JOHN DASSOULAS and MICHAEL D. GRIFFIN

THE CREATION OF THE DELTA 180 PROGRAM AND ITS FOLLOW-ONS

The Delta 180 Program was spawned by a rare conjunction of circumstances: a major national need; the new, forward-looking Strategic Defense Initiative Organization; available funding; adaptable hardware; and, most important of all, an innovative and imaginative group of people in government, in industry, and at APL that became the Delta 180 team. This team became a driving force in the follow-on Delta 181, Delta 183, and MSX programs.

DELTA 180

The Strategic Defense Initiative Organization (SDIO), in its early days and with only a limited technical staff in place, urgently needed the assistance of other governmental and not-for-profit organizations with experience in space and weapons systems. David Finkelman, on loan from the Army Missile Command and who had worked with APL before, met with members of APL's Fleet Systems and Space Departments and the Director's Office on 17 April 1984. Samuel Koslov was charged to see whether some low level of technical support could be provided in areas such as guidance, control, structures, thermodynamics, and electronics. Toward the end of the year, SDIO also sought APL's views on some "quick response" space missions. This got our attention! As a result of the request, the Space Department accepted from Fleet Systems the lead role within the Laboratory, with Koslov continuing to act for the Director. At that time, Vincent L. Pisacane, Head of the Space Department, appointed John Dassoulas to be the Program Manager and asked Michael D. Griffin to be the Systems Engineer. On 20 November 1984, as part of the tasking for a work statement, we were asked to define a near-term flight experiment to support the concept of a boost-phase intercept, that is, destroying an Intercontinental Ballistic Missile (ICBM) during powered flight.

The Laboratory had long been concerned with the design and operation of land- and sea-based test ranges. Carl O. Bostrom, Director of the Laboratory, saw this type of experiment as an initial step leading to his concept of a space test platform. Pisacane, Koslov, Dassoulas, and Griffin met to discuss this new opportunity; with the Director's approval, we agreed to undertake a six-week study to define a near-term space intercept for SDIO. The only guidelines we were given were that the mission would be compliant with the 1972 Anti-Ballistic Missile Treaty, "look down, shoot down," and accomplished within two years—if it expanded to 30 months SDIO would lose interest in it.

Preliminary Planning

We assembled a design team and began to derive mission requirements. Before we had started, we were asked, "What can you do in a year?" This turned our thinking around completely, and we began to consider things we could lay our hands on. Returning from a meeting in Washington, D.C., we laid out some ground rules that might allow the mission to be done in a year. We assumed (1) it would not be a shuttle launch (payload integration and safety requirements for a manned space flight would take too long to satisfy), (2) it would be necessary to use only existing technology, and (3) only minimal documentation could be tolerated. We generated a master schedule and were well on the track to telling SDIO what they could have in a year and how it could be done.

Before the meeting, we had been considering several interceptor guidance technologies, including laser radar (ladar), passive infrared, passive ultraviolet, and millimeter wave radar. Since we were expert in the Aegis and Standard Missile 2 systems, a semiactive homing system using target illumination by missile ships was one of the first concepts considered. We were seeking something that could lead directly to a first-generation Strategic Defense Initiative/Kinetic Energy Weapon platform. We were talking about hit-to-kill, based on the results of the Army's Homing Overlay Experiment, but with guidance upgrades to deal with an accelerating target. The Homing Overlay Experiment had intercepted an incoming ballistic missile with a ground-launched interceptor using infrared homing.

With a firm one-year schedule, we (Dassoulas and Griffin) considered only conventional radar, which we felt was proven. (Later, we realized that we could have had the ladar. We were too conservative!) On the basis of tactical experience, we knew that hit-to-kill was not a high probability with this technology but felt that any self-respecting guidance system should be able to place an interceptor within 100 feet of a target vehicle. The actual demonstration of a modified proportional guidance system was, in itself, an important experimental objective. We calculated how much loose steel (ball bearings) the spacecraft would have to carry to saturate a reasonable area (a few hundred square feet) with lethal pellets. We then thought that this was at least close to the size of a typical blast fragmentation warhead carried on a surface-to-air or air-to-air missile. When this thought occurred, we consulted with Michael W. Roth, in the Fleet Systems Department, who indicated that there had been considerable analysis of Standard Missile's capability against space targets and that this idea was not completely ridiculous. So, by the end of that crucial day, late in January 1985, we had derived a "kluged up" interceptor composed of a tactical missile radar seeker with a warhead, an unspecified control system, and rocket motors for propulsion. Obviously, the aerodynamic guidance systems in the available missiles were not going to be useful. We had not yet identified an interceptor vehicle for a particular target. Our early baseline was Standard Missile but we had agreed to investigate Phoenix, the Advanced Medium Range Air-to-Air Missile (AMRAAM) (in development), and others to determine the best candidate.

We began considering launch vehicles for both the target and the interceptor and had previously agreed "no shuttle," but we had not yet discussed this matter with SDIO. The results of inquiries regarding the availability of Atlas and Titan vehicles were not promising, and the Scout payload capability was too low. Only Delta remained. McDonnell Douglas Astronautics Corp. indicated that two, possibly three, vehicles were available because NASA had off-loaded payloads from Delta to add to the shuttle manifest. A call to the Delta Office at Goddard Space Flight Center provided confirmation. We then assumed that we would launch on a Delta vehicle.

During the first week in February 1985, Koslov, Pisacane, Dassoulas, and Griffin met with SDIO officials to brief them on the basic approach. Col. (now Gen.) Malcolm R. O'Neill was pleased with the concept and would carry it forward to Gen. James Abrahamson. He also informed us of a peer review of our concept and others to be held on 20 February 1985, at Lockheed's Washington Headquarters.

Compliance with the Anti-Ballistic Missile Treaty

Before the meeting, Col. O'Neill arranged for Koslov, Dassoulas, and Griffin to discuss Anti-Ballistic Missile Treaty compliance with members from the legal and political staffs of the Department of Defense and State Department. During the meetings, we received a rude awakening. Until then, we had been loosely planning to shoot at some separately launched target such as Scout, Minuteman, or Poseidon but soon learned that to be compliant with the Treaty we had to launch the target vehicle suborbitally, from either Kwajalein Atoll or White Sands Missile Range. Neither site had the means to orbit anything. Not using those sites imposed severe restrictions on target identity (no ICBM or components thereof, no object on an ICBM-like trajectory or velocity). We had discussed a possible launch from Kwajalein but promptly abandoned that idea after learning that the launch facilities had been disassembled after completion of the Homing Overlay Experiment Program and could not be restored within a reasonable time or for a reasonable cost.

For a short while, we were between "a rock and a hard place," trying to find a viable mission within the Treaty constraints. It occurred to Griffin that the Delta second stage (D2) was a restartable NASA stage, and not an ICBM, thus satisfying Treaty compliance. After orbit insertion and interceptor deployment, we could restart the D2 along a non-ICBM trajectory and let the interceptor go after it. This idea was well received because of its high probability of approval by DoD and the State Department. During the approval cycle, some cooperation by the target was requested to help ensure success of both the approval process and the intercept. The response was manifest in the form of a corner reflector that provided (as it turned out, very desirable) target enhancement. The meeting concluded with the final piece of the basic mission scenario in place.

