An Overview of Meteorological Satellites
Ann Mazuk, John Haas, W. John Hussey, Leslie Belsma, and John Bohlson

Accurate weather forecasts have a direct bearing on military operations and commercial enterprises. Aerospace has played an integral role in helping to develop and enhance U.S. meteorological satellite systems.

Overview and History of the Defense Meteorological Satellite Program
Steven R. Strom and George Iwanaga

Aerospace support for the military’s weather satellite program was initially limited—but increasing involvement over the years has helped the system achieve remarkable capability and reliability.

The Near Real Time Processing Effort
Jim O’Neal

The Aerospace Corporation played a key role in helping NASA provide data from environmental research satellites to operational weather organizations. These efforts have made a significant contribution to military and civil programs for monitoring global weather and climate.

The NPOESS Preparatory Project: Architecture and Prototype Studies
Samuel Gasster, Sheri Benator, and David Bart

Aerospace helped NASA develop a system segment architecture for the NPOESS Preparatory Project using C4ISR as well as an advanced ground system prototype design using grid computing technology.

Space Weather and the Upper Atmosphere
James Hecht

Aerospace researchers have been helping to develop satellite-based instruments for studying the outer reaches of the atmosphere.
NOAA’s Move Toward an Enterprise Architecture
Constance Killion and Thomas Adang

The Aerospace Corporation’s technical expertise has been critical in helping NOAA develop a comprehensive system for managing the collection, processing, and transmission of environmental data.

Going the Distance: GOES-R and the Future of U.S. Geostationary Environmental Satellites
Nathaniel Feldman, Samuel Lim, Michael Madden, Jim O’Neal, and Kenneth Shere

The next generation of geostationary environmental satellites, GOES-R, represents a significant technological advancement in terms of the quality and quantity of meteorological and environmental data. Aerospace is supporting all aspects of this program, including acquisition, instruments, ground systems, communications, and architectural studies.

From the Editors

The Defense Meteorological Satellite Program (DMSP) certainly ranks among the most successful and long-running programs in the history of national security space. This constellation of polar-orbiting satellites helped spur the development of sophisticated remote-sensing instruments and data-processing systems. Its transition to civilian oversight helped bring these remarkable capabilities to diverse sectors ranging from shipping and agriculture to disaster prevention. The convergence of military and civilian polar-orbiting satellite programs, which will culminate in the National Polar-orbiting Operational Environmental Satellite System (NPOESS), will usher in a new era in global meteorological science. Similarly, the next generation of Geostationary Operational Environmental Satellites (GOES) will bring significant enhancements in the quality and timeliness of satellite imagery and environmental data products.

Aerospace support to these programs spans several decades and cuts across numerous disciplines, from information architecture to instrument concept studies to postlaunch verification of onboard sensors. Future systems will generate significantly more raw sensor data, and making full use of this data will be no simple task. With Aerospace assistance, mission planners are determining the optimal means of collecting, transmitting, analyzing, categorizing, packaging, and archiving this unprecedented volume of data. Aerospace’s impartial engineering assessments, combined with specialized expertise in bandwidth-efficient communications, architecture development, distributed computing, ground-system infrastructure, enterprise resource management, and similar technologies, have helped provide a sound basis for making critical program decisions.

The National Oceanic and Atmospheric Administration (NOAA) is the primary agency in charge of U.S. weather satellites. Aerospace has been helping NOAA as it repositions itself to better manage the next generation of meteorological and environmental sensing systems. Part of this effort has focused on organizational and architectural concepts, while other aspects have focused on risk reduction and technology demonstrations such as the NPOESS Preparatory Project and the GOES-R communications testbed. Similarly, Aerospace support to the Near Real Time Processing Effort helped NASA make data collected by the Earth Observing System satellites more useful to NOAA and other operational weather agencies.

This issue of Crosslink takes a close look at some of the forces shaping the future of meteorological and environmental satellite systems. We also introduce a new feature, Research Horizons, highlighting some of the cutting edge work being done under the auspices of the Aerospace independent R&D program.
Successful Launch for GPS

The Global Positioning System (GPS) grew more robust with the successful launch of GPS IIR-13 on November 6, 2004. The launch from Cape Canaveral marked the 61st consecutive success for the Delta II rocket. The satellite will replace an aging unit that has been in orbit since 1991. The addition of GPS IIR-13 brings the constellation up to 30 satellites.

The Aerospace Eastern Range Directorate participated in vehicle operations, said Bob Fillers, Principal Director for Medium Launch Vehicle Verification. These efforts included electrical, mechanical, and propulsion systems; ground equipment; and facilities. Aerospace reviewed testing and processing procedures and monitored critical vehicle processing from receiving, storage, and vehicle assembly through vehicle erection and spacecraft mating through subsystem and system-level checkout, integration, and testing on the pad. Aerospace also reviewed launch-day documentation, Fillers said, including the countdown manual, launch constraints document, and contingency plans. Aerospace participated in readiness evaluations and tests, walk-down inspections, and mission dress rehearsals.

The launch of the Delta II was delayed several times, first because of four hurricanes, Charley, Frances, Ivan, and Jeanne. Another delay was incurred to exchange the battery on the third stage. Aerospace played a role in assessing damage from the hurricanes by reviewing nondestructive test results and participating in inspections after the storms, said Dan Marten, Senior Project Leader, Medium Launch Vehicle Verification. Aerospace pointed out that the third stage battery had not been qualified for the length of time it had been installed on the vehicle, Marten said, which prompted Boeing to exchange the battery for a new one.

Several more GPS launches are planned for this year, including the first launch of the GPS IIR-M, which will carry a more powerful dedicated military signal.

Critical Milestone for EELV

The Air Force’s Evolved Expendable Launch Vehicle (EELV) program closed out the year with a demonstration flight of the Delta IV Heavy launch vehicle from Cape Canaveral on December 21, 2004. This vehicle uses an unprecedented combination of three cryogenically fueled core rockets strapped together, two of which are jettisoned during ascent. The flight had been delayed three times because of weather and technical glitches.

A planned two-month post-flight review of the Delta IV Heavy demonstration mission is under way, said Ken Holden, General Manager, Evolved Expendable Launch Vehicles. Preliminary assessments continue to indicate that this mission successfully demonstrated the capability of the Delta IV Heavy ground and flight systems, he said. Significant test objectives were met, including: activating and employing the heavy version of the Delta IV launch pad; flying three common booster cores; separating the two strap-on common booster cores from the center booster core; flying the first 5-meter diameter payload fairing and separating it from the vehicle; flying the first 5-meter diameter cryogenic upper stage; flying the new upper stage through a long duration, 3-burn profile of its engine; and separating the primary payload.

While successfully meeting these test objectives, the Delta IV did not perform exactly as expected. The first-stage burn ended prematurely, so the first and second burns of the second stage were lengthened to compensate. As a result, the rocket ran out of liquid oxygen propellant during its final burn prior to reaching its intended orbit. The inert, demonstration payload (Demosat) was deployed in an elliptical orbit rather than the desired circular orbit just above geosynchronous altitude. Aerospace is actively engaged in the anomaly investigation to support implementation of corrective actions before the DSP launch aboard a Delta IV Heavy later in 2005, Holden said.

Designed to replace the Titan IVB, the Delta IV Heavy can generate enough thrust to heave 21,890 kilograms of payload into low Earth orbit and 12,750 kilograms to geosynchronous transfer orbits. The last Titan IVB is expected to launch in the summer of 2005.

Aerospace to Support Space Exploration

NASA’s Exploration Mission Directorate has awarded Aerospace a grant to develop new approaches and tools to design and assess space exploration campaigns. Matthew Marshall of Civil and Commercial Operations and Patrick Smith, Principal Director of Risk Assessment and Management, submitted the proposal in response to a broad NASA announcement to develop partnerships to help accomplish its new Vision for Space Exploration.

Of the nearly 4000 submissions received, NASA funded only 70 and described the Aerospace proposal as “among the best received.” The proposal, “Campaign Methodologies for Exploration-Driven System-of-Systems Architectures,” will share a pool of more than $1 billion through fiscal year 2009 to support research and technologies that will enable human and robotic exploration beyond low Earth orbit.
“Aerospace will develop multimission and multidecade space exploration campaigns that will have built-in flexibility to respond to changing objectives, policies, or discoveries,” said Marshall. “Exploration campaigns that extend over multiple launch opportunities and exploit both robotic and human exploration will make use of both infrastructure and campaign-specific elements developed in this research,” he said. “This effort will pave the way for the development of future exploration systems.”

Aerospace will also coordinate the activities of a team from industry, academia, and research organizations. Smith will lead Aerospace contributions in the areas of availability analysis and probabilistic risk assessment. Other members of the team include Axiomatic Design Solutions, Inc., University of Michigan, and NASA’s Jet Propulsion Laboratory and Johnson Space Center.

Marshall plans to apply tools that Aerospace has already developed for assessing military campaigns. He said his key technology challenge will be developing a flexible software toolkit to visualize and create a campaign decision tree that flows down from campaign objectives and decision criteria based on design optimization and visualization.

The tools, concepts, and strategies developed from this research promise huge benefits for the design and deployment of future exploration systems. For example, the system-of-systems architecture promises to integrate diverse projects into responsive enterprises capable of both exploiting new research and weathering occasional failures and changing priorities. Similarly, the generalized availability program will be indispensable for determining the optimal mix of redundant assets and resupply schedules for human and robotic exploration campaigns.

New Institute to Focus on National Security Space

The Air Force Space Command recently established the National Security Space Institute (NSSI) to provide specialized space education and training to space staff members and planners. The institute, which evolved from the Space Operations School previously managed by the Space Warfare Center in Colorado Springs, was inaugurated in October 2004. The goal is to develop a cadre of space professionals who can manage and maintain space systems, draft and prioritize warfare requirements for future systems, and acquire and operate systems based on strategic and tactical needs.

Aerospace, through its corporate university, The Aerospace Institute, will support NSSI as it develops and expands its curriculum. Aerospace will help ensure that course content is rigorous, structured, technically correct, and representative of current and future systems.

Aerospace will provide recommendations for the overall NSSI curriculum and assess the technical content of individual courses. Aerospace personnel will also assist with course development.

With its experience in space-professional education, Aerospace is in a unique position to recommend curriculum improvements and course enhancements. The Aerospace Institute will also encourage government and military personnel to participate in education and training originally developed for the Aerospace technical staff.

“We hope to leverage our experience in developing and teaching courses in space systems architecting and engineering to the needs of the NSSI,” said Dave Evans, Executive Director of The Aerospace Institute. “We have acquired some valuable lessons about space education and training that can enhance the effectiveness of the NSSI.”

NSSI expects roughly 2500 students annually. Nearly 60 percent will come from the Air Force; the remainder will come from other military branches and from agencies such as the National Reconnaissance Office.

