CHAPTER 7

Coming of Age:

Operation Desert Storm and Normalizing Military Space Operations

On 2 August 1990, 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. The Iraqi action threatened vital Western oil reserves in Kuwait and neighboring Saudi Arabia, which for many years had served as the basis for American policy in the Arab world. American President George Bush reacted promptly by convincing the United Nations to condemn the invasion, implement economic sanctions, and demand an unconditional Iraqi pullout. At the same time, the world body authorized President Bush to forge a multinational military alliance and force compliance if the Iraqis did not withdraw by 15 January 1991. 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.[1]

The Iraqi challenge found the United States already well on its way toward adjusting to new political and economic realities. The so-called New World Order that emerged after the 1989 political revolutions in eastern Europe and the impending demise of the Soviet Union, which finally occured in late 1991, precipitated a major reassessment of a military force structure designed to meet the threat of global nuclear war. In the new "multi-polar" world, regional crises and conflicts seemed more likely to test the United States. To prepare itself for new responsibilities as the only remaining superpower, America's national security strategy now focused more directly on revitalizing its domestic economy as a basis for strong international leadership, supporting emerging democracies, and maintaining traditional alliances. The Gulf War would show that joint and coalition warfare, rather than unilateral action, represented the wave of the future.[2]

The Gulf conflict also would demonstrate that national strategy could no longer support large prepositioned forces in a "forward defense" role. Rather, leaders envisioned restructured, smaller armed forces in the future, characterized by high readiness, technological superiority, and extensive mobility. Such forces would be capable of rapidly projecting power anywhere in the world without benefit of a supporting infrastructure already in place. Moreover, the armed forces of the 1990s should be able to emerge victorious from two simultaneous regional conflicts. Air Force Chief of Staff General Merrill McPeak termed the Air Force role in the new force structure as one of providing "global reach and global power." A central element in this Air Force vision would be the application of military space capabilities. Space forces would lead the way by providing global coverage, a nonthreatening forward presence, and inherent flexibility that guaranteed real-time and near-real-time support across the spectrum of military conflict.[3]

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."[4] By all accounts, space forces provided the vital edge in ensuring the victory of the U.N. Coalition. Their contribution proved more impressive because of the difficulties that had to be overcome. Space systems, up to this point, had focused primarily on strategic rather than tactical requirements. Some embryonic planning and testing of tactical uses of space capabilities had emerged by the late 1980s; however, ensuring nuclear warning and monitoring arms control agreements had been more important than supporting tactical operations. As a result, Coalition planners had to make important adjustments in both the satellite and ground segments of their space forces in order to meet tactical contingencies. Although remarkably successful, a number of persistent deficiencies could only be minimized, never overcome. In their many postwar assessments of space system performance, military authorities attempted to use the lessons learned from the desert conflict to ensure that space systems would better support the tactical warfighter in the future. The Air Force saw in its Gulf War experience a springboard for charting the future of the nation's military space program and assuring its own leadership role in space for the century ahead.[5]

To be sure, military space systems had provided important operational wartime support long before the Gulf War.[6] As early as the Vietnam conflict, weather and communications satellites furnished useful data and imagery to commanders in Southeast Asia and linked them with Washington, D.C. More recently, satellite communications had proven important in the British Falkland Islands campaign and in Urgent Fury, the Grenada invasion of 1983. In 1986, during Operation Eldorado Canyon, space systems provided a vital communications link and supplied important mission planning data to aircrews that bombed targets in Libya. In 1988, Operation Earnest Will witnessed the first use of GPS test satellites to support ships and helicopters during mine sweeping operations in the Persian Gulf. During Operation Just Cause in Panama in 1989, DSCS satellites provided long-haul communications links and DMSP supplied important weather data.[7]

These operations, however, involved only portions of the military space community for a relatively brief period of time, and the contribution of space systems was not widely understood or appreciated. Desert Storm, by contrast, involved the full arsenal of military space systems. Nearly sixty military and civilian satellites influenced the course of the war and helped save lives. Communications satellites established inter- and intra-theater 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.[8]

Operation Desert Shield—Preparation

At the outset of Desert Shield in early August 1990, communications satellites served only an American administrative unit in Bahrain and two training groups in Saudi Arabia, while the priorities lay elsewhere for weather, navigation, early warning, and remote sensing satellites. Much time and effort would be required to reconfigure satellite systems and overcome shortfalls before the Coalition's enormous space potential could be decisively marshaled. As for Iraq, it possessed no space assets of its own and had to rely on the international Intelsat and Inmarsat networks as well as the two Arabsat regional telecommunications satellites. During Desert Shield, the Iraqi leadership made little or no effort to integrate space into their military planning. Coalition forces, on the other hand, took advantage of a five-month "grace period" before the onset of Desert Storm to orient their space systems for maximum support to the warfighter. They faced a formidable challenge in all areas of space support.

Communications—Defense Satellite Communications System (DSCS). Analysts of the Gulf conflict found it difficult not to overplay the role of communications satellites (COMSATs) because of their vital importance to the success of every aspect of Desert Shield and Desert Storm operations. Although Saudi Arabia possessed a modern communications system, it did not service key areas of the potential battlefield or possess the circuit capacity needed to support the requirements of a half-million personnel. During Desert Shield preparations the Coalition put into place ten different COMSAT systems, which carried over 90 percent of U.S. communications to and from the Gulf area. Of this, commercial satellites accounted for 24 percent of the traffic. Communications satellites also furnished tactical links within the theater and served as relays for terrestrial radio systems suffering from line-of-sight limitations. They provided total communications to air, sea, and ground forces, and brought the war to television screens around the world.[9]

Establishing effective communications during Desert Shield presented a major challenge. Satellites needed to be repositioned or activated from standby status. To meet the high demand for communication circuits, military leaders reallocated circuits from other users to U.S. Central Command, leased civilian COMSAT circuits, and deployed thousands of terminals to the operational area. Coalition forces received communications support from the Defense Satellite Communications System, Fleet Satellite Communications (FLTSATCOM), NATO III, and Skynet systems, as well as commercial satellites. The variety of systems required considerable coordination with individual agencies and extensive integration before the communications system could function smoothly and efficiently.[10]

Of the various communications satellite systems involved in the Gulf operations, Air Force attention centered on the super high frequency (SHF) Defense Satellite Communication System, which had long met the bulk of global, long-haul communication requirements for all branches of the armed forces. At the outset of Desert Shield, the DSCS constellation appeared in good shape. In 1989 the launch of DSCS II and DSCS III satellites ended the marginal status of the constellation in the wake of the *Challenger* disaster. In August 1990 the DSCS network consisted of two DSCS II and three DSCS III operational satellites, together with one DSCS III reserve and two DSCS II limited-use spacecraft.[11]

Nevertheless, from the outset of Desert Shield Lieutenant General Thomas S. Moorman, Jr., commander of Air Force Space Command, expressed concern that military satellite communication links between the United States and the Middle East, and especially DSCS circuit capacity, would prove insufficient. Although his command was responsible for the space segment, overall DSCS management remained in the hands of the Defense Communications Agency (DCA). On 15 August General Moorman requested from the DCA the status of network allocations in support of U.S. Central Command. In a reply two days later, the agency did not seem worried, because the dedicated circuits had received little use. Circuits on two DSCS satellites had been earmarked to support Gulf operations. On an older DSCS II satellite positioned over the Indian Ocean (*DSCS IO-II*), 85 percent of channel 3 had been reserved for U.S. Central Command, but only 30 percent was in use. As for the DSCS III Eastern Atlantic spacecraft (*DSCS EA-III*), DCA, as system manager, had allocated 100 percent of channel 2, 85 percent of channel 4, and 100 percent of channel 3. Yet, usage figures for the three channels amounted to 10 percent, 20 percent, and 0 percent, respectively.[12]