The Final Resolution

By the time of the meeting on 20 February, Lt. Col. Michael J. Rendine, Special Assistant for Space Experiments, SDIO, was on board. The meeting was chaired by Col. O'Neill and was attended by most of the major aerospace contractors and representatives of the Air Force Space Division. Most of the presentations were Treaty-noncompliant, expensive, and not responsive to the schedule's urgency. The APL concept, however, as presented by Griffin, met all the criteria. By the end of the day, Col. O'Neill indicated that he had seen nothing to dissuade him from pursuing the APL mission concept, and he was going forward with it to Gen. Abrahamson.

High-level meetings of members from SDIO and NASA Headquarters resulted in the dedication of the Delta vehicles to the SDIO mission. Although the launch vehicle situation had been settled, we still had not identified the seeker or the propulsion hardware by the end of February 1985. A quest for residual hardware from the Homing Overlay Experiment Program proved fruitless. It occurred to Dassoulas that McDonnell Douglas might have some spare second-stage engines, and perhaps one of them might be about the right size. In a conversation with Kenneth Englar (McDonnell Douglas Delta Chief Engineer), a quick mission assessment to size the propulsion system was accomplished. Fate smiled on us—they had the hardware to do the job. The following week we had our first face-to-face meeting with McDonnell Douglas, and from then on they were on the team as much more than just the launch vehicle contractor.

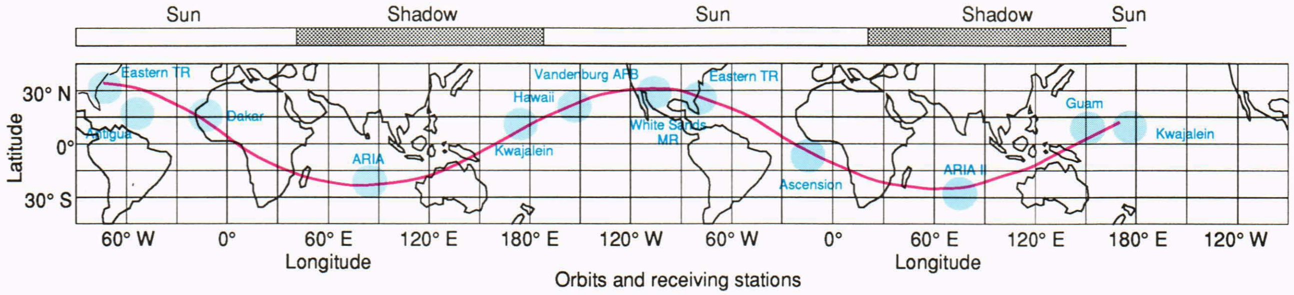
We were also converging on the Phoenix missile as having the seeker of choice. Its active radar seeker in homing mode was, essentially, a sealed system adaptable to space use. Lt. Col. Rendine managed to open official channels through NAVAIR, who approved a visit to Hughes Aircraft Co. by James C. Hagan, Roth, and Griffin. Phoenix clearly was the best available seeker in March 1985. We examined several alternatives but for various reasons did not go with any of them.

Our briefing to Gen. Abrahamson was set for 1 April 1985. Guidance and control simulations were under way to analyze the end game. The Fleet Systems Department had undertaken this task because they had a large base of experience with intercept guidance analysis. One of the early conclusions to emerge was that the encounter had to be approximately head-on because the interceptor did not have a significant acceleration advantage over the target. (A guideline for the suitability of basic proportional navigation for intercepting a maneuvering target is that the interceptor must have at least a 3:1 lateral acceleration advantage.) The head-on intercept was concurred with by Lt. Col. Rendine. The resultant orbital geometry became a cross-orbital plane intercept, where the target and interceptor were placed perpendicular to the orbital plane before intercept initiation. This geometry posed some challenges for real-time tracking and orbit determination to allow the end game to be properly established. Figure 1 shows the plan.

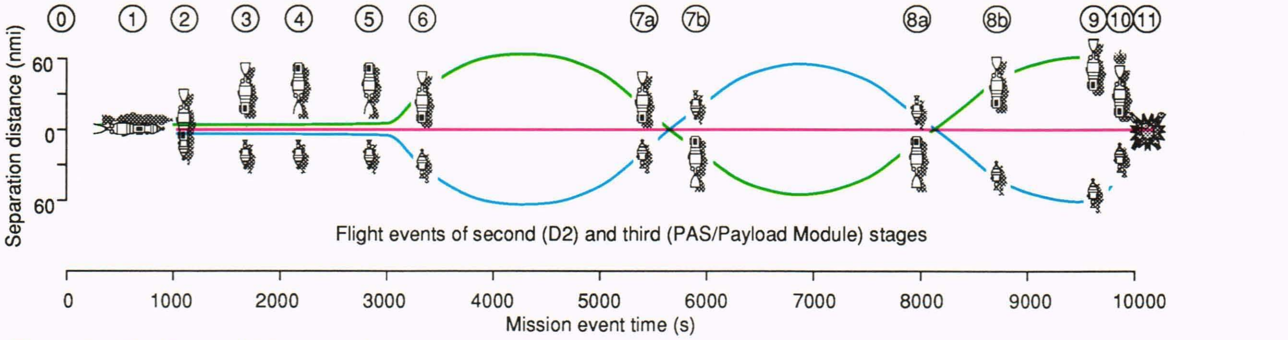
By the last week of March 1985, we had a conceptual design that most of us believed would hold up. After several dry runs, we briefed Gen. Abrahamson on 1 April 1985. Follow-up questions and "what ifs" resulted in starting the encounter from a longer initial range than had been planned (220 instead of 20 km) and inserting a coast period into the end game to prevent the final speed from exceeding the relative velocity that the Phoenix Doppler radar could handle. Otherwise our approach remained unchanged.

On 12 April 1985, we received word from Lt. Col. Rendine that Gen. Abrahamson had given a "go" for the mission, with a nominal 14-month schedule from the time of receiving authority to proceed. Program kickoff occurred on 15–16 May 1985 at APL and rapidly accelerated to a full-bore program. The Preliminary Design Review was held in June 1985.