Hubble Review

After announcing in January 2004 that it would not use the space shuttle to service the ailing Hubble Space Telescope, NASA asked Aerospace to develop and examine a wide range of servicing alternatives. NASA had developed a concept for robotic servicing.

The Aerospace study sought to provide a nonadvocate assessment, and a team of more than 50 members of the technical staff worked through the summer to prepare an analysis. The team regularly consulted with the Hubble program office and the space science community to understand the implications of various capabilities to science needs.

Dave Bearden, a colead of the Aerospace study, presented the findings to NASA, including the Associate Administrators for Exploration Systems and Science. The National Academy of Sciences, which had also been asked by NASA to look at servicing alternatives, requested a presentation of the Aerospace study as part of its fact-finding efforts. Although the complete Aerospace report is only available to NASA, the National Academy of Sciences posted Aerospace’s summary charts on its Web site.

NASA’s Associate Administrator for Exploration Systems, Admiral Craig Steidle (ret.), sent a letter thanking Aerospace for its contribution. In addition, the Aerospace study received national media coverage, including mention by National Public Radio and a New York Times editorial in December 2004.
Dave Gorney has been at The Aerospace Corporation for more than 25 years, and he still drives to work with enthusiasm every day. He’s held many jobs during his career, and he said he is always fondest of whichever job he’s working at the time, which today is General Manager of the Navigation Division.

“There are absolutely no limits to where your career can take you—that is one of the wonderful things about this company,” Gorney said in a recent interview. “The opportunities are out there. I’ve absolutely enjoyed every one of my jobs. Right now I’m working on GPS (the Global Positioning System), and right now it’s my favorite program—the system has been providing just tremendous capabilities. It’s the best job in the world and I love it.”

One job that Gorney said holds a special place in his heart has been his work with DMSP (Defense Meteorological Satellite Program) because this program introduced him to Aerospace. The research he was doing on his Ph.D. in atmospheric sciences at UCLA was in line with the data coming from the DMSP satellites, then being worked on in the Aerospace labs. He became acquainted with Aerospace scientists working on DMSP, the data he obtained filled a lot of gaps in his research, and his connection with the lab led to his first job with Aerospace in 1979.

“It really was the trigger for my career in national security space systems. And over the years I’ve been back to DMSP several times, either to provide technical advice to the program or to be program manager. Its importance to my career is such that whenever I think about satellites—even though I’ve worked on hundreds of them, probably—the mental image that comes to my mind is a DMSP satellite. It’s the icon in my mind for what a satellite is,” he said.

Gorney was also with DMSP during its transition in the late ‘90s from the Department of Defense to the follow-on program NPOESS (National Polar-orbiting Operational Environmental Satellite System) under NOAA (the National Oceanic and Atmospheric Administration). That was a very interesting yet uncertain time, he said, because the weather program was undergoing an upheaval caused not only by government reorganization but also by the many industry contractor mergers and consolidations occurring at the same time. When one contractor closed its factory in New Jersey, for example, DMSP satellites had to be boxed and shipped to a Sunnyvale, California, factory whose engineers had not designed, built, or cared for the satellites. Aerospace helped provide the continuity and stability for the program to get through some very distracting external events.

Such transitions occur regularly in the space industry, Gorney explained, and can be accompanied by emotional as well as technical turmoil. Natural rivalries between those who feel proprietary about the legacy program and those who are eager to move ahead with the modernized program sometimes cause barriers against the flow of information, but good management support can get these two groups talking and turn this rivalry to productive ends. Aerospace has played a key role in making that happen during many such transitions so that the modernized program can benefit from all the lessons learned from the legacy program.

“I would have to say as far as success for the entire DMSP mission, continuity was absolutely our most critical contribution to that program and to that transition,” Gorney said. “Aerospace engineers had worked with DMSP throughout its entire life while the satellites were designed and built and initially tested and are now able to provide the experience and lessons learned to NPOESS.”

At this late stage, even though its replacement is in production, Gorney said DMSP is still undergoing change, primarily to remedy technology obsolescence either from wear caused by age or from inconsistency with the evolution of the technology on the ground. The current satellites have more sophisticated sensors than were ever imagined for DMSP, but Gorney believes the most important technological developments today can be seen in the ground systems that are using the satellite data. The advent of new computer capabilities and new modeling techniques means the true potential of DMSP data is finally being realized on the ground, he said.

“DMSP always provided wonderful pictures and wonderful quantitative data, but I might estimate that the majority—greater than 50 percent—of that data was not being used at its full potential. Following the conflict in Kosovo, and certainly the Persian Gulf war, and without doubt Operation Iraqi Freedom and Operation Enduring Freedom, we finally started seeing the full potential of the sensing capabilities of DMSP along with the ground capabilities of processing that data and turning it into useful products coming together. It truly is a much more capable system than was envisaged in the ‘60s and

**Profile** The People Who Keep Aerospace at the Forefront of the Field

**A Chance to Succeed**

Fresh out of grad school, Dave Gorney found a home in the Aerospace labs. More than 25 years later, he’s still finding opportunities to learn and apply new skills.

Donna J. Born

Dave Gorney, Research Scientist.
‘70s when the first blocks were coming about and just pictures were being produced—valuable pictures, but compared with what’s being done with the data now, almost a trivial utilization of the capability.’

Aerospace’s involvement with DMSP has been primarily with military applications, ensuring that systems and requirements of the military users are being met. But Gorney said another important role Aerospace plays in all these dual-use systems is in designing the system architecture so that these tremendous assets can be available for civil and commercial use. “We are really providing the war fighters with what they need out of these systems to fight and win wars, but we have such an ability to provide a systems-level view that we are looked at by the commercial users, civil users, and even international users, as a trusted agent or broker for their needs.”

Aerospace continues to have an integral engineering and program office function in the NPOESS program office, and Gorney believes that will continue in the future. “Throughout that system, I would have to say that Aerospace’s roles, responsibilities, influence, and potential for future contributions are as strong as they ever were in DMSP. Customers change, but Aerospace’s role and commitment to that mission continue.”

Many new opportunities and technical challenges for Aerospace’s future work in all space systems, Gorney said, will involve the tight integration of space and terrestrial technologies. “Already we are seeing the payoff of having space systems and ground systems tightly integrated. Aerospace has a long history of serving as an integrator between systems and forming systems of systems, so our talents will be very pivotal in these future integration opportunities.”

Gorney has been Principal Director of several offices, including Research and Technical Applications, Technology Operations; Research Engineering, Engineering and Technology Group; Defense Support Program; and Meteorological Satellite Systems. He has most recently been Corporate Chief Architect/Engineer. “Aerospace has offered me tremendous opportunities not just to do interesting work, but to see interesting work being done by really capable people. My job opportunities that came available at Aerospace had very little to do with my specific training. At Aerospace you are immersed in a continuous learning environment, with some of the best ‘teachers’ in the world,” he said. “We just don’t call it learning or teaching, we call it ‘working.’”

Gorney learned from his father, a first-generation immigrant from Europe, to seize opportunity and to stretch himself and try different things. “My father saw the opportunity offered in the United States, even though that opportunity was just a chance to have a job in the coal mines of Pennsylvania. He led a terribly hard life in the coal mines, raising a family, and dying young. Through it all, he kept encouraging me. I remember him saying, ‘Someday you’re going to be a research scientist.’ I still have his miner’s carbide lantern on my office shelf at home, and underneath I have my business card that says: ‘Dave Gorney, Research Scientist.’ He’s my hero.”

In high school, Gorney was also fortunate to have a teacher who saw he “might have a little spark of interest” in science and math and gave him a box of his college textbooks. “We were a very poor town and didn’t have a lot of resources. He didn’t tell me what to do, he just gave me the box of books, and I went through the stuff, and it was a gold mine, and it was fascinating. And when I went from this small school in Pennsylvania into the college environment, I was coming from nowhere, but I knew calculus, I knew spherical trigonometry, and that little push allowed me to get over the hurdle and then get on with my career.”

He feels strongly about providing similar opportunities to young people. He helped establish the Aerospace Academy to improve science and engineering education at local high schools. For the curriculum, he developed a new science course and helped raise funds for lab equipment. “I’m doing this because someone did this for me. That’s how I hope to mentor these students—to give them materials and learning opportunities, and encourage them with the excitement that we all feel about science and engineering.” Aerospace encourages employees to participate in such community outreach programs, Gorney said. “It is a great corporation that provides great opportunities to its people, not just for their careers, but for their personal development and then to contribute to the community development.”

Gorney is very much aware of the opportunities he has been given to come just one generation away from the coal mines, an extremely tough existence, to a really quite influential and quite responsible area within the space industry. Doing the jobs and having some degree of success and customer satisfaction have been rewarding, he said. “But the most rewarding thing to me from a personal and professional growth opportunity is not so much doing the separate jobs, but in each job seeing the vast variety of other people doing their jobs with tremendous talent and capabilities. Watching all that go on in the whole landscape of Aerospace is absolutely remarkable.”

A portrait of the scientist as a young man.
In late summer 2004, a series of powerful hurricanes swept through the southeastern United States. Homes and businesses were demolished, roads and bridges were washed away, and coastal structures were carried out to sea. Fortunately, local authorities were notified early enough to begin evacuations and emergency preparations. These early warnings were made possible by the fleet of weather satellites circling the globe. The ability to track potentially devastating storms is just one benefit of these weather satellites; other applications range from detection of burning forests to identifying the frozen boundaries between snow and ice. Weather satellites help the agricultural sector determine the best time to plant and harvest crops and help the transportation sector chart optimal air and sea routes. They play a role in monitoring Earth’s climate change and have proved useful in identifying global transport of air pollutants. The military uses information from weather satellites in planning combat missions and assessing conditions within theaters of operation.

To get a complete picture of emerging and evolving weather patterns, two types of satellites are needed. Geostationary satellites, which maintain a constant view of one complete hemisphere, provide a more immediate assessment of existing weather conditions. Polar-orbiting satellites, circling the globe at a much lower altitude, provide global coverage needed to support longer forecasts and weather models. In the past, organizations such as the Department of Defense and the National Oceanic and Atmospheric Administration (NOAA) maintained separate polar systems. The constellation includes two primary satellites and several backup units in sun-synchronous polar orbit (850-kilometer altitude). The two primary spacecraft circle the globe every 102 minutes; one is in a morning orbit (crossing the equator from north to south at 7:30 a.m. local time), and the other is in an afternoon orbit (crossing the equator from south to north at 1:40 p.m.). The satellites are generally known by their NOAA designation—alphabetical before launch (e.g., NOAA J) and numerical on orbit (e.g., NOAA 14).