Air Force Space Command remained troubled about potential saturation of the communication links. By late August *DSCS IO-II* usage had risen to 85 percent of allotted capacity under pressure from the growing buildup of forces in the region. Moreover, Air Force Space Command's staff became concerned with the vulnerability of DSCS satellites and other Coalition spacecraft to Iraqi jamming of satellite transponders, either by using the fire control radar for SA-6 surface-to-air missile batteries or by overrunning the U.S. Diplomatic Telecommunications Terminal at the American embassy in Kuwait City. In the latter event, Coalition forces might have to rely on naval ultra-high-frequency communications provided by the Navy's FLTSATCOM and additional commercial satellite support. Unfortunately, FLTSATCOM also was susceptible to jamming, and its large terminals made its bandwith unsuitable for tactical requirements.[13]

By mid-September, the problem of circuit loading could no longer be overlooked. Although use of the Eastern Atlantic spacecraft had reached only 60 percent of capacity, the figure for the Indian Ocean satellite's channel 3 had skyrocketed to 98.4 percent. The staffs of Air Force Space Command, DCA, the Joint Chiefs of Staff, U.S. Space Command, and U.S. Central Command considered several possible solutions, including moving users to different channels on the Indian Ocean satellite or entirely to the Atlantic Ocean satellite. Doing so, however, would temporarily sever connections with deployed forces in the theater, and U.S. Central Command declined to take this risk. Instead, DCA authorized the unprecedented step of realigning *DSCS EA-III*'s high-gain multibeam antennas to enhance its Middle East communications traffic capacity. Officials also continued to emphasize "bandwidth discipline" to users to prevent misuse of the strict channel allocations. But what if the current DSCS satellites experienced partial or complete system failure? The DSCS II satellite, after all, had been operating well beyond its projected "lifespan."[14]

Another potential solution to bolster Gulf support involved repositioning one of the satellites in orbit or launching a new DSCS satellite. This became a subject of serious debate in the fall, especially after U.S. Central Command realized that available funding for launch vehicles could not support a "launch on demand" requirement for additional DSCS satellites. Even with additional funding, however, it immediately became clear that a new DSCS launch could not take place before the spring of 1991. On 26 September Air Force Space Command initially recommended the activation of an orbiting NATO III Flight D spare satellite to relieve the two DSCS satellites of non-Desert Shield communications, but by the end of October growing political opposition to the use of a NATO asset for non-European operations ended consideration of this alternative.[15]

Meanwhile, Air Force Systems Command's Space Systems Division proposed a "spare-DSCS alternative," which involved using an old spare DSCS II, Flight D-14, and newly developed portable terminals to furnish SHF communications for Coalition war orders. The technical specialists also believed that Flight D-14 could be moved closer to the Gulf to provide the narrow coverage required for the use of small terminals in the theater. The first contingent of U.S. troops brought with them 48 tactical terminals, and by late September, with 200,000 additional troops on their way, the number of sets had increased to 58. The spare-DSCS option gained momentum, and by mid-November DCA requested that U.S. Space Command obtain permission from the Joint Chiefs of Staff to reposition Flight D-14, a "West Pacific Narrow Coverage Reserve" satellite, from its parking slot at 174 degrees east to 65 degrees east, over the Indian Ocean. On 17 November Air Force Space Command's 3rd Satellite Control Squadron initiated the move, and, at a drift rate of 4 degrees per day, Flight D-14 arrived at its new location on 19 December. After three days of intense testing, the second "Indian Ocean" DSCS satellite, began providing direct support to Desert Shield users on 22 December.[16]

By this time, Coalition authorities had arranged to use the British Skynet 4B satellite positioned at 53 degrees for additional SHF links, along with several categories of UHF satellites. These included two small experimental MACSATs (Multiple Access Communications Satellites) which had been launched by Scout boosters just prior to the Iraqi invasion. The minisatellites used "store-and-retrieve" procedures to relay logistics information between the United States and Saudi Arabia. U.S. forces also relied on geostationary FLTSATCOM spacecraft, largely for nontactical naval communication requirements, and commercial satellites. At the time of Desert Shield, the Hughes Corporation operated an orbiting network of five leased satellites (Leasats), although one had failed. For Gulf contingency support, Hughes moved one Leasat to provide better coverage of Iraq. At the same time, DCA contracted for the launch on 9 January 1991 of another commercial satellite, "Syncom" IV-5 1990-002B. Even if the commercial circuits were to prove unnecessary, Air Force Space Command felt more secure realizing that the commercial satellites could provide "redundancy" should the military systems fail.[17] The satellite communications network established during Desert Shield reflected considerable system flexibility and cooperation among the military, civil, and commercial space sectors.

Navigation—Navstar Global Positioning System (GPS). The Global Positioning System became the best known space system during the war. It proved capable of answering the age-old questions of "where am I" and "where am I going" in the featureless desert. Ironically, the military had been slow to accept GPS, partly because of reluctance to forego existing navigation systems. As for the Air Force, it seemed at times unable to dedicate itself to a multi-service system. As a result, a lower funding priority for GPS translated into delays, made worse by the *Challenger* Space Shuttle disaster. Not until 1989 did the Air Force launch the first five Block II operational satellites aboard the new Delta II booster to join the test satellites that had been supporting user equipment evaluations at Yuma, Arizona, since the late 1970s. Planners did not expect the full configuration of 21 operational and three spare satellites to be in orbit providing 24-hour, worldwide three-dimensional coverage and positioning information before late 1992 or early 1993. Meanwhile, to meet an interim deadline of April 1991 for 24-hour, global two-dimensional coverage, authorities decided in early 1990 both to begin repositioning the satellites from their test locations to their operational positions and to launch additional GPS satellites.[18]

Desert Shield sparked urgent efforts to provide navigation coverage to forces in the field. In early August, GPS rephasing already was well underway. By the 22nd of the month, when U.S. Space Command notified U.S. Central Command that GPS II-8 had been activated just twelve days after launch, the fourteen-satellite constellation consisted of six prototype and eight Block II operational satellites. With the buildup continuing, the previously scheduled launches of GPS II-9 and II-10 on 2 October and 26 November, respectively, increased the configuration to sixteen satellites on the eve of Desert Storm. Planners also decided to alter the orbit of GPS II-9 to optimize its coverage over Baghdad, especially at night. With the rephasing process completed by year's end, program managers expected the constellation to provide 24-hour two-dimensional and 19-hour three-dimensional coverage of Gulf operations.[19]

The optimistic plan threatened to go awry in December, however, when prototype satellite #6 failed. First launched in 1980 with a projected lifespan of only five years, the test satellite had finally succumbed to old age. Although the launch of GPS II-11 scheduled for 30 January 1991 would compensate for the loss of the prototype satellite, its launch was delayed after engineers discovered a flaw in the solar array drive-control electronics unit. By late December, work to revive the test satellite continued, while General Donald J. Kutyna, the commander-in-chief of U.S. Space Command, and General Moorman, commander of Air Force Space Command, convinced Space Systems Division to give high priority to solving GPS II-11's design flaw. Meanwhile, Air Force Space Command delcared GPS II-10 ready for operations on 15 January, well below the normal check out time of 30 to 60 days, and one day before the air campaign began.[20]

Problems with the GPS ground segment proved more alarming than the challenge of achieving the optimum satellite configuration. In August planners found themselves woefully short of receiver terminals. The system relied on two main types of receivers at the outset of Desert Shield. Rockwell International produced some 550 manpack/vehicular sets weighing approximately 18 lbs. each at a cost of $45,000 per set. Their design called for "Selective Availability," the capability of receiving encrypted precision-coded signals from the satellites that resulted in positional accuracies to within thirty feet. Because of their weight, most of these sets had been vehicle-mounted, while the high cost had limited their production to only 550 sets.[21]

Meanwhile, other companies had begun to produce commercial receivers to meet the growing demand in the private sector. One of these, Trimble Navigation of