There was an urgent need for more infrared data on rocket plumes and bodies and on backgrounds in space. Also, there was a nagging question, but almost no available data, on whether ultraviolet sensors could yield information useful to SDIO. The primary original purpose of the Delta 180 Program was to understand the problems of tracking and guidance for a space intercept. The possibility of using ladars was intriguing, but there also was the overwhelming concern of trying to build a complex, multipurpose spacecraft on a short schedule. After much soul-searching, the decision was made to go ahead with a Science Module. The absolute rule was, however, that nothing involved with the Science Module, no function (or malfunction), could interfere with the primary intercept mission. The go-ahead was given to try to assemble off-the-shelf sensors, including a ladar and an ultraviolet/visible system and two infrared systems that could function completely independently, receiving only a single signal from the D2 guidance system to start the Science Module timing sequence. The Laboratory had agreed to act as technical advisor for



Orbits and receiving stations



Flight events of second (D2) and third (PAS/Payload Module) stages

Figure 1. The Delta 180 Program flight events. (0) The Delta 180 experiment is launched from the Eastern Test Range, Cape Canaveral, Fla., on 5 September 1986. (1) After burnout of the first stage, the combined second (D2) and third (Payload Adapter System, PAS) stages are placed in a 220-km circular orbit by the D2 rocket engine. (2) The combined D2/PAS structure is rotated to fly cross-plane to the flight orbit. (3) The D2 is separated from the PAS by means of springs but continues in the same orbit. Instruments on the D2 view the separation. (4) The D2 is turned through 180°. Its instruments view the Earth limb and Earth. (5) The D2 rocket engine thrust provides a slightly altered orbit. The D2 instruments view its own rocket exhaust plume. (6) The D2 and PAS are turned to face each other again, nose-to-nose. The D2 laser tracks the separation distance between the D2 and the PAS. (7a) Just before Cold Pass 1, the D2 is maneuvered so that its instruments acquire an Aries 1 rocket launch from White Sands Missile Range, N. Mex., at a distance of 480 km. (7b) The D2 and PAS are turned again to face each other nose-to-nose. (8a,b) Near Cold Pass 2, the D2 and PAS are turned again so that the D2 instruments continue to face the PAS. (9) At maximum separation (220 km), the D2 and PAS rocket engines are ignited to provide thrust for the two spacecraft to accelerate toward each other. The D2 instruments obtain ultraviolet, visible, and infrared signatures of the PAS. (10) After a coasting phase, the D2 and PAS rocket engines are ignited again at a separation distance of 60 km. The PAS guidance system provides terminal homing. (11) Collision takes place in space between the two accelerating bodies 9871.6 s after launch and 36.7 s after step (9).

the overall experiment. It now took on the responsibility of designing a spacecraft essentially without propulsion and guidance (which were supplied by the D2 stage). In June 1986, the Science Module was shipped to Cape Canaveral for the start of launch preparations (Fig. 2). Vector Sum (the program code name) launched Delta 180 on 5 September 1986, 16 months after the program's start. Approximately 10,000 seconds (2¾ hours) later, a direct hit occurred at a closing velocity of 2.9 km/s (Fig. 3).

What Was Left Unsaid

Many key events that occurred after the program began deserve mention but are not elaborated in this article. They included the addition of Draper Laboratory to our guidance analysis team, the regularly held reviews, the development of the instrument complement and the Science Module, the advanced Mission 2 (which became Delta 181), mission design discussions concerning in-plane versus cross-plane scenarios, the warhead modification that removed the fragmentation jacket to reduce the "junk" in space, the orbit debris and safety panel, the Delta 178 failure and the subsequent modifications to the Delta 180 launch vehicle, extensive flight operations involving all major ranges, the precise photometric coverage of the intercept (both airborne and from the ground at Kwajalein Missile Range), and the late addition of an Aries rocket launch at White Sands to provide additional opportunities for scientific measurements (or observations). At the very last was the tedious process of clearing a launch time with the Air Force and others, including the consideration of foreign government assets in space that might be placed in jeopardy by our mission.

This mission would not have been possible without the talents and dedication of the Delta 180 team members. Several key individuals at APL undertook major responsibilities for tasks vital to the achieved performance. Thomas B. Coughlin managed the Science Module design, development, instrument acquisition, and integration. Thomas L. Roche directed the integration of experiments and subsystems and was test conductor. Larry J. Crawford undertook the task of intercept verification and aircraft instrumentation, and flew to the Cape from Kwajalein with the video films confirming the intercept. Richard W. Eakle organized and led the team that managed flight operations, establishing the vital communications links and coordinating the activities of all ranges involved. He also was responsible for the timely issue of the three-day report of mission performance. James F. Smola guided the effort to acquire and launch from White Sands Missile Range an Aries rocket with an instrumented reentry vehicle designed to produce data for a future mission. This was accomplished in less than one year, and the launch was flawless. It produced plume data and exercised the infrared instruments on the Science Module. (The ultraviolet systems had to be turned off for fear of overloading the sensors.)

James C. Hagan accepted responsibility for analyzing the orbit debris and developed the operations plan for launch-window clearance and evaluation. This work has become the benchmark against which future missions will be compared. Charles Brown directed the modification program in which the warhead igniter and fuze were redesigned. Later, the fragmentation jacket was removed because of debris considerations. He and his team from the Naval Weapons Center, China Lake, and the Naval Surface Warfare Center delivered a redesigned, *and* fully tested, blast-only warhead to the mission. Glen H. Fountain took on the task of designing a new ultraviolet/visible imager/spectrometer sensor that produced data of incalculable value to SDIO. A truly su-

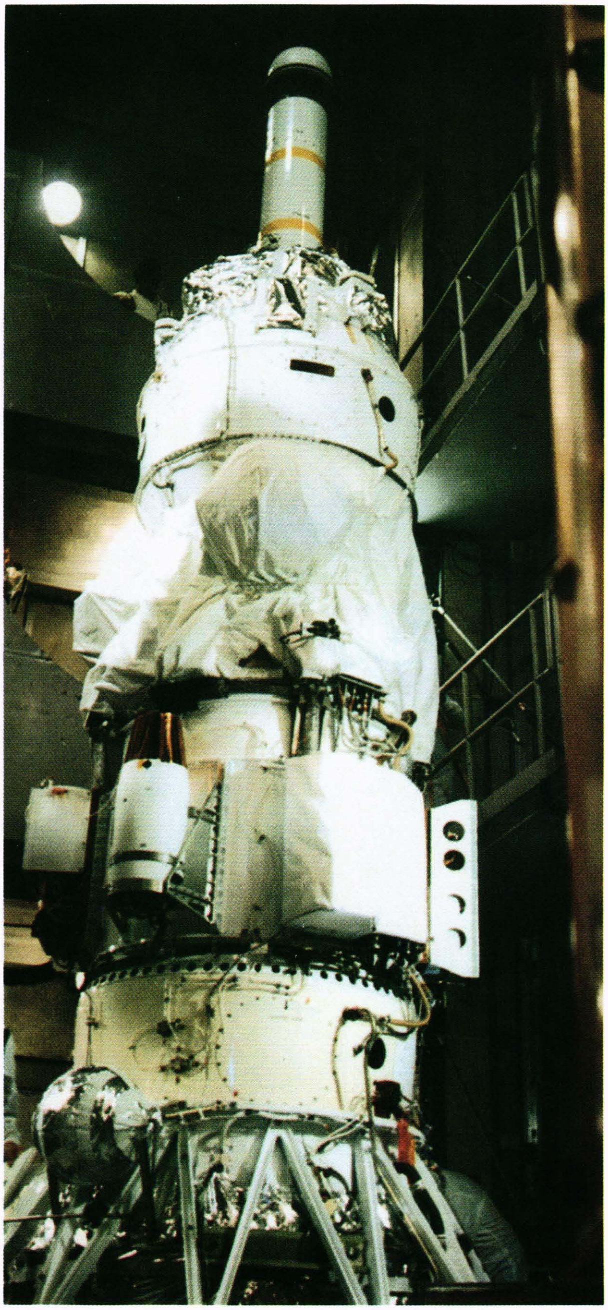


Figure 2. The Sensor Module (the target) and the third stage (the interceptor) on the Delta 180 launch vehicle at Cape Canaveral, Fla.

