vehicles could not. Responsive launch also benefited from range standardization and the transformative shift from old instrumentation to space-based operations by GPS-Metric Tracking, the Autonomous Flight Safety System, and the promise of national spaceports forecasted in the Range of the Future 2028 initiative.

Another major innovation introduced with EELV involved acquisition. Whereas the Air Force had purchased legacy vehicles outright and remained responsible for launch preparation and actual launch, EELV ushered in the era of buying a service from the contractor rather than buying a vehicle. The Air Force saw no need to take delivery of the vehicles because it expected the commercial providers to be launching more than the military missions and developing the necessary expertise. Beginning with EELV, the contractor owned not only the technical baseline but also the launchpad and the supply chain. Contractor personnel performed all logistics functions and processed and launched the vehicles, thereby contributing to Air Force cost and personnel efficiencies.

The Air Force protected its interests through government mission assurance procedures and a rigorous process of readiness reviews. Establishing the practice of "insight" rather than traditional "oversight" of contractor operations during the initial EELV development phase, the program office initiated remote access to all contractor data and monitored contractor operations accordingly. Air Force personnel then implemented the BAR I recommendation that called for an additional layer of oversight, referred to as "value added" government mission assurance. As Bongiovi argued, "When you have an independent government mission assurance oversight, the demonstrated reliability goes up by a lot." At the same time, accountability for launch readiness remained with the SMC commander and delegated mission director on the day of launch.[55]

If continued improvements in launch responsiveness were to be realized, they likely would center on payload availability. In a sense, space launch always had been payload driven. In the early days of the Titan III and the classified reconnaissance satellite programs, the Titan III launched rapidly, only weeks or months apart. Then, satellites became more capable, and complicated, and costly. Because of their expense they were made more reliable, and Congress stopped funding spares. With satellites lasting longer and being replaced less often, launch rates declined and costs increased. In McKinney's words, "We had become the victims of our own success."[56]

For launch personnel, the issue was never booster availability, but satellite availability. To develop a resilient, responsive launch scheme, satellites with short operational life spans would be needed. Their production line would be running continuously so that a satellite would always be prepared for rapid processing and launch. In addition to available payloads, this type of responsive launch capability would require considerable preapprovals of launch authority and trajectories, plus prepositioning of personnel and infrastructure. The cost for such an enterprise seemed prohibitive.

The Space Enterprise Vision, Space Warfighting Construct, and the newly created Space Force reflected concerns about the growing threat to US space assets, a threat that very well could produce a validated requirement for a responsive launch-on-demand capability. Until then, however, responsive launch seemed best realizable through rideshare opportunities offered by NSSL-class launches and the myriad experimental small rocket and payload initiatives, such as the TRSL project directed by Kirtland's RSLP.

Conclusions

In the year 2021, the NSSL enterprise appeared satisfactorily positioned to preserve the fundamental policy of assured access to space by ensuring "the availability of at least two space launch vehicles (or families of space launch vehicles) capable of delivering into space any payload designated by the secretary of defense or the director of national intelligence as a national security payload." For near-term NSSL missions, SMC's Launch Enterprise could rely on the last of ULA's Atlas V and Delta IV Heavy launchers, plus SpaceX Falcon 9s, to provide assured access.[57]

Anticipating new providers for heavy-lift missions in the near future, Colonel Bongiovi confidently predicted, "We're going to see additional cost savings because industry has designed launch systems that don't require this gigantic, expensive, unique configuration to launch those high-end performance range payloads." Moreover, the advent of reusable boosters and fairings pioneered by SpaceX also promised to lower launch costs. Given the success of the EELV program, the new launch landscape could be expected to demonstrate exceptional reliability through industry's capabilities and government mission assurance practices. Buttressed by "a robust space launch infrastructure and industrial base," responsive launch initiatives then underway promised to deliver significant improvements in the NSSL arena and help "sustain the availability of rapid, responsive, and reliable space launches for national security space programs."[58]

Confronting the challenges ahead, the national security launch enterprise already was realizing Moorman's charge to the nation and defense establishment. "As a nation," he declared, "we need to continue to adequately fund space launch operations and develop the next-generation technologies that will increase responsiveness, improve reliability, and reduce costs. Through these actions, we can ensure the Nation will have continuous, uninterrupted access to space for decades to come."[59]

Notes

1. Bongiovi, interview, 21 November 2019.

2. Bongiovi. After Colonel Bongiovi became director in December 2017, the Launch Systems Enterprise Directorate was renamed the Launch Enterprise Systems Directorate. As a result of SMC commander Lt Gen John T. Thompson's 2.0 reorganization initiative in 2019, the Launch Enterprise Systems Directorate was redesignated simply Launch Enterprise (SMC/ECL), a three-letter organization within the Enterprise Corps. Mulcahy, email; Garges, "SMC Stands Up New Launch Systems Enterprise Directorate"; and SMC, "Launch Enterprise Systems Directorate."

3. Bongiovi, interview, 21 November 2019; Mulcahy, email; Garges, "SMC Stands Up New Launch Systems Enterprise Directorate"; and SMC, "Launch Enterprise Systems Directorate."

4. Spires, *Beyond Horizons*, 323.

5. Spires, *Beyond Horizons*, 287. For the essay evaluating the Space Commission's findings and the report itself, see Spires, *Orbital Futures*, 1208–43.

6. AFSPC/DRS, "Final Mission Need Statement"; Doggrell, "Operationally Responsive Space," 42–49; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 246–51.

7. Near space is considered "above the typical operational altitudes for aircraft and below the orbital regime, roughly between 65,000 and 325,000 feet. Doggrell, "Opera-

tionally Responsive Space," 42–44; Doggrell, email, 29 July 2019, 9 August 2019; Doggrell, interview; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 251, 254, 257; and Cebrowski and Raymond, "Operationally Responsive Space: A New Defense Business Model," 67-77.

8. AFSPC, *History of the Air Force Space Command, 1 January 2007–31 December 2008*, 346–47; John Warner National Defense Authorization Act for Fiscal Year 2007, "Operationally Responsive Space," 677–84 (Sec. 914, final version); DOD/NSSO, "Plan for Operationally Responsive Space: A Report to Congressional Defense Committees"; Deputy Secretary of Defense, "Establishment of the Operationally Responsive Space Office"; Spires, *Beyond Horizons*, 323; AFDD 2-2, 25–26; and Doggrell, email, 29 July 2019.

9. Doggrell, "Operationally Responsive Space," 43, 45–46; AFSPC, *History of the Air Force Space Command, 1 January 2007–31 December 2008*, 348; and Spires, *Beyond Horizons*, 325.

10. Apparently, SpaceX credited the Naval Research Laboratory for the cancelled launch. Riddle, "Manuscript Review Comments." TACSAT-1's proposed launch vehicle was the Force Application and Launch from the Continental United States Small Launch Vehicle (FALCON). Spires, *Beyond Horizons*, 325; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 262–64; and AFSPC, *History of the Air Force Space Command, 1 January 2007–31 December 2008*, 348.

11. Riddle, "Manuscript Review Comments"; Spires, *Beyond Horizons*, 325–26; AFSPC, *History of the Air Force Space Command, 1 January 2007–31 December 2008*, 348–49; AFSPC, *History of the Air Force Space Command, 1 January 2009–31 December 2010*, 242–44; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2011*, 35; and McDowell, "Satellite Catalog," accessed 20 January 2019.

12. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 36; Airforce Technology, "ORS-1 Reconnaissance Satellite," accessed 30 October 2021; Airforce Technology, "ORS-5 Surveillance Satellite," accessed 30 October 2021; McDowell, "Satellite Catalog," accessed 20 January 2019; Gruss, "Rail-launched Supler Strypi Rocket Packed with Cubesats Fails in Debut"; and Riddle, "Manuscript Review Comments."

13. Spires, *Beyond Horizons*, 325; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 92, 101–5; SMC, *History of the Space and Missile Systems Center, Draft of 2016 History*, 48-49; and AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 62–64.

14. Riddle, "Manuscript Review Comments"; Spires, *Beyond Horizons*, 325; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2006*, 251, 255, 259, 265; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2011*, 29–34; Global Security, "FALCON Small Launch Vehicle"; and Doggrell, email, 29 July 2019.

15. Riddle, "Manuscript Review Comments"; SMC, *History of the Space and Missile Systems Center, 1 January 2013–31 December 2015*, 101–3; AFSPC/A5R, "Capability Production Document for Spacelift Systems," 13–14; AFSPC, "Assured Space Access Operating Concept," 40–41; Global Security, "Minotaur," accessed 26 August 2019; and Global Security, "Minotaur IV," accessed 26 August 2019. Surprisingly, the cost to retrofit and launch the refurbished vehicle proved to be as much as four or five times the DARPA objective of $5 million.

16. IDIQ contracts offer a more streamlined contract process and are normally five-year contracts used when specific supplies or services required cannot be determined beforehand. Antares is a two-stage booster, with a liquid propellant first stage and solid propellant second stage capable of lofting 18,000 pounds to LEO. SMC,

History of the Space and Missile Systems Center, 1 January 2013–31 December 2015, 104–5; AFSPC, *History of the Air Force Space Command, 1 January 2012–31 December 2013*, 30–31; Mayo, interview; Northrop Grumman, "Antares"; and Gongora, "USAF Orbital/Suborbital Program (OSP-3)."

17. Riddle, "Manuscript Review Comments"; Riddle, interview; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2016*, 49–50; AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 150; Gongora, "USAF Orbital/Suborbital Program"; Mayo, interview; Doggrell, email, 9 August 2019; and Doggrell, interview.

18. DOD, "Operationally Responsive, Low-Cost Launch (ORLCL) Congressional Report," 3–11; and GAO, *Space Acquisitions: GAO Assessment of DoD Responsive Launch Report*, 9–12.

19. Headquarters, AFSC, "Space Rapid Capabilities Office (SRCO) Organization Change Request (OCR) Questions"; Headquarters, US Air Force, "Responsive Launch," 1–13; US Code, Title 10, Section 2273a, "Space Rapid Capabilities Office," accessed 5 July 2019; Mayo, interview; Doggrell, email, 9 August 2019; and Doggrell, interview.

20. Rose, interview.

21. Rose, interview; Riddle, interview; Erwin, "Pentagon Budget Funds 'Small Launch Services' "; and Erwin, "Air Force Selects Eight Launch Providers."

22. Riddle, interview; Kelsey, interview; and Erwin, "Air Force Selects Eight Launch Providers."

23. Rose, interview; Riddle, interview; and Erwin, "Air Force Touts Deal."

24. Riddle, interview. Riddle explained that his division used to do considerable work for the Missile Defense Agency, but several years ago that agency decided to do its own contract work. 30th Space Wing Public Affairs Office, "Vandenberg AFB Supports Missile Test Flight"; AFCEA, "Air Force Contract Launch Services for the Sounding Rocket Program 4"; and "Kratos and Space Vector Partner for USAF Sounding Rocket Program-4."

25. On 13 August 2021, Space and Missile Systems Center was officially renamed the Space Systems Command. Rose, interview; Riddle, interview; Erwin, "Vector Relinquishes Air Force Launch Contract"; and Riddle, email, 25 January 2022. Ursa Major, the engine supplier, chose not to produce the version that Aevum had designed for, compelling the company to redesign and requalify for the version they expect to produce.

26. Rose, interview; Riddle, interview; and Erwin, "Air Force to Schedule Nine Small Launch Missions in 2020."

27. Bongiovi, interview, 21 November 2019; Rose, interview; and Kelsey, interview.

28. Riddle, email, 2 November 2021; and Erwin, "Space Force's Small Launch Program."

29. AFSPC, *History of the Air Force Space Command, 1 January–31 December 2015*, 46–47; AFSPC, *History of the Air Force Space Command, 1 January 2017–31 December 2018*, 143–44; Harwood, "ULA Touts New Vulcan Rocket," 1–14; and ULA, "Vulcan."

30. SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 135–36; Smith, "Orbital ATK, EELV, and the Chinese Word for Crisis," 1–12; Haskell, "Northrop Grumman Cancels Omega Rocket"; and "Update: USSF's Monolith R&D Smallsat."

31. Bongiovi, interview, 21 November 2019. OTAs, in contrast to standard acquisition contracts, provided SMC the flexibility to "leverage ongoing investment by commercial industry" and adopt and incorporate business practices. OTAs required contractors and the government to share R&D investment costs. The OTA public-

private partnership normally found the government paying two-thirds and industry paying one-third of the costs. Mayo, interview; SMC, *History of the Space and Missile Systems Center, 1 January 2016–31 December 2018*, 141–42; Drew, "U.S. Air Force Issues RFP for Next-Gen Space Launch Vehicles," 1–4; Erwin, "Air Force Awards Launch Vehicle Development Contracts"; and Batto, "What Will Be the Response?"

32. Bongiovi, interview, 19 November 2019; AFSPC, "Acquisition Strategy for Evolved Expendable Launch Vehicle (EELV) Program," 13–14, 19, 21–22, 32; Batto, "What Will Be the Response?"; Smith, "Orbital ATK, EELV, and the Chinese Word for Crisis," 1–12; Erwin, "Congressional Auditors Raise Red Flags"; Messier, "An Update on the Evolved Expendable Launch Vehicle Program," 1–6; Thompson, "Air Force Space Launch Plan Multiplies Risks"; and Mayo, interview.

33. Bongiovi, interview, 19 November 2019; AFSPC, "Acquisition Strategy for Evolved Expendable Launch Vehicle (EELV) Program," 13–14, 19, 21–22, 32; SMC, "National Security Space Launch"; Erwin, "Air Force Confident NDAA Will Back Its Launch Procurement Strategy"; Albon, "Air Force Awards Launch Support Contracts"; Erwin, "Air Force Awards $98.5 Million"; *GovTribe,* "National Security Space Launch (NSSL) Phase 2 Launch Service Procurement (LSP) Request for Proposal (RFP)"; and USAF, "Space Force Awards National Security Space Launch Phase 2 Launch Service Contracts to ULA, SpaceX."

34. AFSPC/PA, "Hyten Announces Space Enterprise Vision"; Gruss, "Hyten's Space Enterprise Vision"; and Clark, "Space Command Readies for War." See an expanded biography of Gen John E. Hyten in appendix A.

35. Rose, interview; Riddle, interview; and Kelsey, interview.

36. AFSPC/A5/8/9, "Reducing Launch Cost and Spacecraft to Launch Vehicle Integration Timelines"; AFSPC/A5/8/9, "SEV Launch Architecture Analysis"; AFSPC A5/8/9, "Space Enterprise Vision: Core Architecture Team"; Mayo, interview; Doggrell, email, 9 August 2019; and Doggrell, interview. The disaggregation concept became a topic for serious consideration. On disaggregation, see AFSPC, *History of the Air Force Space Command, 1 January 2012–31 December 2013*, 22–26; AFSPC, *History of the Air Force Space Command, 1 January–31 December 2014*, 22–26; AFSPC, "Resiliency and Disaggregated Space Architectures"; Space Dynamics Lab (SDL), "A Disaggregated Vision for Space 2025"; Taverney, "An Answer to Affordability of Space Systems"; and Taverney, "Resilient, Disaggregated, and Mixed Constellations."

37. Mayo, email, 5 August 2019; Mayo, interview; Kolodziejski, "Enabling the Air Force Space Enterprise Vision"; and Bongiovi, interview, 21 November 2019.

38. AFSPC/A/5/8/9, "Space Enterprise Vision: Core Architecture Team"; HQ AFSPC, "Space Warfighting Construct," May 2017; AFSPC, "Space Warfighting Construct," 5 April 2007; Mayo, email, 31 July, 5 August 2019; Mayo, interview with the author; and AFSPC, "Space Warfighting Construct," 7 April 2017. See an expanded biography of Gen John W. "Jay" Raymond in appendix A.

39. Bongiovi, interview, 21 November 2019; Riddle, interview; Rose, interview; AFSPC, "Acquisition Strategy for Evolved Expendable Launch Vehicle (EELV) Program," 25–26; Space and Missile Systems Center, "SMC Ready for 'Summer of Launch' Lift Off"; and Kroeker, "Launch Enterprise Systems Directorate Uses SMC 2.0 Initiatives to Streamline."

40. The Mission Manifest Office has also been referred to as the Mission Management Office. Bongiovi, interview, 21 November 2019. RSLP chief engineer Randall Riddle also commented on this "first": This "would have never been allowed to happen in the previous thinking." Riddle, interview.

41. Bongiovi, interview, 21 November 2019; Riddle, interview; and Spaceflight Industries, "Spaceflight, Inc. General Payload Users Guide."

42. Bongiovi, interview, 21 November 2019; and Kolodziejski, interview.

43. For the full report, with accompanying analysis, see Spires, *Orbital Futures*, vol. 2, 1208–44; and Spires, *Beyond Horizons*, 287–98. The twelve commission members included four highly respected, recently retired Air Force space advocates: a chief of staff, Gen Ronald R. Fogleman; two commanders of Air Force Space Command and the United States Space Command, Gens Charles A. Horner and Howell M. Estes III; and Gen Thomas S. Moorman Jr., a career space officer, who held the positions of Air Force Vice Chief of Staff and commander of Air Force Space Command. Moorman also had chaired two important Blue Ribbon panels on space in the 1990s, and his views clearly are reflected in the commission's final report. The other members were Duane Andrews (deputy undersecretary of defense for Command, Control, Communications, and Intelligence); Robert Davis (undersecretary of defense for Space); Jay Garner (commander, Army Space and Strategic Defense Command); William Graham (president's science advisor); David Jeremiah (Vice Chairman of Joint Chiefs of Staff); Douglas Necessary (House Armed Services Committee staff); Glenn Otis (commander, Army Training and Doctrine Command); and Sen. Malcolm Wallop, R-WY.

44. *Report of the Commission to Assess National Security Space Management and Organization*, hereinafter cited as *Space Commission Report*, 82–87.

45. Spires, *Beyond Horizons*, 296–97; and Lambeth, *Mastering the Ultimate High Ground*, 14, 18–21. Randall Riddle pointed out that a Space Force would reduce the ever growing span of control challenge for military space. Riddle, interview.

46. For a discussion of various analogies and arguments on these issues, see Lambeth, *Mastering the Ultimate High Ground*, 72–75; and Hays, *United States Military Space*, 18–21.

47. *Space Commission Report*, 81, 89–90; and Spires, *Beyond Horizons*, 297–98. On 1 October 2001, DOD directed that space budgeting be consolidated as a virtual Major Force Program; Spires, *Orbital Futures*, vol. 2, 1254–64. Together with management and organization changes at the national level, the Secretary of Defense on 3 June 2003 designated the Secretary of the Air Force the Department of Defense Executive Agent for Space, then he directed that the Air Force Secretary redelegate this position to the Undersecretary of the Air Force, who also served as Director of the National Reconnaissance Office. This was done on 7 July 2003.

48. Moorman, interview, 23 December 2019.

49. President, "Space Policy Directive-4: Establishment of the United States Space Force"; Koren, "The U.S. Space Force Is Not a Joke"; Erwin, "U.S. Space Force Begins to Organize"; Congressional Research Service (CRS), "Toward the Creation of a U.S. "Space Force"; and US Space Force, "United States Space Force Fact Sheet."

50. Koren, "The U.S. Space Force Is Not a Joke"; Erwin, "U.S. Space Force Begins to Organize"; and US Space Force, "United States Space Force Fact Sheet."

51. Koren, "The U.S. Space Force Is Not a Joke"; Erwin, "U.S. Space Force Begins to Organize"; US Space Force, "United States Space Force Fact Sheet"; McKinney, interview; and Spires, *Beyond Horizons*, 284–98. The Space Commission and Secretary of Defense Rumsfeld's subsequent action created a "virtual" Major Force Program for space that still gave USAF leaders leverage to adjust funding in favor of airpower.

52. Acquisition arrangements remained to be finalized. Established at the end of August 2019, the new US Space Command would identify and deliver its requirements to the Space Force acquisition element for fulfillment. At this point, the 2020 NDAA identifies the Space Development Agency, established in March 2019 to unify and integrate DOD's space development efforts, as subordinate to the assistant secre-

tary of the Air Force for Space Acquisition and Integration. Likewise, the assistant secretary also oversees and directs the Space Rapid Capabilities Office and SMC, although the latter is subordinate to the US Space Force. In 2020, the Space Development Agency began transferring to the Space Force, but its organizational relationship to SMC has yet to be determined. The Space Development Agency expects to complete the transition in October 2022. Senate Armed Services Committee, *FY 2020 NDAA Summary*; Erwin, "Space Development Agency to Start Building Its First Constellation; and Vergun, "Space Development Agency Transitioning to U.S. Space Force."

53. *Space Commission Report*, xviii, 39–40; and Spires, *Orbital Futures, II*, 1121–26.

54. McKinney, interview.

55. Bongiovi, interview, 19 November 2019.

56. McKinney, interview.

57. US Code, Title 10, Section 2273, "Policy Regarding Assured Access to Space: National Security Payloads."

58. US Code, Title 10, Section 2273, "Policy Regarding Assured Access to Space: National Security Payloads"; and Bongiovi, interview, 19 November 2019.

59. Moorman, "Framing the Assured Access Debate," 12.

Appendix A

Expanded Biographies

Edward Cleveland Aldridge Jr.

The Honorable Edward C. "Pete" Aldridge Jr., the sixteenth secretary of the Air Force, was born on 18 August 1938 in Houston, Texas. He received a bachelor's degree in aeronautical engineering from Texas A&M University in 1960 and a master's degree, also in aeronautical engineering, from the Georgia Institute of Technology in 1962. Before joining the Department of Defense in 1967, Aldridge held various staff and management positions with the Douglas Aircraft Company, Missile and Space Division, in Santa Monica, California, and in Washington, DC. In 1967 he joined the staff of the assistant secretary of defense for systems analysis as an operations research analyst and, together with Norman Augustine, wrote the initial development concept paper for the Defense Support Program. He then served as director of the Strategic Defensive Division and as an advisor to the Strategic Arms Limitation Talks in Helsinki, Finland, and Vienna, Austria.

He reentered private industry in 1972 for two years, then returned to the DOD in February 1974. At the Pentagon, Aldridge first served as deputy assistant secretary of defense for strategic programs and then as director of planning and evaluation, a principal advisor to the secretary of defense in the planning and program evaluation of US military forces and support structure. In March 1977, Aldridge again returned to private industry before becoming undersecretary of the Air Force and director of the National Reconnaissance Office in August 1981. As undersecretary of the Air Force, his responsibilities included all Air Force space programs, including launch and on-orbit operations, plus planning for future space capabilities.

Secretary Aldridge became alarmed by the policy of phasing out expendable launch vehicles (ELV) and launching all civil, commercial, and military national security payloads on the space shuttle. He called for a "mixed fleet" alternative of commercially produced, affordable backup boosters. Proclaiming the need for "assured access to space," he championed the effort to preserve ELV production lines, which led to the Titan IV, Titan II, Atlas II, and Delta II space launch vehicles. In 1986, he was named secretary of the Air Force and served in that capacity until 16 December 1988.