Sunnyvale, California, had introduced a Small, Lightweight, GPS Receiver (SLGR) in 1989. The SLGR provided positional accuracy of between 50 an 100 feet. Less accurate than the Rockwell military receiver, the SLGR weighed only 4 lbs., cost about $3400, and proved small enough to fit into a soldier's pocket. The Army had purchased 500 demonstration SLGRs for testing before Desert Shield, and it distributed the sets to forces that deployed in August. Although every available military and commercial set quickly found its way to the Middle East, the dramatically increased demand could not be met. In an area of difficult terrain, few landmarks, and poor maps, GPS quickly assumed vital importance. After the Army Space Command expressed an "urgent need" for additional SLGRs, the GPS joint program office initiated two emergency requisitions for the commercially produced SLGR. In September, Trimble began shipping to the theater 1,000 SLGRs and 300 vehicle installation kits. Later, in December, Trimble contracted for an additional 7,178 SLGRs, with most earmarked for Army use.[22]

Along with a shortage of receivers, authorities also had to face the issue of protecting GPS signals broadcast by means of Selective Availability. In contrast to the military P-code sets, the commercially produced SLGRs received a coarse acquisition signal, which could be further degraded to deny precise navigational data. On 10 August Selective Availability was turned off to permit use of the Army's initial batch of commercially produced SLGRs. It remained off when it became apparent most sets would be commercially procured and, also, at the request of U. S. Special Operations Command. At the same time, GPS authorities made an additional compromise by permitting GPS course acquisition transmissions to occur without introducing additional error. The "open" signal resulted in the relatively high accuracy of approximately 100 feet for the commercial receivers, in contrast to half that figure with Selective Availability turned on.[23]

Beyond the difficulties of receiver shortages and signal usage, GPS users faced considerable challenges in establishing sets and terminal networks, ensuring effective linkage between field units and commands and, especially, in familiarizing themselves with the space equipment and its capabilities. Fortuitously, on the eve of Desert Storm, GPS officials had nearly finished the major improvements to the satellite constellation and had "solved" the receiver shortfall problem.

Environmental Monitoring. Defense Meteorological Satellite Program (DMSP), Landsat and SPOT. Coalition leaders understood the importance of weather satellite data and imagery for mission planning from the beginning of Desert Shield. The United States averaged six meteorological satellites in orbit simultaneously during the Gulf conflict. These included the military's three polar sun-synchronous DMSP satellites, the two National Oceanic and Atmospheric Administration (NOAA) TIROS polar-orbiting spacecraft, and the civilian GOES geostationary satellite. In addition, coalition forces received weather information from Japan's GMS system, positioned at 140 degrees east, two European METEOSATs located at 50 degrees west and 0 degrees west, and twelve Russian polar-orbiting METEOR satellites. Both civilian and military satellites played important roles, because they frequently complemented each other's coverage.[24]

DMSP proved to be the most useful system in providing cloud-cover imagery and temperature and moisture data in its twice daily sweeps of the Gulf. At the beginning of Desert Shield, the DMSP configuration consisted of a standard, two-satellite constellation. Flight 8 had been launched on 19 June 1987 and Flight 9 on 2 February 1988. Both had been performing without major incident. Air Force officials, in fact, had stressed improvements to the control segment of the program by creating a new operations center at Fairchild Air Force Base, Washington, to replace the Offutt facility, as well as upgrade the Thule, Greenland, tracking station to replace the site at Loring Air Force Base, Maine. By August 1990 most of these changes had been completed.[25]

Traditionally, the weather satellite program had followed a "launch on need" strategy, which required at least a 90-day wait before the request from the Air Weather Service resulted in a launch. In mid-1990, prior to Desert Shield, planners decided to replace the two orbiting DMSP satellites with Flights 10 and 11, scheduled for launch aboard Atlas E boosters in October 1990 and July 1991, respectively. After the Iraqi invasion of Kuwait, Air Weather Service officers met with their Air Force Space Command counterparts to determine the need for launching Flight 10, now rescheduled for 21 November. Problems with the Operational Linescan System (OLS) on Flight 9 convinced them to proceed with the launch. As it turned out, the launch took place on 1 December, but it proved far from routine. Apparently, the apogee kick motor exploded leaving the satellite in an incorrect, lower orbit. Although it would be replaced in less than a year, it nevertheless supplied useful information for the Gulf operations. By year's end, three healthy DMSP satellites stood ready for weather support.[26]

The main difficulty with the DMSP system proved to be its lack of tactical mobility. A system originally designed to fulfill strategic requirements only it recently had stressed tactical applications. Successful operations depended on establishing high-quality communication links between field units and the central DMSP Mark IV van. This 26,000-lb vehicle required a C-130 for transport. On 20 August the first of six Mark IV "tactical" terminals deployed to the theater to receive downlink imagery from the satellites. Five supported marine aviation and amphibious operations; one Air Force van was positioned at Riyadh together with the theater Tactical Forecast Unit. The latter transmitted weather data to more than thirty sites within the region by means of secure weather fax. The Navy also had DMSP terminals on its carriers and command and flag ships.[27]

Given the focus on tactical operational requirements, however, officials preferred a more mobile DMSP terminal. During Desert Shield, the Air Force moved rapidly to acquire three so-called Rapid Deployable Imagery Terminals (RDIT), which could be transported by two people with a weapons-carrier vehicle. But the search for more tactically-oriented terminals continued. On 7 November, Military Airlift Command proposed to Air Force Space Command the development of a lightweight, rapidly-deployable "Small Tactical Terminal" for each unit to receive near-real-time data. General Moorman approved the concept, and developers hoped the tactical terminals could replace the single DMSP van early in 1991.[28]

From the beginning of Desert Shield, Coalition forces supplemented DMSP forecasting with weather data form the civilian satellites. NOAA's TIROS spacecraft, for example, provided useful transmissions at 2 P.M. local time on the late-afternoon jet stream that affected evening weather patterns in the desert. For the Army, the geostationary civilian satellites proved to be more useful than the military polar-orbiting satellites. The civilian satellites re-imaged the same portion of the earth every thirty minutes in contrast to the twelve-hour cycle of the polar satellites. Moreover, although DMSP provided a smaller-scale weather picture, which proved useful for identifying fog and sandstorms, the Army suffered from limited access to DMSP data because of the small number of receivers in the theater. Since the Mark IV terminal did not meet Army mobility requirements, Army units below theater level relied on a commercial weather receiver, the German-made WRAASE terminal. Available prior to Desert Shield, the civilian weather receiver could obtain imagery from civilian satellites of four nations, but not from U.S. military DMSP satellites. Most DMSP readouts did not reach Army units, which prompted the Air Force to develop a small, high-resolution tactical terminal for direct satellite-to-user transmission of imagery and data. In mid-December a small experimental DMSP receiver had proven successful in at the Army's Central Command headquarters. At year's end, it remained uncertain whether the tactical terminals could arrive in sufficient quantity in time to be useful in Gulf hostilities.[29]

Weather satellites represented one avenue to gaining a better understanding of the battlefield environment. Another involved the use of wide-area and multi-spectral imagery (MSI) from space systems to prepare accurate maps and to support terrain analysis requirements. MSI images depict features beyond human visual capability, including spectral change resulting from ground disturbances. In the Persian Gulf region, where accurate mission planning maps did not exist, multi-spectral imagery could benefit all the services.[30]

For multispectral imagery and wide-area coverage of the area of operations, Coalition forces relied on two civilian sources, the U.S. Commerce Department's *Landsat* 4 and 5 satellites, and the French-owned earth resources satellite system, SPOT (Satellite Probatoire d'Observation de la Terre/Exploratory Satellite for Earth Observation). Both of these earth resources imaging satellites provided essential wide-area surveillance of the battlefield area not available from the high-resolution sensors aboard the U.S. national reconnaissance satellites. Landsat satellites imaged each part of the earth every sixteen days in seven different bands of the spectrum with a spatial resolution of thirty meters. Their ability to image a 185-kilometer wide area on each pass produced a wide field of view that enabled mapmakers to create products with a scale of approximately 1:80,000. SPOT satellites, although not MSI-capable, performed in like fashion. The primary SPOT sensor used three different bands at a 20-meter resolution, and one 10-meter panchromatic band to achieve an image map scale of 1:25,000. In contrast to Landsat, SPOT satellites viewed each part of the earth every twenty-six days, and the width of its pass measured approximately sixty kilometers. Owners of both systems required users to purchase the requested imagery and refrain from sharing it with third parties. Coalition leaders, worried that Iraq might acquire multispectral imagery, convinced Landsat and SPOT officials not to make it available to Saddam Hussein's regime between August 1990 and March 1991.[31]