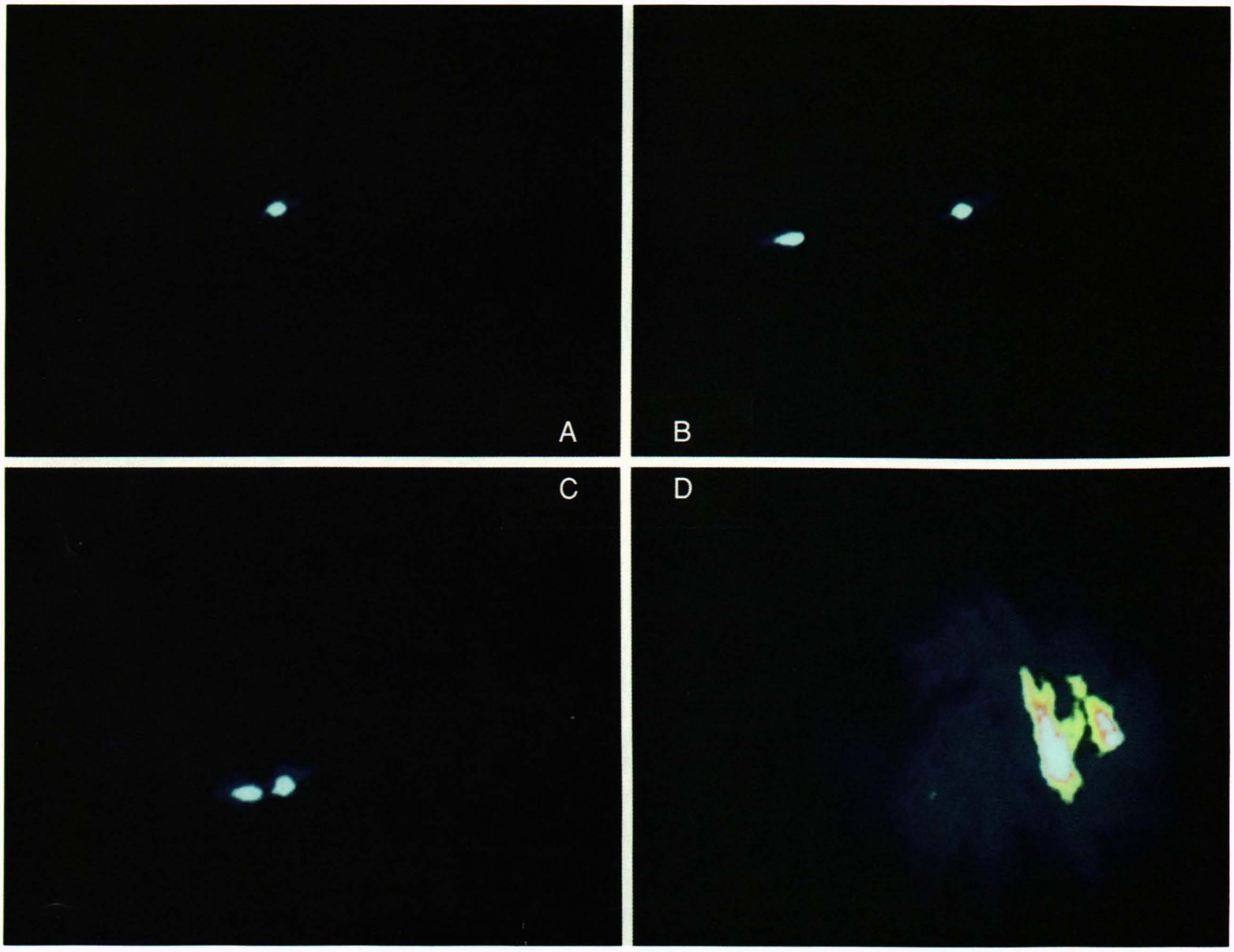


Figure 3. The intercept (computer-enhanced) as viewed in the visible spectrum from an observing aircraft. **A**. The Sensor Module. **B**. The interceptor approaches. **C**. Close approach. **D**. Direct hit.

perb instrument! Koslov took on the role of Program Scientist for the first year to oversee the initial development of the Science Module. Ching I. Meng later followed as Program Scientist for Delta 180/181, predicting instrument performance and the implications thereof. He led the post-flight analysis effort and presented the results in both oral and written reports. The data yield has been surprising and monumental. Bruce B. Holland was designated Assistant Program Manager. He undertook the administrative and fiscal aspects of Delta 180 while assuming the growing technical and managerial responsibilities for Delta 181, which was maturing as a parallel effort. J. Courtney Ray, with his creativity and systems-oriented approach to space mission design and spacecraft systems engineering, was an absolutely essential member of the Delta 180/181 team.

Detailed aspects of this mission are discussed elsewhere,[1] but we felt that a stirring of the "primordial soup" was in order, to acquaint the readers with the creative processes that led to this most rewarding and technically significant mission.

Epilog

On 2 December 1986, John Dassoulas and Michael D. Griffin were awarded Department of Defense Distinguished Public Service Medals. On 11 May 1987, Lt. Col. Michael J. Rendine was awarded the Defense Meritorious Service Medal.

DELTA 181

Background

Delta 181 went through a remarkable evolutionary process before its emergence as the mission that was finally implemented. As early as August 1985 (over a year before the Delta 180 launch), mission planning was underway on the follow-on. First thoughts involved a more ambitious intercept than could be accomplished by the Delta 180. Mission 2, using Delta 181 and 182 boosters, was conceptualized but never implemented because it would have stressed the 1972 Anti-Ballistic Missile Treaty. The SDIO scrupulously adhered to the Treaty, and as much attention was devoted to Treaty compliance as to technical reviews. The Delta 182 launch vehicle was eventually used to deploy an urgently needed Indonesian communications satellite. Their extant system was rapidly degrading, and the dispersed islands composing Indonesia use spacecraft as their principal means of communication.

By September 1985, another concept was proposed that incorporated a full-spectrum complement of sensors, and Delta 181 became a comprehensive phenomenology mission. A probe (an independent vehicle) was included on the spacecraft in addition to a large complement of test objects for calibrating the sensors and whose physical characteristics would be observed by the sensors. The Army became a major program participant, providing the test objects and dispensing apparatus. The Air Force undertook the probe development. The instrument complement was selected, and the conceptual design of the spacecraft was initiated. On 20 January 1986, Gen. Abrahamson was briefed on the mission; he then gave the "go ahead." Funding was provided, and detailed design and mission planning got under way. In parallel with this effort was the Delta 180 fabrication, systems integration, and testing. The successful conduct of the Delta 180 experiment resulted in the deletion of the probe from Delta 181 and the incorporation of a plume generator. A gas-release experiment was also added as Science Package 5. Additional studies were conducted on a variety of mission enhancements that were not implemented but which resulted in some schedule relief and a new ship-to-the-Cape date of 30 November 1987.