After his government service, Aldridge was president of McDonnell Douglas Electronic Systems Company until 1992, when he accepted the position of president and chief executive officer of Aerospace Corporation. In 1991, he chaired a space policy advisory board that developed the Spacelifter concept, which envisioned producing a family of affordable vehicles based on a common core and paved the way for evolved expendable launch vehicles. After serving as undersecretary of defense for acquisition, technology, and logistics during 2001–2003, he chaired the Commission on the Implementation of US Space Exploration Policy. In 2020, Secretary Aldridge continued to serve on a variety of boards and panels.

His many awards and honors include the Secretary of Defense Meritorious Civilian Service Award, three Department of Defense Distinguished Civilian Service Awards, the Department of Defense Distinguished Public Service Award, the Air Force Exceptional Civilian Service Award, the Army Distinguished Civilian Service Award, the National Intelligence Distinguished Service Award, the National Space Club Robert H. Goddard Memorial Trophy, the Air Force Association Jimmy Doolittle Fellow, the Air Force Association Ira Eaker Fellow, and two Air Force Academy Foundation Distinguished American Awards. He also received the Max Kriendler, W. Stuart Symington, and Gen Bernard Schriever Awards from the Air Force Association.

Benjamin Paul Blasingame

Dr. Benjamin Paul Blasingame was born in State College, Pennsylvania, on 1 August 1919. He attended Pennsylvania State College, where he majored in mechanical engineering and joined the Reserve Officer Training Corps (ROTC) program. He graduated from Penn State in 1940 and worked for DuPont in a cellophane production plant until called to active duty in early 1941. As a second lieutenant, he worked on ground-based radar systems in Panama before the

Army Air Forces assigned him to the Armament Laboratory at Wright Field, Ohio.

Under Air Force sponsorship in the summer of 1947, Blasingame began graduate studies in Charles Stark Draper's Instrumentation Laboratory at Massachusetts Institute of Technology (MIT). He completed a thesis titled "Optimum Parameters for Automatic Airborne Navigation" and received his doctor of science degree in 1950. Bernard A. Schriever, then a colonel on the Air Staff, immediately recruited this newest member of Draper's "inertial mafia" to work in the recently formed Office of Development Planning. While there, he developed specifications for a new Strategic Air Command (SAC) bomber, with attention toward base hardening to ensure security and safety of the new aircraft and its crews.

In 1954, when Dr. John von Neumann's Strategic Missiles Evaluation Committee recommended accelerating the intercontinental ballistic missile (ICBM) program, Schriever was appointed to lead that effort as commander of the newly established Western Development Division (WDD). Authorized to handpick his initial cadre, Schriever identified then-Colonel Blasingame as one of his first four choices.[1] Not long after reporting to WDD in July 1954, Blasingame met with Schriever and convinced him that too little attention had been paid to the security and safety of the planned ICBM bases. From then on, everything was reexamined with an eye toward hardening the missile bases for survivability and safety.

As chief guidance and control project officer, Blasingame soon became an in-house advocate for equipping ICBMs with inertial guidance, putting him at odds with many experts who considered it too experimental and too heavy compared to radio guidance. After talking "late into the night" with Draper, however, Blasingame was convinced that AC Spark Plug Division of General Motors Corporation, backed by MIT, could produce a workable inertial guidance system for the ICBM. Consequently, he won approval for using inertial guidance as a backup for radio guidance on the Atlas ICBM and as the primary guidance system on the Thor intermediate range ballistic missile (IRBM).

From 1956 to May 1958, Blasingame served as the first program manager for WS 107A-2, the Titan ICBM. He recommended ways to accelerate Titan development and worked on plans for using storable, noncryogenic propellants in a second-generation Titan.

Blasingame left Air Force Ballistic Missile Division (AFBMD) for an assignment at the newly constructed US Air Force Academy near Colorado Springs, Colorado, where he created the Department of Aeronautics and Astronautics. In a September 1958 interview with *New York Times* reporter Clayton Knowles, Blasingame explained that his objective as the first chair of the Astronautics Department was to “turn out future commanders of ballistic missile squadrons—not space cadets.”

Having been recruited by industry, Blasingame resigned his commission in 1959 to become director of engineering, later manager, at AC Spark Plug, the Electronics Division (Delco) of General Motors Corporation in Milwaukee, Wisconsin. In April 1959, AC Spark Plug had received an Air Force contract to build the guidance system for Titan II, the first all-inertial Air Force ICBM. On the civilian side, Blasingame contributed extensively to development of the highly precise Carousel inertial navigation and guidance system for the Boeing 747. During the late 1960s, Carousel IV was the subject of the largest ever single military procurement of such equipment, when it was chosen by the USAF for the C-5A Galaxy and C-141 Starlifter transports and KC-135 tankers. Also widely used in missile and satellite launches, Carousel has been integrated with GPS capabilities for highly accurate, highly reliable guidance and navigation.

Under Blasingame’s leadership, Delco became the prime contractor for building NASA’s Apollo guidance and navigation system, plus the Lunar Roving Vehicle used on the last three lunar-landing missions. As a member of the Apollo Executive Committee voting in November 1968 on whether to proceed with the *Apollo 8* circumlunar mission, Blasingame confidently stated, “G&N hardware is completely ready. Generalizing to the mission as a whole, when we risk the lives of people, we ought to get something for the risk. A lunar orbit flight looks like the right size of step to make.”[2]

Blasingame later moved westward to manage the Santa Barbara, California, operations of the Delco Electronics Division of General Motors. There, he worked to advance so-called rotorcraft or helicopter technology. Even after his retirement from Delco in 1979, he continued to serve on National Research Council committees and panels that advised NASA on its role in development of rotorcraft technology. He also worked as director of Santa Barbara Bank and Trust from 1975 to 1994.

Over the years, Blasingame patented some of his innovative designs and shared many of his insights in publications. The US Patent Office granted him rights to an "Electrical Network System or Simulator" in 1958, a "Gravimeter" for precise measurement of the acceleration of gravity in 1965, and an "Inductive Multi-Speed Resolver" in 1966. Meanwhile, he delivered a paper on "Guidance and Navigation Problem Areas for Interplanetary Missions" at an international symposium on Space Age Astronomy in August 1961 and contributed to *Space Logistics Engineering,* edited by Kenneth Brown and Col Lawrence D. Ely, in 1962. Blasingame's own textbook, simply titled *Astronautics*, appeared in 1964 as part of the McGraw-Hill Series in Missile and Space Technology.

Among his many honors, Dr. Blasingame received the Penn State University Distinguished Alumni Award in 1970 and was elected to the National Academy of Engineering in 1971. The Institute of Navigation presented him its prestigious Hays Award in 1978. He died on 26 November 2015 at age 96.

Joseph Sylvester Bleymaier

Maj Gen Joseph S. Bleymaier, the son of German immigrants, was born on 31 December 1915 in Austin, Texas. He graduated from the University of Texas in 1937 with a bachelor's degree in business administration. His military career began when he enlisted, in May 1941, in the Army Air Corps. One year later, he accepted a commission and served as an aerial gunnery officer with the 11th Bombardment Group in the Southwest Pacific from 1943 to 1945, completing 25 combat missions in B-24 Liberator aircraft. After the war, he was assigned as deputy for test operations, Air Proving Grounds, Eglin AFB, Florida.

After graduating from the Air Command and Staff College at Maxwell AFB, Alabama, in 1950, Bleymaier became assistant director of the Command Support Division, Deputy for Development, Headquarters US Air Force, Washington, DC. While assigned to Headquarters, Air Research and Development Command (ARDC), Baltimore, in 1954, he graduated from Air War College at Maxwell AFB. Remaining at Headquarters ARDC until October 1958, he became assistant director of astronautics. Next, he went to Headquarters, AFBMD, Los Angeles, California. As AFBMD's assistant for subsystems development and deputy commander for ballistic missiles, Bleymaier accepted responsibility for development and integration of components—propulsion, guidance, and reentry vehicle subsystems—of Air Force Atlas, Titan, and Minuteman intercontinental ballistic missiles.

His focus on space programs began in April 1961, when he was designated Deputy for Launch Vehicles, Space Systems Division at Los Angeles Air Force Station, California. In that role, he supported DOD's launch vehicle and facilities standardization program. He also managed the Air Force portion of the NASA Ranger and Mercury programs, plus the Navy navigation satellite program.

On 27 November 1961, Bleymaier became system program director for the standardized, heavy-lift Titan III, the first Air Force rocket designed specifically to be a space launch vehicle. Referred to as the "DC-3 of the Space Age," Secretary of Defense Robert S. McNamara judged Titan III as "the best managed program in the Department of Defense."[3]

In March 1963, Bleymaier became deputy commander for manned systems at Space Systems Division. Two years later, in October 1965, he relocated to Vandenberg AFB, California, to command the Air Force Western Test Range.

On 1 July 1967, after his promotion to major general, Bleymaier became responsible for the Air Force's high-profile Manned Orbiting Laboratory (MOL), a modified Gemini capsule launched by a Titan III. In that capacity, he served as deputy director of both the Manned Orbiting Laboratory Program, Office of the Secretary of the Air Force, and the MOL Systems Office at Space and Missile Systems Organization, Los Angeles Air Force Station. In June 1969, however, Secretary of Defense Melvin R. Laird cancelled MOL and its advanced Titan IIIM launch system. Four months later, on 1 December 1969, Bleymaier retired from active duty.

Recognized for his military service with the Distinguished Service Medal, Legion of Merit, and Air Medal with 10 oak leaf clusters, Bleymaier also was honored earlier, in 1965, with the Arnold Air Society's John F. Kennedy Memorial Award for outstanding contributions to space research and development. After retirement, he joined Morrison-Knudsen Corporation, first as general manager of its Saudi Arabia Consortium and later as president of Morrison-Knudsen Forest

Products Corporation. He also served as chair of the Committee of the Future, a group of privately funded, distinguished space activists that promoted Project Harvest Moon, an effort to explore and exploit the moon. Major General Bleymaier died on 10 October 1998.

Robert Paul "Rob" Bongiovi

Col Robert P. "Rob" Bongiovi was born in Boston on 26 February 1970 and grew up in Ohio, where he graduated from the University of Dayton in 1992 with a bachelor's degree in mechanical engineering. He would immediately earn a master's degree in mechanical engineering at Virginia Polytechnic Institute and State University in Blacksburg, Virginia, and later, a master's degree in management through the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. Commissioned through ROTC, he began his space career with his first assignment, in September 1993, at the Space and Missile Systems Center (SMC), Los Angeles AFB, California. There, over the next four years, he worked on the Space Based Infrared System (SBIRS), served as an Aerospace Corporation adjunct employee, and went on to manage the inertial upper stage (IUS) program for the Titan IV space launch vehicle. In the latter role, he was responsible for system integration of all IUS launches and for ground operations at Cape Canaveral, Florida, including the successful launch of the DSP-18 early warning satellite.

Beginning in May 1997, Bongiovi joined the National Reconnaissance Office (NRO), where he worked for the next seven years. Initially, he served as chief of Airborne Collection Operations, then as deputy chief of the Systems Engineering/Integration Advanced Science and Technology Directorate at NRO headquarters in Chantilly, Virginia. In June 2001, his NRO duties took him to Buckley AFB, Colorado, where he became chief of space systems integration and mission director of the Aerospace Data Facility. In June 2005, after he devoted a year to earning his second master's degree, Bongiovi began a two-year assignment in the Office of the Undersecretary of the Air Force as Program Element Monitor (PEM) for launch and ranges, with special focus on the evolved expendable launch vehicle program. In October 2007, he began his final NRO assignment, serving as chief of staff, Office of Space Launch, and directing legislative liaison with Congress.

In June 2008, Bongiovi transferred to SMC, where he became commander of the SBIRS Sensors Branch, supervising the payload team that prepared for the program's initial spacecraft launch to geosynchronous orbit and, also, arranging contracts for the third and fourth SBIRS launches and getting the production line started. In June 2011, he began a one-year assignment as executive officer to the SMC commander before returning to the Pentagon, where he served as the Launch and Positioning, Navigation and Timing (PNT) Portfolio Manager in the Office of the Undersecretary of Defense for Acquisition, Technology, and Logistics. Promoted to colonel, he shifted to the Office of the Assistant Secretary for Acquisition in Air Force headquarters as Chief of the Space Support and Force Application Division in July 2013. In that position, he supervised the PEMs for launch, SBIRS, and PNT.

A year later, in July 2014, Bongiovi returned to SMC as chief of the acquisition division in the Launch Enterprise Systems Directorate, with responsibility for acquiring future Air Force, NRO, and other National Security Space Launch systems. He culminated his extensive background in space acquisition by becoming director of the Launch Enterprise System Directorate in December 2017. In that position (subsequently redesignated Space Systems Command Launch Enterprise), where he remained as of late 2021, he oversaw acquisition, integration, development, production, operation, and sustainment of both the National Security Space Launch program (formerly the EELV program) and the small launch initiatives of the Rocket Systems Launch Program, centered at Kirkland AFB, New Mexico.

Karel J. "Charlie" Bossart

Karel J. "Charlie" Bossart was involved in the early development of rocket technology with Convair Corporation and is known as the "father of Atlas." Bossart was largely responsible for conceiving in 1946 the design of the propellant tanks, which served as the primary structure for the Atlas launch vehicle. The tanks were a unique design consisting of pressure-stabilized, thin steel, a monocoque structure with a common inter-tank bulkhead—a "steel balloon." One writer described Bossart's design as "one of those brilliant, innovative, and yet simple ideas, that have withstood the test of time as a major contribution to the advancement of astronautics."[4]

Born in 1904 in Belgium, Bossart graduated from the University of Brussels in 1925 with a degree in mining engineering. He won a scholarship to MIT from the Belgian-American Education Foundation. At MIT he studied aeronautics, specializing in structures. He remained in America working on several airplane projects. By 1945, he was chief of structures at Consolidated-Vultee Aircraft in California (Convair, later General Dynamics). As chief of structures, he worked on a proposal for Project MX-774, the first US study of the V-2 and long-range missiles. Intrigued by the potential for such vehicles to do things airplanes could not, he was challenged by the skepticism about their feasibility. Bossart emerged as the driving force who successfully transformed the MX-774 from a study to a vehicle test program. When the Air Force requested that Convair develop a rocket with an 8,200-kilometer range, Bossart was put in charge of development.

The Air Force agreed to the construction of 10 MX-774 vehicles, with three different developmental stages. Stage A, the Teetotaler, was a subsonic, self-navigational jet plane. Old Fashioned, Stage B, was a test missile to try out the design work for the final stage. Stage C, the Manhattan, was to be the end result—a rocket with a range of 8,200 kilometers. The MX-774 was cancelled in 1947 due to budget restrictions. Bossart, however, convinced the Air Force to fund the completion of the three vehicles, allowing Convair Corporation to launch three MX-774s with less than satisfactory results. The tests, which concluded in December 1948, however, successfully demonstrated several design concepts, including Bossart's pressurized, monocoque tanks.

In 1949, in response to the Soviet Union's detonation of its first atomic bomb, interest in the MX-774 project was rekindled. Bossart again led efforts to revive the program in 1951 as the Project MX-1593. Because of its familiarity with the MX-774, Convair was awarded the contract. Karel Bossart again headed the team, which renamed the system "Atlas" in honor of the mythological being who bore the weight of the world on his shoulders. In addition to the integral, pressurized, monocoque tanks, Bossart is credited with conceiving gimballing of entire rocket engines. He also experimented with various means of separating the nose cone warhead as a solution to the reentry problem. All these experiments would prove important in designing the Atlas. The Atlas finally went into production in 1955 and remains one of the most weight-efficient designs ever developed.

A member of his team at Convair described Bossart as "a one-man System Requirements and Functional Analysis Group . . . and much more effective. He could quickly understand all the requirements of a subsystem and then conceptualize a design that would perform all the critical functions most efficiently."[5] He recognized that for the Atlas liquid propellant tanks to be efficient they had to serve as both the primary vehicle structures and the propellant containers.

Karel Bossart retired from General Dynamics in 1967 and died in 1975. Among the awards he received recognizing his contributions to engineering and the Atlas program were the US Exceptional Civilian Service Award in 1958 and the 1959 Collier Trophy for the US Air Force and General Dynamics.

Sebastian Frank "Seb" Coglitore

Brig Gen Sebastian F. Coglitore, the son of Italian immigrants, was born on 18 May 1943 in Passaic, New Jersey. After graduating from Passaic High School in 1961, he attended the New Jersey Institute of Technology in Newark. In his senior year, he commanded that institution's Arnold Air Society, an honorary service organization of the ROTC and, in 1965, graduated with a bachelor's degree in electrical engineering. Commissioned as a second lieutenant on 8 June 1965, he joined the Minuteman II 321st Strategic Missile Wing at Grand Forks AFB, North Dakota, and simultaneously earned a master's degree in management from the University of North Dakota, Grand Forks, before becoming an ROTC instructor at the University of Lowell, Massachusetts, in June 1970.

Three years later, in June 1973, Coglitore entered the space field, joining the 6595th Space Test Group at Vandenberg AFB, first as a satellite engineer, then as test manager and assistant launch manager for Titan-boosted satellites. During his four years at Vandenberg, all 22 classified satellite launches from SLC-4 succeeded. Coglitore's responsibilities embraced classified KH-8A Gambit 3 flights on Titan IIIBs, KH-9 Hexagon launches on Titan IIIDs and, especially, the new KH-11 Kennan, the first NRO digital imaging spacecraft, also launched by the Titan IIID. Near the end of his Vandenberg assignment, he became familiar with the Thor/Delta launch vehicle when he was asked to review and assist the Defense Meteorological Satellite Program, which had experienced two consecutive failures.

When Coglitore joined the Los Angeles Special Projects Office, in June 1977, he worked on Damon, a new program that was to serve as the DOD pathfinder payload for launching from the space shuttle. When the Air Force abandoned that program, Coglitore developed a restructured program to fly as DOD 82-1 on flight STS-4, a seven-day mission, in June–July 1982, that marked the last operational test flight of the shuttle.

In June 1983, Coglitore transferred to the Pentagon, where he served as deputy to the deputy assistant secretary of the Air Force for Space Plans and Policy. As the primary interface between the Air Force and NASA, his office coordinated intimately with the NRO staff, OSD, and acquisition and operational elements. He focused particularly on the "mixed fleet" strategy to buy 10 additional Titan heavy-lift vehicles to complement the shuttle and, thereby, support the Air Force's "assured access to space" strategy. Coglitore and Gen Donald Kutyna, the deputy commander for space launch and control systems at Space Division, represented the Air Force in negotiations with NASA over procuring the Titan IVs. Although opposed by NASA, President Reagan accepted the Air Force proposal.

After attending the Industrial College of the Armed Forces at Fort McNair in Washington, DC, Coglitore became Secretary of the Air Force Edward C. Aldridge's military assistant for space, in May 1986. In that capacity, he monitored Titan IV development and the Atlas and Delta production lines that had been restarted. He returned to Los Angeles in July 1987 as director of the Titan IV System Program Office. He witnessed the first Titan IV launch of a DSP early warning satellite, on 14 June 1989, shortly before relocating to Colorado Springs, where he served as vice director of plans for US Space Command before becoming command director of North American Aerospace Defense Command (NORAD).

In August 1991, Coglitore returned to Vandenberg AFB as the first commander of the 30th Space Wing, where he oversaw the wing's establishment that November. He returned to the Pentagon for his final active-duty assignment, serving as director of space programs in the Office of the Secretary of the Air Force.

Coglitore retired on 31 January 1995. He received the Air Force Distinguished Service Medal and was awarded the Defense Superior Service Medal for exceptionally superior service to the Department of Defense.

After his retirement, he joined Lockheed Martin Missiles and Space in Sunnyvale, California, where he became director for several space programs. Along with serving on Air Force senior review panels, he chaired the board of directors for the General Schriever (Los Angeles) Chapter of the Air Force Association (AFA) and, also, the board of directors for the Secretary of the Air Force Special Projects (SAFSP) Alumni Association.

Leighton Ira Davis

Lt Gen Leighton I. Davis was born on 20 February 1910 in Sparta, Wisconsin. He attended high school in Dawson County, Montana, where he graduated in 1927. He then worked as a US Internal Revenue Service clerk in Helena, Montana, until he entered the US Military Academy in 1931. After graduating in 1935, he attended flying training at Randolph and Kelly Fields, Texas, receiving his pilot wings in 1936. His first tactical assignment was as an engineering officer, Sixth Pursuit Squadron, 18th Group, in Hawaii. In January 1939, he became an instructor in the Department of Mechanics at West Point and received the Legion of Merit for developing electronic pressure-time and pressure-volume equipment for teaching at the US Military Academy. He received his master of science degree in aeronautical engineering in 1941 at MIT and would later be awarded an honorary doctorate of laws degree by New Mexico State University and an honorary doctorate of space science by Brevard Engineering College, Melbourne, Florida.

After a stint as director of the Ground School at West Point in 1942, Davis transferred to Air Materiel Command at Wright Field, Ohio, where he remained—serving in various capacities and earning more accolades—until August 1949. From project officer at the Armament Laboratory, he rose to technical executive and, later, its chief. In 1946, for his work on the design and development of the A-1 and A-4 series of gun-bomb-rocket sights for fighter aircraft, he received an oak leaf cluster to his Legion of Merit. The following year, for his work in developing fire control equipment, he received the Thurman H. Bane Award for 1946 from the Institute of Aeronautical Sciences. In July 1947, Davis became assistant chief of the Engineering Plans Branch, chief of the Applied Research Section at Wright Field, before advancing to chief, Office of Air Research at Air Materiel Command before August 1949. After attending Air War College, from which he graduated in July 1950, Davis became deputy and later commandant of the Institute of Technology at Wright-Patterson AFB, Ohio.

Moving from Ohio to Baltimore in 1951, Davis served successively as director of armament, then as assistant for development and support research, and finally as director of development, ARDC, Andrews AFB, Maryland. In September 1954, he moved westward to serve as commander, Holloman Air Development Center (later redesignated the Air Force Missile Development Center) at Holloman AFB, New Mexico. Eastbound in July 1958, he returned to ARDC headquarters, where he spent a year as deputy commander for research.

In August 1959, Davis was appointed assistant deputy chief of staff for development at Headquarters US Air Force in Washington, DC. He held that position until June 1960, when he undertook his first space assignment as commander of the Air Force Missile Test Center at Patrick AFB, Florida, and became the DOD's single point of contact for Project Mercury. On 20 May 1963, President John F. Kennedy awarded the National Aeronautics and Space Administration Medal for Outstanding Leadership to Davis for his role in planning and implementing DOD support to the Project Mercury spaceflight missions. He also represented DOD for coordinating with NASA on range support. Having supervised a joint study of possible launch sites for Project Apollo missions, he was instrumental in NASA's purchase of 80,000 acres on Merritt Island for what became the site of Kennedy Space Center. Furthermore, he ensured Air Force Titan III launch sites would be located on the southern portion of NASA's Merritt Island property.

After his Florida assignment, he returned to Andrews AFB in May 1964 as commander of the National Range Division and DOD manager for manned spaceflight support operations. On 1 July 1967, Davis became Commandant of the Industrial College of the Armed Forces in Washington, DC. He retired from active duty on 1 August 1968.