These satellites are equipped with high-resolution radiometers, infrared sounders, visible sensors observe reflected light in the 0.4 to 1.1 micron region of the electromagnetic spectrum, the same as the human eye. The infrared sensors observe emitted radiation in the 3 to 14 micron region and work by detecting differences in temperature. Weather satellites also carry special radiometers, either microwave or infrared sounders, which provide profiles of temperature and moisture at different levels in the atmosphere as well as information on Earth’s surface.

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Artist’s rendering of a NOAA satellite in orbit, part of the Polar-orbiting Operational Environmental Satellite (POES) system.
and advanced microwave sounders. They also include a system to collect data from moving platforms (e.g., buoys) and a space environment monitor. Data from these sensors contribute to global climate models by providing global atmospheric temperature and humidity profiles from Earth’s surface to the upper stratosphere. The data are also used to determine ocean surface temperature, total atmospheric ozone levels, precipitable water, and cloud height and coverage.

Aerospace support to the POES program started in 1997, during its operational convergence with the Defense Meteorological Satellite Program (DMSP) at NOAA's Suitland, Maryland, facility. Aerospace was instrumental in preparing the ground system for the launch and operation of NOAA N and N', and also developed the ground-system specification upgrades for these two spacecraft. Aerospace also provided in-depth support for the NOAA N Microwave Humidity Sounder instrument and interface. In the course of this work, Aerospace developed command procedures, developed a database, validated instrument data, and conducted simulations. The Microwave Humidity Sounder provides vertical water vapor profiles from Earth’s surface to about 12 kilometers for use in global forecast models. Aerospace also supported NOAA 15–17 simulations, launch, checkout, and anomaly resolution.

GOES
NOAA's geostationary weather satellites trace their roots to NASA's Applications Technology Satellite (ATS), launched in December 1966. ATS incorporated a spin-scan camera: The motion of the satellite spinning about its axis, which was parallel to Earth’s axis, generated the east-west scan motion, while a stepping motor provided the north-south scan motion. This innovative concept enabled meteorologists to track severe storms and cloud motions and derive wind speed and direction at cloud altitude.

NOAA eventually assumed operational responsibility for the ATS system, using it as a model for its subsequent Geostationary Operational Environmental Satellite (GOES) system. Today, the GOES system consists of two geostationary spacecraft located at 75 degrees and 135 degrees west longitude. They provide constant coverage of the contiguous 48 states, the southern part of Alaska, Hawaii, and adjacent ocean areas through visible and infrared sensors. The version now in development, GOES-R, will scan Earth nearly six times faster than the current system and provide about 60 times the amount of data. The first launch is planned for 2012.

Aerospace support to the GOES program started in 1993, when Aerospace researchers began simulations for the first of the three-axis stabilized spacecraft, GOES I, which eventually flew as GOES 8 (the naming convention for GOES is similar to that of TIROS—alphabetical before launch, numerical after). In this effort, Aerospace was able to apply specialized expertise gained through years of experience with three-axis-stabilized meteorological spacecraft. Aerospace supported all GOES I–M simulations, launches, and checkout. Aerospace was an integral part of the GOES N–P development.
process, including integration, test, and simulations. Aerospace developed GOES N fault-protection command procedures for safely changing spacecraft modes, using the spacecraft contractor’s guidelines to develop actual spacecraft commands and procedures. Aerospace was also instrumental in testing the new GOES N–P ground system, including the archive subsystem.

DMSP

DMSP is the military counterpart to POES. The DMSP spacecraft are in polar sun-synchronous orbit at about the same orbital period and altitude as the POES spacecraft. The sensors aboard each system differ, and unlike POES data, DMSP data are encrypted. DMSP data are continuously transmitted for real-time use within its path and also stored onboard and relayed to central weather agencies around the world.

DMSP began as an all “blue suit” Air Force program with surge Aerospace support, starting with the recovery of a tumbling F-1, the first Block 5D-1 satellite, launched in 1976. Since then, Aerospace has provided increasing technical support to all phases of the program. The impact of Aerospace’s general systems engineering and integration expertise was the dramatic improvement in satellite lifetime starting with F-6, the first Block 5D-2 series of satellites, and enhanced reliability of the primary cloud-imaging sensor, the Operational Line Scan.

The Operational Line Scan sensor produces cloud imagery globally at smooth resolution (2.77 kilometers) and, for areas of special interest, at fine resolution (0.55 kilometer). The DMSP cloud-cover imagery is used to find, track, and locate targets during combat and to assess mission impact after engagement. Aerospace is directly involved in developing applications that exploit DMSP and other weather satellite data to support tactical operations. In 1999, Aerospace developed a prototype system to convert DMSP and POES imagery to high-resolution quantitative assessments of percent cloud cover, type, and height used in combat mission planning in Bosnia. Aerospace continues to develop this system and has recently added NASA Earth Observing System (EOS) Moderate-resolution Imaging Spectroradiometer (MODIS) data for the first operational use of MODIS cloud products by the Air Force Weather Agency.

In addition to cloud cover, many other atmospheric phenomena such as aerosols, smoke, and haze can affect a weapon’s ability to detect and acquire a target. The Operational Line Scan sensor’s visible channel can detect smoke and dust storms and identify snow and ice fields. The system has provided vivid images of dust storms blanketing the Iraqi desert and has helped pinpoint oil fires.

Combat forces rely on surface winds and ocean data for planning amphibious landings and soil moisture data for assessing ground maneuverability of armored divisions. Both atmospheric moisture and sudden increases in temperature with height (inversions) can affect high-precision targeting of artillery gunfire and ballistic missiles. It can also affect aircraft performance. DMSP carries a suite of microwave sensors for imaging, temperature sounding, and moisture sounding. On the most recent DMSP satellite, launched in the fall of 2003, these three sensors were combined into one unit. The microwave imager is used to specify wind speed over the oceans; it can detect snow cover and, for some snow conditions, provide estimates of snow depth. It can detect and distinguish sea ice from its surrounding waters and determine surface types over land, classifying bare soil and identifying vegetation.

The Operational Line Scan sensor is the only operational weather sensor sensitive enough in the visible spectrum to view clouds by moonlight; thus, it can provide low-light (nighttime) visible imagery. The nighttime infrared imagery can help mission planners visualize the cloud cover and weather conditions over areas of interest and determine which sites are optimal to target. Nighttime imagery also plays a role in battlefield damage assessment; comparing images before and after the mission can indicate whether a target has been hit.

During the recent conflicts in Bosnia, Afghanistan, and Iraq, DMSP data collected over combat theaters were used daily in the planning of air, sea, and ground operations. The weather affects military planning at every level and timescale. By observing developing weather systems in the polar regions and over the oceans, weather satellites have vastly improved the capability to forecast many days in advance in support of strategic planning. At the other end of the spectrum, the instant data downlinks allow satellite data over the area of interest to be swiftly integrated in aerial mission planning, even for the 30-minute targeting time line.

Weather forecasts (typically cloud cover and visibility) also influence weapon selection. Electro-optical, infrared, and laser weapons use sensors to guide them to the target and require a clear line of sight. Pilots use weather forecasts produced prior to takeoff to predict the probability of target acquisition, and, consequently, target prioritization and weapon selection.

NPOESS

In 1994, President Clinton signed a directive merging DMSP and POES into a single system, the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The evolution from the current POES and DMSP programs will take place over the next five to nine years, with full operational capability in 2013.

The operational concept for NPOESS consists of a constellation of spacecraft flying at an altitude of 828 kilometers in three sun-synchronous orbital planes (crossing the equator from south to north at 1:30, 5:30, and 9:30 p.m. local time). The satellites will carry visible, infrared, and microwave imagers and sounders, with special emphasis on atmospheric temperature and moisture sounding.

The 13 different instrument payloads on NPOESS will observe significantly more phenomena than their predecessors. In fact,
Microwave Data

Microwave sensors can collect data through cloud cover and darkness, revealing details that visual and infrared sensors cannot. Satellite microwave sensors are among the most valuable sources of data for monitoring and tracking typhoons and hurricanes.

The Special Sensor Microwave Imager on DMSP F-8 through F-15 detects sea ice, snow, and surface winds over oceans. It provides ship captains with information needed to plan to the most efficient routes and avoid heavy seas, high winds, and ice—all of which can affect schedules, increase fuel consumption, and damage cargo. Before satellite coverage was available over the oceans, ship captains used less reliable weather data from buoys or other ships.

The Special Sensor Microwave Imager is proving to be a valuable tool in detecting climate change because it provides a long, continuous record from which to construct sea ice climate histories. For example, arctic sea ice retreats to a minimum each year in September, when it covers an area reaching about to the magenta line in the figures below. Data from the Special Sensor Microwave Imager indicate that ice coverage has fallen far short of its median September position in recent years. In fact, in 2002, September ice coverage was at a record low (left image) with extreme ice minimums observed again in 2003 and 2004. Three extreme minimum years in a row is unprecedented in the satellite record.

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**NPOESS environmental data records (EDRs), listed by sensor.**

- VIIRS: 25
- CMIS: 19
- CHR/ATMS: 3
- OMPS: 1
- SES: 13
- GPSOS: 2
- ERBS: 5
- TSIS: 1
- ALT: 3
- APS: 4
The Polar Orbit

Satellites such as DMSP, POES, NPOESS, and TIROS circle the globe in so-called polar orbits, passing over the North and South Poles as Earth rotates beneath them. Each satellite crosses any point on Earth up to two times a day and has an orbital period of about 100 minutes, thus providing nearly complete global coverage every six hours. In contrast with geostationary satellites, which remain far enough away to match Earth’s daily rotational period, polar-orbiting satellites travel at a low altitude, generally around 850 kilometers. They can therefore provide images with relatively high resolution.

In addition to spinning on its axis, Earth also circles the sun, at a rate of about 365 days per revolution. There are 360 degrees in a circle, so Earth is moving, or precessing, nearly 1 degree per day. If a satellite were in a truly polar orbit, circling the globe at 90 degrees relative to the equator, it would move with the planet, experiencing different conditions throughout the year. However, if the orbit is tilted or inclined slightly away from a true north-south orbit, the asymmetric gravitational pull of the planet will cause a slow precession in the orbital plane. At an inclination of 98.7 degrees, the orbital plane will precess nearly 1 degree per day, the same rate as Earth’s yearly rotation around the sun. Thus, the orbital plane will seem fixed with respect to the sun, and the satellite will cross the equator at the same solar time every day. This so-called sun-synchronous orbit is particularly useful for meteorological satellites.

For example, sun-synchronous spacecraft can provide imagery of a certain point under the same lighting conditions every day. Of course, the clouds change with each orbit, but their broad patterns and positions remain mostly unchanged in the short orbital periods involved. Daily mosaics can be made from the swaths, which are a good general summary of global weather patterns for that period.