The U.S. Army's topographical battalion arrived in the Gulf in August with maps based on 1987 Landsat imagery. By November, however, it had established three operational MSI workstations and had begun receiving updated imagery. Yet officials did not have an effective courier system to deliver the imagery to users until late January 1991, and they worried that units might not have sufficient time to fully exploit it.[32]

The U.S. Air Force relied on Landsat imagery for a variety of purposes, including construction of large airfields in Saudi Arabia. Specialists converted Landsat imagery of existing airstrips into engineering drawings for use in planning and building some of the world's largest air bases. For mission planning and rehearsing, however, both the Air Force and the Marine Corps preferred using SPOT imagery because of its 10-meter resolution. In September the Air Force purchased a sizable amount of SPOT images and offered to share the data with the Army. But the Army had no funding available to pay the royalty fees and, as a result, Army units did not have access to SPOT data during the Gulf War.[33]

During Desert Shield, Coalition forces became convinced that multispectral imagery could provide direct warfighting support. Beyond its use in preparing accurate maps, terrain analyses, and strike planning, it enabled U.S. Central Command leaders to keep abreast of Iraqi activity. By comparing Landsat imagery taken in August and December along the Kuwaiti-Saudi Arabian border, planners could determine the changes that had occurred. Bright spots appeared when the data was displayed on a single image, which indicated ground cover had been altered. At the same time, Coalition authorities realized that multispectral imagery could also give the Iraqis insight into Allied planning. Shortly before the ground war, the Defense Intelligence Agency intervened to prevent U.S. news media from obtaining Landsat data of the Kuwait-Iraq-Saudi border, which might have revealed the Coalition buildup in preparation for the "left hook" offensive maneuver at the war's start. Although users of multispectral imagery during Desert Shield would have preferred a system more timely, accurate and responsive to tactical requirements, the imagery clearly provided Coalition forces an important advantage in preparing for the conflict ahead.[34]

Early warning—Defense Support Program (DSP). Early warning Defense Support Program satellites would play a crucial role in detecting tactical ballistic missiles. Well aware that Iraq possessed Scud tactical missiles, United States military planners worked from the start of Desert Shield to optimize the strategic early warning satellite system for coverage of the tactical threat. In August 1990, the DSP network consisted of three operational satellites and two spares in geostationary orbit. Originally designed for strategic requirements, DSP's primary mission continued to be warning of ballistic missile launches. Secondary missions included detection of space launches and nuclear detonations for test ban monitoring. One satellite positioned over the Indian Ocean at 70 degrees east monitored intercontinental ballistic missile (ICBM) launches from the Asian landmass, while the other two focused on the sea-launched ballistic missile (SLBM) threat from their positions in the South Atlantic at 70 degrees west and over the eastern Pacific at 135 degrees west. Although in 1989 and 1990 the Air Force had launched the first two of its new-generation DSP satellites, DSP-1/Block 14, it elected to use its two oldest orbiting spacecraft to monitor Scud launches, because they were better positioned to support Gulf operations.[35]

During the Desert Shield buildup officials worried about timeliness of detection and warning. Technically, the spacecraft's infrared telescope scanned an area larger than it could observe at a particular time because it was mounted off-angle to its rotational axis. Rotating six times per second, the satellite required ten seconds to re-image an area where a missile had been detected. As a result, the longer time needed to determine launch site, trajectory and impact point became especially troublesome for Coalition forces challenged to destroy short-range tactical missiles. Air Force planners sought to increase early detection of Scud launches by repositioning the Indian Ocean satellite farther westward in order to maximize its coverage of the Gulf region.[36]

DSP program managers also attempted to reduce the time it took to process and relay warning data to Patriot antiaircraft missile crews in the Gulf. DSP procedures called for the Indian Ocean satellite to transmit data first to the Air Force Space Command ground station at Woomera, Australia, then up to a Defense Satellite Communications System (DSCS) satellite for relay over the Pacific to the ground terminal at Buckley Air National Guard Base, Colorado, and onward from there to the U.S. Space Command's Missile Warning Center, Air Force Space Operations Center, and Space Command Center at Cheyenne Mountain. There, analysts determined the likely impact zone of the missile and transmitted this information to U.S. Central Command and air defense commanders by way of a DSCS satellite over the Atlantic Ocean. The entire process from launch detection to warning took up to five minutes. With a Scud flight time of only seven minutes, Patriot crews and civilian target areas would receive precious little warning.[37]

To enhance the Coalition's ability to defeat the Scud threat, personnel at U.S. Central Command, Air Force Space Command, and U.S. Space Command emphasized training and straightforward procedures—and they worked hard to improve warning and response efficiency during Desert Shield. At the same time, Air Force Space Command sought, unsuccessfully, to reduce the warning time by deploying DSP terminals to the theater. By doing so, the delay could have been reduced from five minutes to as little as 90 seconds, thereby increasing up to five minutes the warning time given to Patriot batteries. Although satellite early warning had been in place since early August, it required the full five and half months of Desert Shield to establish the secure communication paths, develop alert procedures and train all involved to achieve the fine-tuning Air Force Space Command believed necessary for success.[38]

In mid-January 1991, on the eve of combat, the military space community could look back on over five months of intense effort to adjust space forces for tactical operations in the Middle East. Often resorting to innovative solutions to support the tactical warfighter, they relied on the inherent flexibility of space systems and their own ingenuity to overcome the limitations of a Cold War space posture. Although confident of success, the planners realized that the system remained fragile in crucial aspects and vulnerable to potential Iraqi counter actions. It remained to be seen whether space would prove decisive in the unfolding conflict.

Operation Desert Storm—Combat

When the United Nations ultimatum on Iraqi withdrawal from Kuwait expired on 15 January 1991, the Coalition decided on immediate military action. Desert Storm began on the night of 16–17 January with a massive air campaign led by F-117 Stealth fighters firing laser-guided weapons at targets in Baghdad. Following the radar-evading fighters came a series of coordinated air strikes in Iraq and Kuwait in conjunction with the launching of Navy Tomahawk cruise missiles. Coalition leaders thought the air assault would last only a few days, but it continued for another six weeks. Observers found the course of the ground war equally surprising. Expected to last several weeks, the land campaign ended after only four days. No one would deny, however, that the "blitzkrieg" ground offensive resulted from the length and effectiveness of the air campaign. Because the combat phase of Desert Storm has been discussed in detail elsewhere—as well as shown to millions of television viewers worldwide—this study will focus on the performance of space systems and Air Force operations in the Gulf War.