In retirement, Davis consulted for various organizations and served as a member of NASA's Aerospace Safety Advisory Panel from

1977 to 1983. His work for NASA included "fact-finding" responsibility for the space shuttle's launch preparations and logistics. He prepared the "Operations and Training" section for the Aerospace Safety Advisory Panel's Calendar Year 1978 report. General Davis died on 6 May 1995.

Krafft Arnold Ehricke

Krafft A. Ehricke was born on 24 March 1917 in Berlin, Germany. Attracted to rocketry and spaceflight at an early age but too young, in the early 1930s, to join other German amateur rocketeers in the *Verein für Raumschiffahrt* (*VfR*; Society for Space Travel), he experimented on his own. During 1936–1938, he fulfilled military service requirements in Germany's new Panzer Corps then earned an aeronautical engineering degree (master's equivalent) from the Technical University of Berlin in 1940.

With World War II underway, Ehricke was recalled to service and wounded during the blitzkrieg on the Western Front in 1940. During recuperation from his wound, he took graduate courses in celestial mechanics and nuclear physics at Humboldt University of Berlin. Returning to duty as an officer in 1941, Ehricke participated in the German attack on Russia but, in early 1942, was wounded a second time. Meanwhile, his earlier engineering work having come to Wernher von Braun's attention, he was recalled from the Eastern Front to join von Braun's rocket development team at Peenemünde, a move Ehricke later credited with saving his life. He spent the next two years with von Braun as a propulsion engineer and became the protégé of Walter Thiel, head of rocket engine development. Under Thiel's guidance, Ehricke worked on the use of liquid hydrogen/liquid oxygen in small engines for upper stages and determined that hydrogen was the best propellant for thermal rockets.

In 1944, he left Peenemünde to become an ordnance lecturer in Köslin (now Koszalin, Poland) until war's end. As the Third Reich collapsed in May 1945, Ehricke returned to Berlin, where he went into hiding to escape being "recruited" by the Soviet Union. Finally, having been located by an American officer in 1946, he was reunited with von Braun and others from the Peenemünde team, who came to the United States under Operation Paperclip. Working for von Braun, once again, but now under US Army auspices, one of his assignments was to assess a Jet Propulsion Laboratory report that claimed liquid hydrogen/liquid oxygen rockets would have superior performance in all circumstances. The production, storage, and handling of liquid hydrogen, however, remained technical unknowns. Chafing under von Braun's conservative technical approach and the southern climate at Huntsville, Alabama, however, Ehricke moved to Bell Aircraft, near Buffalo, New York, in 1952. While there, he worked on what became the Agena upper stage rocket. Two years later, he left to join the Convair division of General Dynamics in La Jolla, California, where he worked with Karel Bossart on the Atlas ICBM. While there, he also pursued his lifelong interest in space travel, focusing on upper stage satellite launch vehicles powered by hydrogen.

Amid heightened interest in space vehicles after the Sputnik flights, in late 1957, he submitted a proposal that led directly to the Centaur program. His design called for an upper stage vehicle for the Atlas, one powered by an Aerojet Rocketdyne engine using liquid hydrogen and liquid oxygen propellants. When the Air Force declined to accept the Convair development plan, Ehricke turned to DOD's Advanced Research Projects Agency (ARPA). Near the end of August 1958, ARPA issued a contract for Convair to produce a high-energy, upper stage vehicle using liquid hydrogen and liquid oxygen propellants in Pratt & Whitney engines. Ehricke, who served as the Centaur program manager, unfortunately failed to resolve certain management issues, and a major NASA inspection, in December 1961, compelled General Dynamics to replace him and adopt a project type of management in place of its matrix organization. Although the program continued to experience management and technical challenges under NASA's tutelage, the Ehricke-designed Centaur would become the nation's premier upper stage booster.

While working on Centaur, Ehricke found time to sketch out advanced concepts for nuclear-powered spacecraft, boosters, and spent-tank, manned space stations. After General Dynamics dismissed him, he went to Rockwell International, where he conducted several advanced studies on space commercialization. He became a popular speaker on the technical lecture circuit during the 1970s, promoting his concept of "The Extraterrestrial Imperative." He considered it humanity's responsibility to sustain development of the species by exploring space and exploiting the resources of the solar system.

Krafft Arnold Ehricke died on 11 December 1984. He received a space burial, on 21 April 1997, when the first flight of the Celestis mortuary satellite carried a small portion of his cremated remains into low Earth orbit.

Trevor Gardner

The Honorable Trevor Gardner was born in Cardiff, Wales, on 24 August 1915. He came to the United States in 1928 and became a naturalized citizen in 1937. He received a bachelor of science degree in engineering from the University of Southern California in 1937. He returned to the University of Southern California to teach freshman mathematics while obtaining his master's degree in business administration, which he was awarded in 1939.

During World War II, Gardner's work at the California Institute of Technology focused on rocket and atomic bomb projects for the Office of Scientific Research and Development. With the end of World War II, Gardner became associated with General Tire and Rubber Company of California as general manager and executive vice president. Three years later, he left to found Hycon Manufacturing Co., an electronics manufacturer. He was president of Hycon until February 1953 when he became the secretary of the Air Force's special assistant for R&D.

President Eisenhower began his first term by initiating a defense policy that sought to significantly reduce spending. Gardner was asked to lead a committee and implement an economy program to reduce missile development activities. Its final report recommended that promising missile projects should be continued. The Atlas, under development since 1951, was America's best hope; however, its development had been constrained by the Air Force due to the belief that missiles required too great an investment in systems that seemed "impossible." Impatient, Gardner requested a scientific review of all Air Force missile programs in April 1953. The impetus came from two directions. First, he was concerned over the growing Soviet threat (in August 1953, they exploded a hydrogen bomb). The second trend was the development of lighter nuclear weapons. The "impossible" ICBM was now much more possible. In October 1953 Gardner established a second committee to review the Air Force's strategic missiles—the Snark, Navaho, and Atlas. He directed the committee to find ways to accelerate the development of the Atlas. The committee issued its report on 10 February 1954. Its thrust called for a "radical reorganization of the . . . [Atlas] project considerably transcending the Convair framework."[6] Gardner developed a five-year plan to accelerate the Atlas, which would yield a preliminary capability by June 1958.

In early 1955, most of the Eisenhower administration assumed that America had a strong lead over the Soviet Union in strategic technology and felt no urgency for the ICBM programs. The Killian report indicated that America was becoming vulnerable and that the ICBM should be given the highest priority. While an Air Force priority, Gardner believed that ICBMs must also be a national priority. He indicated that the US could have a rudimentary ICBM by mid-1958 if the program was conducted on a crash basis. Eisenhower requested a briefing, and on 28 July 1955, Gardner, Dr. John von Neumann, and Gen Bernard A. Schriever made a presentation to the president and the National Security Council. As a result, the National Security Council recommended the ICBM be designated a "research program of the highest priority" which the president approved on 13 September 1955. Gardner had achieved his goal.

In January 1955, the Scientific Advisory Committee urged the Air Force to develop a tactical ballistic missile. All three services developed plans, and the interservice rivalry led to a compromise with the Air Force building the Thor and the Army and Navy in charge of the Jupiter. Gardner viewed this approach as dangerous since the IRBM could drain resources from the ICBM and threaten its early delivery. His fears were realized when President Eisenhower assigned the ICBM and the IRBM highest national priority jointly. The ICBM program no longer had a unique status. Trevor Gardner felt betrayed and resigned his position in protest on 10 February 1956.

After the election in 1960 Gardner again became active in public life. He served on the President's Space Task Force Commission to review the nation's space program and chaired the US Air Force Space Task Force. He also became involved in preventing the use of weapons, playing a major role in establishing the US Arms Control and Disarmament Agency and named to its General Advisory Commission on 1 March 1962. At the time of his death on 28 September 1963, Gardner was actively participating in Project Forecast, which was to chart the future course of the Air Force for the next decade.

Otto J. Glasser

Lt Gen Otto J. Glasser was born in Wilkes-Barre, Pennsylvania, on 2 October 1918. He graduated from Cornell University in 1940 with a bachelor's degree in electrical engineering. In May 1940, he earned a commission as a second lieutenant and began active duty in February 1941. He entered flying training in September 1943, graduated the following June, and then received transition training in the B-17, B-24, and B-29. After World War II, he attended Ohio State University, where he earned his master's degree in electronic physics in 1947. Glasser served as the director of the Atlas ICBM program, the nation's highest priority military project in the mid-1950s. An original member of Gen Bernard A. Schriever's "Schoolhouse Gang" of four at the WDD, his leadership provided the nation with its first deployed ICBM.[7]

In February 1956, Glasser became the director of the Atlas program. The Atlas program was distinctive, and its urgency deterred the Air Force from undertaking a testing program like the one the Germans had used in their V-2 program. The Germans had performed 3,000 flight tests to produce an operational missile, but during the Cold War, using that many flight tests was impracticable. The constraints of time, energy, money, and resources militated against it.

Instead, Glasser engineered a program that tested individual parts, then components and assemblies, subsystems, and stages, eliminating all possible sources of error before committing the subsystem to a completely integrated missile. Next, personnel tested the integrated missile, firing it up, checking it out, while a captive stand held it down—eliminating, so far as possible in this artificial environment, sources of error. However, captive testing carried with it the advantage of rigor. In this atmosphere, the Air Force used sophisticated monitoring instrumentation that it could not use while the Atlas was in flight. After static evaluation, the organization flight-tested missiles, carrying out a specific list of tests on each flight. However, as Glasser anticipated, the Atlas program encountered difficulties and he included leeway for mishaps resulting in lost time.

At the same time, he was alert to new possibilities. In early 1957, he deemed that the time was ripe to inaugurate a solid-propellant missile program. Accordingly, Schriever sent the personable and persuasive Glasser as his emissary to Washington to sell the idea to Air Force Secretary Donald A. Quarles. Glasser persuaded him to permit the start of a solid-propellant missile "technology program." A year later, the Air Force was able to initiate the solid-propellant Minuteman ICBM program.

In October 1959, Glasser became chief, Ballistic Missiles and Space Systems Division, and later the assistant deputy chief of staff, Research and Engineering at ARDC. In February 1961, he became the special assistant to the commander, ARDC, with the additional duty as the chief of the Command Special Projects Office. When Robert S. McNamara became secretary of defense, he urged the chief of staff of the Air Force, Gen Thomas D. White, to reorganize the Air Force's systems management immediately so that McNamara could assign the military space program to the Air Force. After consultation with General Schriever, General White chose Glasser to study and recommend a method for reorganizing the Air Force's systems management. As a result of Glasser's work, the Air Force established Air Force Systems Command and Air Force Logistics Command.

In July 1962, Glasser became vice commander of the Electronic Systems Division, Air Force Systems Command. In July 1965, he moved to Headquarters United States Air Force; first as deputy director of Operational Requirements and Development Plans, and then assistant deputy chief of staff, R&D. In February 1970, Glasser became the deputy chief of staff for R&D and the military director of the USAF Scientific Advisory Board (SAB). Here, he supervised the systems integration and testing and guidance and control support and oversaw postboost propulsion system testing and in-place and in-flight hardness testing for the Minuteman III.

Lieutenant General Glasser retired from active duty on 1 August 1973. From 1973 to 1986, he served in several positions with General Dynamics Corporation, culminating as vice president for Government Relations. He retired in 1986 to Sarasota, Florida, where he died on 26 February 1996.

Edward N. Hall

Col Edward N. Hall was born in New York City on 4 August 1914. He received a bachelor of science degree in engineering from College of the City of New York in 1935 and a professional degree in chemical engineering in 1936. In 1948, he earned a master of science degree in aeronautical engineering (propulsion option) from California Institute of Technology.

Hall entered the Air Corps on 26 September 1939. During World War II, he served in England in engineering assignments associated with aircraft repair. His introduction to missiles came near war's end when he was assigned to acquire intelligence on Germany's wartime propulsion work. He analyzed German rocket equipment, insofar as parts recovered from exploded V-2 specimens or retrieved through spy networks allowed. At war's end, he led an Air Force Propulsion Group through German rocket plants—especially the underground assembly facilities at Work Camp Dora—and subsequently assisted in the division of captured missile equipment between the US and England.

After a second European tour, which covered further propulsion developments, Hall became assistant chief, Non-Rotating Engine Branch, Power Plant Laboratory, Wright-Patterson AFB, where he participated in the development of solid and liquid rocket power plants. This included work on the propulsion systems for the Bomarc, Navaho, Snark, Rascal, and Falcon. In 1951, he was one of four people at Wright Air Development Center (WADC) who was instrumental in the initiation of Project MX-1593, the Atlas program. During this period, Hall authored and delivered a paper to the American Rocket Society about solid propulsion for long-range rockets. Between November 1953 and February 1954, he served as the WADC representative at meetings of the Air Force Strategic Missiles Evaluation Committee—popularly dubbed the Teapot Committee.

On 3 August 1954, Hall joined WDD as Chief, Propulsion Development, where he was responsible for the programs leading to development of engines for the Atlas, Titan, and Thor missiles. In the summer of 1957, after receiving the Goddard Award, he became director of the WS–315A (Thor) development program and subsequently oversaw the installation of Thor missiles in England. He next took advantage of a Navy request for DOD approval of a solid-propellant ballistic missile and obtained permission for the Air Force to undertake general work on such a capability. Led by Col Charles Terhune, his immediate supervisor, Hall briefed Air Force Deputy chief of staff Gen Curtis LeMay on the potential of solid-propellant ICBMs. The briefing so impressed LeMay that he arranged for Hall to brief the secretary of defense, who as a result supported acceleration of the Air

Force effort with a $50 million infusion of funds. Hall directed the WS–133A (Minuteman) program until the eve of the missile's first complete flight test, when he received orders to report to Paris.

After his success with the Minuteman program, Hall was expected to take the lead in designing, developing, producing, and deploying a nuclear-tipped IRBM for the North Atlantic Treaty Organization. Hall served as founding director and chief engineer for a group of French, German, Italian, and English engineers who set up the largest solid rocket engine plant in Europe at St. Medard, France. Their labor resulted in the only European nuclear IRBM, the French Diamant. After retiring from the Air Force on 27 October 1959, Hall joined United Aircraft Corporation and, later, Chromalloy American Corporation. During those years, he played major roles in numerous innovative projects. These included solid and nuclear rocket-propulsion systems, high-powered laser development, design of "The Air City," ocean farming, bioengineering (synthetic sight and hearing), computer-aided design and manufacturing, the turbo train, and the Space Transport System design. Colonel Hall died on 15 January 2006.

John Earl Hyten

Gen John E. Hyten was born on 15 July 1959 in Huntsville, Alabama, where his father worked on the Saturn V rocket. After graduating from Huntsville High School, he attended Harvard University in Cambridge, Massachusetts, on an ROTC scholarship and graduated with a bachelor's degree in engineering and applied sciences in 1981. Commissioned as an Air Force officer, he spent the first 12 years of his military career in engineering and acquisition assignments.

Hyten's initial four-year assignment took him to Gunter AFB, Alabama, where he became chief of the Configuration Management Division in the Automated Systems Program Office. In December 1985, he transferred to Los Angeles AFB, California, for another four-year assignment, becoming chief of the Software Development Branch and chief of the Engineering and Acquisition Division in the Space Defense Programs Office. In August 1989, he began the first of four, one-year assignments, as a special advisor to the US Army Kinetic Energy Anti-Satellite Program Office in the Army Strategic

Defense Command at Huntsville. After that assignment, Hyten went to Los Angeles AFB, as deputy for engineering in the Strategic Defense Initiative Program Office and, from there, to the Office of the Assistant Secretary of the Air Force for Acquisition in the Pentagon, serving first as executive speechwriter and systems analyst, then as PEM for Advanced Technology Programs.

Hyten began his space focus in July 1994 when, after attending Air Command and Staff College at Maxwell AFB, Alabama, he accepted a joint assignment as mission director for US Space Command at Cheyenne Mountain Air Force Station in Colorado. Two years later, he became the last active-duty commander of the 6th Space Operations Squadron at Offutt AFB, Nebraska, which had backup command-and-control responsibility for the Defense Meteorological Satellite Program. After a year as a National Defense Fellow at the University of Illinois in Urbana, where he wrote a far-sighted thesis that described space as a contested military domain, he returned to the Pentagon in June 1999. Over the next four years, he served first as chief of the Space Branch, Defense and Space Operations Division, deputy director for operations for the Joint Staff, then as chief of the Space Control Division in the Directorate for Space Operations and Integration, Deputy chief of staff for Air and Space Operations. In June 2003, he returned to Colorado as director of the Commander's Action Group at Air Force Space Command, Peterson AFB, and followed that one-year assignment with two command postings at Schriever AFB, Colorado, first with the 595th Space Group and thereafter with the 50th Space Wing. While assigned to the latter, he spent six months deployed to Southwest Asia as the Air Force Director of Space Forces for US Central Command.

In May 2007, Hyten became director of requirements at Air Force Space Command headquarters before returning to the Pentagon for three assignments: director of cyber and space operations in the Directorate of Operations, deputy chief of staff for operations, plans, and requirements at Air Force headquarters; director of space acquisition in the Office of the Undersecretary of the Air Force; and director of space programs in the Office of the Assistant Secretary of the Air Force for Acquisition.

From Washington, DC, Hyten returned once more to Colorado Springs, in May 2012, as Air Force Space Command vice commander. Then, in August 2014, he assumed command of Air Force Space Command. That year, the general announced his Strategic Enterprise

Vision (SEV), which his command had developed jointly with the NRO the previous year. With space now considered a potential warfighting domain, the SEV envisioned an integrated architecture blueprint that, by 2030, would produce a resilient space force capable of deterring aggression in the space arena and, if necessary, prevailing in any conflict that involved space.

In November 2016, Hyten left Air Force Space Command to assume command of the US Strategic Command at Offutt AFB. During his three-year tenure in that capacity, he played a key role in orchestrating the re-establishment of a unified combatant command for space and creation of a US Space Force. He returned to the Pentagon, in November 2019, as vice chairman of the Joint Chiefs of Staff, and retired in November of 2021.

Claude Robert Kehler

Gen C. Robert “Bob” Kehler was born in Danville, Pennsylvania, on 7 April 1952 and graduated with distinction from Pennsylvania State University, in 1974, with a bachelor’s degree in education. Commissioned through the ROTC, he entered the active-duty Air Force in April 1975. Kehler spent the first 20 years of his career in the missile field, interspersed with education assignments, such as Carnegie Mellon University’s Program for Executives (1998); the National Security Leadership Course at Syracuse University’s Maxwell School of Citizenship and Public Affairs (2002); and the Program for Senior Executives in National and International Security at Harvard University’s John F. Kennedy School of Government (2006).

After initial Missile Combat Crew Operational Readiness Training at Vandenberg AFB, California, in 1975, he spent six years with the 341st Strategic Missile Wing at Malmstrom AFB, Montana, as a Minuteman II crew member, instructor, senior evaluator, and Emergency War Order instructor. From Malmstrom AFB, Kehler transferred to Offutt AFB, where he joined Strategic Air Command headquarters as a missile operations staff officer. In January 1985, he relocated to Washington, DC, and served in the Air Force Office of Legislative Liaison as chief of the Strategic Missile Branch. In that capacity, he was “point man” on Capitol Hill for matters regarding

President Ronald Reagan's ICBM Modernization Program. Then, after graduating from the Armed Forces Staff College in Norfolk, Virginia, and earning a master's degree in public administration, in 1987, from the University of Oklahoma, he was assigned as a nuclear employment and policy planner in the Nuclear and Chemical Division of the Joint Staff at Washington, DC.

In July 1991, Kehler became commander of the 508th Missile Squadron at Whiteman AFB, Missouri. A year later, he advanced to the position of 351st Operations Group deputy commander, with responsibility for all three missile squadrons at Whiteman AFB. In February 1993, he returned to Malmstrom AFB as commander of the 341st Operations Group.

Kehler began his focus on space in July 1995 when, after attending the Naval War College in Newport, Rhode Island, where he earned a master's degree in national security and strategic studies, he became both inspector general and deputy director of operations at Air Force Space Command headquarters in Colorado Springs, Colorado. A year later, in June 1996, he transferred to Vandenberg AFB, where he assumed command of the 30th Space Wing. In June 1998, he moved to the Office of the Deputy Chief of Staff for Plans and Programs at Air Force headquarters, where he became, first, chief of the Space Superiority Division and chair of the Space Superiority and Nuclear Deterrence Panel and, later, special assistant to the Director of Programs.

In August 2000, shortly after his promotion to brigadier general, Kehler transferred to Peterson AFB to assume command of the 21st Space Wing, which provided missile warning and space situational awareness to unified combatant commanders worldwide. In May 2002, he returned to the Pentagon for a three-year tour working on NRO issues as director, National Security Space Integration, in the Office of the Undersecretary of the Air Force.

In May 2005, Kehler was appointed deputy commander of US Strategic Command at Offutt AFB. Two years later, he returned to Colorado Springs as Air Force Space Command commander. Among several key programs initiated during his tenure was a fundamental change in the conduct of space launch and range operations, which became the Launch and Range Enterprise Transformation, to decrease the instrumentation segment enroute to a space-based range architecture. As key elements in this program, Global Positioning System Metric Tracking and the Autonomous Flight Safety System represented essential first steps toward a space-based range that supported operationally responsive launch systems. In January 2011, Kehler returned to Offutt AFB as US Strategic Command commander. He retired from active duty on 1 January 2014.

Kehler's military awards included the Defense Distinguished Service Medal, the Air Force Distinguished Service Medal with Oak Leaf Cluster, the Defense Superior Service Medal, the Legion of Merit with two oak leaf clusters, and the French Legion of Honour. In addition to receiving the AFA's H. H. Arnold Award, that organization's highest honor in national security to a member of the armed forces, in 2014, two AFA chapters honored him earlier: the General Bernard A. Schriever Chapter, in Los Angeles, California, with its prestigious General Thomas D. White US Air Force Space Trophy (2010); and the Lance P. Sijan Chapter, in Colorado Springs, with the General Jerome F. O'Malley Distinguished Space Leadership Award (2010). The Rocky Mountain Chapter of the National Defense Industrial Association (NDIA) awarded Kehler the General James V. Hartinger Award for outstanding achievement in the military space mission (2009).

After his retirement, Kehler accepted a position as National Defense University senior fellow, supporting Pinnacle, Capstone, and Keystone programs. He also served on the boards of Mitre Corporation and Inmarsat, plus as an affiliate of Stanford's Center for International Security and Cooperation. In November 2016, Kehler became an independent director and Risk Committee chair for Maxar Technologies, a global provider of advanced space technology solutions. The retired general held positions, in 2019, as chair of BEI Precision Systems & Space Company, and as president at Kehler & Associates LLC.

Donald Joseph Kutyna

Gen Donald J. Kutyna, the grandson of Polish immigrants, was born on 6 December 1933, in Chicago, Illinois. After graduating at age 17 from Lane Technical High School in Chicago, he enrolled at the University of Iowa as a chemical engineering student. In his second year as an undergraduate, he applied for and received an appointment to the United States Military Academy at West Point, graduating with a bachelor of science degree in 1957.