Although Delta 181 became solely a phenomenology and test-object sensing platform, its development oversight continued from the Kinetic Energy Weapons Office of SDIO.

Mission Description

The Delta 181 Mission conducted a number of experiments, crucial to development of the Strategic Defense Initiative, using instruments integrated in the Sensor Module. The experiments were designed to fulfill the principal objectives of the mission, which were the observation and characterization of various test objects, rocket exhausts, and vehicle outgases. Secondary mission objectives consisted of the observation and characterization of various space, Earth, and Earth-limb backgrounds and the quantification of spacecraft glow phenomena.

The Delta 181 Mission itself represented one of the most complex and ambitious unmanned experiments ever conducted. The McDonnell Douglas Delta rocket boosted the various instruments, computers, test objects, and observation rockets into a low earth orbit. The test objects were ejected from the satellite for observation and tracking against the natural backgrounds expected to be seen by an attacking ballistic missile in midcourse flight.

After deployment of the test objects, several rockets were launched to provide exoatmospheric plume signatures for the instruments to observe. A subsatellite released test gases to simulate vehicle outgases in space. The Delta platform executed more than 200 maneuvers expected to be needed for a low-orbit battle station. The maneuvers offered the passive instruments opportunities to sample rapidly changing backgrounds, view test objects against such backgrounds, and possibly determine the extent of contamination presented by the spacecraft glow phenomenon.

To attain these objectives, the mission used an array of state-of-the-art observation instruments covering wavelengths from the far ultraviolet through the visible and out to the long-long wavelength infrared range. The passive and active instruments, along with support functions (power, telemetry, recorder, flight processor, etc.), were mounted on the exterior of a 12-foot extension of the D2 that was a component of the spacecraft in orbit (Fig. 4). The spacecraft's flight processor, working with sen-

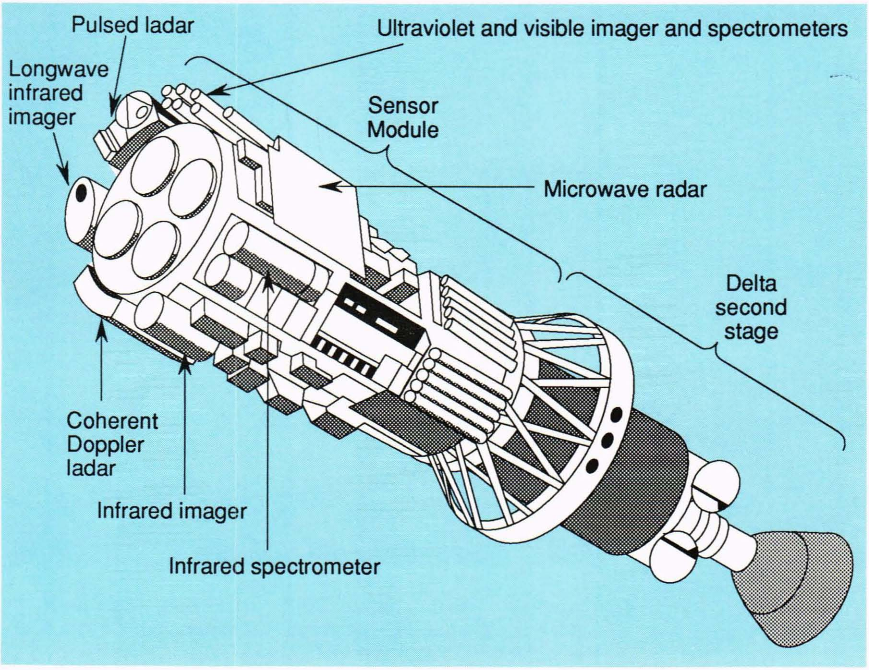


Figure 4. The Delta 181 Sensor Module and second stage, showing the arrangement of the scientific instruments.

sor measurements, maneuvered the 6000-lb spacecraft as it made the observations. Closed-loop tracking, acquisition, and reacquisition of multiple objects were required during conduct of the mission, and the data are being used for future system development.

The seven-instrument complement for the SDI space platform experiment consisted of two infrared imagers, an infrared spectrometer, an ultraviolet and visible instrument, two laser instruments, and a microwave radar. The Lockheed-built infrared imager generated a multicolor image in the short and medium wavelengths, while the Aerojet infrared instrument provided imagery in the long-wavelength regimes. Spectral information in the infrared range was derived from the two variable-wheel spectrometers of Space Systems Engineering's instrument. The integrated Sensor Module and launch operations are seen in Figures 5 through 9.

The APL-developed Sensor Module consisted of six sensors: an ultraviolet imager and a visible imager to complement the infrared imagers, and four linear-reticon spectrographs whose ranges overlapped to observe the visible and ultraviolet ranges.

Delta 181's active instruments included the pulsed ladar built by GTE Government Systems Corp., a coherent Doppler ladar built by Martin Marietta Orlando Aerospace, and a continuous wave Doppler radar built by Teledyne Ryan Engineering. The instruments were integrated into the Sensor Module during the summer of 1987 and underwent environmental testing at NASA's Goddard Space Flight Center in November 1987. The Sensor Module was delivered to Cape Canaveral in early December for integration with other flight elements. Launch was on 8 February 1988.

The mission operations were conducted in two phases: data acquisition during test-object and phenomenology observations, and data retrieval, planned for two weeks but carried out for two months owing to extended battery life. Delta 181 reentered on 2 April 1988 over the Atlantic Ocean equatorial region.[2]

Mission results have been published in five documents. The raw data now reside in the Army's Space Defense Command Thrusted Vector Central Data Facility in Huntsville, Ala.

DELTA 183 (DELTA STAR)

Background

Delta 183 was conceived in the field while preparations for the Delta 181 launch were in progress. Col. L. J. Otten of SDIO arrived at our Cape Canaveral Office on 6 January 1988 with the germ of an idea from Gen. Abrahamson. A very simple concept for a Scout class payload and a launch within four months was required. The launch was to precede the next summit meeting of the United States and the Soviet Union. The "simple concept" rapidly escalated to a Delta-class mission with the arrival of Lt. Col. Rendine, Griffin, Pisacane, and Coughlin. Note that an increase in mission complexity at this time did not result in any schedule relief.