A further refinement of the sun-synchronous orbit is the dusk-to-dawn orbit. In this case, the satellite never casts a shadow on Earth, but travels with its orbital plane always facing the sun, riding above the line that separates day from night. Thus, the satellite can constantly view clouds at dawn or dusk, where cross light from the sun best highlights their shapes and sizes as well as the ocean texture beneath. In dual-satellite constellations, one satellite might maintain a dusk-to-dawn orbit, while a second might be oriented closer to the noon-midnight line, passing through the point of brightest day and the darkest night.

NPOESS is expected to deliver about 8 terabytes of data per day, more than the current POES and DMSP systems combined. Each NPOESS spacecraft generates data at a rate of 20.0 megabits per second. Thus, the entire volume of data generated by the civil POES system in its 40 years of operations would be generated in less than 12 days by NPOESS. This increase in data volume will increase demands on the front-end processors and data-assimilation systems used to initialize and update global and regional numerical weather prediction models. To minimize delays, NPOESS stored mission data will be relayed to national weather processing centers located in the continental United States within 28 minutes from observation.

NPOESS spacecraft are being designed for precise orbit control to maintain altitude, nodal crossing times, and repeat ground tracks (repeat cycles of approximately 17 days). Because the requirements for data refresh are different for many of the 55 environmental parameters monitored, not all instrument payloads will fly in each orbit. In addition, certain orbital characteristics, as well as considerations of instrument field of view, have determined the payload configurations for each orbit. In addition, as a result of discussions between the United States and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), sounding data acquired from the Infrared Atmospheric Sounding Interferometer and the Microwave Humidity Sounder onboard the European Metop satellite (also to be in polar orbit, crossing the equator from north to south at 9:30 a.m.) will augment NPOESS data.

Final design, prototype, and fabrication of the sensor suites and algorithms necessary to support NPOESS has begun, with delivery of the first flight units scheduled for 2005 to support the NPOESS Preparatory Project, a risk-reduction mission for NPOESS and a data-continuity mission for NASA. Aerospace has been involved since the program’s inception, providing technical guidance on requirements definitions and developing the requisite source-selection documentation for each sensor and system. Aerospace now serves as the technical lead for the majority of the developmental sensors as well as the algorithms and ground system. In fact, Aerospace participation extends to every level of the project, from broad program management to individual task groups.

Conclusion

The sensors aboard POES, GOES, and DMSP provide information about surface winds over broad areas of the oceans, cloud water content, rain rate, water-vapor content, and land surface temperature. As these systems merge and evolve, Aerospace will work to ensure that practical requirements for atmospheric, oceanic, terrestrial, climatic, and solar-geophysical data will guide the development of visible, infrared, and microwave imagers and sounders that will achieve greater accuracy and timeliness of observations.

Acknowledgement

The authors thank Rich Pastore for his assistance in preparing this article.
Shortly after the launch of Sputnik in 1957, the U.S. House Select Committee on Astronautics and Space Exploration asked several space experts for their forecasts of what the U.S. space program might achieve during the next decade. Their report, *The Next Ten Years in Space: 1959–1969*, predicted that “great improvements in weather forecasting will become possible with a satellite providing rapid overall data on cloud cover and atmospheric transmissions, albedo, and emission. This has tremendous implications, both civilian and military.” There was consensus among several contributors that better weather coverage, particularly cloud-cover photography, could be immensely helpful to U.S. intelligence efforts.

These predictions proved quite accurate. In the ensuing years, meteorological satellites played a critical role in supporting military planning and reconnaissance operations around the globe. The Air Force’s pathbreaking weather satellite program, which began in secrecy, vastly improved scientific knowledge of Earth’s climate and environment, enabling more useful models and more accurate forecasts for diverse users and applications. Along the way, Aerospace made important but little-known contributions that helped the Air Force maintain its considerable capabilities in meteorological observation.
An Auspicious Beginning

In 1958, the Department of Defense (DOD) began work on what would become the first meteorological satellite, TIROS (Television Infrared Observation Satellite). Within the year, the program was transferred to the newly formed National Aeronautics and Space Administration (NASA), with the U.S. Weather Bureau designated to provide satellite instrumentation, data reduction, and analysis of observations. TIROS was placed into orbit in April 1960, and TIROS-2 followed soon thereafter. Congress subsequently commissioned NASA to develop a national operational meteorological satellite system to serve both commercial and military users.

The TIROS spin-stabilized polar-orbiting satellites offered limited coverage of the globe. Air Force Undersecretary Joseph Charyk, who also headed the National Reconnaissance Office (NRO), recognized an immediate and increasing need for better coverage of Eurasia. Better knowledge of weather conditions—particularly cloud cover—would improve planning of photographic surveillance of the Soviet Union, China, and other nations of interest. In April 1961, Aerospace prepared a development plan for the Air Force’s Space Study Committee that recommended using components of TIROS in a new satellite, launched by a Blue Scout rocket. The initial emphasis would be on cloud-cover photography with provisions for the later addition of more sophisticated equipment as development allowed. After Charyk determined that the planned NASA system could not meet military needs, he gave his conditional approval in August for the Air Force to begin its own program of satellite weather observation based at least in part on the Aerospace proposal. This program ultimately became known as the Defense Meteorological Satellite Program (DMSP).

The DMSP program office was located at Los Angeles Air Station (now Los Angeles Air Force Base) and overseen by the Space Systems Division, although personnel reported to NRO. Because Congress had already authorized and funded NASA to develop a national weather satellite system, knowledge of DMSP was limited to “need-to-know” personnel, and complete secrecy surrounded the program in its early years.

As a result of certain DMSP constraints that differed from the usual Space Systems Division programs—including fixed-price, fixed-schedule contracting—Aerospace and the Air Force agreed that Aerospace would not assume general systems engineering/technical direction (GSE/TD) for the program. Nevertheless, Aerospace helped develop instrumentation and sensors for the early DMSP spacecraft. Ernst H. Rogers, David F. Nelson, and Robert L. Sempek, for example, performed work that led to the formulation of new concepts for the production of primary and secondary sensors and new methods of data processing and display. During the program’s early years, the Space Sciences Laboratory also developed X-ray detectors to observe the aurora from DMSP orbits.

Setbacks and Successes

DMSP began operations with five attempted Block 1 satellite launches from Vandenberg Air Force Base in 1962 and 1963 using the Scout launch vehicle. All but one of them failed, but later attempts using the Thor Agena and Thor Burner I had greater success. The data transmitted from the DMSP satellites were received by two command/readout stations located near Loring Air Force Base in Maine and Fairchild Air Force Base in Washington. The data were then forwarded to Air Force Global Weather Central at Offutt Air Force Base in Nebraska and converted into photographs. By the time the Block 2 and Block 3 series went into operation in the mid-1960s, DMSP was becoming increasingly important in planning Vietnam War operations. The satellites supplied cloud-cover information to headquarters in Saigon and to aircraft carriers stationed in the Gulf of Tonkin, which allowed for more precise planning of tactical air missions.

As a result of the increased use of DMSP data by the military, the DMSP program office began reporting directly to the Space Systems Division in July 1965. From 1966 to 1969, a series of increasingly sophisticated satellites were launched as part of the Block 4 constellation. From 1970 to 1976, 11 satellites in the Block 5A, B, and C series were launched using the Thor Burner II as booster. After more than a decade of operations, DMSP was declassified in 1973, and civilians were allowed to share the program’s data.

The Aerospace role in DMSP took on a new significance in 1976. That year, the Air Force began work on a new series of satellites that could provide higher-quality photographs both day and night. The satellites would be launched using Thor Delta rockets. That year, the Space and Missile Systems Organization (descendant of the Space Systems Division) requested Aerospace assistance with the review of a Thor launch vehicle failure, and James H. Elliott led the Aerospace effort. Elliott’s team prepared an in-depth reconstruction of several past Thor flights and developed a performance model that revealed a critical fuel shortage. The model was accepted and subsequently employed on a series of successful DMSP launches. Later in 1976, the Air Force requested that Aerospace establish a program office and increase its assistance to DMSP, with full responsibility for general systems engineering and integration (GSE/I). The Aerospace DMSP program office, initially headed by Ernest LaPorte, began operation in early 1977.

A Last-Minute Save

In addition to helping improve launch vehicle reliability, Aerospace helped overcome problems with the satellites themselves. The first of the more sophisticated Block 5D satellites was launched in September 1976, only a few months before Aerospace assumed responsibility for GSE/I. Although the initial orbit insertion appeared successful, a telemetry signal soon revealed control problems, and the spacecraft began tumbling. The satellite’s batteries were quickly depleted because the solar-cell array was not locked on the sun, and all systems were dead after 16 orbits. The Air Force formed a failure review team that included Aerospace members, including LaPorte and David L. Grieb, director of the Control and Electromechanical Subdivision.

The technical review determined that the cause of the failure was a high-pressure nitrogen leak from a B-nut connector. The expanding gas from the leak impinged on the solar panel, which produced an unforeseen torque. The identification of the leak, which interfered with the operation of a long boom supporting the solar panel, was made possible by Grieb’s development of a dynamic model using a digital-analog computer. During the next few weeks, tracking of the satellite continued. In early October, after the solar panel received enough sunlight to begin generating power again, the solar-array system was successfully switched to a battery-charging mode. As a result, it became possible, using environmental forces generated between the satellite and Earth’s magnetic field, to control the spin vector. However, the spacecraft was still performing three revolutions per minute, which did not allow the satellite to fulfill its photographic mission.
During the next weeks, simulations were developed for the solar panel and spacecraft combination. They indicated that the solar panel could be pulled out to a stable position at the current rate of spin, but if the rate of spin quickly dropped, the panel could fall back to its previous position. Aerospace then developed a series of simulations of the entire satellite system, using a CDC 7600 computer (precursor to the Cray supercomputer). The satellite’s Earth-sensor system was used to measure the spin rate and the spin angle. In December, a simulation by Aerospace scientists demonstrated that pulsing currents through magnetic coils in the satellite could produce small interactions with Earth’s magnetic field—and if these were properly applied, it might slow the spin.

By late February 1977, Griep and his team were ready to apply their findings to the satellite itself, and they temporarily relocated to Offutt Air Force Base, the DMSP control center. The CDC 7600 computer was now linked to Offutt, which enabled the Aerospace team to conduct a series of simulations; however, the new simulations indicated that as the spin rate slowed to one-fifth of a revolution per minute, problems with the gyro suddenly developed, and rapidly grew worse. A defective gyro would limit the operational life of the craft after recovery, so a solution had to be found quickly. In the two weeks before the recovery effort (scheduled for the end of March), Draper Laboratory developed new computer software that would enable the spacecraft to function normally without the gyro by shifting the control to the satellite’s Earth sensor. But questions remained about whether the software would work properly onboard the satellite. A series of rapid simulations was now required to verify the software modifications, and in one 8-hour period, Aerospace conducted 40 simulations, each one covering from 5 to 10 orbits of the satellite.