Communications—DSCS. As Chairman of the Joint Chiefs of Staff General Colin L. Powell observed near the end of Desert Shield:

> When we started our deployment, we had only the most rudimentary communications infrastructure in Southwest Asia and the challenge of distance was daunting. Thanks to good planning and to our understanding of the importance of satellites, we quickly and smoothly transitioned to a mature tactical theater network.[39]

The military satellite communications network quickly proved its worth. When Coalition air forces began on 16–17 January what would become a 39-day air assault, they had the unprecedented advantage of access to a single data base, or Air Tasking Order (ATO). Communications satellites also made possible immediate updates of target assignments and provided "positive" control of combat operations from pre-mission planning to post-mission aircrew debriefing. Executing over 700,000 transactions daily, satellites made Desert Storm air operations the most efficient and accurate to date. Once Desert Storm started, satellite communications more than doubled. By this time, the Coalition communications satellite network transmitted to more than 1,500 satellite communications terminals in the theater. More than three quarters of these were single-channel "manpack" military and commercial receivers.[40]

DSCS proved to be the most important intra-theater long-haul, multichannel communications system. DSCS satellites carried over 50 percent of communications traffic during the war and ensured effective command and control for both strategic and tactical operations throughout the conflict. DSCS provided the daily tasking order to every air base in the theater, and continued to link air and ground units to their bases in the States. It handled a 75 percent increase in intelligence relay to the United States for analysis, then back to the U.S. Central Command for use by deployed warfighters.[41]

By the end of Desert Shield, more than 120 DSCS tactical terminals had been delivered to the Gulf. When the ground forces initiated their "left hook" attack, many units moved with tactical DSCS terminals, some on flatbed trucks to avoid reassembling the satellite antenna during relocation. At the conclusion of hostilities, 33 DSCS terminals supported the warfighters in Kuwait and Iraq. In short, DSCS helped guarantee the command and control vital to the success of the war effort.

Navigation—GPS. By mid-January 1991, Air Force Space Command had declared the problem-plagued satellite #6 fit for operations, but engineers could not alleviate GPS II-11's design flaw in time to affect the conflict. As a result, the GPS constellation remained at sixteen satellites during Desert Storm. U.S. Space Command's postwar evaluation would characterize GPS as "perhaps the most visible example of space systems support to U.S. troops in Operations Desert Shield and Desert Storm."[42] Most attention has focused on the navigation system's vital contribution to ground forces in the land campaign—and rightly so. After all, its precise positional data and time readouts provided an average accuracy of 7.5 meters. GPS supported every type of ground operation, from large-scale maneuvers to individual soldiers moving through the featureless desert. The Rockwell "man-pack," which troops mounted on trucks or helicopters, and the SLGR, affectionately known as "Slugger" and carried by individual soldiers, enabled units to plot and achieve objectives and relocate tactical operations centers, Special Forces personnel to operate effectively in enemy territory, artillery observers to target enemy positions and direct friendly fire, and troops to clear land mines. In short, GPS gave the Army eyes to operate in the desert and made possible the successful envelopment maneuver that brought the ground war to a rapid conclusion.

GPS also served the other services. Not only did it furnish Marine artillery units with precise positioning data, it helped naval forces clear mines and provide precise coordinates for cruise missile strikes against Baghdad targets. The Air Force benefited from GPS in a variety of ways. For one, the system gave B-52 bombers an all-weather flight capability for their missions. For another, in the opening hours of the war, Special Operations Forces Pave Low helicopters with GPS teamed with Army Apache attack helicopters to destroy two Iraqi radar sites and, thereby, create a major gap in the Iraqi air defense network. F-16 aircraft also used GPS for passive navigation to the initial point of the bomb run. Of nearly 200 F-16s in theater, 80 to 90 possessed GPS receivers. Especially valuable in bad weather, the precision navigation system freed the pilot to take care of other business and optimize his use of weapons. Fuel permitting, GPS enabled aircraft to remain in the target area as forward air controllers, who could furnish to later strike aircraft precise coordinates and current battlefield data. GPS also promoted superb close-air-support coordination with GPS-equipped ground units. Possessing a GPS receiver and a laser compass, ground troops could triangulate on a target and pass the coordinates to the GPS-equipped F-16 which, in turn, could relay them to strike aircraft. In light of the traditional Army-Air Force divisiveness over the close-air-support mission, space-based GPS foreshadowed the advent of a new era in air-ground cooperation.[43]

Environmental Monitoring—DMSP, Landsat and SPOT. When coalition forces launched the air war, they confronted the worst weather experienced in the Gulf in fourteen years. As Air Force Chief of Staff General Merrill McPeak later recalled, weather conditions were "at least twice as bad as the worst-case estimates."[44] Moreover, Coalition forces learned during Desert Shield that weather in the region proved notoriously susceptible to sudden changes. Heavy coastal fogs, blinding sandstorms, and heavy rains could seriously hinder operations. On 24 January 1991, for example, DMSP imagery depicted a clear Baghdad and overcast Basra, yet a second DMSP readout less than two hours later showed the reverse. Given these conditions, DMSP and supporting civil weather satellites made possible the planning and execution of the most sophisticated air campaign in history. Over the course of the 39-day air campaign, Coalition forces averaged over 2,500 sorties per day. Imagery and data transmitted from the three-satellite DMSP constellation, in particular, helped planners develop real-time schedules, make immediate, accurate retargeting decisions for reconnaissance and tactical missions, and aid in bomb damage assessments. The tactical operator could effectively choose the best weapon for the target based on known weather conditions in the target area. Current weather data proved especially useful for enhancement of night vision and infrared targeting. In this regard, DMSP weather reports proved vital for the success of precision-guided laser and optical ordnance, which depended on clear weather for accurate target designation.[45]

In addition to DMSP's importance for tactical air operations, it aided in the movement of troops during the ground war. Moreover, it helped predict and track rainstorms and sandstorms, oil fires and oil spills, and cloudcover, as well as analyze the potential spread of chemical agents and correlate storms with flood threats. General Norman Schwarzkopf, commander-in-chief of U.S. Central Command, thought so highly of DMSP that he always kept the most current DMSP data within arm's reach for quick reference. On balance, DMSP proved to be a crucial "force multiplier" during the conflict.[46]

Although the Landsat and SPOT remote sensing satellites played a larger role in Desert Storm planning, their multispectral imagery also supported tactical operations during the battle. The special capabilities of SPOT sensors proved very useful for engineers, who could adjust the optical images for off-nadir observing. This allowed any site to be viewed up to almost 1,000 kilometers on either side of the satellite's path. As a result, the normal period before revisiting the particular location could be reduced from twenty-six days to two. Aircrews in the Gulf used a data base of stereoscopic images to prepare flight routes and target attack procedures. One mission that used this system to great advantage involved an attack on Kuwait's Mina al Ahmadi oil complex, which Iraq had used to create a massive oil spill in the Persian Gulf. The U.S. F-111 pilots who bombed the well heads stated afterward that, in effect, they had flown the mission long before taking off.[47]

Although Landsat and SPOT wide-area surveillance contributions received well-deserved accolades, U.S. national reconnaissance satellites also played a key role in the space surveillance and intelligence war. Likewise, these space systems confronted the challenge of adapting their strategic capabilities to meet tactical requirements. It has been widely reported that the sensitive intelligence program directed by the National Reconnaissance Office used both optical imaging KH-11 "Keyhole" satellites and radar-imaging "Lacrosse" satellites for intelligence collection in the Gulf War. With their multispectral optical sensors, the Keyhole spacecraft are reported to be capable of achieving a resolution of nearly ten centimeters during daylight hours in clear weather. The Lacrosse radar imaging satellite gave Gulf forces the benefit of day and night coverage in all types of weather with resolutions reported to be between one and 1.5 meters.[48]

Battlefield commanders usually preferred the wide-angle imagery of the civil satellites to the incredibly large-scale detail depicted by the intelligence collectors. Yet, in many cases these satellites furnished analysts superb battle damage imagery. The ability to determine detailed damage caused by precision, "smart" weapons, for example, made it unnecessary to dispatch of reconnaissance aircraft to overfly the heavily-defended target area. Intelligence satellites also contributed to one of the most challenging missions of the war, locating Iraq's mobile Scud launchers for destruction before the DSP early warning satellites became involved.[49]

Early warning—DSP. Saddam Hussein saw in the surface-to-surface Scud missile a terrorist weapon that could split the allied Coalition and bring Israel into the war. DSP's role was to detect and provide sufficient warning for strikes against the launchers and for the Army's Patriot batteries to intercept incoming missiles. Like the intelligence satellites, DSP had been designed for national strategic objectives rather than battlefield support. Nevertheless, the measures taken during Desert Shield to make the system more tactically responsive proved successful. DSP satellites detected Scuds in time to alert civilians and military defense personnel to don their chemical protection suits and take cover, and for Patriot batteries to engage the missile.[50]