Most of the experts in the APL Space Department and McDonnell Douglas Delta Program were in the field,

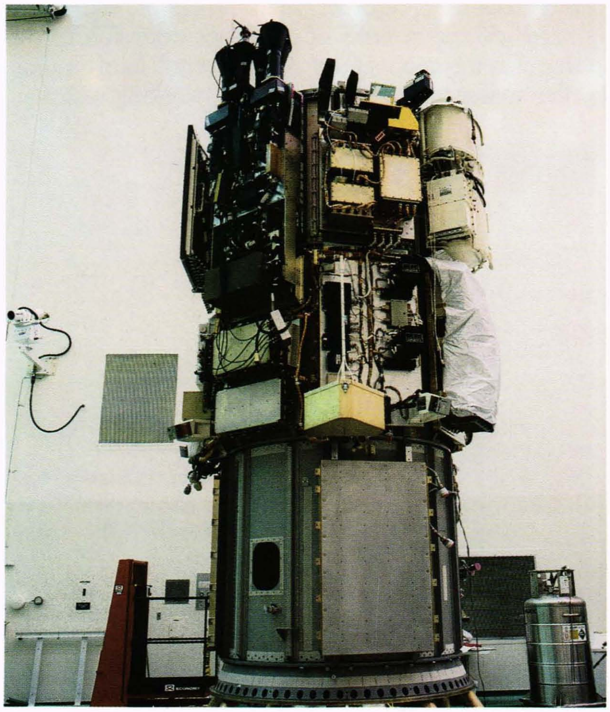


Figure 5. The Delta 181 Sensor Module in a test area at Cape Canaveral. The ultraviolet and visible imagers and spectrometers, the pulsed ladar, and the long-wave infrared imager are seen at the top.

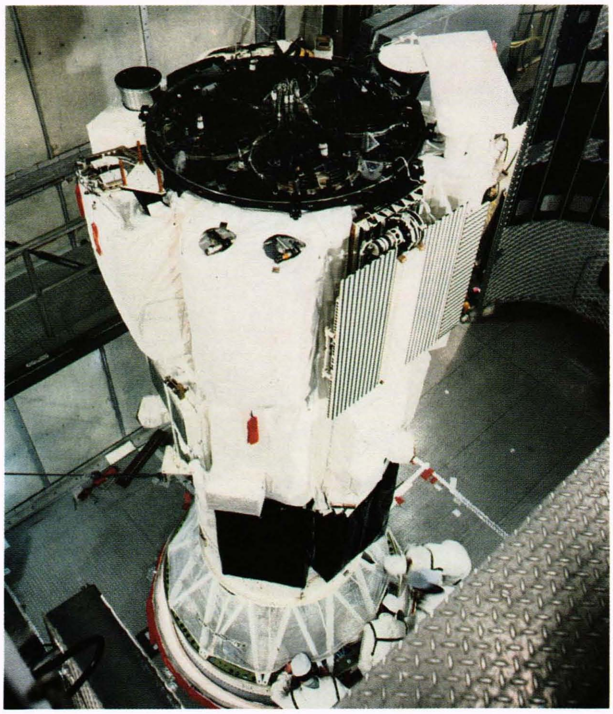


Figure 6. The integrated Delta 181 Sensor Module on the launch vehicle at Cape Canaveral. The test object dispenser and the microwave radar are visible.

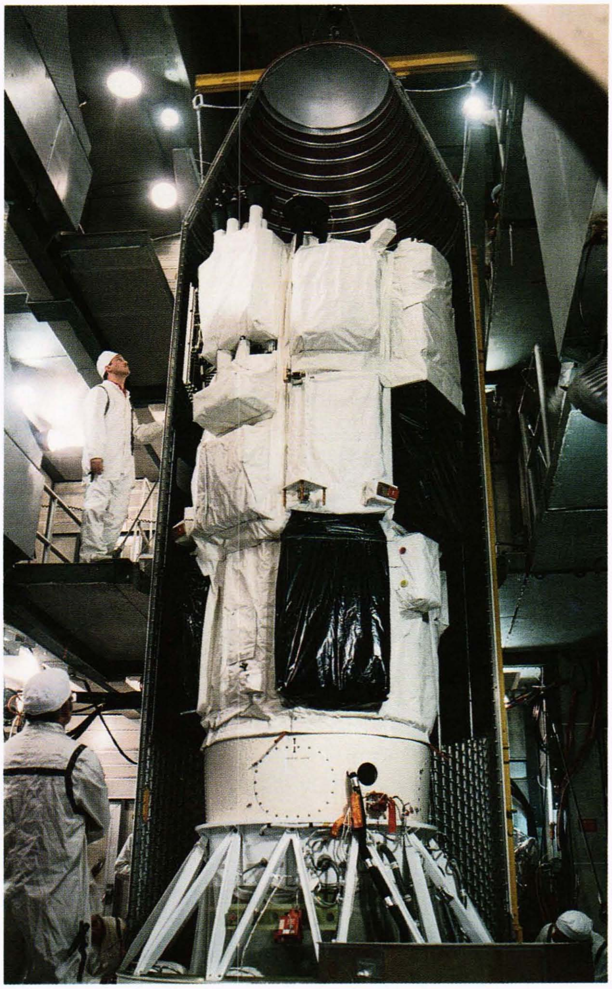


Figure 7. The heat shield being installed on the integrated Delta 181 Sensor Module. Thermal blankets cover the spacecraft.

Figure 9. Lift-off of the Delta 181 on 8 February 1988, 2207 UT.

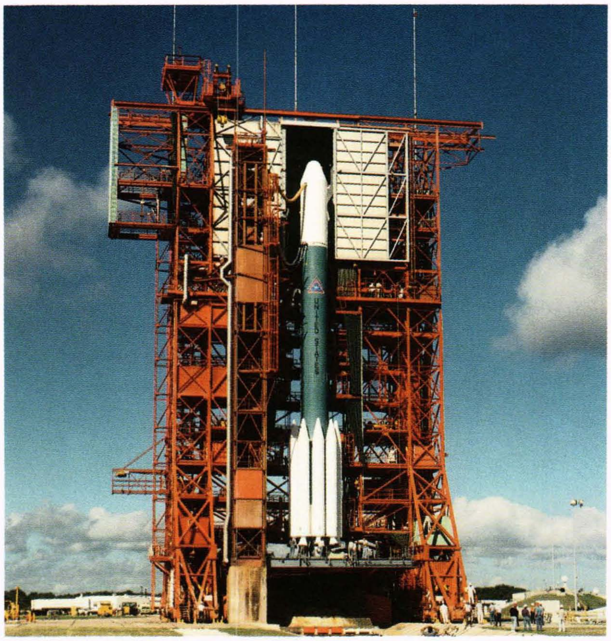


Figure 8. The Delta 181 launch vehicle and spacecraft. The service tower is ready to be rolled back for the launch.

and it was not surprising that the new mission developed while the team was at Cape Canaveral. Pisacane designated Coughlin to lead the Delta 183 effort, and mission definition began in the McDonnell Douglas "boxcar" at the Cape. Most of the APL effort was carried out by staff members who had worked on Delta 180. Roche led the Sensor Module development and test effort. By the effective use of residual components and systems from Deltas 180/181 and a superb team effort on new devices, the Sensor Module was delivered to McDonnell Douglas, Huntington Beach, Calif., within nine months of the go-ahead. The Power Module was integrated with the second stage, and the spacecraft was shipped to Cape Canaveral exactly one year after Delta 181 was shipped.

Delta 183 was the third in the Delta series of experiments conducted by SDIO. It continued the line of research of its predecessors, focusing on rocket plumes from a variety of boosters and performing high-latitude observations of environmental backgrounds. Several sounding rockets were launched during the experiment, enabling the sensors to collect characteristic plume data. The sensors also gathered data on other space launches and made observations of auroral phenomena. The data are being used in the design and engineering of a broad range of systems for strategic defense.