On March 24, just one day before the problems with the gyro would have made recovery impossible, stabilization of the satellite was achieved. Aerospace corporate historian Everett Welmers wrote that after “six months of ingenuity, analyses, simulations, and hard work,” the satellite was declared operational on April 1, 1977. Nonetheless, the Aerospace team was summoned again when another crisis with the same satellite occurred in mid May. This time, the satellite’s yaw gyro had begun to drift. After a series of investigations, Aerospace corrected the drift and recommended the implementation of a control system that did not use gyroscopes. Despite some continuing problems with yaw oscillation, stabilization of the satellite was ultimately achieved. As a result of the major Aerospace effort in helping the Air Force save its 5D-1 satellite, DMSP acquired, in Ivan Getting’s words, “a new significance to The Aerospace Corporation.” In the remainder of 1977, Aerospace also assisted with the reactivation of two more DMSP satellites that encountered on-orbit failures.

**Convergence**

Although the manner in which Aerospace joined the DMSP team was dramatic, the Aerospace program office continued to provide equally critical and timely support to DMSP operations, right up to the present. For example, Aerospace was integrally involved in the Block 5D-2 satellite missions, which
Aerospace researchers David Nelson and Ernst Rogers reviewing DMSP photos of an auroral display in July 1973, the year the program was declassified.

Aerospace president Ivan Getting and trustees review imagery from DMSP satellites with Aerospace researchers in June 1975. From left to right: David Nelson, Ernst Rogers, Ivan Getting, Gen. Bernard Schriever, and E. Hornsby Wasson.

Aerospace researchers who worked on the recovery of a DMSP Block 5D-1 in April 1977, around the time that the Aerospace DMSP program office began operation. From left to right: William Russell, Ray Skrinska, W. L. Hayden, Jesse Lopez, Morey Gibbs, and David Griep.

DMSP’s Operational Line Scan instrument is sensitive enough in the visible spectrum to view clouds by moonlight and can generate nighttime imagery of Earth’s surface. This picture shows the aurora borealis in October 2003. Areas of dense urbanization also appear as bright lights.
were characterized by aggressive government oversight, intensive monthly program reviews, reduction of single-point failures, addition of critical redundant components, and implementation of lessons learned from previous launches. All of the Block 5D-2 missions were successful, beginning with the first in 1982 and proceeding through eight more from 1983 to 1997. In addition, Aerospace led an effort to replace the lubricant and bearings on the Operational Line Scan instrument (the primary cloud-imaging sensor on Block 5 satellites), which served to increase satellite life.

From the time that DMSP was declassified in 1973, proposals were periodically made to merge the program with the civilian meteorological satellite program managed by the National Oceanic and Atmospheric Administration (NOAA). Finally, in May 1994, President Clinton issued a directive merging the two polar-orbiting satellite programs. An integrated program office, comprising NASA, DOD, and NOAA personnel, assumed responsibility for major systems acquisition for the next-generation National Polar-orbiting Operational Environmental Satellite System (NPOESS) satellite. In 1998, DMSP satellite operations were transferred to NOAA, which jointly operates both military and civilian meteorological satellites, but the acquisition function for NPOESS remains with DOD. The first phase of NPOESS is concerned with the development of critical sensors, and Aerospace is providing technical support for nine sensor contracts. Aerospace is also involved in planning the NPOESS Preparatory Project, which will provide global observations and scientific information as a follow-on to NASA’s Earth Observing System. In addition, Aerospace provided important planning support to the convergence of ground operations when NOAA assumed authority over the program.

The present generation of DMSP satellites, Block 5D-3, became operational in November 2003. As DMSP enters its fifth decade of service, the program continues to provide valuable assistance in planning and protecting military operations around the world. The support that Aerospace provided has helped achieve Ivan Getting’s goal of making Aerospace “the nation’s technical repository for military satellite systems.”

Acknowledgement

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The Near Real Time Processing Effort

The Aerospace Corporation played a key role in helping NASA provide data from environmental research satellites to operational weather organizations. These efforts have made a significant contribution to military and civil programs for monitoring global weather and climate.

Jim O’Neal

NASA’s Earth Observing System (EOS) is a research mission designed to study Earth and its environment. Operating in sun-synchronous polar orbit, the EOS satellites, Terra and Aqua, rely on two primary remote-sensing instruments. The first, the Moderate-resolution Imaging Spectroradiometer (MODIS), has 36 spectral bands for measuring visible and infrared radiation; it can detect dust over land and ocean, detect low clouds at night, and generate high-resolution true-color imagery. The second instrument, the Atmospheric Infrared Sounder (AIRS), is a grating spectrometer containing 2378 infrared channels and four visible/near-infrared channels; it’s designed to obtain highly accurate temperature profiles of Earth’s atmosphere along with a variety of other environmental parameters.

NASA recognized that data from EOS could be useful to civilian and military weather services; however, EOS data latency (or timeliness) was too slow to permit use in operational activities. NASA initiated a program known as the Near Real Time Processing Effort (NRTPE) to try to reduce data latency. The self-imposed latency goal was 3 hours from time of observation by the satellite to product delivery to the users.

Challenges

NASA asked Aerospace to assemble the NRTPE team. In addition, an Aerospace representative was appointed lead systems engineer, providing day-to-day management of the entire effort. The NRTPE team included members from NASA, the National Oceanic and Atmospheric Administration (NOAA), the Air Force Weather Agency, the Naval Research Laboratory, and the Naval Oceanographic Office.

The first challenge involved the identification, procurement, and installation of the high-speed processing and distribution systems needed to achieve the 3-hour latency goal. NASA allocated $3 million for the project—not much, considering the sort of infrastructure that would be needed. That meant that NRTPE would have to make maximum use of existing systems; however, it was clear from the outset that additional high-speed processing capability would have to be procured. Hence, the bulk of NASA funding was used to acquire high-speed computers, a control terminal, data storage, and system maintenance. An active NASA contract enabled the rapid purchase and installation of the processing capability. The system was then loaded with NASA software for generating weather-data packages.

While the enhanced processing capability was being procured, the NRTPE team began implementation of the networks needed for distribution of data from Terra and Aqua. This effort was complicated because users were scattered at varied locations and had widely differing system capabilities. With virtually no funding to purchase a new communication/distribution system for all

Top-level schematic of the EOS Terra/Aqua data flow. Key: GSFC—Goddard Space Flight Center; NESDIS—National Environmental Satellite, Data, and Information Service; NRL/MRY—Naval Research Laboratory, Monterey; AFWA—Air Force Weather Agency; FNMOC—Fleet Numerical Meteorology/Oceanography Center; NAVOCEANO—Naval Oceanographic Office.
participants, the NRTPE team had to make use of the several different existing systems. The group evaluated various alternatives and determined that the best solution for the military was the Defense Research and Engineering Network. For civil customers, a combination of internal networks and shared processing protocols would be used.

**Latency Reduction**

Once the new processing systems were integrated with the old data distribution networks, testing began to determine their ability to achieve the 3-hour latency goal. In 2002, initial testing revealed latencies in the 8–10 hour range—well beyond that needed for most operational weather applications. The NRTPE team began a series of activities designed to optimize the flow of satellite data throughout the system, including modification of existing ground processing equipment and procedures. Several of these efforts led to a significant reduction in data latency.

For example, Terra satellite data are uplinked to the Tracking and Data Relay Satellite System (TDRSS) and then downlinked to the receiving station in White Sands, New Mexico. Prior to NRTPE, the operational procedure was to downlink the Terra data once per orbit. Thus, because of the orbital period, some of the data were already 100 minutes old when downlinked. Aerospace and NASA arranged for a dual TDRSS contact schedule, which reduced data latency by nearly 50 minutes.

The NRTPE team also expedited the return link from White Sands. Previously, the data playback from White Sands to NASA’s Goddard Space Flight Center was done manually. With additional funding provided by NASA, this process was automated, significantly reducing data playback time.

Further gains were made via data streaming. Prior to NRTPE, data from Terra would be held at White Sands until the complete orbital data set was received. The information was then forwarded to Goddard Space Flight Center. The NRTPE defined and implemented a new procedure to immediately stream the data back to Goddard.

**Conclusion**

These latency improvements, coupled with many other processing and procedural upgrades, resulted in data latencies of 2–3 hours. Data provided by the NRTPE system have made and continue to make significant contributions to military and civil applications. As a result of NRTPE, NOAA is processing and distributing global AIRS calibrated and navigated data with short lag time for use by numerical weather prediction centers in various products, including forecast models. By providing MODIS data to the operational weather centers, NRTPE enabled new applications based on previously unavailable spatial and spectral information. Notably, the NRTPE system was in place before the conflict in Iraq, enabling generation of new products to support the war effort.

**Further Reading**


The Atmospheric Infrared Sounder (AIRS) is a grating spectrometer containing 2378 infrared channels and four visible/near-infrared channels designed to obtain highly accurate temperature profiles of Earth’s atmosphere and related information. As a result of the NRTPE, NOAA is processing and distributing global AIRS calibrated and navigated data for use by numerical weather prediction centers in various products, including forecast models. Shown here is an example product using AIRS data.
The National Polar-orbiting Operational Environmental Satellite System (NPOESS) represents a convergence of systems previously operated by the Department of Defense and the National Oceanic and Atmospheric Administration (NOAA). Scheduled for launch in 2009, it will support a broad range of activities in global environmental monitoring, meteorology, and climatology.

The NPOESS Preparatory Project (NPP) is a joint mission managed by NASA’s Goddard Space Flight Center and the NPOESS Integrated Program Office. It provides NASA with a bridge for continuing the global-change observations of the Earth Observing System (EOS) while awaiting full NPOESS operational capability. It also serves as a risk-reduction mission for NPOESS, flying early versions of key sensors and deploying portions of the ground segment. The NPP satellite will be launched into a circular sun-synchronous polar orbit similar to that of the current EOS satellites. The current estimate is a launch sometime in fiscal year 2007.

This article describes architecture and prototype studies performed by Aerospace in support of the NPP mission. During the course of these studies, the NASA acquisition strategy for NPP was changed. As a result, NASA did not directly apply the results of the architecture and prototype studies to the acquisition of an NPP ground system; however, the results of these studies provided both NASA and Aerospace with valuable lessons learned on many aspects of ground system architecture and design.

The Science Data Segment: An Overview
The NPOESS Preparatory Project consists of space and ground segments. One of these, the Science Data Segment, became a particular area of focus for Aerospace. NASA asked Aerospace to assist in the acquisition of the Science Data Segment in 2000. This task initially focused on the development of a baseline specification for the segment architecture and related requirements, although the scope of this work later expanded to include architecture and requirements studies.