Upon completion of pilot training at Vance AFB, Oklahoma, in September 1958, Kutyna was assigned to the 33rd Bombardment Squadron at March AFB, California, where he served as a B-47 combat crew commander until June 1963. During the next two years, he studied at MIT, earning a master's degree in aeronautics and astronautics in June 1965. He went from MIT to the Aerospace Research Pilot School, Edwards AFB, California, as a staff director, training test pilots and astronauts for US aircraft and space programs.

From December 1969 to January 1971, Kutyna did a combat tour with the 44th Tactical Fighter Squadron at Takhli Royal Thai AFB, Thailand, completing 120 combat missions in the F-105 tactical fighter. Upon his return from Southeast Asia, he was assigned to Headquarters US Air Force, Washington, DC, as a development planner in the Office of the Deputy Chief of Staff for Research and Development. In June 1973, after serving with the Air Force SAB, he was assigned as executive officer to the undersecretary of the Air Force.

Kutyna transferred, in July 1976, to Electronic Systems Division, Hanscom AFB, Massachusetts, where he became assistant program director for the E-3A Airborne Warning and Control System aircraft and, later, deputy for surveillance and control systems. In the latter position, he oversaw development and acquisition of sensors and command centers for use by NORAD and, later, US Space Command.

Kutyna became deputy commander for space launch and control systems at Space Division, Air Force Systems Command, Los Angeles Air Force Station, California, in June 1982. In that position, he managed the Department of Defense space shuttle program, including design and construction of the launch complex for the space shuttle at Vandenberg AFB; acquisition of space shuttle upper stage boosters; and operational aspects of launching military payloads on the shuttle. His responsibilities also encompassed the development, acquisition, and launch support of all Air Force ELVs.

In June 1984, the general became director of space systems and command, control, and communications, Office of the Deputy Chief of Staff, Research, Development, and Acquisition, at Air Force headquarters. After the loss of the space shuttle *Challenger*, in January 1986, Kutyna chaired the Accident Analysis Panel of the Presidential Commission on the Space Shuttle *Challenger* Accident and was instrumental in determining the cause of the tragedy. For his contribution to that investigation, Kutyna received the National Geographic Society's General Thomas D. White United States Air Force Space

Trophy. He returned to Los Angeles Air Force Station as vice commander of Space Division, in June 1986, to oversee all space system acquisitions but especially programs associated with the Strategic Defense Initiative.

In November 1987, General Kutyna became commander of Air Force Space Command, the newest major command in the Air Force. Three months later, he became the chief advocate for transferring the space launch mission from Air Force Systems Command to Air Force Space Command. He argued persistently that space boosters represented operational rather than developmental systems and, therefore, should be the responsibility of the operational command. His efforts succeeded, finally, in the fall of 1990. Earlier that spring, he had assumed command of US Space Command and NORAD. He retired from active duty on 1 July 1992.

After his retirement, General Kutyna served on a variety of defense-related boards and committees. He became vice president for Space Technology of Loral Space and Communications Company and, later, vice president for Lockheed Martin Corporation's Advanced Space Systems.

Hans Michael Mark

Dr. Hans M. Mark, the thirteenth secretary of the Air Force, was born on 17 June 1929 in Mannheim, Baden-Württemberg, Germany. The child of Austrian parents, he spent his early childhood in Vienna before his family escaped the Nazi Anschluss via Switzerland to England. His father, a prominent polymer chemist, secured a position with a Canadian paper company, and the family emigrated to Canada in 1938. Early in 1940, his father accepted the offer of an adjunct professorship at the Polytechnic Institute of Brooklyn, and the family moved to New York City that summer. He attended Public School 92 in Brooklyn until entering Stuyvesant High School, from which he graduated in 1947.

Having become a US citizen in June 1946, Mark attended the University of California, Berkeley, where he earned a bachelor's degree in physics in 1951. He completed his doctorate in physics at MIT in 1954 and remained there as acting head of the Neutron Physics

Group, Laboratory for Nuclear Science, until 1955. Over the next decade, he climbed the academic ladder, moving back to the UC Berkeley campus, then to its Lawrence Radiation Laboratory in Livermore, back to MIT, and finally back to California. By 1969, he had been a full professor at UC Berkeley for several years, chaired its nuclear engineering department, served as administrator of the Berkeley Research Reactor, and consulted for the Institute for Defense Analyses (1958–1961) and the National Science Foundation (1966–1969).

In 1969 Mark accepted a position with NASA as director of Ames Research Center, where he oversaw both aeronautical and space research projects. During his tenure, he supervised management of the Pioneer planetary exploration program, including *Pioneer 10*, which launched in 1972 to become the first spacecraft to fly past Jupiter and, eventually, the first human object to leave the solar system. He simultaneously continued lecturing at the UC Davis campus until 1973 and, thereafter, was consulting professor of engineering at Stanford University. In addition, he served as a consultant to the Air Force SAB (1969–1976), to Vice President Nelson Rockefeller (1974–1976), and to President Gerald R. Ford's Advisory Group on Science and Technology (1975–1976) and was appointed to the Defense Science Board in 1975.

In 1977, President Carter chose Mark to be undersecretary of the Air Force and director of the NRO, giving him responsibility for US satellite reconnaissance. Subsequently, Mark served as secretary of the Air Force from May 1979 to February 1981. While in those leadership positions, he influenced Air Force space operations in several specific ways: he urged his predecessor, John Stetson, to authorize a "Space Missions Organizational Planning Study" that laid out five alternatives in its top-secret February 1979 report, one being establishment of an operational major command for space, which Dr. Mark subsequently advocated; he initiated efforts to build a new military satellite control facility, which became Schriever AFB, Colorado; he committed adequate Air Force funds for an operational GPS; and he fostered using the space shuttle for on-orbit military operations by initiating a Manned Spaceflight Engineer program to train military astronauts. Later, he unsuccessfully advocated for Air Force Space Command acquiring its own fleet of military shuttles, and he became the Air Force's most vocal spokesman for eliminating ELVs and relying on the space shuttle to transport all US satellites into outer space.

As NASA deputy administrator during 1981–1984, Mark supervised the first 13 space shuttle flights and oversaw initial US efforts to develop an International Space Station. He then became chancellor of the University of Texas (UT) system (1984–1992), was a professor of aerospace engineering and engineering mechanics at the University of Texas at Austin (1988–1998), held the John J. McKetta Centennial Energy Chair in Engineering (1992–1998), and worked after 1990 on US Army advanced weapon systems through the university's Institute for Advanced Technology.

In July 1998, the Senate confirmed Mark as Director of Defense Research and Engineering (DDR&E). On leave from UT, he served as DDR&E until 2001. He returned, thereafter, to UT, where he taught courses in aerospace engineering, spaceflight history, and the role of technology in the Cold War.

Among his many publications, Mark wrote *The Space Station: A Personal Journey* (1987), coauthored and edited the two-volume *Encyclopedia of Space Science and Technology* (2003), and crafted his autobiographical *An Anxious Peace: A Cold War Memoir* (2019). His articles include "Warfare in Space" (1984) and "A White Paper on the Defense Against Ballistic Missiles" (2001). He was one of seven distinguished authors of an Institute for Defense Analyses report to Congress titled "Leadership, Management, and Organization for National Security Space" (2008). Elected to the National Academy of Engineering in 1976, Mark subsequently won many accolades: NASA Distinguished Service Medal (1972, 1977); Air Force Exceptional Civilian Service Medal (1979); DOD Distinguished Public Service Medal (1981); NASA Exceptional Scientific Achievement and Exceptional Engineering Achievement medals (1984); George E. Haddaway Medal for Achievement in Aviation (1999); Military Astronautics Award from the American Astronautical Society (2006); and the Space Foundation's General James E. Hill Lifetime Space Achievement Award (2008). In 2012, Dr. Mark was inducted into the Air Force Space and Missile Pioneers Hall of Fame.

Richard William McKinney

The Honorable Richard W. McKinney was born on 1 February 1951 at Camp Breckenridge, Kentucky, and raised in Lacey, Washington, where he attended North Thurston High School. He graduated with distinction from Washington State University in 1973, having earned a bachelor's degree in business administration/marketing and a commission through Air Force ROTC. Later, he received a master's degree in business administration from the University of Montana, Missoula (1980), and a second bachelor's degree, in electrical engineering, from the Air Force Institute of Technology (1982). After missile training at Vandenberg AFB, he joined the 341st Strategic Missile Wing at Malmstrom AFB, where he served as a Minuteman II Combat Crew Commander before joining the Squadron Officer School faculty at Maxwell AFB in August 1977. In March 1982, McKinney transferred to Norton AFB, California, where he managed the guidance and navigation program for the Peacekeeper ICBM before serving as executive officer to the commander of the Ballistic Missile Office.

Assigned to the Pentagon in January 1987, McKinney was a PEM for the GPS and the Titan IV space launch vehicle. After two years as a PEM, he became the executive officer to the Assistant Secretary of the Air Force for Acquisition. In June 1992, he added logistics to his acquisition experience by transferring to Tinker AFB, Oklahoma, where he became Director of Propulsion, with responsibility for half of the jet engines in the Air Force. Four years later, in June 1995, McKinney was selected as the first system program director of the fledgling Evolved Expendable Launch Vehicle (EELV) Program Office. Although assigned to the SMC in Los Angeles, California, he reported directly to the Assistant Secretary of the Air Force for Acquisition. Over the next four years, McKinney directed the EELV source selection process and implemented innovative practices, such as the "government insight" program and remote access to all contractor data that helped ensure contract compliance and effective vehicle development. Consequently, development and initial delivery of the Delta IV and Atlas V launch vehicle families occurred on time and under budget, with the EELVs ultimately achieving an unprecedented record of no launch failures. In July 1999, McKinney left his assignment as EELV program director and returned to the Air Staff as deputy director of the Directorate of Space and Nuclear Deterrence in the Office of the Secretary of the Air Force for Acquisition.

Although he retired from active duty as a colonel in May 2001, McKinney reentered government service, in January 2002, as a member of the senior executive service. He worked in several space acquisition positions under both the undersecretary and the secretary of the

Air Force. In September 2007, he interrupted his Pentagon assignments for a two-year posting to Paris, France, where he served as director, European Space Liaison, Office of the Undersecretary of the Air Force, a position created specifically for him. After returning to the Pentagon, McKinney became deputy undersecretary of the Air Force for Space, coordinating activities across the Air Force space enterprise and advising the secretary of the Air Force on restructuring management and responsibilities in the Headquarters Air Force space organization. He also was responsible for establishment of the Defense Space Council (DSC) that provided oversight of the Space Virtual Major Force fiscal program, and as DSC co-executive secretary, he advised the DOD Executive Agent for Space and advocated to Congress for defense space acquisition programs. McKinney retired from the senior executive service in November 2013.

McKinney's military and civilian awards included the Legion of Merit with two oak leaf clusters, Meritorious Service Medal with three oak leaf clusters, Department of State Superior Honor Award, Outstanding Civilian Career Service Award, and Secretary of Defense Meritorious Civilian Service Award. In "retirement," he founded the aerospace consulting firm R. W. McKinney LLC and consulted for several space-related companies, including Lockheed Martin Space. He also served on the Aeronautical Space and Engineering Board of the National Academies of Science, Engineering and Medicine; the Museum of Flight space committee; and SMC's Launch Enterprise Independent Advisory Group. In June 2018, the Center for Naval Analyses appointed him to its newly established Space Advisory Council. He was among 42 former defense and intelligence officials who, in 2019, signed an open letter stating their strong support for establishment of a US Space Force.

Ever mindful of the academic role Washington State University (WSU) had played in preparing him for the future, McKinney served on the WSU Foundation Board of Trustees, on the advisory board of its College of Business, and created the Richard McKinney Honors Study Abroad Scholarship in the WSU Honors College. He also created, in WSU's Carson College of Business, the R. W. McKinney Scholarship for any undergraduate or graduate student with a demonstrated desire to work in public service.

Joseph Donald Mirth

Brig Gen Joseph D. "Don" Mirth was born on 30 March 1931 in Flint, Michigan. Raised in Chicago, Mirth graduated from Calumet High School in 1949, then attended Wilson Junior College and the University of Illinois before joining the US Air Force as an aviation cadet in 1952. The next year, having earned his pilot wings and a second lieutenant's commission at Greenville AFB, Mississippi, he became an instructor pilot at Vance AFB. Subsequently, Mirth entered Oklahoma State University, where he earned both bachelor's and master's degrees in mechanical engineering in 1959.

Before graduating, Mirth already had been recruited for the first Air Force satellite program, Weapon System (WS) 117L, which included Discoverer/Corona, Samos, and MIDAS systems. He relocated to Sunnyvale, California, where he participated in an industry tour with Lockheed Missiles and Space Company, contractor for production of all three types of satellites. Mirth followed the development of Agena, the Corona upper stage vehicle, all the way from subsystem and full system testing through launch. This satellite, known as *Discoverer 13*, delivered the first capsule successfully recovered from space in August 1960.

In 1960, Mirth was assigned to the early test and launch organization at Vandenberg AFB, where he served as project officer for acceptance, processing, and launch of all Samos E1, E2, E5, and E6 satellites and Gambit imaging spacecraft. He also became project chief and launch director for the MIDAS infrared missile detection satellite, and for SNAPSHOT (Systems for Nuclear Auxiliary Power) 10A, a nuclear reactor launched on an Atlas-Agena vehicle in April 1965. Later, Mirth was named chief of the Satellite Control Section, Engineering Division for the Gambit-cubed program in the SAFSP Office at Los Angeles. He also served as launch operations coordinator for every Gambit-cubed launch until 1970. During this period, he also advised on the MOL payload.

Mirth volunteered for Vietnam service in 1970. During that deployment, he managed electronic ground sensors throughout Southeast Asia for Seventh Air Force. After his return to the United States in 1971, he attended the Industrial College of the Air Force, graduating in 1972. He then became chief of the F-15 division at Air Force Systems Command headquarters before rejoining his space colleagues in 1976 as Space and Missile Test Center vice commander at Vandenberg.

Mirth's last active-duty assignment took him to Space Division (SD) in Los Angeles in 1978, where he served as the SD deputy for space launch and control systems and as the Air Force space shuttle program director. In the latter capacity, he was responsible for the management, development, and activation of numerous shuttle-related facilities, including Space Launch Complex 6 and seven other new facilities at Vandenberg AFB; the Consolidated Space Operations Center near Colorado Springs; the Air Force "Controlled Mode" Firing Room at Johnson Space Center, Houston, Texas; and the Shuttle Payload Integration Facility at Kennedy Space Center (KSC). He was also responsible for IUS and Titan 34D rocket developments. General Mirth retired from active duty in June 1982.

From 1982 to 1994, Mirth worked for United Technologies Corporation (UTC), where he initially managed the Joint STARS radar program for UTC's Norden Systems Division. Later, as UTC's Space Flight Systems Division vice president, Mirth developed the Cargo Shuttle (Shuttle C) concept and did concept studies for the Air Force Advanced Launch System. He later became Pratt & Whitney's United Space Boosters Inc. (USBI) Senior Vice President for Advanced Engineering and Technology. As vice president and director of USBI operations at KSC in the early 1990s, Mirth had responsibility for the fourth largest contracting activity at KSC: refurbishing and prelaunch processing of space shuttle solid rocket booster non-motor components. He also taught global trade classes in Florida schools, as a volunteer instructor, for a quarter century. In 2018, Brigadier General Mirth was inducted into the Air Force Space and Missile Pioneers Hall of Fame.

Thomas S. Moorman Jr.

Gen Thomas S. Moorman Jr. was born on 16 November 1940 in Washington, DC. He earned his bachelor's degree in history and political science from Dartmouth College and was commissioned through the Air Force ROTC in 1962.

Moorman served in a variety of intelligence and reconnaissance-related positions within the United States and worldwide. He initially served with two aircraft units before a tour in Thailand where he was responsible for the processing and interpretation of tactical imagery collected over North Vietnam and Laos during the Vietnam War. After completing his Southeast Asia tour of duty in November 1967, Moorman had assignments in Germany and Massachusetts and earned two master's degrees before accepting, in August 1975, the position of executive officer, then deputy director of plans and programs, Office of Space Systems, Office of the Secretary of the Air Force, Washington, DC. During this four-year tour, he helped draft the national space policies of Presidents Ford and Carter and participated in several Defense Department and Air Force space studies.

In 1979, he was selected as deputy military assistant to the secretary of the Air Force and served two secretaries, the Honorable Hans M. Mark and the Honorable Verne Orr. He was next assigned to the NORAD Command, Cheyenne Mountain Complex, Colorado, as director of space operations. In this position, he was responsible for integration of the worldwide space surveillance network and maintenance of the space catalog.

In March 1982, he became deputy director, space defense, Office of the Deputy Chief of Staff for Plans at Peterson AFB, where he was deeply involved in the planning and organizing for the establishment of Air Force Space Command. While at Peterson, Moorman was named the first director of the Commander's Group and vice commander of the 1st Space Wing, at that time the most global of all Air Force wings.

In March 1985, he became director of space systems, Office of the Secretary of the Air Force. In that capacity, he was director of staff for the NRO and oversaw development of the plan to recover the nation's expendable launch capability in the aftermath of the space shuttle *Challenger* disaster. In October 1987, Moorman became director of Space and Strategic Defense Initiative Programs, Office of the Assistant Secretary of the Air Force for Acquisition at the Pentagon, where he provided program management direction for the development and procurement of Air Force surveillance, communications, navigation and weather satellites, space launch vehicles, antisatellite weapons, and ground-based and airborne strategic radars, communications, and command centers.

As commander and vice commander of Air Force Space Command from 1990 to 1994, Moorman was responsible for operating military space systems, ground-based missile warning radars, the nation's space launch centers at Patrick AFB and Vandenberg AFB, a worldwide network of space surveillance radars and electro-optical cameras, as well as maintaining the intercontinental ballistic missile force. He oversaw the complex transfer of space launch from the R&D community to the operational command. Units under Moorman's command also provided Air Force space support to the coalition forces during Desert Shield and Desert Storm. In 1994, Moorman chaired a congressionally directed study to examine modernization of the country's space launch capabilities. This study identified a number of modernization options and, ultimately, resulted in development and fielding of EELVs.

Moorman began his final military assignment in July 1994, as vice chief of staff, United States Air Force. In that position, he oversaw and managed the day-to-day activities of the Air Staff, chaired the Air Force Council and Air Force Board of Directors, and represented the Air Force in a number of joint and interagency organizations. He retired from active duty on 1 August 1997.

After retirement, General Moorman held important positions in a variety of space-related organizations: trustee of the Falcon Foundation, chairman emeritus of the Space Foundation, member of the Senior Advisory Group of the US Strategic Command, member of the Council of Foreign Relations, and vice chairman of the Board of Trustees of the Aerospace Corporation. General Moorman also received numerous awards for contributions to the nation's and the Air Force's space programs, including the National Geographic Society's General Thomas D. White US Air Force Space Trophy (1991), the National Space Club's Dr. Robert H. Goddard Memorial Trophy (1995), the United States Space Foundation Space Achievement Award (1998), and the Space Foundation's James E. Hill Lifetime Space Achievement Award. In 2016, General Moorman was inducted into the Air Force Space Command Air Force Space and Missile Pioneers Hall of Fame. He died on 18 June 2020.

Elon Reeve Musk

Elon R. Musk—technology entrepreneur, investor, and engineer—was born on 28 June 1971 in Pretoria, Transvaal, South Africa. Graduating with distinction from Pretoria Boys High School in 1988, he spent five months at the University of Pretoria. Then, when documents approving his emigration to Canada arrived, he flew to North America and enrolled at Queen's University in Kingston, Ontario, Canada, in 1989. Musk transferred to the University of Pennsylvania, in 1992, with a full scholarship, and graduated cum laude, in May 1997, with a bachelor's degree in economics from the Wharton School of Business and a second bachelor's degree in physics from the college.

Meanwhile, during the summer of 1994, Musk had held internships with two start-ups in Silicon Valley: Pinnacle Research Institute, which researched electrolytic ultracapacitors for energy storage; and Palo Alto-based Rocket Science Games. The following year, Stanford University had accepted him to begin doctoral studies in applied physics and material sciences, but he deferred entry to pursue an entrepreneurial career. After creating several internet companies, Musk became a US citizen in 2002. In May of that year, he founded Space Exploration Technologies Corporation, more commonly known as SpaceX, to pursue his dream of reducing space transportation costs to achieve the colonization of Mars. Musk realized that his company could build affordable rockets by applying vertical integration, producing most of the launch hardware in-house, and using the modular approach from software engineering. He also believed that a key to making space travel cost-effective would be to develop recoverable, rapidly reusable launch vehicles.

SpaceX launched its initial Falcon 1 rocket in March 2006. The Falcon 1, in September 2008, became the first privately funded, liquid propellant launch vehicle to place a satellite in orbit. In December 2010, SpaceX successfully launched its first Falcon 9 rocket, together with a Dragon spacecraft. Two years later the Dragon became the first commercial spacecraft to dock with the International Space Station. With his Falcon 9 and Falcon 9 Upgrade, Musk asserted that his company could offer medium-to-heavy-lift launches of DOD payloads at much lower prices than United Launch Alliance (ULA) could with

Delta IV or Atlas V EELVs. After a contentious effort to break ULA's 10-year monopoly on EELV-class launches, SpaceX achieved certification of its Falcon 9 in May 2015, its Falcon 9 Upgrade in January 2016, and its Falcon Heavy in June 2019. SpaceX became the first and most successful new competitor for DOD launches, having successfully performed its initial national security mission with the launch, on 1 May 2017, of an NRO satellite on a Falcon 9 Upgrade.

In December 2015, SpaceX had launched its initial Falcon 9 Upgrade mission and, for the first time, landed the first stage booster on solid ground nine minutes after liftoff. On 30 March, a communications satellite became the first payload to fly on a reused first stage, and the first to have its payload fairing remain intact after splashdown and recovery. By the spring of 2020, SpaceX had successfully landed its first stage boosters 54 times.

Musk took special interest in the inaugural flight of his Falcon Heavy on 6 February 2018. The widely publicized flight proved incredibly popular, with over 2.3 million concurrent views of the live webcast showing the launch of Musk's red Tesla electric roadster, with mannequin "Starman" at the steering wheel and wearing SpaceX's latest spacesuit, while the car's sound system looped the symbolic David Bowie songs "Space Oddity" and "Life on Mars?" After placing the payload into its heliocentric Mars-Earth orbit, the two strap-on boosters landed simultaneously on adjacent pads at Cape Canaveral.

Musk continued to focus on launch services and spacecraft support to both DOD and NASA, while envisioning space travel to Mars. In late 2017, he unveiled SpaceX's design for its next-generation launch vehicle and spacecraft system—the Big Falcon Rocket, later renamed Starship—that would support all SpaceX launch-service-provider capabilities with a single set of very large vehicles and would totally replace the Falcon 9, Falcon Heavy, and Dragon vehicles in the 2020s. Starship would have a 30-foot diameter core. Significant development on the vehicles began in 2017, and Musk unveiled an initial prototype in September 2019. Development of Raptor, the new rocket engine, already had begun in 2012, with a first test flight in August 2019.