Sensor Module and Instruments

The 49-in.-high Sensor Module had an outside diameter of about 86 inches, including instruments, and weighed about 1538 pounds. Among the instruments were seven video imagers, a ladar, an infrared imager, and a materials experiment. The experiments were mounted around the exterior of the module.

The ultraviolet and visible instruments included four imagers and four photometers. Two were high-sensitivity intensified video cameras responsive to ultraviolet light. Two other cameras imaged in visible light with different fields of view. These instruments were built by APL. One of the ultraviolet video cameras was built by the Air Force Academy; the other, for imaging selected targets in four ultraviolet bands, was built by the Jet Propulsion Laboratory.

A third optics-based experiment was the midwave infrared video camera, developed by General Electric's Astro-Space Division. Designed for the space shuttle and modified for the Delta Star mission, it acquired infrared information on plumes and the space environment and acquired and tracked targets. This tracking ability was used to keep the target within the fields of view. The long-wave infrared camera was developed by the Hughes Aircraft Co.

Together, these instruments provided greater understanding of plume emissions and the environmental backgrounds against which they may be observed. The observations included the detection of sounding rockets launched from Wallops Island, off the Virginia coast.

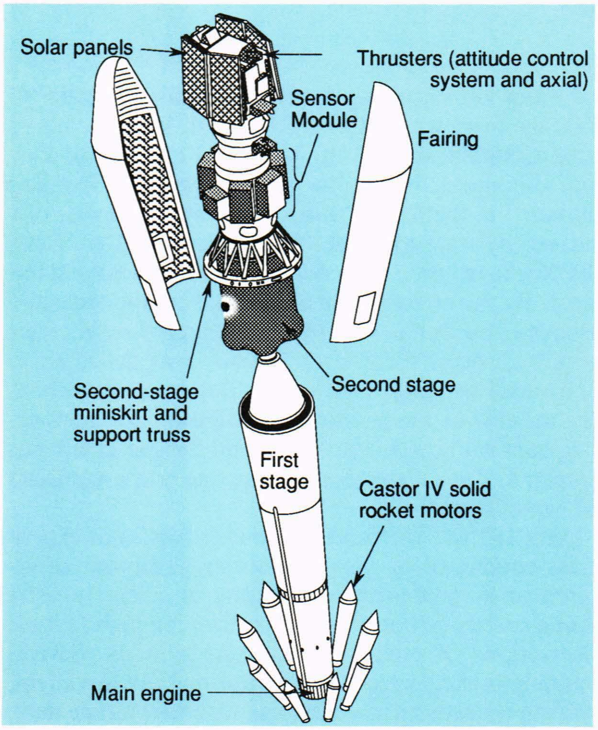


Figure 10. The Delta 183 (Delta Star) spacecraft and launch vehicle.

Built by McDonnell Douglas Astronautics, the pulsed laser ranging and tracking instrument helped to guide the spacecraft. It used optics to determine distances between objects in space. The last instrument was a materials experiment designed and built by Sparta to test the effects of the space environment on various coatings, materials, and high-temperature superconductors.

Integration of the instruments onto the Sensor Module took place at APL during the summer and fall of 1988. The Module was delivered in late November 1988 to Cape Canaveral, where it underwent prelaunch tests and flight preparations until launch on 24 March 1989. Figure 10 shows the launch configuration and Figure 11 the orbital configuration. Once the spacecraft was stabilized in orbit, data from the instruments were collected by recorders encapsulated inside the Sensor Module and transferred to a ground station for analysis. The data are being added to information gained by the Delta 180 and 181 missions. Delta Star continued to operate until its attitude control fuel was exhausted in December 1989.

Epilog

On 27 November 1989, Thomas B. Coughlin, Program Manager, was awarded the Department of Defense Medal for Distinguished Public Service.

MSX, THE MIDCOURSE SPACE EXPERIMENT

The Midcourse Space Experiment, MSX, is the next major effort in sensing technology. The program is being conducted by APL for the SDIO Sensor and Interceptor Technology Directorate (SDIO/TN/S). The MSX will be primarily a data collection experiment, concentrating on the phenomenology of target detection and tracking. It

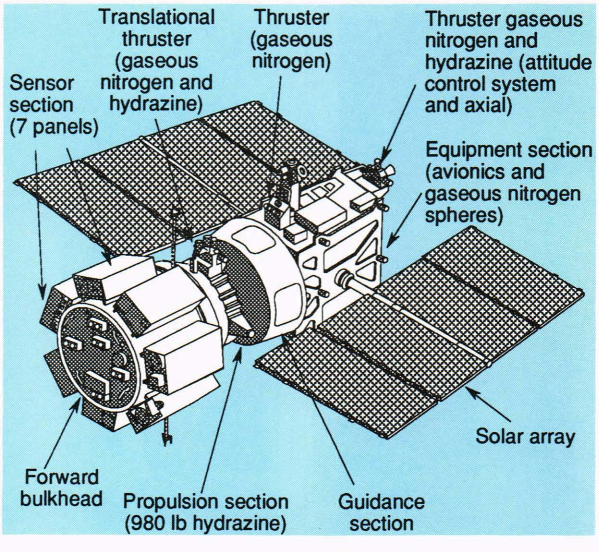


Figure 11. Design features of the Delta Star. Its mission life is greater than 180 days, it makes maximum use of available hardware, and it can accommodate all the required equipment and sensors to achieve the mission objectives.

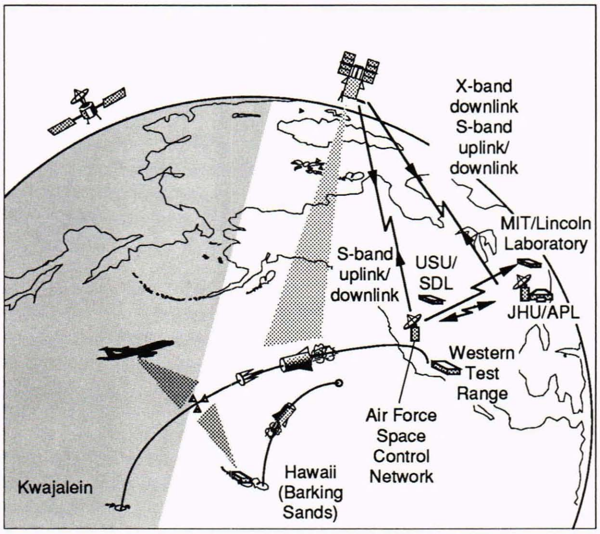


Figure 12. The concept of the Midcourse Space Experiment (MSX) mission. The spacecraft will be in an 888-km-altitude, sun-synchronous orbit and will feature on-board data storage. Targets will include dedicated ICBM's and sounding rockets, cooperative ICBM's, and satellites, against Earth-limb and celestial backgrounds.

will also gather both celestial and Earth-limb background data and data on the understanding and control of spacecraft contamination.