The primary function of the Science Data Segment is to facilitate the ingestion of raw data records from the Interface Data Processing Segment. These records consist of raw sensor data packets that have been...
downlinked from the NPP satellite. They are converted to engineering units, calibrated, and geolocated to create Level 1B data products, similar to NPOESS sensor data records. The Level 1B products are the primary data sets used by the NASA science team and other researchers to generate high-level data products and science-quality climate data records. The Level 1B products and climate data products are made available to the NASA science team and stored via the Archive and Distribution Segment.

The Science Data Segment will also perform a number of related functions. For example, when new sensors are first deployed, their on-orbit calibration must be verified, and the data products derived from these instruments must be validated using spatially and temporally coincident correlative observations. The Science Data Segment will perform the calibration and validation activities.

Climate data processing and analysis involves the development of lengthy time series based on decades of measurements that often link observations made by different instruments. As instruments age and algorithms improve, it often becomes necessary to reprocess many years of measurements in less time than originally required to collect and process the data. Thus, the Science Data Segment must also provide the capability to reprocess any data as the need arises.

Given the high data rates from the NPP sensors, the system is expected to generate 2 petabytes (2 million gigabytes) of raw and processed data products over the 5-year mission life. The Science Data Segment must provide for the processing, distribution, storage, and archiving of this data. All of these functions must be managed and scheduled to allow seamless operation.

**Architecture Studies**

One of the key tasks that Aerospace performed in support of the NPP mission was the development of a set of baseline architecture documents. The architecture was developed and documented in accordance with the Department of Defense Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Architecture Framework. This framework provides for the description of system architectures from three different, but related, perspectives: operational view, systems view, and technical view.

The operational view focuses on what the system must do to fulfill its mission; it describes tasks and activities, operational functions, and information flows. The systems view reflects the system being built, along with related functions and characteristics; it describes systems, segments, elements, subsystems, and interconnections providing or supporting mission functions. The technical view prescribes standards and conventions; it is the minimal set of rules governing the arrangement, interaction, and interdependence of the system entities.

For the NPP mission, these three perspectives are codified in a set of architecture documents that Aerospace developed and delivered to NASA. Aerospace was responsible for the first volume, Overview and Summary Information, and the third volume, System View. The second volume, NPP Mission System Description and Operations Concept, was developed by a separate group. The first volume contains a high-level description of the NPP mission and its environment. The third volume focuses on the system hierarchy (from system down to segment to element to subsystem) and associated capabilities and interfaces; it also includes a set of C4ISR views that illustrate and describe each project segment and element functionality and the external and internal segment interfaces. This architecture documentation supports the following systems-engineering functions.

**Requirements Management.** Preparation of a large number of requirements and operational concept documents began during the period of NPP formulation, which ran concurrently with the concept definition phase of the NPOESS program. The baseline requirements for the NPP program must remain consistent with the requirements baseline of the NPOESS program as they proceed through their respective phases of implementation. The NPP architecture helps correlate the operational activities derived from the system and operational concept with the system segments, elements, and subsystems being developed by the contractors.

**Interface Engineering.** Facets of the NPP mission include multiple contractors, each responsible for one or more segments, and, in certain instances, for one or more elements within a segment. These contractors support integration of their elements and deliver their products for final integration and testing. The NPP architecture supports the interface

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**Grid Computing: An Overview**

Grid computing refers to an infrastructure that enables the integrated, collaborative use of high-end computers, networks, databases, and scientific instruments owned and managed by multiple organizations. Grid applications often involve large amounts of data and computing, and often require secure resource sharing across organizational boundaries, and are thus not easily handled by current Internet and Web infrastructures.

The term “grid computing” was coined in the early 1990s based on advanced concepts for distributed computing architectures and infrastructure, and by analogy with the electric power grid. The fundamental capabilities embodied by grid computing are the cross-institutional sharing of computing resources and dynamic problem solving.

A key concept in grid computing is the service. Computational resources (computers, storage systems, network infrastructure, software libraries, and tools, etc.) will present themselves within the grid as a service. This could entail resource brokering and scheduling services, or even computational services, such as database services. Applications may also present themselves as higher-level services that rely on other lower-level services (computing and storage). For example, a service could allow a user to search a catalog of remote-sensing data for data sets that satisfy a specific temporal and geographic query, then extract a subset of this data and move it to another system for additional data processing, such as feature identification.

Capabilities that are most relevant to the Advanced Data Grid project include:

**Resource Discovery.** In an open-ended environment, the user must be able to find the required resources. This can be done through a combination of search engines and catalogs that form an information service; however, standard metadata schemas must be developed to enable the discovery process.

**Resource Brokering and Scheduling.** Once desirable resources are found, their actual use may have to be brokered and scheduled.

**Security.** Simple passwords do not provide sufficient security; the grid computing community has adopted the use of X.509 certificates to enable strong authentication and authorization.

**Monitoring.** Grids will have both health and performance monitoring systems that are integral to their operation.
Advanced Data Grid (ADG) prototype architecture involved the sharing of resources between three sites, with possible extension to a fourth. Goddard Space Flight Center (GSFC) provided the primary data processing, storage, and metadata catalog services. Ames’ Information Power Grid (ARC/IPG) and Aerospace provided additional computing and storage resources. Aerospace provided a science user simulation capability as well. All sites were connected using the NASA Research and Engineering Network (NREN). MODIS sensor data was to be provided from Goddard’s Distributed Active Archive Center (DAAC) using standard FTP downloads.

definition, compatibility check, and maintenance of complete external interfaces and intersegment interfaces where they cross contractor boundaries. It also supports the definition of intrasegment interfaces, which are needed when different contractors provide interfacing elements.

System Integration and Testing. The NPP architecture will support integration and testing at the mission level. Managers and planners use the architecture to help identify and define mission scenarios for end-to-end integration and testing. The architecture will help NASA determine which system elements are required for these tests. The mission scenarios will influence the formulation of integration and testing plans and procedures. NASA may also use the architecture to support similar activities at the segment level, though it’s primarily geared to support integration and testing at the mission level.

The three volumes provide a comprehensive description of the configuration of the NPP system and its interfaces as well as the functionality and operations that allow it to meet mission requirements. They establish the controlled baseline architecture of the NPP system and its operations. They will be used to manage changes to the NPP architecture and operations over the life of the system. They also provide a means to introduce personnel and organizations to the fundamental characteristics of the mission.

Advanced Data Grid

While working with Aerospace to develop the NPP architecture documentation, NASA realized the Science Data Segment presented novel challenges in terms of ground system design and implementation. NASA asked Aerospace to suggest possible approaches for the Science Data Segment in early 2001. Based on initial architecture definition and requirements, Aerospace recommended an emerging technology known as grid computing. Because of the relative lack of maturity of this approach, Aerospace also recommended the development of a prototype implementation that would allow NASA to investigate key features as it moved to procure the full operational Science Data Segment. This prototype implementation was named the Advanced Data Grid.

The primary goal of the Advanced Data Grid project was to assess the applicability, effectiveness, and scalability of advanced data processing and data management technologies to the design and implementation of future Earth-science data processing systems. A key objective was to perform this assessment in the context of Science Data Segment requirements and workflow using grid computing technologies. An additional objective was to demonstrate the execution of a scientifically meaningful climate application requiring the management of massive data sets that would be representative of the type of application that the NPP science team might develop. Part of the overall task for Aerospace was to define this application.

An analysis of mission requirements determined the need to develop a ground data processing, storage, and archival system capable of handling data rates greater than 10 megabits per second, with possible reprocessing requirements of 20 times

the data rate. The system would have to store and distribute petabytes of data to a geographically distributed team over the 5-year expected mission life.

Grid computing seemed like a natural choice for the Science Data Segment prototype because it directly addresses the issues of integrating distributed heterogeneous resources as well as the dynamic scheduling of these resources, discovery and distribution of data for scientific applications, and the general sharing of computing resources. In addition, the system could be expanded as needed. Thus, the project office would not need to implement full system capability at the start, but could expand the system over the mission lifetime. This would allow better performance over time and significant cost savings.

Aerospace worked with NASA to define the Advanced Data Grid implementation. To simulate and test a wide range of representative workflows, researchers decided to not only set up sites at Goddard and Aerospace, but to incorporate the existing grid-computing capabilities developed at the Ames Research Center as part of the NASA Information Power Grid. Thus, the physical implementation for the Advanced Data Grid involved tying together resources at these three sites using the NASA Research and Engineering Network. Goddard provided the primary data processing and storage, Aerospace provided science user simulation and test management, and the Information Power Grid provided additional data processing and storage. The Advanced Data Grid team determined that petabytes of data would not be needed for the workflow simulations; rather, the testing could be performed using about 60 gigabytes of data and replaying the data where necessary.

A major function that the Advanced Data Grid needed to demonstrate was the management of a large data set. The selected approach involved the implementation of a metadata catalog, tools for searching the catalog, interfaces to back-end storage systems, and tools for retrieving the found data sets. The implementation would then allow any user to search the metadata catalog using key words common to a specific problem domain. The search would return logical pointers to the data sets that match the user query. The pointers would then be passed to a replica location service that would identify the physical data set and allows data transfer to the user’s designated site. Implicit in this process are the authentication and
Aerospace developed a plan and schedule that divided the Advanced Data Grid project into four phases to be executed over approximately three years. In the initialization phase, the basic hardware and software would be acquired and installed at each site; the team would also conduct internal testing and training, initiate acquisition of test data sets, develop additional project documentation, and install project configuration management tools. In the baseline phase, data grid functionality and interoperability would be demonstrated across all sites; the team would also establish benchmarks and start defining and developing science applications. Next, in the grid testing phase, the team would conduct major data grid testing, performance analysis, and assessment. Finally, the application demonstration phase would perform an appropriate climate data application. The Distributed Active Archive Center at Goddard would serve as the primary source of test data (the team planned to use MODIS sensor data). The team was also exploring the possibility of developing a grid capability and a future grid interface between the Distributed Active Archive Center and the Advanced Data Grid.

Aerospace and Goddard were well into the initialization phase by summer of 2003, having implemented initial data processing and storage capabilities at Goddard, purchased computing hardware for the Aerospace site, and negotiated network access and Information Power Grid resource use. Then, faced with programmatic and budgetary constraints, NASA headquarters revised the acquisition plan for the Science Data Segment, and the Advanced Data Grid Project was cancelled.

Nonetheless, the Aerospace and NASA team members learned important lessons about ground–system design and implementation using grid computing technologies. Their experience suggests that grid-based ground systems architectures have considerable potential for a wide range of Aerospace customers because of their ability to support a wide variety of problem domains, provide cross-program interoperability, and enable distributed workflow. Grid-based architectures also have significant potential for cost savings over the life of a program by allowing the purchase of commodity computing hardware. This allows a program to keep pace with the rapid change of technology for reasonable cost.