Elon Musk continued to view space exploration as an important step toward multiplanetary life and consciousness as a hedge against threats to survival of the human species. "When something is important enough," he asserted, "you do it even if the odds are not in your favor."[8] Meanwhile, his SpaceX team continued to secure Air Force contracts to launch national security satellites in the 2020s.

John Louis Piotrowski

Gen John L. Piotrowski, the son of Polish immigrants was born on 17 February 1934 in Detroit, Michigan. He graduated from Henry Ford Trade School, Dearborn, Michigan, in 1951, and enlisted in the US Air Force in September 1952. As his military assignments allowed, he attended Arizona State University and Florida State University, ultimately earning a bachelor of science degree from the University of Nebraska at Omaha in 1965. He did postgraduate work at the University of Southern California and Auburn University and, later, completed Harvard University's program for management development.

After basic training at Lackland AFB, Texas, Piotrowski went to Keesler AFB, Mississippi, to attend courses in basic electronics and ground radar. He transferred, in July 1953, to Harlingen AFB, Texas, for navigator and observer training in the aviation cadet program. After graduating with distinction, in 1954, he was commissioned a second lieutenant and assigned to the 67th Tactical Reconnaissance Wing in South Korea and Japan as an electronic warfare officer and RB-26 navigator.

Piotrowski returned to the United States, in May 1957, for pilot training at Marana Air Base, Arizona; Bainbridge Air Base, Georgia; and Bryan AFB, Texas, followed by F-86F advanced gunnery training at Williams AFB, Arizona, where he was assigned as armament-and-electronics maintenance officer before moving to Luke AFB, Arizona, in the same role. He moved, in May 1961, to Eglin Air Force Auxiliary Field 9, Florida, where he joined the initial cadre of Project Jungle Jim, which became the 1st Air Commando Wing. After serving in Southeast Asia, from November 1961 to May 1963, as a munitions maintenance officer and T-28 and B-26 combat aircrew member, he testified before the US Army's Howze Board on Air Force support of engaged ground forces. He also testified on the reliability and utility of counterinsurgency aircraft before the Senate Armed Services preparedness subcommittee.

After assignments at the Air Force Fighter Weapons School, Nellis AFB, Nevada, and Headquarters US Air Force, Washington, DC, he spent four years honing his operational leadership skills in Europe. In April 1974, Piotrowski returned to the United States to become chief of the Air Force Six-Man Group that advised the chief of staff on force development and employment. He transferred to Keesler AFB, Mississippi, in 1975, to serve as vice commander of the service's Technical Training Center.

Taking command of the reactivated 552nd Airborne Warning and Control Wing at Tinker AFB in July 1976, Piotrowski was instrumental in establishing the E-3A Sentry Airborne Warning and Control System aircraft as an operational weapon system. After assignments at Langley AFB, Virginia, as Tactical Air Command's deputy chief of staff for operations and vice commander, he became 9th Air Force commander at Shaw AFB, South Carolina, in October 1982. Three years later, in July 1985, he was appointed US Air Force vice chief of staff.

On 6 February 1987, Piotrowski began his brief space career, becoming "dual-hatted" as commander in chief of NORAD and US Space Command, with consolidated headquarters at Peterson AFB. As commander in chief of the unified combatant command, Piotrowski sought to focus its mission responsibilities by championing operationally responsive space launch capabilities and future operational payload requirements that would support theater and tactical commanders. His advocacy was instrumental in transferring the Air Force space launch mission from the R&D community to Air Force Space Command.

Piotrowski retired from active duty on 31 March 1990. His decorations included the Defense Distinguished Service Medal, Air Force Distinguished Service Medal, and Legion of Honor. He received the Eugene M. Zuckert Management Award for 1979. On 13 May 2017, he was inducted into the Michigan Aviation Hall of Fame at Kalamazoo, Michigan.

Piotrowski formed Aerospace and Management Consulting, Inc., in 1991, serving as its president and CEO. He continued writing and speaking extensively, however, on space and national security issues and served on numerous defense-related committees and corporate boards. He became an advisor to the Missile Defense Agency and to Sandia, Lawrence Livermore, and Los Alamos national laboratories. He was president of Science Applications International Corporation (SAIC) from 1995 through January 2000, then a consulting employee until retirement in February 2004. He also served as independent director of Semtech Corporation until 2016.

Simon Ramo

Dr. Simon Ramo was born in Salt Lake City, Utah, on 13 May 1913. Ramo earned a bachelor of science degree in electrical engineering at the University of Utah and, at 23, a doctoral degree in electrical engineering and physics at Cal Tech. General Electric (GE) hired him immediately. At GE, he served as section head of the general engineering laboratory and head of the physics section of the electronics research laboratory. As a GE scientist, he attained world recognition as a pioneer in microwave technology and developed GE's electron microscope. In 1946, unhappy about GE's diminishing prospects in high technology and eager to return to California, Ramo joined Hughes Aircraft Company.

At Hughes, Ramo served as the director of research in the electronics department and held the titles of vice president and director of operations. Ramo instituted high technology R&D at the company. Largely because of his work, Hughes received initial contracts from the Air Force for advanced military electronics and for R&D of guided missiles.

In 1953, Ramo and Dean E. Wooldridge, who was codirector of R&D laboratories at Hughes, wished to discuss possible solutions to several management problems with Howard Hughes, but Hughes avoided them. Frustrated, the two resigned from Hughes on Friday, 11 September 1953. By the following Wednesday, they had established Ramo-Wooldridge Corporation and by Friday afternoon had a contract to provide science and engineering analysis to a Defense Department strategic missile planning effort.[9]

The "Teapot Committee" or, as it became known officially, the Strategic Missile Evaluation Committee, provided overall guidance for the USAF's ballistic missile effort. It was established by Trevor Gardner, who invited both Ramo and Wooldridge to serve on this 11-person committee. It concluded that a beginning operational capability in long-range missiles could be attained in six years if the US instituted proper management, allocated sufficient funds and the highest priority to the program, and relaxed missile performance standards. The outcome would be the Air Force's project to develop the ballistic missile; a crash program about twice as big and complex as the Manhattan Project to develop the atomic bomb.

The WDD (later the Ballistic Missile Division) and Ramo-Wooldridge spearheaded the American effort. By December 1957, the two organizations were supervising over 150 first-line contracts. Observers estimated that the Air Force ballistic missile program, in the late 1950s, employed about 2,000 system and subsystem contractors with more than 40,000 personnel. The endeavor not only bested the Soviets in the race to set up the first operational ICBM force but also was remarkably free of major cost overruns, schedule slippages, and waste. The ballistic missile program was one of great urgency and the highest priority.

Ramo left the ballistic missile effort in October 1958; his effective leadership in the program had provided the scientific foundation and forged the essential cooperation between the Air Force and industry necessary to begin the nation's military space program. He helped the United States become the world's leader in space technology and its applications. For his role as the leading civilian in the Air Force's ballistic missile program, the Air Force awarded him a special citation of honor.

After his days in the ballistic missile program, he remained active in business and served as a key advisor to the government on science and technology. He chaired the President's Committee on Science and Technology under President Gerald R. Ford and was co-chair of the Transition Task Force on Science and Technology under President Ronald Reagan. He also was a member of the White House Energy Research and Development Council, the Advisory Committee to the Secretary of State on Science and Foreign Affairs, the Advisory Council to the Secretary of Commerce, and the Roster of Consultants to the Energy Research and Development Administration. In addition, he was a consultant for the White House Office of Science and Technology Policy and a member of the Department of Defense's Advisory Committee on the Strategic Defense Initiative. He cofounded two Fortune 500 companies. One of these was TRW, an enormously successful defense electronics firm that put together the complex systems required for the first American ICBM. The other was Bunker-Ramo, a computer venture; Allied Corporation, now Allied Signal, acquired it in 1981. He also has served on the National Science Board. Dr. Simon Ramo died on 27 June 2016 at the age of 103.

John William Raymond

Gen John W. "Jay" Raymond was born on 30 April 1962 in Monterey County, California, and raised in Alexandria, Virginia. He graduated from South Carolina's Clemson University, in 1984, with a bachelor's degree in administrative management and was commissioned through Air Force ROTC. He later earned a master's degree in administrative management from Central Michigan University (1990) and a second master's degree in national security and strategic studies from the Naval War College (2003).

His initial four-year assignment took him to 321st Strategic Missile Wing, Grand Forks AFB, where he served successively as Minuteman ICBM crew commander, flight commander, instructor crew commander, and missile procedures trainer operator. His long career in the space arena commenced in October 1989, when he transferred to Vandenberg AFB. Assigned to the 1st Strategic Aerospace Division, he later became the first executive officer of the newly established 30th Space Wing. Four years later, he was reassigned to Air Force Space Command headquarters at Peterson AFB, where he served successively as chief of Commercial Space Lift Operations, assistant chief of the Current Operations Branch, and deputy director of the Commander's Action Group.

In June 1997, Raymond transferred to the Air Staff, where he was responsible for Expeditionary Aerospace Force Space and Program Integration in the Expeditionary Aerospace Force Implementation Division. He remained at the Pentagon until April 2000, then transferred to Royal Air Force Feltwell, United Kingdom, to assume command of the 5th Space Surveillance Squadron, whose operational responsibilities focused on the Low Altitude Space Surveillance System and the Deep Space Tracking System. The following spring, Raymond went back to Peterson AFB as deputy commander of the 21st Operations Group. In June 2003, he began a two-year Pentagon assignment as transformation strategist in the Office of Force Transformation. He returned to the operational arena, in June 2005, as commander of the

30th Operations Group at Vandenberg AFB but also served four months as Director of Space Forces at the Combined Air Operations Center in Southwest Asia. Transferred back to Peterson AFB, in June 2007, Raymond took command of the 21st Space Wing, then became director of plans, programs, and analyses at Air Force Space Command headquarters.

From December 2010 to July 2012, Raymond served as 5th Air Force vice commander and 13th Air Force deputy commander, Yokota Air Base, Japan. From Japan, he went to Offutt AFB, Nebraska, as director of plans and policy, US Strategic Command. He returned to Vandenberg AFB, in January 2014, for an eighteen-month assignment as commander of 14th Air Force and commander of US Strategic Command's Joint Functional Component Command for Space. In August 2015, he reported to Air Force headquarters as deputy chief of staff for operations, serving in that position until October 2016, when he was appointed commander of Air Force Space Command. While in that position, Raymond also assumed command of US Space Command (USSPACECOM), newly established on 29 August 2019. With the signing of the National Defense Authorization Act for 2020, Air Force Space Command, a major command of the Air Force since 1982, was redesignated as the United States Space Force (USSF). Shortly thereafter, on 14 January 2020, General Raymond was appointed Chief of Space Operations, USSF, while officially retaining command of USSPACECOM.

General Raymond's awards and honors included the Air Force Distinguished Service Medal with Oak Leaf Cluster, Defense Superior Service Medal with oak leaf cluster, and Legion of Merit with oak leaf cluster. He also received the AFA's General Jerome F. O'Malley Distinguished Space Leadership Award (2007) and its General Thomas D. White Space Award (2015); the NDIA's Peter B. Teets Government Award (2016); and the NDIA Rocky Mountain Chapter's General James V. Hartinger Award (2017).

William Lloyd Richardson

Maj Gen William L. Richardson was born on 14 December 1901 in Saginaw, Michigan. He graduated from high school in Dixon, Michigan, before attending the University of Michigan during 1919–1920. While there, he accepted an appointment to the US Military Academy at West Point, where he graduated on 12 June 1924. His active-duty career began in the Coast Artillery Corps. Assigned to the 63rd Coast Artillery (Antiaircraft) at Fort Winfield Scott, California, he was assigned the additional duty of liaison officer with the Air Corps at Crissy Field, California. He became commanding officer of the US Army mine planter *Colonel Armistead* in June 1925. A year later, he joined the 15th Coast Artillery at Fort Kamehameha, Hawaii, then transferred to the 55th Coast Artillery in August 1926, where he later commanded Headquarters Battery and Battery A.

In September 1930, Richardson entered the Coast Artillery School at Fort Monroe, Virginia, and graduated the following June. He remained at Fort Monroe with the Second Coast Artillery until detailed to the Civilian Conservation Corps in March 1933, where he organized and commanded a camp in Allegheny National Forest near Kane, Pennsylvania. Returning to Fort Monroe that December, he worked on developing antiaircraft materiel and served as liaison officer with the Air Corps at Langley Field, Virginia.

Ordered to the Philippine Islands in May 1936, Richardson joined the Sixth Coast Artillery at Fort Mills and became liaison officer with the Air Corps at Nichols Field. He entered the Command and General Staff School at Fort Leavenworth, Kansas, in September 1938. After graduating in June 1939, he became an instructor in tactics at West Point. Joining the War Department General Staff in June 1941, he was assigned to the Planning Branch of the Operations and Training Division, which developed the Tank Destroyer Force and highly mobile, rapid-fire antiaircraft weapons.

Transferred to England in August 1942, Richardson joined the 8th Air Force staff, where he organized and trained its airdrome defense units before relocating to Fort Bliss, Texas, in March 1943, to organize and train antiaircraft artillery units for overseas duty. Returning to the European Theater in December 1943, Richardson organized and trained the 9th Air Defense Command of the 9th Air Force and planned the air defense operations for the D-Day invasion of the continent.

Two years later, on 1 January 1947, Richardson became chief of Guided Missiles Division & Air Defense Division, Office of the Assistant Chief of the Air Staff for Operations, Headquarters US Army Air Forces, Washington, DC. He transferred to the Air Force on 1 May 1947, and after establishment of US Air Force headquarters that

September, his division was placed under the deputy chief of staff for operations; in November, his division was redesignated the Guided Missiles Group, with Richardson retaining his position as chief. Under his leadership, the Guided Missiles Group assessed the future capabilities of guided missiles in terms of operational characteristics and requirements. In December 1949, he became chief of the Joint Long Range Proving Ground Group in the Office of the Deputy Chief of Staff for Materiel at Air Force headquarters.

In April 1950, Richardson assumed command of the Air Force division of the Joint Long Range Proving Ground base (renamed Patrick AFB on 1 August 1950), located three miles south of Cocoa Beach, Florida. Under his guidance, the envisioned Florida missile test range became a reality. He retained command of the organization when it was redesignated the Long Range Proving Ground Division, in May 1950, and the Air Force Missile Test Center, in July 1951. That October, the Long Range Proving Ground itself was renamed Cape Canaveral Auxiliary AFB. Under Richardson's leadership, the Air Force Missile Test Center and the Cape experienced a period of rapid growth. By the fall of 1952, the Cape had in place four missile launch sites with access roads, missile assembly buildings, and a central cruise missile control station. Richardson also oversaw construction of Port Canaveral, at the Cape's southern end, and completion of seven downrange island instrumentation sites stretching to Puerto Rico.

Richardson retired from active duty on 31 July 1954 and joined the Radio Corporation of America in the newly created post of manager, Defense Projects Coordination for the Engineering Products Division. His military decorations included the Air Force Distinguished Service Medal, Army Design (1954) and Legion of Merit (1945). Among his foreign awards, earned during World War II, were the French Legion of Honor (Chevalier) and Croix de Guerre with palm; the Belgian Order of Leopold II (Commander) and Croix de Guerre with palm; and the Luxembourg Order of Adolph of Nassau and Croix de Guerre. General Richardson died on 21 March 1973.

Robert Alan Rosenberg

Brig Gen Robert A. "Rosie" Rosenberg was born on 16 November 1934 in Kansas City, Missouri. He graduated from Leavenworth High

School in 1953 and entered the US Naval Academy, where he received a bachelor's degree in general engineering in 1957. Because his eyesight had significantly deteriorated, the Navy insisted he would qualify only as a supply officer, "stacking skivvies by the score in the Supply Corps."[10] To improve his chances of better serving the United States, he turned to the academy's Air Force liaison officer and asked if the Air Force would accept him. "Of course," the officer responded, "I'm going to send you to guided-missile school, son, . . . someday the Air Force will be in Space."[11] Cold War events, such as the launch of Sputnik (4 October 1957) and the shoot-down of the American U-2 piloted by Gary Powers (1 May 1960), meant the National Security Space Age became Rosenberg's opportunity of a lifetime.

Rosenberg began his career in June 1957, attending the Guidance System Officer Course at Lowry AFB, Colorado, before heading to Forbes AFB, Kansas, in April 1958 as a flight line maintenance officer in Strategic Air Command's 90th Strategic Reconnaissance Wing. From September 1959 until September 1962, he was assigned to the Air Force Ballistic Missile Division, Vandenberg AFB, where he contributed to initial development, testing, and launch of Atlas-Agena programs, especially Samos and MIDAS satellites. Among the first generation of space launch officers, Rosenberg put his guidance specialty to good use by siting guidance equipment in optimum locations. In one instance, he ignored the Navy's recommended site for establishing a second Atlas launch complex—Space Launch Complex 4—in favor of one he deemed more appropriate.

After earning a master's degree in aerospace engineering in 1964 from the Air Force Institute of Technology, Rosenberg reported for duty at the NRO. He served as mission controller for photographic and signals intelligence satellite operations at the Satellite Test Center. The Gambit reconnaissance satellite program successfully launched 19 of 22 (Program 110) and 35 of 38 (Program 206) missions, for which Rosenberg provided additional target data and improved target-selection software. He served four years as the "targeteer" for intelligence satellite programs. Continuing with the NRO in 1970, he became responsible for the development and acquisition of the advanced-mission-planning and command-and-control software needed to enhance satellite reconnaissance missions, thereby supporting the creation of Hexagon, the next-generation search and surveillance program.

Upon graduation in 1972 from the Industrial College of the Armed Forces, Rosenberg moved to the Air Staff as a division chief under the assistant for research, development, and acquisition programming. Two years later he joined the Office of Space Systems at NRO headquarters, serving successively as deputy director for programs, principal deputy, then acting director for National Reconnaissance Space Programs.

Rosenberg next served on the President's National Security Council staff under both the Ford and Carter administrations. He advocated for the space shuttle program and initial funding for the GPS and became the architect for President Jimmy Carter's National Space Policy.

In March 1980, Rosenberg returned to the Pentagon as assistant chief of staff for studies and analyses, Headquarters US Air Force, supporting the chief of staff, secretary of the Air Force, and other DOD officials with operations research, critical force structure, weapon system tradeoffs, operational and cost effectiveness, efficiency, and utilization questions. From September 1983 to July 1985, he served as NORAD Command vice commander in chief and Air Force Space Command assistant vice commander. Thereafter, Rosenberg became director of the Defense Mapping Agency. During his tenure, product quality improved, which increased situational awareness for warfighters.

Rosenberg retired on 1 October 1987 but continued to play an active civilian role within the national security space community, serving on numerous advisory groups. For his contributions over three decades of national service, he received the Defense Distinguished Service Medal, Air Force Distinguished Service Medal, and Legion of Merit with four oak leaf clusters. Rosenberg also was honored with induction into the National Geospatial Intelligence Hall of Fame (2005), the NAVSTAR GPS Hall of Fame (2014), and the Air Force Space and Missile Pioneers Hall of Fame (2016). On 6 June 2017, he became the thirteenth recipient of the United States Geospatial Intelligence Foundation Arthur C. Lundahl–Thomas C. Finnie Lifetime Award for a "substantial contribution to the art and science of geospatial intelligence."[12]

Robert Walker Roy

Col Robert W. "Rob" Roy was born on 4 May 1928 in Fort Lauderdale, Florida. After attending Pennsylvania State College, he accepted an appointment to the United States Naval Academy and graduated with a bachelor's degree in 1951. Congressionally approved for commissioning as a second lieutenant in the US Air Force on 1 June 1951, he began his active-duty career as a launch control officer with the 6555th Guided Missile Squadron at Patrick AFB, Florida.

From 1952 to 1958, Roy oversaw approximately 50 Matador missile launches—from initial static testing through launch to target impact—at Cape Canaveral. He recognized the need for standardized procedures and equipment to improve mission performance and codesigned an integrated-checkout-equipment prototype for the Matador program. He subsequently did the same while managing other types of early missile and space launches, such as when he served as launch controller on approximately 30 flights of the X-17, a three-stage, solid-propellant rocket used for atmospheric reentry testing of long-range missiles. Before leaving Patrick AFB, Roy also coordinated missile launches for testing MIDAS infrared tracking sensors aboard a B-36 aircraft.

Roy's innovative ideas for improving rocket launch reliability did not go unnoticed by senior Air Force officers. In 1958, they sent him to Vandenberg AFB as chief launch control officer for Space Systems, one of 12 officers—the "Dirty Dozen"—originally assigned to West Coast space and missile launch operations. While there, he oversaw activation of Space Launch Complexes 1, 3, and 4 and managed a total of four complexes (two Thor-Agena and two Atlas-Agena). From those complexes, he controlled more than a dozen of the earliest Thor-Agena Discoverer satellite launches, including those that sent the first human tissue and live mice into orbit. As controller for more than 20 Corona satellite launches on Thor vehicles, Roy established a successful space-based reconnaissance capability. He introduced the concept of "task sequencing" to ensure orderly cross-subsystem checkout between different contractors and the practice of sending spacecraft directly to the launchpad instead of going to the Mission Assembly Building first for testing and assembly. His innovations assured readiness for launches of national security payloads, particularly Corona, MIDAS, and Samos reconnaissance satellites. Roy also trained the first generation of launch controllers, establishing procedures and an operational focus for future launch officers to follow.

Roy earned a master of science degree from the Air Force Institute of Technology in 1965 and was assigned to work with GE, where he oversaw in-plant production of a military satellite operating system and sought ways to improve predictability of launch failures or on-orbit problems. From 1967 to 1970, he served as Strategic Defense Division chief at Air Force Systems Command headquarters, where he managed development planning of radars and warhead destruction systems plus investigated on-orbit warhead platforms. In 1970, his last active-duty move took him to the Armament Development and Test Center (ADTC) at Eglin AFB, where he became deputy commander for procurement and initial acquisition of non-nuclear munitions and, in 1973, deputy commander for armament development. Colonel Roy retired from active duty in 1976.

After retirement Roy became a management consultant for companies such as Goodyear Aircraft Corporation, Motorola Government Electronics, RDM Incorporated, and General Research Corporation (GRC). He later served on GRC's technical staff, where he developed and performed independent cost estimating of ADTC programs. In the 1980s, he taught graduate-level mathematics and systems management at Troy State University in Alabama. In 1986, he founded Decision Sciences Incorporated (DSI), a company offering professional engineering services. Its Air Force Warrior Support System, developed in 2000 for the Air Armament Center, assessed the munitions industry's potential to surge production during warfighting contingencies. Two subsequent DSI programs, the Industrial Base Assessment Tool and the Status Tool Environmental Program, continued to support all facets of industrial base management. At age 90, Roy led DSI's development of modeling tools for improvement and execution of munition programs critical to effective warfighting. In 2018, he was inducted into the Air Force Space and Missile Pioneers Hall of Fame.

John H. W. Rubel

The Honorable John H. Rubel was born on 27 April 1920 in Chicago, Illinois. Four years after his father Harry W. Rubel's death in 1927, he moved with his mother to California, where he graduated from Los Angeles High School and earned an undergraduate degree in engineering with honors from the California Institute of Technology (Caltech) in 1942.