Like DSP, Patriot had not been designed for tactical ballistic missile warning in desert conditions. Limited to a 50-mile range, the system's target radar could not spot a Scud before the missile's terminal phase of flight. At the same time, the fire control electronics system often overheated in the Gulf's desert climate, which led battery operators to keep the radar systems in an inactive, standby mode until DSP satellites detected a Scud. Initially, missile crews had as little as 90 seconds after DSP warning to acquire, track, lock-on, and launch to destroy the Scud. Often the Patriot intercepted the missile at ranges of five miles or less, in full view of ground observers and a worldwide television audience. In cases where television broadcast the attack, the allies worried that Iraqi viewers could adjust to more accurately re-target the site. As the war progressed, the arrival of recently-tested Constant Source terminals in the theater gave Patriot batteries as much as five minutes warning time. In fact, DSP acquired all of the Scud launches. On balance, the missile defense system gave a good accounting of itself. Of the reported forty missiles launched against Israel and forty-six against Saudi Arabia, the vast majority either fell victim to Patriot crews or dropped harmlessly well away from their intended targets.[51]

Lessons Learned and Normalizing Military Space

Military analysts concluded that, in Desert Storm, space systems contributed to victory in the political battle, ensured effective command and control, and helped make the war a short conflict, which saved lives. Speaking for many after the conflict, General Moorman, commander of Air Force Space Command, observed:

> Desert Storm was a watershed event for space systems. Satellites, and the ground systems and people trained to control them, played a crucial role in the outcome of the conflict. Space owned the battlefield. We had a robust on-orbit constellation and the inherent spacecraft flexibility to alter our operations to support specific needs of the terrestrial warfighter.[52]

In many ways the most impressive element of the Gulf War proved to be the ability of space personnel to adapt their systems for the tactical warfighter. At the outset of Desert Shield, few of the space systems were in position to provide the support upon which Coalition forces would come to depend. Most had been designed during the Cold War to satisfy strategic requirements. Planners needed the full five months of Desert Shield to optimize space and ground segments and to create the necessary inter- and intra-theater infrastructure. Fortunately, in Saddam Hussein, the Coalition faced an enemy without significant space assets of his own, and one unwilling to prevent the buildup or seriously menace the vulnerable space network in place by January 1991. At the same time, Coalition members benefited from not having to face another conflict while dealing with the Gulf crisis. They remained well aware that their good fortune could not be guaranteed in future situations.

While basking in the glow of a justly-praised, decisive victory, the U.S. space community sought to learn and improve. The Air Force was at the core of this effort. Postwar analyses correctly emphasized deficiencies and the challenges ahead. Above all, analysts realized that in spite of mounting the largest contingent of space-based forces to date, their systems proved insufficiently designed for tactical use, and ground personnel often lacked the necessary equipment and training to fully exploit space capabilities. Even systems traditionally more oriented toward tactical operations encountered problems. In order to meet the challenge of supporting the warfighter, Air Force leaders realized that they must lead the effort to modernize space infrastructure, continue technical improvements to space systems, and extend space awareness throughout the Air Force and the armed forces as a whole. They expected Desert Storm to provide the momentum in the early 1990s for improvement in every area of space operations. The attention of the military space community focused on systems and capabilities represented by the four mission areas first established in the mid-1980s: space control, force application, force enhancement, and space support.

Space control referred to operations to maintain friendly use of space and deny the same to potential enemies. Over the years authorities in this area, had been most successful in developing protective measures for satellite systems by means of hardening, increasing the number of satellites, applying better tactics, and deploying mobile ground segments. Likewise, space surveillance capabilities had improved with more effective radar, electro-optical, and passive radio frequency sensors. Although attempts to deploy an operational antisatellite system had proven unsuccessful, Desert Storm renewed interest in developing such a capability.

Ever since the beginning of the space race, the Air Force had stated a need for an antisatellite system. By the mid-1980s, the service began testing an F-15-launched heat-seeking antisatellite weapon, termed the Miniature Homing Vehicle. Concerned about expense and the system's potential impact on the arms race, however, Congress in 1988 banned further testing. The Air Force subsequently canceled the program. Although the congressional decision addressed orbital testing specifically, the Army proceeded with tests of a ground-based kinetic energy interceptor as part of the Strategic Defense Initiative. Program managers remained unenthusiastic about the Army's antisatellite requirement, even as they continued to develop the weapon in the early 1990s.[53]

The Gulf War convinced commanders of the importance of satellite reconnaissance and the need to deny it to potential enemies. General Charles A. Horner, commander-in-chief of U.S. Space Command and commander of Air Force Space Command after Desert Storm repeatedly argued for the capability to destroy foreign satellites, even those belonging to allies if they were aiding an enemy. Other Air Force leaders agreed on the need to control space. As Air Force Secretary Sheila Widnall asserted in the fall of 1994, "Part of the Air Force mission is control of space, our ability to deny the use of space if necessary." Despite the pleas from Desert Storm leaders, the antisatellite program was confined at mid-decade to a research effort by all three services.[54]

The force application area confronted similar roadblocks to the use of military weapons in space. This element comprised fire support operations from space against enemy forces by means of ballistic missile defense and "power projection" operations against terrestrial targets. The latter represented only a theoretical application, and no plans existed to include power-projection space weapons in the force structure. Ballistic missile defense, which had developed under the auspices of the Strategic Defense Initiative, called for layered defenses comprised of both terrestrial and space assets. Space-based elements included Brilliant Eyes and Brilliant Pebbles. Both programs had experienced considerable change over time as a result of the SDI's uncertain fortunes. In the early 1990s, Brilliant Pebbles envisioned satellite interceptors designed to demolish ballistic missiles in their midcourse and terminal phases of flight. But, like the antisatellite program, the Strategic Defense Initiative Organization's space-based interceptor was limited to a technology base program, with the objective only of developing technologies as security against potential future threats.[55]

Brilliant Eyes, however, drew more interest from Air Force space officials who sought to improve theater space surveillance capabilities after Desert Storm. The Brilliant Eyes concept called for a "distributed" satellite network consisting of several hundred spacecraft with infrared and laser sensors orbiting at 700 kilometers, capable of tracking missiles in their midcourse phase, discriminating among reentry vehicles and decoys, and predicting impact points. Like national reconnaissance assets, these satellites would also perform an arms control monitoring function. Air Force Space Command had been interested in Brilliant Eyes because of its relationship with plans to upgrade the DSP early warning satellites. On the other hand, it seemed that the project did not address the command's space surveillance requirements. Following the Gulf War, the issue became more complicated when the Strategic Defense Initiative Organization decided to refocus the program to emphasize theater missile defense. The new concept called for development in stages to provide both national and global protection against ballistic missiles. The reoriented Brilliant Eyes distributed sensor program, now managed by Air Force Space Command, led Air Force space authorities to reexamine the operational implications for their own missile warning and space surveillance requirements.[56]

In the mid-1990s both the ballistic missile defense and antisatellite programs continued, but only as research efforts that reflected considerable debate about their necessity, feasibility, and cost-effectiveness. By contrast, postwar interest in improving the military space posture centered on programs embraced by the mission areas of force enhancement and space support.

The elements of the force enhancement area involved space combat support operations, which had proven the most visible and important during the Gulf conflict. Dating back to the Eisenhower era, they represented the traditional defense support functions of communications, tactical warning and attack assessment, navigation, environmental monitoring, reconnaissance, and surveillance.