One of the key benefits of grid computing is the creation of “virtual organizations” by enabling the sharing of computing resources across traditional organizational and administrative boundaries. This requires strong teamwork, the involvement of all the stakeholders, and careful negotiation of policy issues (e.g., security). On the other hand, the chosen approach to metadata catalogs did not allow for their federation, so metadata catalog services were a potential single point of failure; this issue will need to be addressed. Grid service standards are changing, and their support by vendors will need to be considered. Since the termination of the Advanced Data Grid project, grid and web service standards have somewhat merged with the goal of providing better implementation and stability.

**Conclusion**

Aerospace’s architecture studies were completed in September 2004, and work on the Science Data Segment prototype was completed in August 2003. Even though the acquisition plan changed and NASA did not release a Request for Proposal as originally intended, these efforts have yielded significant benefits. For example, the architecture and specification documents that Aerospace developed for NASA will be useful in guiding future development of the Science Data Segment. In addition, both NASA and Aerospace have gained additional insight into ground systems engineering, system design and implementation, and grid computing as a result of these two projects.

**Further Reading**


The advent of meteorological satellites has significantly improved scientific knowledge of Earth’s weather and climate. But while models of the troposphere have grown quickly during the past few decades, models of the upper atmosphere (above 100 kilometers) remain relatively undeveloped. One class of research, for example, involves how—and how much—does the input of auroral energy affect this region.

When energetic electrons and protons from the sun reach Earth, they interact with components of the upper atmosphere. In addition to producing the luminescent aurora borealis, this interaction can generate winds and push atmospheric constituents to higher altitudes, where they can increase the drag on satellites. The energetic particles can also ionize the molecular nitrogen and atomic oxygen in the upper atmosphere, which can radically alter the ionosphere and interfere with satellite-based communications.

Operational civilian and military systems can benefit from fast information on auroral heating effects, but ground-based systems can’t supply this information on a global scale. Optical sensors are limited by weather or daylight considerations, while radar systems may be constrained by expense and geography. Ground-based systems can certainly be useful in developing and testing models and instruments, but only satellite-based remote-sensing systems can provide the breadth and depth of data needed for operational use. Aerospace has recently been involved in building satellite instruments to measure auroral energy inputs into the atmosphere. These instrument concepts have been adopted for NASA research missions and will play a part in future versions of the Defense Meteorological Satellite Program (DMSP) and the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

Probing the Aurora

The intensity of colors in the aurora borealis can reveal characteristics about auroral energy and heating. When auroral electrons collide with atmospheric nitrogen molecules or oxygen atoms, their energy gets absorbed, and photons are emitted. The more auroral particles there are, the more photons are emitted. Precipitating auroral electrons whose energies are more than 1000 electron volts typically result in significant green emission (at 5577 angstroms) originating near 100 kilometers in altitude, while lower-energy auroral electrons produce significant red emission (at 6300 angstroms) above 200 kilometers. Thus, measuring the brightness of the green emission can help determine total energy input, and calculating the ratio of red to green can identify the average energy of the auroral particles. Emissions at other wavelengths depend on the densities of atmospheric components such as nitrogen or atomic oxygen as well as on total and average energy input.

Based on this phenomenon, Aerospace scientists identified a set of auroral colors that are bright enough to be measured in a few seconds and that can be used to calculate the total and average energy input, as well as the ratio of the atmospheric molecular nitrogen to atomic oxygen density. Researchers then developed a simple filter camera system, consisting of a telescope...
Nighttime ratio of atomic oxygen to molecular nitrogen during a period of extreme auroral activity. The arrow indicates satellite track. Note the considerable reduction of atomic oxygen over Alaska. Less than 24 hours earlier, levels were more consistent with model predictions.

with a 1-degree field of view of the sky, a filter wheel with four filters to separate auroral colors, and a photomultiplier tube to detect the auroral photons. This computer-controlled system is situated at Poker Flat, Alaska, and operates every night from October to April.

Global Ultraviolet Imager

The ideas behind the ground-based instrument at Poker Flat also provided the basis for a satellite-based instrument known as the Global Ultraviolet Imager. Built jointly by the Johns Hopkins Applied Physics Laboratory and The Aerospace Corporation, the Global Ultraviolet Imager is a far-ultraviolet (115–180 nanometer) scanning imaging spectrograph. It provides horizon-to-horizon images in five selectable ultraviolet wavelengths, or “colors.”

The Global Ultraviolet Imager operates on much the same principle as the ground-based instrument in Poker Flat, although the underlying physics is somewhat different. For example, average energy is obtained by comparing the intensity of two ultraviolet colors. However, one of these colors is absorbed more by molecular oxygen, which increases at lower altitudes. A greater concentration of high-energy electrons, which penetrate to lower altitudes, produces a different color ratio than a mix with more low-energy particles.

The Global Ultraviolet Imager was launched in 2002 aboard NASA’s TIMED (Thermosphere, Ionosphere, Mesosphere, Energetics, and Dynamics) satellite, which was designed to characterize the energy inputs to the upper atmosphere below 200 kilometers. TIMED flies at a relatively low altitude (roughly 620 kilometers) and has a revisit time of 97 minutes. Thus, the imager can provide a detailed snapshot of the effects of auroral heating in a particular region of auroral precipitation. These images provide useful information on parameters such as the ratio of atomic oxygen to molecular nitrogen at spatial sizes of several tens of kilometers.

The instrument can also obtain atomic oxygen and molecular nitrogen from dayglow emissions—nonthermal emissions produced by the interaction of solar radiation and Earth’s atmosphere that appear during daytime. Thus, observations from the imager can provide a global picture of composition change over a restricted local time on the sunlit portion of Earth. This means that composition change can be monitored at middle and low latitudes not accessible by auroral sensors operating in the polar regions.

Data obtained from the Global Ultraviolet Imager have raised many interesting questions. For example, ground-based measurements have shown that the ratio of atomic oxygen to molecular nitrogen can fall dramatically during periods of heightened auroral activity. Such composition changes can influence the ionosphere, a knowledge of which is important for communications. The Global Ultraviolet Imager has also recorded this phenomenon, tracking oxygen-depleted regions of the upper atmosphere as they expand to cover more of the globe and following them as they shift in response to changing upper-atmosphere winds. Still, the mechanism for the rapid drop in atomic oxygen has not yet been identified.

Future Applications

Aerospace work with the Global Ultraviolet Imager has had direct implications for defense and civil satellite programs. For example, the Air Force recently launched the DMSP F-16 satellite, which included a number of new space weather sensors. One of these, the Special Sensor Ultraviolet Spectrographic Imager (SSUSI), is almost identical to the Global Ultraviolet Imager. The experience Aerospace gained with the Global Ultraviolet Imager is being used to help integrate SSUSI into an operational sensor. In addition to information on global atomic oxygen and molecular nitrogen, SSUSI will provide information on the extent of the aurora and the height and strength of the ionosphere using information from the same five colors used on Global Ultraviolet Imager.

NPOESS will also include an instrument similar to SSUSI. The data from DMSP and NPOESS sensors will eventually feed large assimilative computer models that could ultimately describe space weather much the same way that large-scale meteorological models describe tropospheric weather today.
NOAA’s Move Toward an Enterprise Architecture

The Aerospace Corporation’s technical expertise has been critical in helping NOAA develop a comprehensive system for managing the collection, processing, and transmission of environmental data.

Constance Killion and Thomas Adang

The National Oceanic and Atmospheric Administration (NOAA) conducts research and gathers information about the oceans, atmosphere, space, and sun. Within the Commerce Department, NOAA performs these activities through five major organizations: the National Weather Service; the National Ocean Service; the National Marine Fisheries Service; the National Environmental Satellite, Data, and Information Service; and the Office of Oceanic and Atmospheric Research.

During the past two years, NOAA has sought to streamline its operations and systems and facilitate coordination among these NOAA organizations. Aerospace, as a member of a Federally Funded Research and Development Center (FFRDC) and Systems Engineering and Technical Assistance (SETRA) contractor team supporting NOAA’s Office of System Development, has been assisting in this effort. By applying specialized expertise in systems engineering and architecture development, Aerospace is helping NOAA move from its traditional focus on individual “stovepipe” systems to its new vision of an integrated enterprise architecture.

A New Strategy

NOAA’s move to increase organizational efficiency began late in 2001 with the arrival of Vice Admiral Conrad Lautenbacher Jr. as NOAA’s administrator. One of Vice Admiral Lautenbacher’s first tasks was to conduct an agency-wide program review to determine whether NOAA’s spending matched its priorities. Of course, this question could not be answered without first identifying priorities and quantifying resource allocations. Thus, the program review team submitted numerous recommendations along these lines—most important, that NOAA should develop a strategic plan, implement a requirements-based resource-management system, and develop a system for planning, programming, budgeting, and execution.

Another important recommendation was to develop an observing-system architecture. Before an “optimal future” or target observing-system architecture can be developed, NOAA needs to develop a comprehensive inventory of its current systems. Then, NOAA must gain an in-depth understanding of how the observing elements and their data-handling elements are supporting NOAA mission goals and identify the performance shortfalls.

Acting on these recommendations, NOAA began developing a strategic plan, and asked Aerospace to help identify strategic goals for an integrated system for environmental global observations and data management. At the same time, NOAA asked Aerospace to help formulate a NOAA-wide concept of operations.

The Baseline

Aerospace developed a preliminary baseline architecture by comparing NOAA’s existing operations with its current systems. In the course of this work, it became clear that NOAA needed not just a baseline architecture for its observing system, but a more comprehensive enterprise architecture for its entire organization. And in fact, this conclusion echoed an assessment by the Congressional General Accounting Office, which told the House Science Committee in July 2002 that NOAA “needed to take an enterprise architecture approach” for its environmental satellite and data information system. Lawmakers wanted to ensure that any increase in NOAA’s observational capabilities would lead to a commensurate increase in data usage and usefulness.

Aerospace began by systematically dissecting all of NOAA’s diverse operations and linking them to one of four NOAA mission goals (concerning ecosystems, climate, weather and water, commerce and transportation). This analysis revealed that NOAA was more than just an oceanic and atmospheric research body, but was really an environmental information clearinghouse. It also revealed that many of the environmental parameters supported more than one mission goal. Thus, the focus on the observing system failed to consider the bigger picture. Rather, the production and dissemination of environmental information must drive the end-to-end decision-making process at the enterprise level.

Aerospace produced a concept of operations that included an overarching schematic of NOAA operations. This schematic, known as the Information Service Enterprise, recognizes four distinct segments within NOAA: User Interface, Observations and

NOAA’s Mission Goals:
1. Protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management.
2. Understand climate variability and change to enhance society’s ability to plan and respond.
3. Serve society’s needs for weather and water information.
4. Support the nation’s commerce with information for safe, efficient, and environmentally sound transportation. Understand and predict changes in Earth’s environment and conserve and manage coastal and marine resources to meet the nation’s economic, social, and environmental needs.
Collections, Archives and Access, and Data Product Processing. Each segment interacts with the other segments, and overall coordination and control is provided by the Methodology, Innovation, and Implementation element and supported by NOAA leadership and support services.