During World War II, Rubel worked on classified defense projects for GE Research Laboratories in Schenectady, New York. At war's end, he returned to California as an engineer for Lockheed Corporation, which he left in 1948 for Hughes Aircraft Company. Eight years later, at the age of 36, he oversaw the avionics business and nearly 20,000 employees, being touted as the "new man" in a *Life* magazine advertisement. His growing national prominence brought him to the Eisenhower administration's attention, where he became Herbert York's Assistant DDR&E at the Pentagon.

With John F. Kennedy's election as president, Rubel became one of the few holdovers from the Eisenhower administration, being elevated to assistant secretary of defense and deputy director of research and engineering and ranking prominently among Secretary of Defense Robert S. McNamara's "whiz kids." Under Rubel's leadership, the government supported spin-stabilized geosynchronous communication satellites, most prominently NASA's *Syncom I* and *Syncom II*, which were developed and manufactured by newly formed Hughes Space and Communications. His sponsorship of geosynchronous communication satellites not only led directly to the creation of the Hughes satellite manufacturing business, but also led to the United States chartering COMSAT Corporation and fostering the broader satellite communications industry.

Although described as "a caustic critic of a military mission in space," Rubel championed the Air Force Titan III space launch vehicle under his Unified Program Concept. His goal was to create standardized workhorse spacecraft and launch vehicles characterized by reliability, simplicity, overall utility, and repetitive use. He called for a space launch vehicle capable of sending 1,500-pound payloads to synchronous equatorial orbit. Under his direction the Air Force produced the heavy-lift, standardized Titan III workhorse booster that compelled Secretary of Defense McNamara to declare the Titan III the best managed program in the Department of Defense. Rubel's concept of space vehicle standardization also included the existing medium launch vehicles, Atlas and Thor, along with their Agena and Centaur upper stages.

After his departure from the Pentagon in 1963, Rubel joined Litton Industries as a senior vice president and, over a 10-year period, designed the world's first automated shipyard at Pascagoula, Mississippi. Using serial production methods, that shipyard produced large ships, including a fleet of five landing helicopter assault (LHA) ships designed under Rubel's leadership. He worked with an amazing group of engineers and Navy personnel to write a 25,000-word book on the LHA ships, with the caveat that no one could edit or change a single word. From the 1970s onward, the shipyard produced the majority of the US Navy's surface warships.

After his decade with Litton Industries, Rubel moved to Tesuque, New Mexico, and earned a master's degree in liberal arts from St. John's College. In 1984, he settled in Santa Fe, New Mexico, where he published numerous books, including an impressive, three-volume set of his memoirs and a collection of poetry. John Rubel died on 13 January 2015.

Bernard A. Schriever

Gen Bernard A. Schriever was born in Bremen, Germany, on 14 September 1910. His family migrated to the United States in 1917 and settled in Texas. He graduated from Texas A&M in 1931, earning a bachelor of science degree in architectural engineering. In June 1932, he entered the Army Air Corps Flying School, graduating in June 1933. He served on active duty from July 1933 until April 1935. On 1 October 1938, he passed the Air Corps examination for commission as a Regular second lieutenant and took an assignment in the Air Corps as a B-18 instrument-flying instructor with the 7th Bombardment Group at Hamilton Field, California. In June 1942, he earned a master's degree in aeronautical engineering from Stanford University.

By the end of World War II, he had advanced to colonel and was commander of the Advanced Headquarters, Far East Air Service Command.

In January 1946, he was assigned to the Pentagon as Chief of the Scientific Liaison Branch in the Office of the Deputy Chief of Staff for Materiel. From July 1950 until May 1954, he served in various development and planning offices. In March 1953, Schriever learned of a scientific breakthrough that appeared to make the ICBM technically feasible much sooner than previously thought possible. At a meeting of the SAB, Dr. Edward Teller, who championed the development of hydrogen weapons, reported on the successful test of a hydrogen device in November 1952. The United States could now build less powerful missiles because of the lighter warheads and could relax the accuracy of missiles because of the warhead's greater destructive power.

In early 1954, President Dwight David Eisenhower assigned the nation's highest priority to the development of an ICBM. Trevor Gardner, special assistant secretary of the Air Force for R&D, asked Schriever, now a brigadier general, to manage the ICBM program. Defense Department officials accorded his office extraordinary authority to streamline review and approval procedures, thus eliminating cumbersome red tape. In June 1954, Schriever became the commander of the ARDC's WDD in Inglewood, California, and the assistant to the commander of ARDC. The progression of the Thor IRBM from program approval to the initial operational capability had taken only three and one-half years. Atlas's development time was little more than five years, better than the 1954 prediction of six to eight years—which at the time was thought optimistic. Titan took less than six years to reach operational status. Moreover, even as the first Titan lifted off from Cape Canaveral, the Air Force was developing the more advanced Titan II. The Minuteman, whose development Schriever began, from start to finish took only four years and eight months to deploy. The first 10 were combat alert in their underground silos in October 1962.

On the space side, the Air Force launched *Discoverer 1* on 28 February 1959, though it tumbled in orbit. *Discoverer 2*, launched 13 April 1959, performed well. On 26 February 1960, *MIDAS 1*, an infrared satellite, blew up during stage separation, but in late May 1960, *MIDAS 2* lifted successfully into orbit. *Samos 2*, a photoreconnaissance satellite, began a fully successful mission on 31 January 1961.

In February 1958, Schriever became deputy commander for ballistic missiles at ARDC for three short months. In April 1959, he became commander of ARDC. When ARDC became Air Force Systems Command (AFSC) in April 1961, he assumed its command, where he remained until his retirement on 1 August 1966. As commander of AFSC, Schriever was responsible for the development of all Air Force weapons. In partnership with NASA, he began transforming his missiles into reliable manned launch systems. He supported NASA's manned space programs by providing modified Atlas and Titan boosters and launch services at Cape Canaveral.

After his retirement, Schriever established a consortium called Urban Systems Associates Inc. to mount an interdisciplinary attack on urban problems. He also consulted with civilian organizations and frequently served as an advisor to the Air Force and the Department of Defense. General Schriever died on 20 June 2005.

Thomas Doukas Taverney

Maj Gen Thomas D. "Tav" Taverney was born on 3 April 1946 in New York City, New York. A graduate, in 1963, from Dickinson High School in Jersey City, New Jersey, he matriculated at the United States Air Force Academy in Colorado Springs, Colorado, graduating with a bachelor's degree in engineering science in 1968. Eight years later, in 1976, he earned a master's degree in systems management from the University of Southern California.

In Taverney's first active-duty space assignment, with the Office of Development Plans, Space and Missile Systems Organization at Los Angeles AFB, he developed and demonstrated a new guidance approach that enabled the miniature homing vehicle to function successfully as a prototype missile interceptor. For that accomplishment, he received the Air Force Scientific Achievement Award in 1969. Soon thereafter, in 1970, he designed the first Air Force Airborne Anti-Satellite (ASAT) system, which the Air Force ultimately developed as the ASM-135 ASAT system and successfully validated in a September 1985 test flight.

Taverney transferred to the Air Force Satellite Control Facility at Sunnyvale Air Force Station, California, in 1972, where he served as a satellite command engineer and shift supervisor. In those roles, his team employed innovative techniques to mitigate two potentially major satellite failures, thereby ensuring the continuation of critical satellite operations.

Returning to Los Angeles AFB in August 1976, Taverney served as director of Operations and, later, director of Launch Guidance with the Secretary of the Air Force Office for Special Projects. When unexplained, intermittent failures in the Titan radio-controlled ascent guidance system grounded the Titan Space Launch System, Taverney and his team solved a major system design problem by developing test procedures to validate guidance system readiness and, consequently, enable resumption of Titan launches. His team significantly reduced the downtime of the Titan launch system from an expected six months to merely seven days. During that same period, Taverney led an effort to build multiple trajectories and redundant ground systems that resulted in an outstanding record of 41 successful radio-guided Titan launches in a row.

Taverney transitioned to the Air Force Reserve in 1979 and continued in the space industry as a civilian. In his Air Force Reserve capacity over the next 17 years, he occupied various leadership positions at Los Angeles AFB, including manager, Portable Mobile Command and Control, Satellite Range Launch and Control System Program Office; manager, Strategic Planning for Future Launch Systems; director, Ground Processing and Ascent Guidance and Control; and manager, Development Planning, Advanced Launch system, National Launch System.

In 1996, Taverney led an independent review of the Advanced Research and Global Observation Satellite (ARGOS) program before serving as mobilization assistant to a series of increasingly higher-ranking commanders: the space test and evaluation director at Kirtland AFB, New Mexico; the Space and Missile Systems Center commander at Los Angeles AFB; and, from November 2001 to March 2006, at Peterson AFB, the Air Force Space Command (AFSPC) commander, to whom he provided technical and managerial support for global military space operations.

In November 2001, during Operations Noble Eagle and Enduring Freedom, Taverney returned to active duty to assure the last Titans launched successfully and the EELV achieved operational capability. From March to October 2006, he served as AFSPC vice commander. He represented AFSPC on the Moorman Commission, tasked with assessing reorganization of America's national security space community to achieve better emphasis on future national security space efforts. Taverney helped the command navigate significant Air Force personnel and budget cuts to ensure national security space capabilities were not severely affected. He retired from military service on 1 October 2006.

Although retired, Taverney continued to play an active role in the space industry, particularly as it related to national security space missions. In 2013, he completed the "Battlefield to Boardroom" course, an exclusive board development program sponsored by the National Academy of Corporate Directors and designed to prepare retired or soon-to-retire military flag and general officers to serve in the boardroom. Taverney served on the SMC Advisory Group, the AFSPC Independent Strategic Advisory Group, and the Director of National Intelligence Acquisition Advisory Group. During 2006–2009, he was governance chair of the board for the California Space Authority. He participated in the 2010 Broad Area Review that assessed, for the secretary of the Air Force, the current space launch program's health and, beginning in 2012, joined the Air Force New Entrant Assessment Team to judge the readiness of new competitors to launch national security space payloads. Taverney also provided insightful contributions to space-related publications and online internet sites.

After entering Air Force Reserve status, Taverney held several important industrial positions, beginning in 1979–1980 as program manager and director of the advanced satellite design group at Rockwell International. Becoming one of the three founders, in 1979, of Infotec Development Inc., he joined its senior managerial ranks as vice president of engineering in 1980 and rose to president of the regional systems before leaving to join Titan, which underwent a series of three mergers during 1996–2001 to become Pacer Infotech Incorporated. Taverney next became a senior vice president, in 2001, with SAIC, later named Leidos, where he led the groundbreaking Commercially Hosted Infrared Payload Program.

Taverney's military decorations included the Air Force Distinguished Service Medal and Legion of Merit. He was recognized in *Who's Who in Aviation* (1972), honored with the AFA Gen Bernard A. Schriever Fellowship (2006), was inducted into the Space Operations Hall of Fame (2010), received the Aviation Week Program Management Excellence Award (2012) and NASA's Stellar Award (2013), and was recognized by AFA Chapter 147, in Los Angeles, with the Gen Bernard A. Schriever National Space Leadership Award (2014). Major General Taverney was inducted, in 2016, into the Air

Force Space and Missile Pioneers Hall of Fame and in September 2018 was given the American Institute of Aeronautics and Astronautics von Braun Award for Excellence in Space Program Management.

Robert Collins Truax

Cdr Robert C. "Bob" Truax was born on 3 September 1917 in Gary, Indiana. His fascination with rockets and spaceflight grew after reading about Robert Goddard's work in magazines like *Popular Mechanics*. After graduating from high school in California in 1933, he matriculated to the University of California–Berkeley and, in 1936, won an appointment to the United States Naval Academy at Annapolis, Maryland, where he began experimenting with liquid-propellant rocket engines and built several small experimental models that burned a combination of compressed air and gasoline. In 1938, he showed one of the thrust chambers he had built and tested to members of the British Interplanetary Society. Although the American Rocket Society published his technical reports, they went largely unnoticed.

During the early 1940s, Truax set up the Bureau of Aeronautics (BuAer) Project TED 3401 and initiated a program to develop liquid-propellant, jet-assisted takeoff (JATO) rockets for the PBY-2 Catalina. He and Dr. Robert Goddard, who was under contract with BuAer, led engineering teams that worked side by side for approximately a year on different JATO designs. Confronted with the requirement for a unit that either could be restarted or idled, Truax worked on controls and propellant-feed systems, leading to a design that employed the pathbreaking, hypergolic combination of red fuming nitric acid and aniline. During the late 1940s, he organized the US Naval Missile Test Center's propulsion laboratory at Point Mugu, California, and headed rocket development within BuAer. He also conceived and organized the US Naval Rocket Test Center at Lake Denmark, New Jersey. By 1955, however, his proposal for a submarine fleet equipped to launch long-range, nuclear missiles had failed to win Navy approval. Consequently, when assistant secretary of the Air Force Trevor Gardner offered him a position in the Air Force's newly established WDD, he accepted. Not long after, the Navy reversed itself and initiated the Polaris submarine-launched ballistic missile program, for which Truax later received proper recognition.

After promising Brig Gen Bernard A. Schriever that he would not be a Navy "spy" amid Air Force personnel, Truax headed the Thor IRBM development program. He was instrumental in selecting the vehicle configuration and writing the original request for proposal, which led to Douglas Aircraft Corporation receiving the Thor production contract. A longtime member of the American Rocket Society (serving as its president in 1957) and a staunch advocate of space exploration, Truax volunteered to manage the Air Force's satellite program and oversee its transfer from Wright Field, Ohio, to the West Coast. He led efforts to formulate a development plan and obtain expanded funding for the WS-117L satellite program that led to Discoverer/Corona, Samos, and MIDAS.

In the spring of 1956, Truax arrived at WDD and helped select Point Arguello as a location for launching polar-orbiting satellites; he continued to champion Air Force launch efforts there even after being reassigned to the ARPA in Washington, DC, in May 1958.

Truax retired from active duty in June 1959 and then headed Aerojet General Corporation's Advanced Developments Division in Sacramento, California, where he proposed a massive, sea-launched rocket called Sea Dragon and performed early, scaled-down testing. He formed Truax Engineering Inc. in 1966 and participated in several important space- and missile-related efforts during the late 1960s, including a recoverable launch vehicle study, sponsored by the American Institute of Aeronautics and Astronautics (1966); the STRAT-X study of future ballistic missile problems, sponsored by the Institute for Defense Analyses (1966–1967); and troubleshooting on the Minuteman ICBM program (1967–1968), sponsored by TRW Corporation. An ardent proponent of low-cost access to space since the 1950s, Truax undertook "Project Private Enterprise" in the late 1970s through the early 1990s, aspiring to build a rocket without any government funding and launch the world's first "private" astronaut into suborbital space. During the late 1980s into the 1990s, he designed the Excalibur rocket for placing 55 metric tons into low Earth orbit and obtained Navy funding to design and test what he dubbed a sea-launched rocket. Commander Truax died on 17 September 2010.

John von Neumann

Dr. John von Neumann was born on 28 December 1903 in Budapest, Hungary. He graduated from the Swiss Federal Institute of Technology with a degree in chemical engineering in 1925. The following year he earned a doctorate in mathematics from the University of Budapest. He subsequently taught at the University of Berlin until 1930, when Princeton University invited him to lecture on mathematical physics. While at Princeton, the founders of the newly created Institute for Advanced Study asked him to accept a chair in mathematics, which he did in 1933. He became a United States citizen in 1937. In 1943, von Neumann began working on the Manhattan Project, where he tackled the immense calculations and formulas required for construction of an atomic bomb. Faced with that daunting task, he became interested in using machines for complicated numerical calculations and resolution of specific mathematical problems. During and after the war, von Neumann's interest in computers grew, and he contributed extensively to the construction of the first modern computers.

In 1953, Trevor Gardner asked him to chair a series of Air Force advisory groups in the fields of missile technology and nuclear physics. In June, the panel met in Los Alamos, New Mexico, to discuss the plausibility of mounting nuclear weapons on ICBMs. The panel determined a hydrogen bomb of 3,000 or fewer pounds could retain an explosive power of two megatons and easily destroy everything within a range of 3.2 to 4.5 miles. The panel's findings excited military and political officials and provided an impetus for further missile R&D.

Later in 1953, Gardner created the Air Force Strategic Missiles Evaluation Committee, commonly known as the "Teapot Committee." Under von Neumann's direction, the committee evaluated the Snark, Navaho, and Atlas strategic missile programs. The committee made recommendations to improve all three missiles but preferred the Atlas ICBM to the others, believing the Atlas missile to have the best reliability and least vulnerability of the three. The Teapot Committee provided an additional impetus for the Atlas program when they expressed concern about Soviet advances in missile technology. With intelligence received from German scientists released by the Soviets after 1951 and other intelligence sources within the government, the committee members believed the Russians were several years ahead of the United States in missile development. Von Neumann predicted that by the late 1950s the Soviets would have an operational ICBM and improved technology capable of defeating US strategic bombers. At its current rate of development, the Atlas missile program was scheduled for operational duty in the early 1960s. To forestall a "missile gap" and catch up to the Soviet missile program, the committee members decided the Air Force needed an organization of specialists dedicated to overseeing the construction of the Atlas missile. As a direct result of committee recommendations, the Air Force created the WDD under Brig Gen Bernard A. Schriever. The WDD assigned highest priority to Atlas research and worked closely with the Ramo-Wooldridge Corporation to ensure a coordinated, expeditious effort in developing the missile.

To retain Teapot Committee expertise, Gardner asked von Neumann to chair the Atlas (later ICBM) Scientific Advisory Committee in 1954. The new committee acquired the task of monitoring and accelerating Atlas missile development. To accomplish this, they attracted talented scientists and engineers to the program. Over the next few years, the committee provided technical advice to all the military branches and the Office of the Secretary of Defense.

Under von Neumann's direction, the ICBM Scientific Advisory Committee spearheaded significant advancements in the Air Force missile program. They suggested developing a backup ICBM for Atlas that eventually became the Titan ICBM program. In 1955, the committee discussed the possibility of developing an IRBM. At first, the Air Force was reluctant to start an IRBM program because it might delay the construction of the Atlas missile. The committee, however, convinced the Air Force that IRBM technology could fall out of the new Titan program and Atlas could remain a separate entity. After reviewing the committee's proposal, the Air Force initiated the Thor IRBM program. That same year President Eisenhower appointed him to the Atomic Energy Commission (AEC), and in 1956 the AEC awarded him the Enrico Fermi Award for his work in the field of nuclear science.

Dr. von Neumann continued his work on projects in both the civilian and military sectors until his death from cancer on 8 February 1957.

Victor William Whitehead

Col Victor W. Whitehead was born on 10 October 1939 in Greenwood, Mississippi. He earned a bachelor's degree in 1961 and a master's degree the following year, both in aeronautical engineering, from Mississippi State University in Starkville. He began his Air Force space career with a four-year assignment at the 6555th Aerospace Test Wing at Cape Canaveral Air Force Station, Florida. There, in his role as assistant Atlas project officer, he participated in the preparation and launch of Atlas space launch vehicles for Project Mercury's *Sigma 7* and *Faith 7* missions and for Project Ranger's sixth flight to photograph the moon. Then, Whitehead served as Agena Project Officer for three launches of Vela Hotel nuclear detection spacecraft and as Gemini Agena Target Vehicle Project Officer for the first three launches of NASA's Gemini Rendezvous Program.

In 1966, Whitehead transferred to Wright-Patterson AFB, Ohio, where he attended the Air Force Institute of Technology, earning a second master's degree in 1968 in aerospace engineering. Remaining at Wright-Patterson, he worked in the Ramjet Technology Division of the Air Force Aeropropulsion Laboratory, where he supervised testing and certification of the hypersonic shock tunnel to allow ramjet engine testing at speeds of Mach 8-12.

In 1969, he became Titan IIIB Program Manager at the SMC, Los Angeles AFB. During that six-year assignment, Whitehead managed all aspects of the procurement, performance upgrade, and launch of the Titan IIIB, which achieved a perfect record of 24 successful launches from Vandenberg AFB. In 1975, Whitehead joined Headquarters, Air Force Systems Command at Andrews AFB. As chief of the Directorate of Space and Ballistic Missiles, he became responsible for space-related programs, such as ELVs, DOD's participation in the space shuttle, Minuteman ICBMs, and the Advanced Ballistic Reentry System.

Whitehead transferred to the Pentagon in 1979 to become PEM for all DOD space launch systems, with responsibility for planning, budgeting, and preparing congressional testimony. In 1983, he chaired the USAF Space Panel and served as chief of the Space Launch and Control Division. In the latter role, he oversaw all DOD ELVs, the DOD space shuttle program, the Air Force Satellite Control Facility, the DOD Space Test Program, and the Defense Meteorological Satellite Program.

In 1983, Whitehead returned for his final active-duty assignment to SMC in Los Angeles, where he was program director for all Air Force expendable launch vehicles—Thor, Atlas, Titan 34D, Titan II, Titan IV, and Scout—and deputy assistant commander for launch systems. In the latter role, he managed the program directors for medium and heavy-lift launch vehicles. Most importantly, he worked directly with Air Force Secretary Edward C. "Pete" Aldrich to implement the "mixed fleet" program to provide ELV as a backup to the space shuttle. Under Aldridge's direction, Whitehead initiated the Titan II, Titan IV, Atlas II, and Delta II space launch vehicle programs. Colonel Whitehead retired from active duty on 30 April 1988.

Ten days after retiring, Whitehead joined Martin Marietta Commercial Titan Inc. (later part of Lockheed Martin) in Denver, Colorado, rising rapidly from director of Titan Acquisition Management to Titan Centaur program manager, then vice president for Space Launch Systems. After leaving Lockheed Martin in 1999, Whitehead consulted for aerospace corporations on space launch and satellite systems. In 2019, he served as a member of the Mission Integration Group advising the NRO and led the Independent Review Team supporting ULA.

Donald Norton Yates

Lt Gen Donald N. Yates was born on 25 November 1909 in Bangor, Maine. After graduating from Bangor High School in 1927, he attended the US Military Academy, graduated in 1931, and went to the Air Corps Flying School at Kelly Field, Texas, where he received his pilot's wings in 1932. For the next six years, he served in various flying assignments in Hawaii and at Brooks Field, Texas. In June 1938, he became a graduate student at Caltech and received a master's degree in meteorology the following year. He went from Caltech to Barksdale Field, Louisiana, where he became executive officer in the Sixth Air Base Group, rising to its commander and, finally, post operations officer. In December 1941, Yates served as assistant chief of the weather section in the operations division of the Office, Chief of the Army Air Corps, then was appointed deputy director of weather at Army Air Forces headquarters in March 1942.

From May to December 1942, Yates lived in the Soviet Union, where he served as a member of a military mission that coordinated weather matters. Then, in February 1944, he became weather service director for the US Strategic Air Forces in Europe and served on Gen Dwight D. Eisenhower's staff. For his participation in selecting 6 June 1944 as D-Day for the Normandy invasion, he was decorated by three governments.