Space-based reconnaissance and surveillance systems. These systems operated under the auspices of the National Reconnaissance Office, which remained a sensitive agency in spite of the first public discussion of its activities in September 1992. Following Desert Storm, in which "national" space sensors proved capable of providing outstanding resolution but little wide-area surveillance, overcoming this coverage limitation became part of a broad effort to increase space-based wide-area surveillance. In the post-Cold War arena, intelligence and surveillance imaging systems required more flexibility to respond to rapidly-developing tactical intelligence needs. Some critics recommended a distributed system of satellites that could be "everywhere, all the time." But did this mean replacing the large, heavy strategic-oriented reconnaissance and radar-imaging satellites with smaller spacecraft carrying lower-resolution sensors? The latter would also have the advantage of not requiring launch by the expensive, heavy-lift Titan IV booster. By mid-decade, planners at the National Reconnaissance Office were reported to be weighing a new system of numerous smaller, lighter satellites against retaining the existing configuration that could be improved to image eight times the area of current satellites.[57]

Nevertheless, the national intelligence space community continued to operate largely independent of the broader military space sector. This had been a major complaint of Air Force space agencies which worried that the intelligence community too often failed to coordinate its space requirements to best support the warfighter. A report by the vice president's National Space Council late in the Bush administration called for reduction and, where possible, elimination of security constraints that continued to work against effective integration of the military, civil, and commercial space sectors.[58]

Environmental monitoring, including weather and earth-sensing satellites. Evaluators of satellite performance in the Gulf War concluded that while DMSP "exceeded expectations," data must be made available in greater volume and more frequently. Criticism centered on the lack of sufficiently mobile receivers in the field. Because Army units below theater level had no access to the non-mobile Mark IV receiver, they had no direct means of using DMSP data and relied, instead, on a commercial receiver for satellite data. Only late in the war did the Air Force introduce two prototype terminals small enough for use in the rear of the Army's High Utility Multipurpose Vehicle, or "Humvee." Air Force analysts agreed that they needed to develop and field sufficient numbers of mobile high-resolution DMSP receivers capable of obtaining imagery and data from both military and civil satellites.[59]

Planners expressed satisfaction with the evolutionary development of the weather satellites and, together with deploying more mobile terminals, expected to replace the current DMSP Block 5D-2 spacecraft with the more capable 5D-3 series early in the new century. On the other hand, the widespread use of military and civil polar-orbiting satellites for weather data precipitated reconsideration of the old issue of combining programs to save money and avoid redundancy. With post-Cold War budget austerity looming, proponents of "convergence," or merging the systems, optimistically forecast success in this eighth major examination of the question. Air Force officials appeared more favorable as long as service requirements could be satisfied. Yet the postwar plans for convergence of the civilian and military systems foundered on the same hurdles that had prevented the success of earlier efforts. NOAA's international commitments meant including the Japanese and Europeans, who balked at participating in a military system and at agreeing to U.S. control of weather data during hostilities.[60]

Postwar reports also examined the need for an advanced multispectral imaging (MSI) capability. Landsat and SPOT, they noted, did not always provide timely or accurate data for mission planning, bomb damage assessment, or use of precision guided weapons. Neither system combined sufficient spectral and spatial capabilities, while efforts to merge MSI data to obtain the required resolution proved slow. National systems, on the other hand, provided superb spatial resolution, but little overall view of the battle area. They lacked sufficient MSI capability and proved awkward to handle because of their security classification. A future system, analysts concluded, should possess a wide-area MSI system, high-resolution and spectral coverage, direct links to users, and timeliness. Meanwhile, in the aftermath of Desert Storm, the Defense Department worked with NASA to achieve improved multispectral imaging capabilities through acquisition of the *Landsat* 7 spacecraft.[61]

Navigation—GPS. Evaluations of the GPS navigation system expressed little criticism of the system's performance, especially after three-dimensional coverage could be supplied. Like DMSP, the assessment of GPS centered on the shortage of mobile receivers. Planners simply had not foreseen the need for sizable quantities of mobile receivers for large maneuvers or operations like Desert Storm. With so few military Selective Availability receivers on hand at the outset of Desert Shield, Coalition forces requisitioned less accurate, but more functional commercial sets. It took up to six months for their arrival, which limited training effectiveness. Above all, use of commercial receivers caused military authorities to forego encryption, which would have provided data with even greater accuracy. Throughout Desert Shield and Desert Storm, managers of the GPS program worried that Iraqi forces might take advantage of the "open" signals. Understandably, their primary postwar recommendation involved securing sufficient crypto-capable GPS receivers and providing thorough training in their use. Even so, Selective Availability remained a source of debate because space officials knew that a process termed Differential-GPS allowed users to work around Selective Availability to achieve highly accurate position information. Air Force priority following the Gulf War involved achieving initial operational status with a full constellation of 24 satellites, which occurred in 1993, and completing installation of receivers in aircraft by the end of the decade.[62]

Tactical warning and attack assessment. The integration of DSP warning and Patriot anti-tactical ballistic missile capability proved to be one of the great achievements of the Gulf conflict. Although the anti-Scud warning system exceeded every expectation, it took months to develop the necessary coordination with a space system that originally had been designed and configured for strategic warning, not tactical defense. Warning time for Patriot crews remained uncomfortably brief, while the satellite sensors could provide only general launch site and impact point identification. Desert Storm had clearly demonstrated the need for improved ballistic missile tactical warning and assessment and midcourse tracking capability. For years the Air Force had sought to improve the warning satellite network. In the early 1980s, the service studied a replacement program called the "Advanced Warning System," which the Strategic Defense Initiative Organization absorbed in 1984 and renamed "Boost Surveillance and Tracking System." By the end of the decade, pressure from a Congress worried about violating the anti-ballistic missile treaty led instead to the Organization's adoption of Brilliant Eyes and the return of the Boost Surveillance and Tracking System to the Air Force as a potential DSP replacement. By 1991 a modified version of the program reemerged as the Follow-on Early Warning System (FEWS).[63]

In the wake of Desert Storm, leaders like General Horner made FEWS their highest priority. The new system would retain its strategic capability but be far more effective against short-range tactical missiles. It would possess greater on-board processing capability and more flexible communications. Mobile DSP receivers would also become part of the improved system. U.S. Space Command's postwar assessment made its number one recommendation the normalization of tactical warning support through provision of the necessary equipment, including requirements in operational plans, and thorough training of personnel. Evaluators went on to declare that "what was said about warning is true for all space systems. All space support should be normalized... [and] institutionalized." In short, space must be integrated into all preexisting and new plans and become part of the mainstream for all services. Air Force space leaders had been promoting this theme for years, and would soon return to it in their renewed campaign for military space leadership.[64]

High costs and technological challenges, however, led FEWS down a rocky road in the early 1990s. A number of studies compared FEWS with various alternatives, including a combination of Brilliant Eyes and DSP satellites and a modified DSP system. Air Force officials also eliminated a number of FEWS sensors to reduce the expense and weight, which made it a candidate for the less costly Atlas II booster instead of the Titan IV. A replacement for DSP still had not been determined by the time the Clinton administration assumed office in early 1993. The new defense team made the issue a major focus of its so-called Bottom Up Review of defense acquisition programs. On the basis of the review, in early 1994 Defense Secretary Les Aspin canceled FEWS, declaring it too expensive. Meanwhile, the search continued for a more effective system than DSP. Replacement options for DSP included an Alert Locate and Report Missiles system (ALARM), that was proposed in the summer of 1994. After assessing several ALARM proposals consisting of both geosynchronous and low-earth orbiting satellites, congressional opposition led planners to settle on a new Space-Based Infrared System, termed SBIRS, that would involve a configuration of four geosynchronous-orbit satellites in its first phase.[65]

Communications. Along with tactical warning and attack assessment, military satellite communications (MILSATCOM) received special attention from the planners and postwar analysts. Not only did the Gulf War highlight both its importance and shortcomings, but for many years projected replacement systems had been among the most controversial space programs under development. Changing requirements, technological challenges, and high costs had led to delays and restructuring—and growing doubts about their operational future. To be sure, communications satellites provided Desert Storm forces the support they needed in spite of the variety of systems used and the fact that they had not been designed to provide intra-theater communications between commanders in the field. Moreover, they were stretched to the limit, highly exposed to jamming, and far less mobile than ground forces desired. DSCS, for example, provided rapidly moving ground forces a multichannel terminal with an 8-foot satellite dish, but available power and bandwidth limited the system's capacity, and prompted use of the higher-gain 20-foot antenna. The trade-off became less mobility and greater exposure to enemy forces.[66]