The MSX spacecraft will make long-duration collections of complete data sets essential for ground data-processing demonstrations by the Space- and Ground-Based Surveillance and Tracking Systems. The Laboratory will develop the spacecraft subsystems, integrate and test the spacecraft and instruments, and provide launch support, mission operations, and data acquisition. Max R. Peterson leads this effort as APL Program Manager.

Various targets will be viewed by the sensors on board the orbiting spacecraft. A space infrared imaging telescope (SPIRIT III) provided by the Space Dynamics Laboratory of Utah State University (USU/SDL) is a cryogenically cooled long-wave infrared radiometer/interferometer designed to track reentry vehicles in space. The Massachusetts Institute of Technology Lincoln Laboratory has supplied a visible wavelength instrument to track other satellites and also reference objects. A signal and data processor experiment, developed by SDIO/TN/S and built by Hughes will demonstrate real-time on-board signal data processing and orbital radiation effects. An ultraviolet and visible imager, a spectrographic imager, and a contamination experiment complement of instruments were provided by APL and/or as Government Furnished Equipment. The contamination experiment will monitor mirror contamination and the overall spacecraft environment, particularly near the sensors.

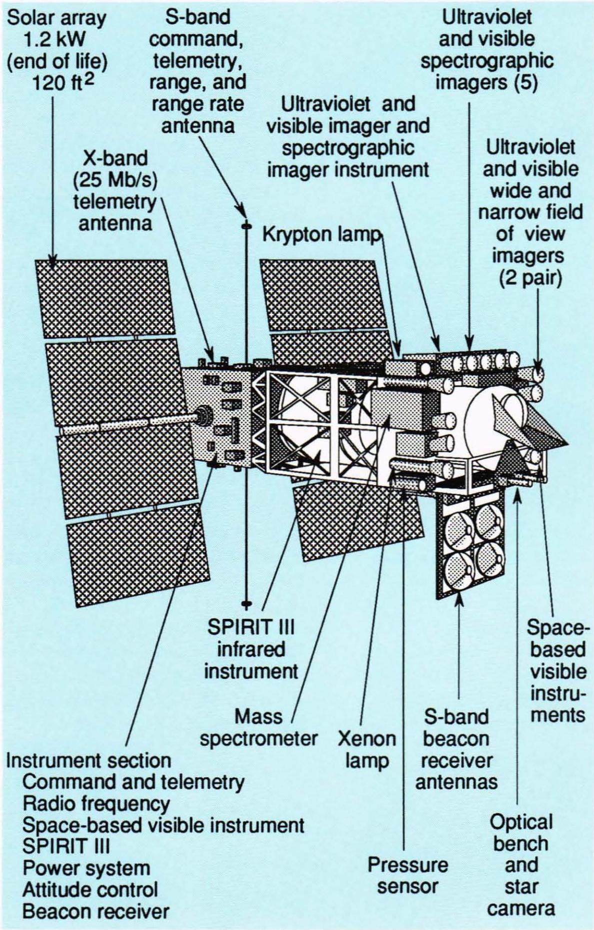


Figure 13. The experiments and instrumentation on the MSX spacecraft.

The MSX will provide the first demonstration, in space, of technology that could identify and track incoming ballistic missiles during their midcourse flight phase. It will be launched from Vandenberg Air Force Base, Calif., into a 99.2°-inclination, 888-km-altitude, sun-synchronous orbit. Launch is expected in mid 1993, using a Titan 2 launch vehicle augmented with eight solid boosters.

Figure 12 is a systems overview of the spacecraft, test objects, and ground system elements. Figure 13 shows the MSX in its deployed orbital configuration.

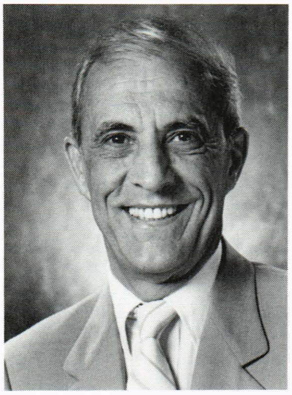
REFERENCES

[1] Griffin, M. D., and Rendine, M. J., "Delta 180/Vector Sum: The First Powered Space Intercept," presented at AIAA 26th Aerospace Sciences Meeting, Reno, Nev. (11–14 Jan 1987).

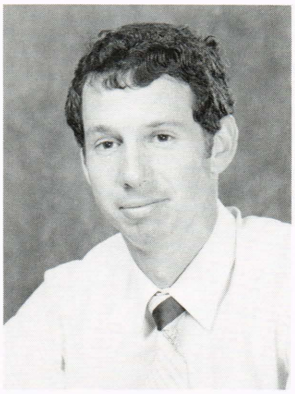
[2] Holland, B. B., Ray, J. C., and Green, A. J., "Delta 181, the Thrusted Vector Mission," presented at AIAA 27th Aerospace Sciences Meeting, Reno, Nev. (Jan 1989).

Note: Details of the Delta 180 Experiment are presented in the *APL Technical Review*, Vol. 1, No. 1 (1988).

THE AUTHORS



JOHN DASSOULAS attended North Georgia College and, after military service in the Army Air Forces during World War II, received a B.A. degree in physics from American University. He joined APL in 1955 and contributed to the design of stabilization and control and auxiliary systems for the Talos, Triton, and Typhon missiles. He joined the Space Department at its inception in 1960. Mr. Dassoulas was responsible for studies of multiple launch techniques, factors in the deployment of the Navy Navigation Satellite System, and the introduction of nuclear power to spacecraft. Since 1962, he has served as Project Engineer or Program Manager for some 13 spacecraft and several instruments. Two of the spacecraft, MAGSAT and AMPTE, received NASA Group Achievement Awards, and TRIAD received the IR-100 award. Recently, he received the Distinguished Public Service Medal, the highest civilian award of the Department of Defense, for his contribution to Delta 180. The AIAA presented him its Space Systems medal. Mr. Dassoulas has taught in the Technical Management Program of The Johns Hopkins University G. W. C. Whiting School of Engineering and was a Visiting Professor at the U.S. Naval Academy in 1985. He is currently Mission Systems Engineer for the Midcourse Space Experiment.



MICHAEL D. GRIFFIN received a B.A. in physics; Masters degrees in aerospace science, electrical engineering, and applied physics; and a Ph.D. in aerospace engineering. He has taught at The University of Maryland and at The Johns Hopkins University. His early work included spacecraft mission operations at NASA Goddard Space Flight Center and flight simulator development at Singer's Link Division. At the Jet Propulsion Laboratory, he participated in advanced studies on the Mars Sample Return and Mars Rover Programs. He then joined APL and was active in the design and performance analysis of hypersonic tactical missiles; led design studies for the Space Telescope, Space Infrared Telescope, and Satellite Gravity Experiment; and was Program Engineer for the Polar BEAR spacecraft. For his role as Project Engineer at APL for the Delta 180 Program, he was awarded the DoD Distinguished Public Service Medal and the AIAA Space Systems medal. Dr. Griffin was a Consulting Engineer for space systems design and mission planning and was retained by SDIO as Technical Director for the Delta 183/Delta Star mission. He is presently serving as Director of Technology for SDIO.