Returning to the United States in January 1945, Yates became chief of the weather division—later part of the Air Weather Service—which he commanded at Andrews AFB. On 17 March 1947, he flew the first scheduled weather reconnaissance mission over the North Pole. In July 1950, Yates was appointed assistant deputy chief of staff for development at Headquarters, US Air Force and became director of research and development the following April.

From 31 July 1954 to 4 May 1960, Yates commanded the Air Force Missile Test Center at Patrick AFB. During that tour, he received the Navy Legion of Merit for supporting the Navy's Vanguard and Polaris programs and the Army Legion of Merit for advancing the development of the Redstone, Jupiter, and Pershing missiles, plus the Explorer satellites. He also played an instrumental role in developing Air Force cruise missile programs and transitioning to ballistic missile and space launch testing and operations. On 10 August 1959, Yates was designated DOD representative for Mercury support operations. A month later, he established the Mercury Project Office (Range) to perform liaison functions between Test Center and NASA officials. Under his leadership, the Air Force provided extensive resources and range support to NASA for its operations at Cape Canaveral.

On 4 May 1960 Yates became deputy director of defense research and engineering (Ranges and Space Ground Support), Office of the Secretary of Defense, Washington, DC, before retiring on 31 March 1961. Yates was awarded the Croix de Guerre with Palm "for exceptional war services rendered in the course of operations for the liberation of France"; Honorary Officer in the Most Excellent Order of the British Empire; and a decoration as Grande Oficial de Ordem Militar de Cristo of Portugal. After retiring from active duty, Yates joined Raytheon Corporation in Lowell, Massachusetts, where he rose to become executive vice president. He also served on numerous advisory organizations and as president of the American Meteorological Society. General Yates died on 28 August 1993.

Notes

1. The other three "Gang" members were Lt Gen Otto J. Glasser, Maj Paul L. Maret, and Lt Col Beryl L. Boatman. Schweibert, "USAF's Ballistic Missiles, 1954–1964," 97.
2. Air Force Space Command, "Dr. Benjamin Paul Blasingame, Inducted 2009," AFSPC.mil, [n.d.], https://www.afspc.af.mil/.
3. US Air Force, "Major General Joseph S. Bleymaier," AF.mil, 1 February 1968, https://www.af.mil/.
4. Spires, *On Alert*, 7.
5. Spires.
6. Spires, *On Alert*, 16.
7. The other three "Gang" members were Dr Benjamin P. Blasingame, Maj Paul L. Maret, and Lt Col Beryl L. Boatman. Schweibert, "USAF's Ballistic Missiles, 1954–1964," 97.
8. Scott Pelley, "U.S., China, Russia, Elon Musk: Entrepreneur's 'Insane' Vision Becomes Reality," *CBS Evening News*, 22 May 2012, https://www.cbsnews.com/.
9. Spires, *On Alert*, 23.
10. Air Force Space Command, "Major General Robert A. 'Rose' Rosenberg Inducted 2016," AFSPC.mil, https://www.afspc.af.mil/.
11. Rosenberg, email, 3 March 2017.
12. United States Geospatial Intelligence Foundation, "USGIF Names Maj Gen (Ret.) Robert A. Rosenberg Recipient of Foundation's Lifetime Achievement Award," USGIF.org, 6 July 2017, https://usgif.org/.

Appendix B

Additional Figures and Tables

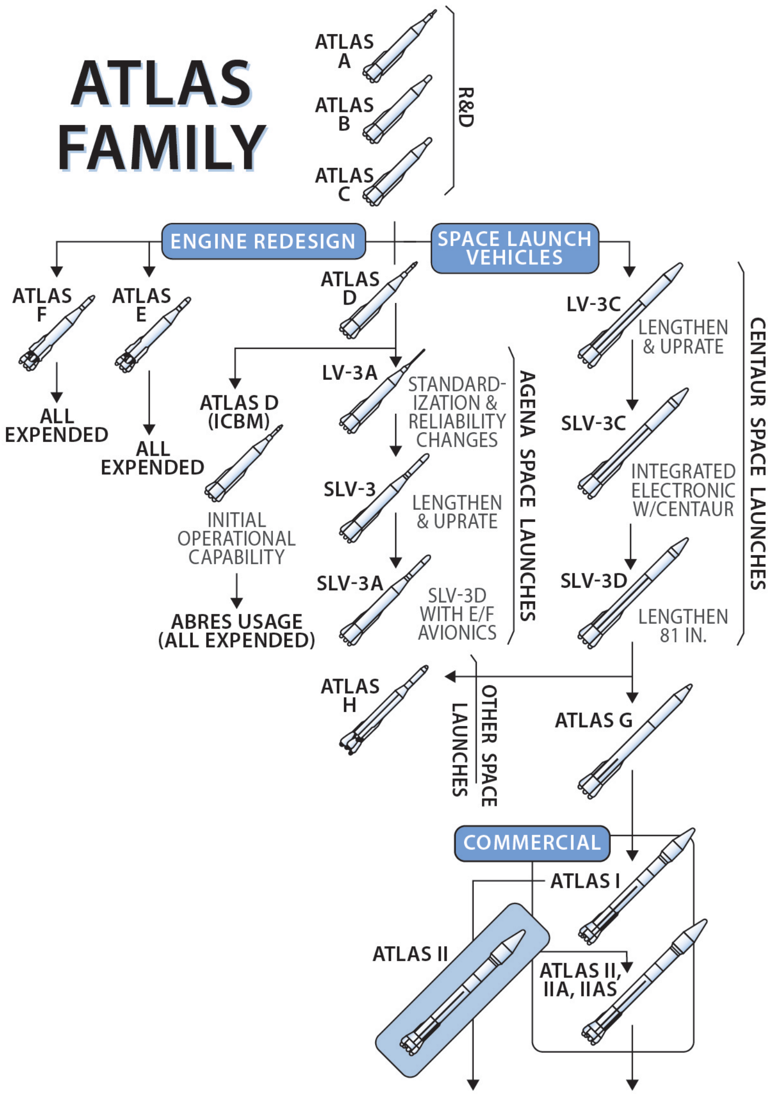


Fig. B.1. The Atlas family tree, from inception to 1972. (Adapted from ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present*, ANSER Space Analysis Division, SADN 97-2 [Arlington, VA: ANSER Space Analysis Division, 1997], B-2.)

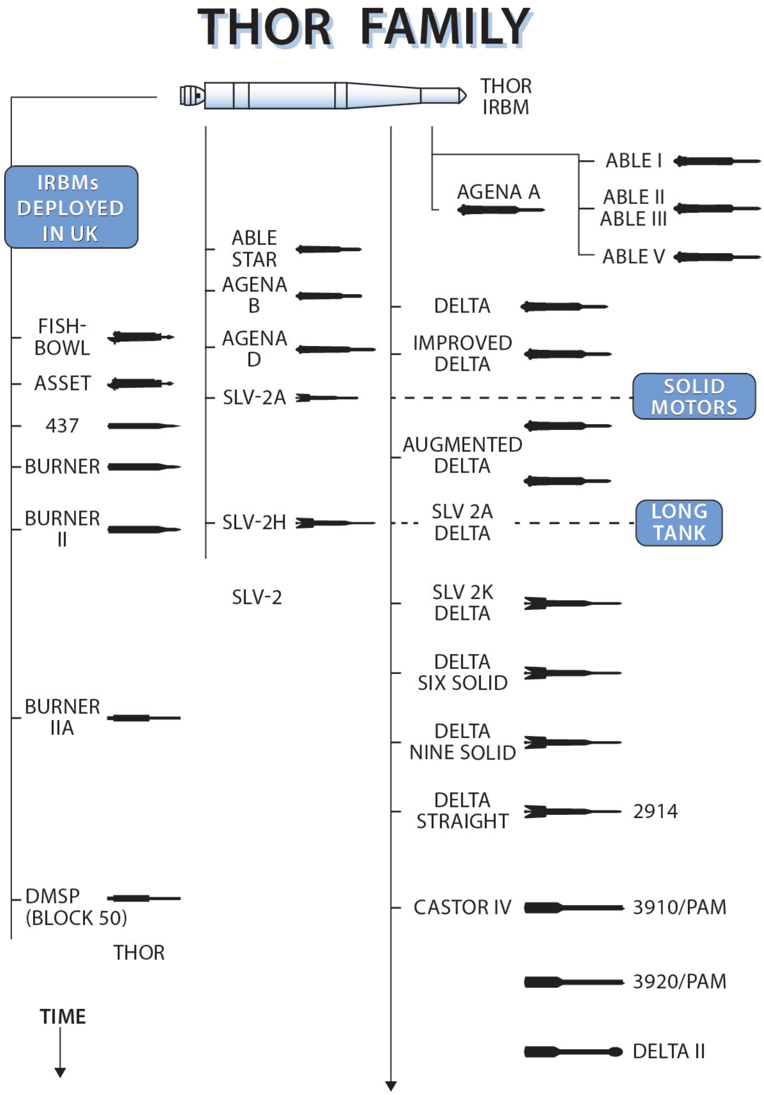


Fig. B.2. Evolution of the Thor space booster. (Adapted from ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present*, ANSER Space Analysis Division, SADN 97-2 [Arlington, VA: ANSER Space Analysis Division, 1997], A-4.)

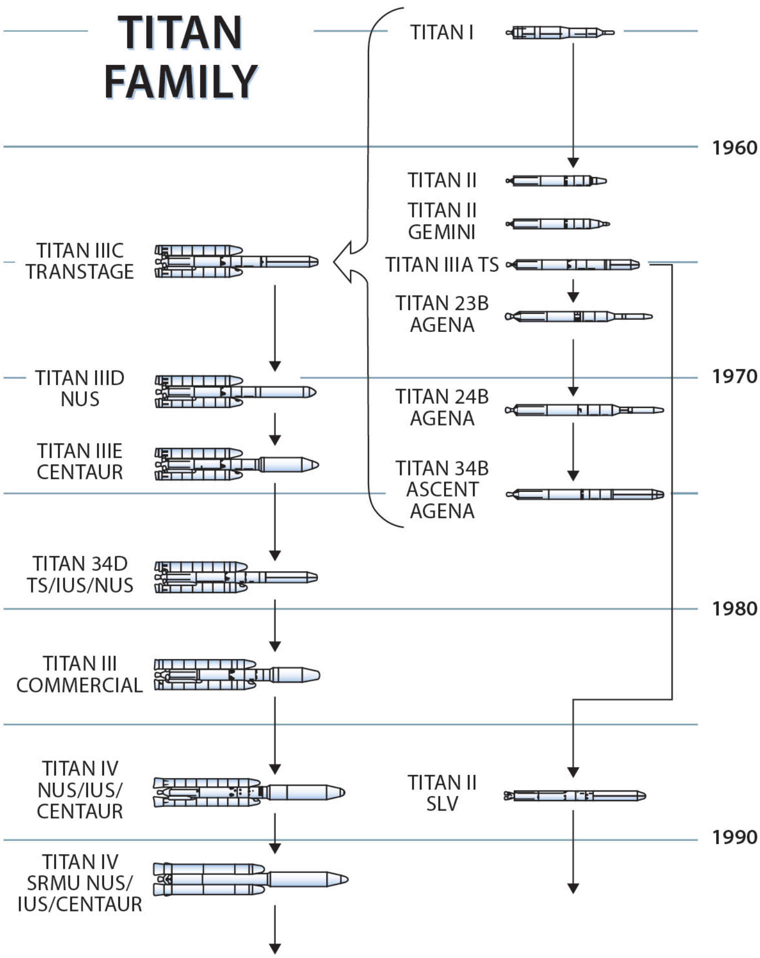


Fig. B.3. The Titan series heritage. (Adapted from ANSER, *A Historical Look at United States Launch Vehicles, 1967–Present*, ANSER Space Analysis Division, SADN 97-2 [Arlington, VA: ANSER Space Analysis Division, 1997], C-2.)

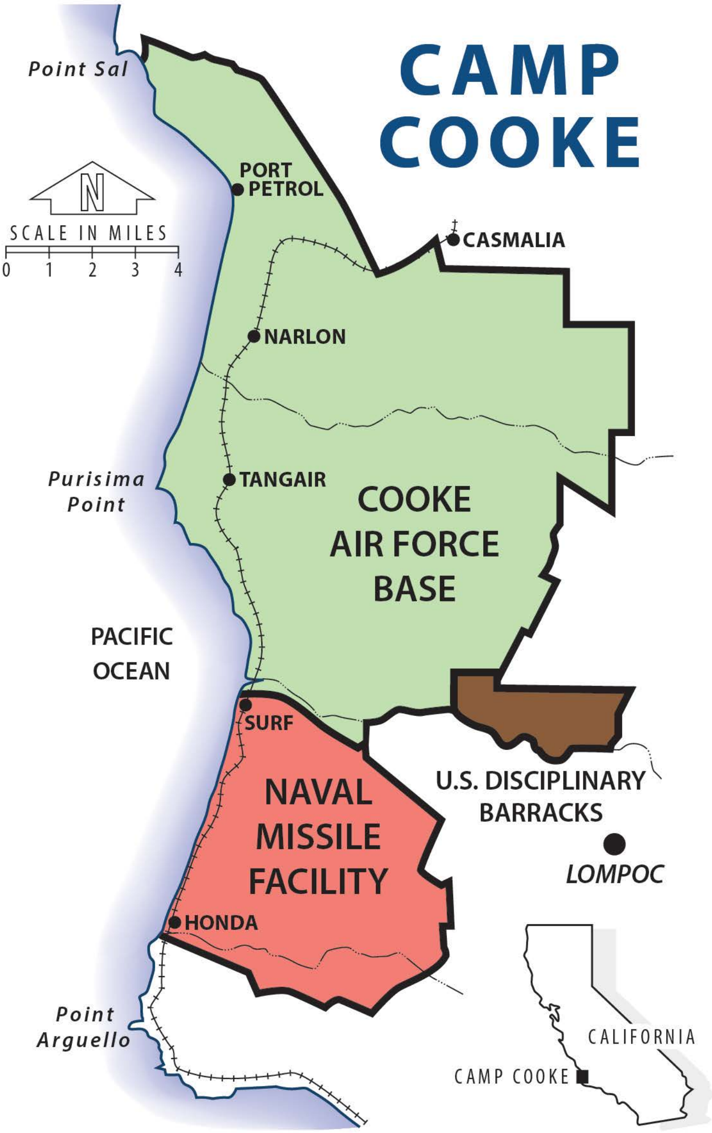


Fig. B.4. Map of Camp Cooke, 1958. (Adapted from Jeffrey E. Geiger, "The Heritage of the 30th Space Wing and Vandenberg Air Force Base" [Vandenberg AFB, CA: 30th SW/HO, 1995], 23.)

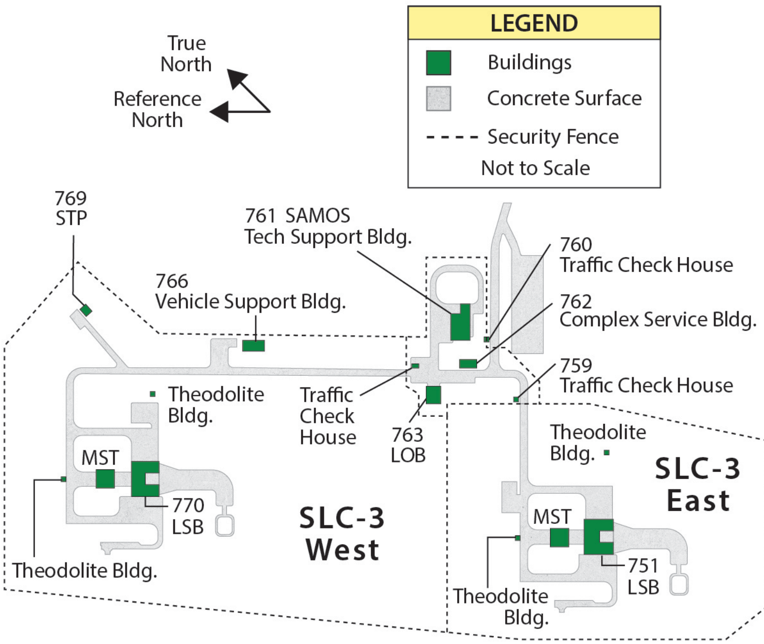


Fig. B.5. Space Launch Complex (SLC)-3, shown in a 1959 configuration. (Adapted from Historic American Engineering Record, National Park Service, Vandenberg Air Force Base, Space Launch Complex 3 [SLC-3], HAER No. CA-133-1 [San Francisco, CA: Historic American Engineering Record, National Park Service, Western Region, March 1993], 64.)

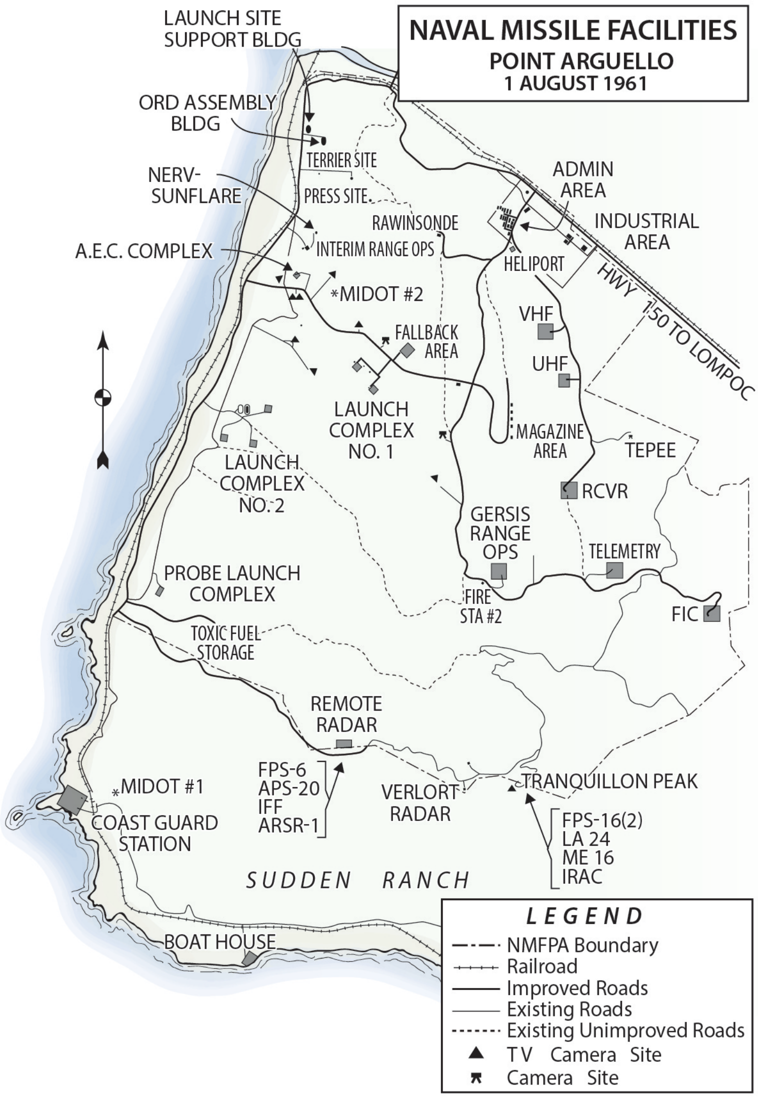


Fig. B.6. Map of Naval Missile Facilities, Point Arguello, August 1961. (Adapted from Naval Missile Facility, Pacific Missile Range, *Command History 1961, An Historical Report*, 1961, iii.)

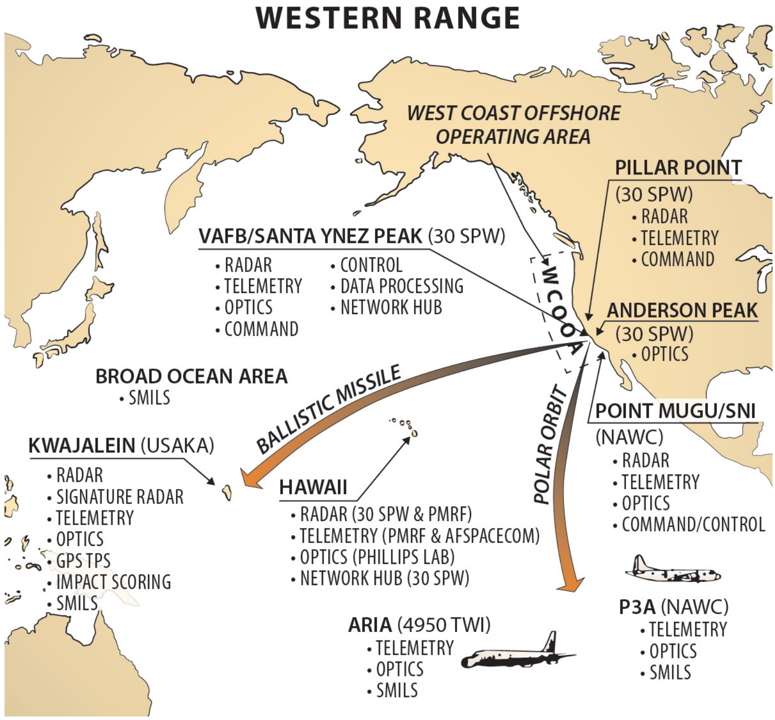


Fig. B.7. Chart of Western Test Range. (Adapted from Jeffrey E. Geiger, "The Heritage of the 30th Space Wing and Vandenberg Air Force Base" [Vandenberg AFB, CA: 30th SW/HO, 1995], 26.)