Military communications authorities looked forward to upgrading existing networks like DSCS, developing more-mobile receiver terminals, and introducing subsequent systems like the Navy's UHF "follow-on" system and Milstar to ensure reliable, global communications support—especially for the tactical operator. Most MILSATCOM concerns centered on the troubled Milstar (Military Strategic and Tactical Relay) program. In 1989 Congress had directed the Pentagon to restructure the program from strategic communications support to tactical requirements at considerably less cost. The Gulf War occurred in the middle of a major effort to reorient Milstar and save the program from outright termination. Desert Storm might well have rescued Milstar from certain cancellation.[67]

Milstar had emerged in the late 1970s from an Air Force proposal for a strategic satellite system (Stratsat). Stratsat was to consist of a four-satellite constellation designed entirely to support nuclear forces. It would avoid potential antisatellite threats by orbiting at supersynchronous orbits of about 110,000 miles, and operate in the extremely high frequency (EHF) range to provide more bandwidth for spread-spectrum anti-jam techniques. Considered too ambitious for so limited a mission, Stratsat gave way in 1981 to Milstar. Planners viewed Milstar as capable of both strategic and tactical operations, and they proceeded to add to the design numerous additional missions and requirements. In 1983 President Reagan accorded Milstar "highest national priority" status, which allowed the program to proceed with little regard for funding restrictions.[68]

From the perspective of systems development, Milstar represented a throwback to "concurrency" procedures which had characterized the Atlas ballistic missile development program of the 1950s. Program leaders tried to develop Milstar's "cutting edge" technology and system procurement concurrently, which led to delays, redesigns, and cost overruns. Thirty years earlier these kinds of problems seemed relatively unimportant to an Eisenhower administration desperately determined to produce an operational missile as quickly as possible. Over the course of the 1980s, however, Milstar's difficulties increasingly drew the ire of a budget-conscious Congress.[69]

Initially designed to provide EHF low-data-rate (LDR) communications, the eight-satellite constellation would benefit from crosslink capabilities and extensive hardening against radiation. The EHF range had the advantage of allowing use of antennas as small as six inches in diameter, which suited highly mobile special operations forces. Launched by the Titan IV, four of the satellites would operate in various polar orbits and the other four in geosynchronous orbits. Because Milstar's chief goal was survivability and not high performance, planners did not design it for high data rates or for each satellite to serve more than fifteen users simultaneously. As a result, it would supplement rather than replace existing satellites like DSCS and FLTSATCOM.[70]

Increasingly plagued by cost overruns and schedule delays, Milstar's original strategic orientation seemed anachronistic in the post-Cold War world. Desert Storm, however, reinforced interest in promoting Milstar's tactical capabilities, and the program underwent several alterations in the early 1990s after Congress demanded its restructure. Milstar also became a subject for the Pentagon's Bottom Up Review in early 1993. By early 1994, the program envisioned six rather than eight satellites, without the vast array of survivability features, and with fewer ground control stations. The first block of two satellites, referred to as *Milstar I*, would retain the limited-use LDR capability, but the next-generation *Milstar II* satellites would be equipped with a medium-data-rate (MDR) package to support tactical forces. On 7 February 1994, seven years after its projected launch, the first *Milstar I* satellite achieved a successful launch and on-orbit checkout. A second Milstar satellite was launched in November 1995, and the following month system operators achieved crosslinking. Plans called for launch of the first *Milstar II* satellite in 1999, and, by the year 2006, Air Force program managers expected to see a transition to a less expensive, lighter *Milstar III* Advanced EHF satellite. In the future, Milstar would supplement the Navy's FLTSATCOM and Ultra High Frequency (UHF) Follow-on (UFO) satellites but coexist with the successor to DSCS III. Nevertheless, in the mid-1990s the jury remained out on Milstar's ability to provide survivable, jam-resistant, global communications to meet the needs of the National Command Authorities, battlefield commanders, and operational forces at all levels of conflict.[71]

Although the Milstar debate drew most of the attention in the early 1990s, Desert Storm also raised the issue of small satellites for tactical communications that had been championed by Air Force operational leaders in the late 1980s. Although the two Scout-launched Marine MACSATs received considerable publicity, most analysts determined that "the war showed there was no limitation of capacity for tactical commanders, so the word is there is no need for small satellites." The Pentagon trend in the 1990s still seemed against light "tacsats" in favor of higher frequencies and other high-power transmission requirements, survivability, and tri-service satellite systems. Even so, DARPA and the services persevered with their modest light-satellite programs, and the debate continued.[72]

Space support. Space launch completed the triangle of special interest space programs in the Pentagon's early 1993 Bottom Up Review of space acquisition systems. It fell within the mission area of space support, which involved deploying and sustaining military systems in space. Desert Shield and Desert Storm had exposed the Achilles heel of the space program. When personnel from U.S. Space Command and Air Force Space Command reviewed U.S. 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. Yet these spacecraft had been scheduled well in advance of Desert Shield. In effect, the U.S. space launch system continued to reflect a policy of launching on schedule, not on demand. It simply could not respond to short-notice requests.[73]

The familiar conditions that had made space launch the space program's weakest link dated to the Eisenhower presidency. Beginning in that era launch systems and infrastructure had supported research and development rather than operational requirements, then fell into decay following the decision to use the Shuttle in place of expendable boosters. Despite the demand for expendable rockets after the *Challenger* tragedy, the space industry could not retool fast enough to meet rising demand. Moreover, military, civil, and commercial launch needs meant supporting three separate launch teams and related equipment. Aging boosters and range system components, as well as inefficient production lines and launch procedures, resulted in an expensive, operationally limited system. Space leaders had been trying for years to solve the launch dilemma.

On the eve of Desert Storm, the Advisory Committee on the Future of the United States Space Program, known as the Augustine Committee after its chairman, Norman R. Augustine, recommended deemphasizing Shuttle operations and developing "an evolutionary, unmanned but man-ratable heavy lift launch vehicle." On 24 July 1991, President Bush announced a new national space launch strategy that incorporated many suggestions offered by the Augustine Committee. Calling for continued use of improved expendable boosters, the President's National Launch System called for a new, heavy lift vehicle that would reduce launch costs and improve performance. Yet, late the following year, in November 1992, the Vice President's Space Policy Advisory Board's Task Group on The Future of the U.S. Space Launch Capability suggested canceling the National Launch System. Chaired by former Air Force Secretary Edward C. Aldridge, the Aldridge Report proposed instead a new program called "Spacelifter." The Spacelifter would be developed under Air Force leadership, using a single "core" vehicle to meet lift requirements of all three sectors of the space community—military, civilian, and commercial. This seemed to reflect Air Force Space Command's interest in developing a family of vehicles leading to operational systems.[74]

The Clinton administration's Bottom Up Review seemed to favor 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. In short, officials decided to proceed with modest improvements to the status quo, which many considered an acceptable solution. In the mid-1990s, the space launch issue remained far from resolved.[75]

In the aftermath of Operation Desert Storm, the Air Force played the central role in evaluating the capabilities of space systems to meet the needs of the warfighter. Air Force leaders realized that they must provide the necessary leadership if military space were to benefit from infrastructure modernization and new technological initiatives and, ultimately, achieve "normalization" of space within the Air Force and throughout the military community. But the momentum for change represented by the performance of space assets in the Gulf War diminished considerably when confronted by the challenges of developing a new generation of space systems and an effective launch capability. Moreover, continued fragmentation of the nation's space community in an era of budget austerity severely hampered efforts to make the changes Air Force leaders deemed essential. The situation called for strong, central direction, and the Air Force responded with another initiative, one designed to chart the course of military space into the post-Cold War future of the 21st century.