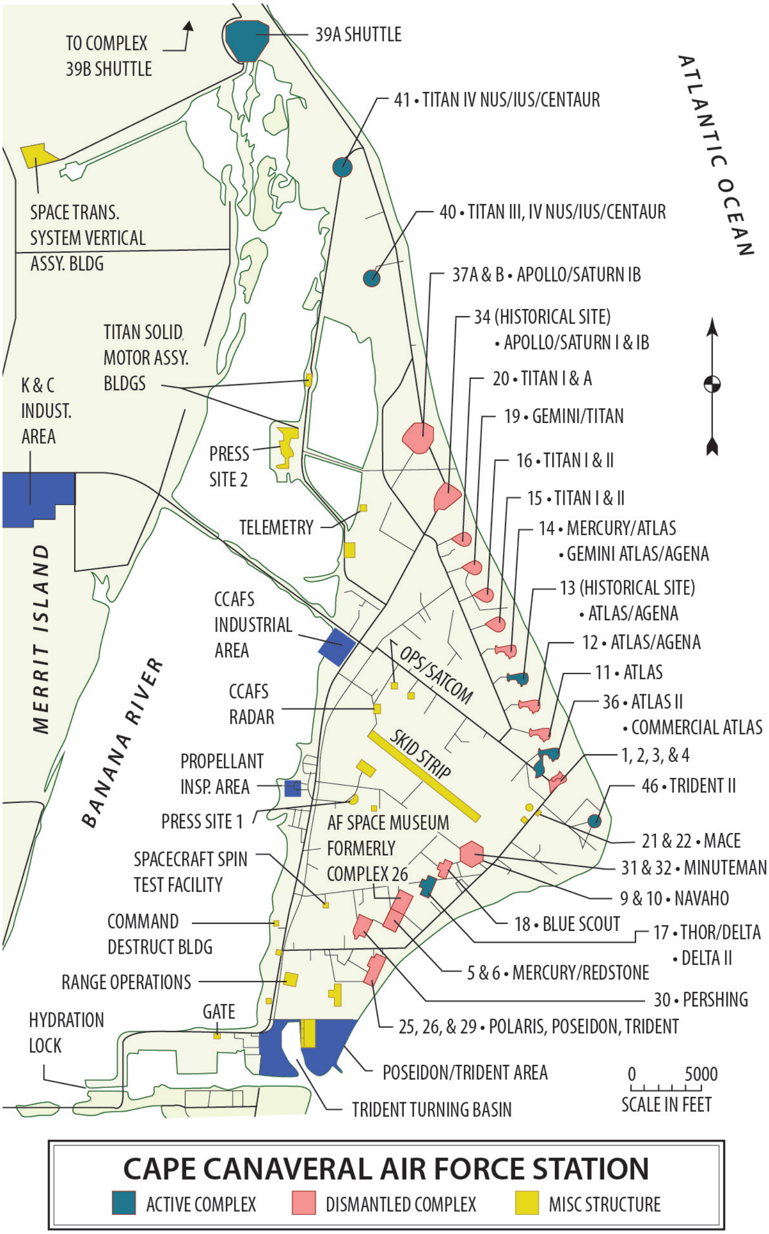
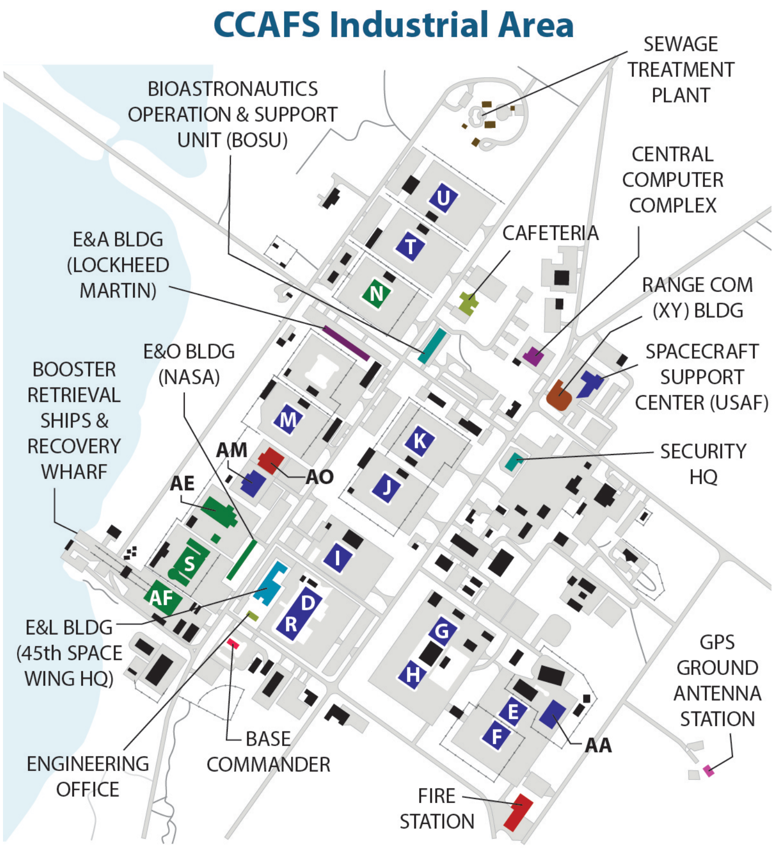


Fig. B.8. Cape Canaveral. (Adapted from 45th Space Wing, *Eastern Range Launch Site Summary: Facilities & Launches, 1950 Through 1993* [Patrick AFB, FL: 45th SW/HO, October 1994], vii.)



HANGAR & BLDG ASSIGNMENTS:		
D - USAF	**M** - USAF (DELTA II) ULA	**S** - NASA
E - USAF	**R** - USAF	**N** - NASA (SOLID ROCKET BOOSTERS)
F - USAF	**T** - USAF	**AF** - NASA (SOLID ROCKET BOOSTERS)
G - USAF	**U** - USAF	**BLDG AE** - NASA (SPACECRAFT PROCESSING MISSION DIRECTORS CENTER)
H - USAF	**AA** - USAF	
I - USAF	**BLDG AM** - USAF	
J & K - USAF	**BLDG AO** - ULA DELTA	

Fig. B.9. Cape Canaveral Air Force Station Industrial Area, circa 1960

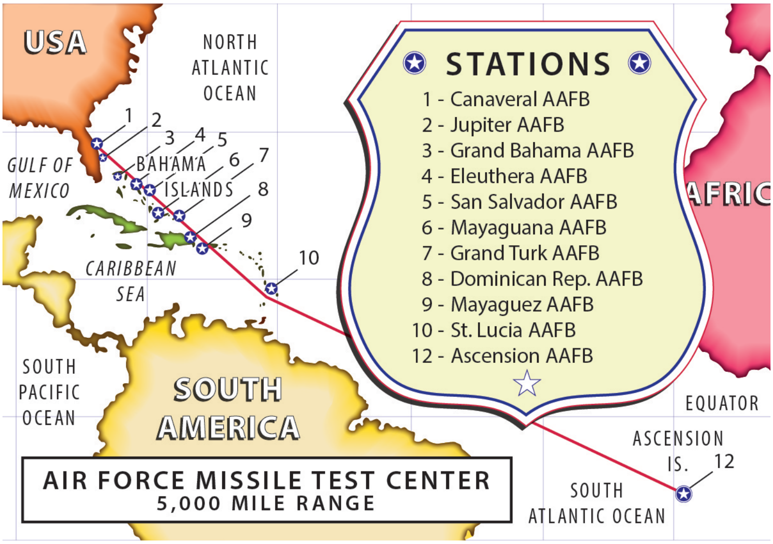


Fig. B.10. Air Force Missile Test Center, 5,000-mile range. (Adapted from Mark C. Cleary, "Development of the Eastern Range," in *The 45th Space Wing: Its Heritage, History & Honors, 1950–2009* [Patrick Air Force Base, FL: 45th Space Wing, 2009.])

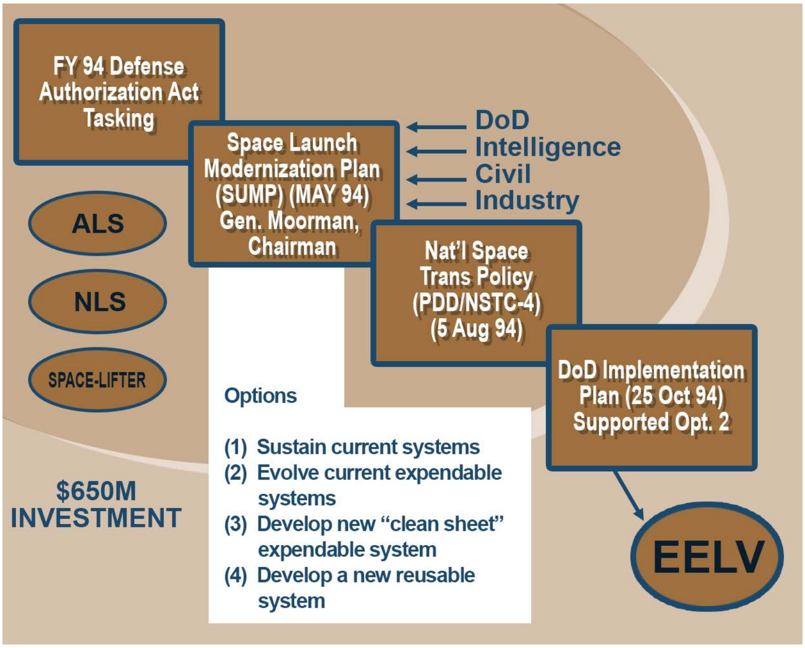


Fig. B.11. Background to the evolved expendable launch vehicles decision. (Adapted from Richard McKinney, n.d.)

Key

ALS	advanced launch system
EELV	evolved expendable launch vehicle
NLS	National Launch System
NSTC	National Science and Technology Council
PDD	Presidential Decision Directive

Fig. B.12. Launch and Test Range System Eastern and Western Ranges, 2005. *(Adapted from* Space and Missile Systems Center, *History of the Space and Missile Systems Center, 1 January 2005–31 December 2008, 98.)*

Table 1. Organizational Chart of Cape Canaveral and Patrick AFB, Florida

Organization headquarters	Installation base	Installation Cape	Installation range
Advance Headquarters Joint Long Range Proving Ground, 1 Oct 1949	US Navy Banana River Naval Air Station 1 Oct 1940–Aug 1947	Operating Sub-Division #1 1950	Bahama Long Range Proving Ground or Long Range Proving Ground 1950
Headquarters, Joint Long Range Proving Ground, 10 Apr 1950	transferred to Air Force on standby status 1 Sep 1948	Cape Canaveral Auxiliary AFB 5 Oct 1951	Florida Missile Test Range (unofficial) 1952
Headquarters, Long Range Proving Ground, 16 May 1950	Joint Long Range Proving Ground 10 Jun 1949	Cape Canaveral Missile Test Annex 16 Dec 1955	Atlantic Missile Range 1 May 1958
Headquarters, Air Force Missile Test Center, 30 Jun 1951	Long Range Proving Ground 17 May 1950	Cape Kennedy Air Force Station 22 Jan 1964	Eastern Test Range 15 May 1964
Headquarters, Air Force Eastern Test Range, 15 May 1964	Patrick AFB 1 Aug 1950	Cape Canaveral Air Force Station 1 Apr 1974	Eastern Space and Missile Center 1 Oct 1979
Detachment 1, Space and Missile Test Center, Eastern Test Range, 1 Feb 1977	(no further changes)	(no further changes)	(no further changes)

(*Adapted* from *Eastern Space and Missile Center Archive*, Patrick AFB, Florida, n.d.)

Table 2. STS Construction Projects at Vandenberg AFB as of September 1981

Year	Project
FY 1979	Launch Pad, Phase I (site preparation)
	Launch Pad, Phase II (construction)
	Launch Pad, Phase III (construction)
	Launch Pad, Phase IIIA (erection mechanism)
	Launch Control Center
FY 1980	Titan IIID resiting
	Orbiter Maintenance and Checkout Facility, Phase I
	Orbiter Maintenance and Checkout Facility, Phase II
	Hypergolic Maintenance and Checkout Facility, Phase I
	Utilities
FY 1981	Airfield and Mate/Demate Facility
	Solid Rocket Booster Processing (Vandenberg)
	External Tank Processing
	Logistics, North Vandenberg AFB
	Thrust Vector Control Hot Fire
FY 1982	Integrated Operations Support Center and Space and Missile Test Organization Management and Engineering Facility
	Boathouse Dock and Tow Route
	Breaker Addition
	Parachute Refurbishment
	Flight Crew System
	Solid Rocket Booster Disassembly (Port Hueneme)
FY 1983	Environmental Shelter
FY 1984	Tile Facility
	Safing and Deservicing
	Hypergolic Maintenance and Checkout Facility, Phase II
	Logistics, South Vandeberg AFB
	Thrust Augmentation

(*Adapted* from *History of Space Division, October 1980–September 1981*, 129.)

Table 3. Expendable Launch Vehicle Family, n.d. [1972]

Management agency	Vehicle system	Launch sites	Remarks
SAMSO/LV	Titan IIB/ Agena Titan IIID Titan IIIC Titan IIIE	Vandenberg/SLC-4W Vandenberg/SLC-4XE AFETR/ITL Complex 40 AFETR/ITL Complex 41	Program: SAF/SP Program: SAF/SP Air Force & NASA For NASA Centaur missions, Helios and Viking Mars Lander
SAMSO/LV	SLV-3A/ Agena SLV-3D	AFETR/Complex 13 AFETR/Complex 36A/B	Program: SAF/SP For NASA Centaur missions & Fleet Satellite Communications
SAMSO/LV	Atlas F	Vandenberg/ABRES A Vandenberg/SLC-3W	Ballistic & Space Missions
SAMSO/LV	Thor LV-2F/ Burner IIA	Vandenberg SLC-10	Program: Defense Systems Application Program (MetSat)
NASA/Langley Research Center	Scout	Vandenberg/SLC-5 Wallops Island, VA San Marcos, Kenya	NASA/DOD (Navy Navigational Satellite)
NASA/Langley Research Center	Thor Delta	Vandenberg/SLC-2 AFETR/Complex 17A/B	NASA NASA and Air Force, Skynet, and NATO satellites
NASA/Langley Research Center	Centaur	AFETR/Complex 41 AFETR/Complex 36A/B	Titan IIIE missions SLV-3D missions

(*Adapted* from *History of Space and Missile Systems Organization, 1 July 1972–30 June 1973*, 34–35.)

Key

ABRES Advanced Ballistic Reentry System
AFETR Air Force Eastern Test Range
ITL integrate-transfer-launch
LV launch vehicle
NASA National Aeronautics and Space Administration
NATO North Atlantic Treaty Organization
SAF/SP Secretary of the Air Force Special Projects
SAMSO/LV Space and Missile Systems Organization/Launch Vehicle
SLC space launch complex
SLV standardized launch vehicle

Table 4. Characteristics of US Space Launch Systems (1994)

Payload class	Spacelift system	Capability (performance launch rate)	Operability	Economics	Mission success for current configuration	Responsiveness
Small	Pegasus	>1,000 lb to LEO (east or polar); 4 per year	Modern, operable design; maintainable; routine operations; contractor logistics support	$14 million per flight; only flight-proven commercial SLV; very producible	1.0 mission success rate	2–4 month call-up; standard interface
Medium	Titan II	4,200 lb to LEO polar; 3 per year	Refurbished ICBM, no enhancements; contractor logistics support	$35 million per flight; hand-refurbished from ICBM	0.75 mission success rate; 1.0 launch success rate	90-day call-up
Medium	Delta II	4,200 lb to GTO; 9 per year	Most dependable ELV; some AF logistics support	$40 million per flight; modern production line	1.0 mission success rate	98-day call-up; 56 days on pad
Medium	Atlas I, II, IIA, IIAS	4,970 lb to 8,450 lb to GTO; 4 per year	Contractor logistics support	$90 million per flight; modern production line	0.863 mission succes rate for Atlas-Centaur system	No call-up; 50 days time on pad
Heavy	Titan IV	Up to 10,000 lb to GEO; 49,000 lb to LEO; 4–5 per year (both coasts)	Contractor logistics support	$250 million to $325 million per flight; very low production rates (3 per year)	0.857 mission success rate; still in development	180+ day call-up; 110 days on pad
Heavy	Shuttle	up to 53,500 lb to LEO; crewed; 8 per year	Contractor logistics support; some operability features	$375 million per flight at 8 per year	0.982 mission success rate (ops flighted only)	12–33 month call-up; 21 days on pad

(*Adapted* from "Characteristics of Current U.S. Space Launch Systems," from "Space Launch Modernization Plan (1994)," in Spires, *Orbital Futures*, vol. 2, 922.)

Key

AF	Air Force
ELV	expendable launch vehicle
GEO	geosynchronous Earth orbit
GTO	geosynchronous transfer orbit
ICBM	intercontinental ballistic missile
LEO	low Earth orbit

Abbreviations

AACB	Aeronautics and Astronautics Coordinating Board
AAF	Army Air Forces
ABM	antiballistic missile
ADCOM	Aerospace Defense Command
AEHF	advanced extremely high frequency
AERODS	Aerospace Defense Squadron
AFBMD	Air Force Ballistic Missile Division
AFMTC	Air Force Missile Test Center
AFRL	Air Force Research Laboratory
AFS	Air Force Station
AFSC	Air Force Systems Command
AFSCF	Air Force Satellite Control Facility
AFSPC	Air Force Space Command
AFSS	Autonomous Flight Safety System
ALDP	Advanced Launch Development Program
ALS	Advanced Launch System
AMC	Air Materiel Command
AMR	Atlantic Missile Range
ANNA	Army, Navy, NASA, Air Force
ARDC	Air Research and Development Command
ARPA	Advanced Research Projects Agency
ATK	Alliant Techsystems
ATW	Air Test Wing
BAR	Broad Area Review
BMD	Ballistic Missile Division
BMEWS	Ballistic Missile Early Warning System
CBC	common booster core
CCAAFB	Cape Canaveral Auxiliary Air Force Base
CCB	common core booster

CELV	complementary expendable launch vehicle
CEP	circular error probability
CIA	Central Intelligence Agency
CIRRIS	Cryogenic Infrared Radiance Instrumentation for Shuttle
CLSRB	Current Launch Schedule Review Board
CTF	combined task force
DARPA	Defense Advanced Research Program Agency
DDR&E	Director, Defense Research and Engineering
DMSP	Defense Meteorological Support Program
DSAP	Defense Satellite Applications Program
DSCS	Defense Satellite Communications System
EELV	evolved expendable launch vehicle
ELV	expendable launch vehicle
EMD	Engineering and Manufacturing Development
ESAO	Enterprise Strategy and Architecture Office
ESPA	EELV Secondary Payload Adapter
FAA	Federal Aviation Administration
FOB	Fractional Orbital Bombardment
FOC	full operational capability
GAO	Government Accountability Office
GEM	graphite-epoxy motor
GEO	geosynchronous Earth orbit
GLV	Gemini Launch Vehicle
GPS	Global Positioning System
GTO	geosynchronous transfer orbit
HLV	heavy lift launch vehicle
ICBM	intercontinental ballistic missile
IDCSP	Initial Defense Communications Satellite Program

IDIQ	indefinite delivery, indefinite quantity
ILC	initial launch capability
ILS	initial launch services
IOC	initial operational capability
IRBM	intermediate range ballistic missiles
IRFNA	inhibited red fuming nitric acid
ISAG	Independent Strategic Assessment Group
ISS	*International Space Station*
ITL	integrate-transfer-launch
IUS	interim upper stage
IWFNA	inhibited white fuming nitric acid
JLRPG	Joint Long Range Proving Ground
JSC	Johnson Space Center
KSC	Kennedy Space Center
LEO	low Earth orbit
LET	Launch and Range Enterprise Transformation
LLVPG	Large Launch Vehicle Planning Group
LOS	launch-on-schedule
LRPG	long range proving ground
LTRS	Launch and Test Range System
MAB	Missile Assembly Building
MDAC	McDonnell Douglas Aerospace Corporation
MIDAS	Missile Launch Detection Alarm System
MMO	Mission Manifest Office
MODS	Military Orbital Development System
MOL	Manned Orbiting Laboratory
MR	Mercury Redstone
NASA	National Aeronautics and Space Administration
NDAA	National Defense Authorization Act

NGLS	Next Generation Launch System
NIIRS	National Imagery Interpretability Rating Scale
NLS	National Launch System
NMF	Naval Missile Facility
NMFPA	Naval Missile Facility, Point Arguello
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NRO	National Reconnaissance Office
NSS	National Security Space
NSSL	National Security Space Launch
NUS	no upper stage
ORLCL	Operationally Responsive Low-Cost Launch
ORS	Operationally Responsive Spacelift
OSC	Orbital Sciences Corporation
OSD	Office of the Secretary of Defense
OSP	Orbital/Suborbital Program
OTA	other transaction agreement
PBAN	polybutadiene-acrylic acid-acrylonitrile
PMR	Pacific Missile Range
R&D	research and development
RALI	Rapid Agile Launch Initiative
RFP	request for proposal
RLV	reusable launch vehicle
RSA	range standardization and automation
RSLP	Rocket Systems Launch Program
SAC	Strategic Air Command
SAFSP	Secretary of the Air Force Office for Special Projects
SAMSO	Space and Missile Systems Organization
SAMTEC	Space and Missile Test Center

SCORE	Signal Communications by Orbiting Relay Equipment
SDI	Space Defense Initiative
SDIO	Strategic Defense Initiative Office
SECOR	sequential collation of range
SERT	space electric rocket test
SEV	Space Enterprise Vision
SEWS	Satellite Early Warning System
SIPRNET	Secret Internet Protocol Routing Network
SIS	standard interface specification
SLBM	submarine-launched ballistic missile
SLV	Standardized Launch Vehicle
SMAB	solid motor assembly building
SMC	Space and Missile Systems Center
SOPC	Shuttle Operations and Planning Complex
SpRCO	Space Rapid Capabilities Office
SRB	solid rocket boosters
SRM	solid rocket motor
SRMU	solid rocket motor upgrade
SRPO	Small Rocket Program Orbital
SSD	Space Systems Division
STAS	Space Transportation Architecture Study
STP	Space Test Program
STS	Space Transportation System
SWC	Space Warfighting Construct
TAT	Thrust Augmented Thor
TCP	Technological Capabilities Panel
TIROS	Television Infrared Observation Satellite
TRSL	Tactically Responsive Space Launch
TRW	Thompson-Ramo-Wooldridge
UDMH	unsymmetrical dimethyl hydrazine
UHF	ultra high frequency

ULA	United Launch Alliance
UTC	United Technology Corporation
VIB	Vertical Integration Building
WDD	Western Development Division

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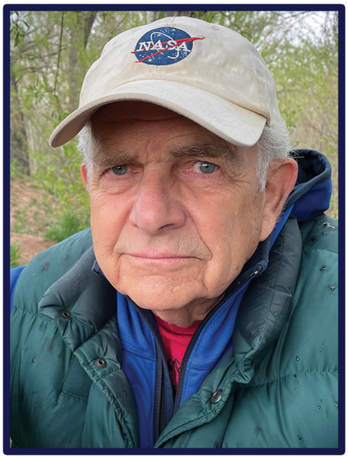

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ASSURED ACCESS

In *Assured Access: A History of the United States Air Force Space Launch Enterprise, 1945–2020,* David N. Spires surveys more than six decades of Air Force launch support for the nation's military, intelligence, and civilian space communities.

From their inception as refurbished ballistic missiles, Air Force boosters have launched national security space payloads for the US Department of Defense and the National Reconnaissance Office, as well as for the National Aeronautics and Space Administration and commercial and other civilian elements.

The basic technology that had produced the expendable launch space boosters of the early Cold War era changed little in fundamental engineering and manufacturing processes from that period until the advent of the evolved expendable launch vehicle (EELV) program at the turn of the new century. Expendable launch vehicles had been the backbone of Air Force space flight until the arrival of the space shuttle, with its promise of routine access to space. By the early 1980s, that promise had become increasingly problematical as space shuttle development and launch rate promises failed to meet projected targets. After 1986, in the wake of the *Challenger* disaster, the Air Force saw in the EELV families of Delta IV and Atlas V boosters the prospect of responsive, reliable, and affordable space launch. Although the EELV program largely achieved those objectives, new competition from SpaceX and other providers created an altered landscape of more efficient launch systems and reusable and partially reusable boosters. The EELV program gave way to the National Security Space Launch program. The emphasis on more responsive space launch to confront a growing threat to US space assets also embraced the small rocket efforts of the Rocket Systems Launch Program. Together, the National Security Space Launch program and Rocket Systems Launch Program promise assured access to space well into the future.