Aerospace provided a strategy, implementation plan, and schedule for the Information Service Enterprise. The implementation plan also called for the creation of a corporate oversight body and the hiring of an enterprise system architect.

Accordingly, NOAA established an oversight body, the NOAA Observing System Council, and brought in an observing-system architect. Development of the target observing-system architecture is also under way. But the process is far from simple. The extensive data collection that Aerospace led while building the baseline architecture revealed a number of important details about the agency. For example, NOAA operates about a hundred observing systems with thousands of globally distributed collector platforms and maintains hundreds of data-management systems. Of these, approximately 60 percent are research-based and 40 percent are operational. In addition, NOAA collects 225 Global Change Master Directory defined environmental parameters.

These revelations point to more questions that must be addressed before (and during) definition of the target architecture. For example, what are the driving needs? What is the gap between the needs and capabilities? When will existing capabilities start to degrade or disappear? What other systems provide these capabilities? Who benefits from the current and future capabilities? Who are NOAA’s partners? How are NOAA systems tied together with systems outside NOAA responsibility?

**Future Directions**

Aerospace has worked on similar efforts for other agencies and is therefore familiar with the complexities of federal enterprise architecting and well versed in the evolving guidance. Aerospace was able to provide reliable evaluation criteria to help NOAA choose a suite of software tools used to develop the observing-system architecture called for by the Information Service Enterprise.

NOAA selected the Metis modeling program for use in establishing the baseline architecture. NOAA’s decision to use Metis for this initiative set the stage for its later use throughout the agency. A different requirements-management tool, DOORS (Dynamic Object-Oriented Requirements System), remains under consideration because it is already in use in several large program offices in NOAA; Aerospace also has significant experience with this tool.

ArcMS is one of several geographical information system tools used by NOAA to help visualize and analyze data in geospatial databases. It’s particularly useful in identifying gaps between system needs and capabilities and recognizing duplicative systems.

CasaNOSA is a Web-based collaboration tool developed by NOAA to collect basic information about the observing system and other architectural elements. Some of these tools are also under consideration for architecture development efforts at the federal and international level where NOAA is a member of the working groups and where Aerospace has been providing key technical support.

The Information Service Enterprise has been codified in Strategic Direction for NOAA’s Integrated Global Environmental Observations and Data Management System, a document principally authored by Aerospace and published by NOAA in July 2004. The Information System Enterprise will be NOAA’s contribution to the U.S. National Earth Observation System, which will in turn contribute to international efforts to develop a Global Earth Observation System of Systems.

Significant consensus building lies ahead before NOAA can begin developing the new systems and programs that will constitute the Information Service Enterprise. In the meantime, Aerospace, with its experience in both global observation and information architecting, will continue to help NOAA realize its ambitious information enterprise goals.

**Enterprise Modeling**

Aerospace provided evaluation criteria to help NOAA choose a suite of software tools used to develop the observing-system architecture called for by the Information Service Enterprise.
The GOES (Geostationary Operational Environmental Satellite) constellation provides continuous monitoring of meteorological conditions in the Western hemisphere. Operated by the National Oceanic and Atmospheric Administration (NOAA), the two active GOES spacecraft also monitor the space environment, receive and transmit search-and-rescue data, and relay ground-based environmental platform data.

A major upgrade to this system, known as GOES-R, is under development, with a first launch scheduled for late 2012. GOES-R is a major step forward in the fields of weather, atmosphere, climate, and ocean monitoring. Its launch will mark the first technological advance in GOES instrumentation since 1994. The combined instrument downlink data rate will increase by a factor of 60, and the number of environmental product types will increase by a factor of 4. The amount of environmental data being rebroadcast to users throughout the hemisphere will increase by an order of magnitude. The total volume of information products will increase from roughly 43 to more than 150.

The Aerospace Corporation created conceptual designs that integrated the satellite bus, instruments, and communications payloads for GOES-R. Aerospace also performed reliability estimates for these segments. These designs and analyses provided a basis for the GOES-R reference architecture. (This reference architecture is not the government-recommended solution, but rather a basis for program planning and estimation only. GOES-R formulation contractors will be expected to define and develop their own architecture solution to meet government requirements.) NOAA and NASA also used Aerospace data in evaluating costs, technology maturity, and schedule for all aspects of GOES-R. Aerospace designs were further used as the basis for an industry-wide architecture study.

**Architecture Studies**

GOES-R system requirements include high reliability and long satellite service life. Aerospace studies suggested that GOES-R could achieve these goals more easily by means of a distributed space-segment architecture. These goals could also be achieved using the current GOES architecture, in which the instruments, communications, and auxiliary services are consolidated on each of the two operational satellites. With a distributed space-segment architecture, these instruments, communications, and
services would be deployed across four satellites—two in each orbital location. Placing the primary instruments (the Hyperspectral Environmental Suite and the Advanced Baseline Imager) on separate satellites would simplify the satellite design and increase satellite reliability. Separating components also simplifies infusion of new technology and allows for more efficient use of spare satellites: An instrument failure could provide an infusion opportunity; NOAA could replace only the affected satellite.

Other architectural options that Aerospace considered include keeping the instruments at geosynchronous orbit, but using a medium Earth orbit for communications and services; this would enable GOES-R to support other missions while helping NOAA transition toward its goal of a global observing system. Another option was to use a dedicated communications satellite at geosynchronous orbit to supply auxiliary services and to rebroadcast environmental data products to the user community. Another option was to use three satellites per orbital location—for example, one for each of the primary instruments and a third to carry communications and auxiliary services payloads.

This study provided the basis for a broader agency announcement issued by NOAA to evaluate alternative GOES-R architectures. Twelve contracts were issued as a result of this announcement. Aerospace assisted the GOES-R program office by cochairing the study, answering questions from vendors, and assessing their results. Reliability studies conducted by Aerospace were made available to the vendors and were widely used.

Aerospace is also assisting the GOES-R program office prepare for the program-definition and risk-reduction phase. Results from the broad agency announcement, along with Aerospace technical documents and acquisition expertise, will be used in the program-definition and risk-reduction phase of GOES-R acquisition.

Satellite Bus and Instruments

As part of the overall architecture study, Aerospace evaluated initial designs for the instruments and bus needed to support the GOES-R spacecraft lifetime of 15 years. The Aerospace Concept Design Center examined several alternative satellite designs to support 5 years of on-orbit storage followed by 10 years of operations. Aerospace created 13 design configurations for various consolidated, distributed, and medium-Earth-orbit constellations. These designs are continually updated and serve as NOAA’s notional reference architecture; they’re also used to create the program’s independent cost estimate.

Aerospace performed trade studies and analyses of all the GOES-R instrument payloads. One primary instrument, the Advanced Baseline Imager, features 16 channels—two in the visible band and 14 in the near infrared and infrared. Spatial resolution is 0.5 kilometer in the visible band, 1 kilometer for the near infrared, and 2 kilometers for the infrared. In contrast, the current GOES imager has only five channels, with resolutions of 2 and 4 kilometers. The Advanced Baseline Imager can provide one full image of Earth, three images of the continental United States, and 30 mesoscale (1000 x 1000 kilometers) images every 15 minutes. Alternatively, it can provide a full Earth image every 5 minutes. The current GOES provides a full Earth image every 30 minutes; GOES-R will therefore provide six times more temporal coverage. Production has begun on this instrument, and Aerospace continues to support it with factory visits, technical reviews, and program reviews.

Aerospace likewise supported the design and analysis of the other primary instrument, the Hyperspectral Environmental Suite, which comprises a sounder and multichannel imager. Aerospace served on the NASA source-selection board for the instrument’s formulation and continues to support program reviews and factory visits with NOAA. The Hyperspectral Environmental Suite is designed to provide high-resolution hemispheric soundings, mesoscale soundings of severe weather systems, and coastal waters imaging. The sounder will cover almost the entire hemisphere with 10-kilometer resolution in the infrared and a 1-hour refresh rate; the two current GOES sounders only cover the lower 48 states. For mesoscale soundings, the instrument will achieve 4-kilometer resolution in the infrared and have a single broadband visible channel for cloud detection. The exact number of sounding channels has not been established, but is expected to exceed 1500. In contrast, the current GOES sounder has 18 infrared channels. For monitoring coastal waters (mainland U.S. and Hawaiian), the Hyperspectral Environmental Suite will also provide at least 14 channels in the visible and near-infrared range, with 300-meter resolution or better and a 3-hour refresh rate.

Other Aerospace instrument support includes the Solar Instrument Suite, the Space Environmental In Situ Suite, and the Geostationary Lightning Mapper. The Solar Instrument Suite will have several instruments for monitoring solar activity—including an X-ray instrument for tracking and measuring solar flares. The Space Environmental In Situ Suite is designed to provide continuous measurement of Earth’s ambient magnetic field along with the proton, electron, and alpha-particle fluxes at geostationary orbit. The Geostationary Lightning Mapper, sensitive enough to detect 70–90 percent of all lightning strikes, will help predict severe storms by continuously tracking the intensity, frequency, and location of lightning discharges; it will provide rapid information that could be correlated with radar returns, cloud images, and other meteorological data. Aerospace will support all these instruments through design, trades, satellite integration, and operations.

Communications

GOES satellite communications involve both direct transmission to and from a processing station on the ground as well as wide-area
broadcasting. Each satellite sends raw data directly to a ground station, where the data are processed and archived. The processed data are compressed and transmitted back to each satellite. A transponder in the satellite downconverts the signal and broadcasts it over the visible Earth. Users equipped with suitable receivers can extract the information they need.

GOES-R communications will be far more challenging than earlier GOES satellite communications because the total raw data rate will probably be between 130 and 200 megabits per second. Even after lossless onboard compression, the onboard instruments can generate a combined raw data rate of up to 100 megabits per second on the downlink, and the GOES rebroadcast data rate after more extensive ground compression may be as much as 24 megabits per second. Previous GOES satellites were only required to transmit instrument data at 2.7 megabits per second to the Command and Data Acquisition Stations and broadcast data at 2.1 megabits per second. Requirements for data quality have also increased: The instrument data must achieve a bit-error rate of around 10^-9 or better, far more stringent than the 10^-6 for the current GOES downlink. The broadcast data must achieve a user receiver bit-error rate of around 10^-6 to 10^-9 as opposed to only 10^-4 for the current user receivers.

The L-band spectrum currently used for instrument data downlink to the Command and Data Acquisition Stations (a few megahertz) is too narrow to meet the required 100 megabits per second, even with compressed data. As a result, instrument data will be transmitted in select portions of the X band. Even with migration to X band, bandwidth constraints still exist. Out-of-band emissions must be stringently controlled to prevent interference with other satellites using adjacent bands (e.g., the Deep Space Network downlink at 8400–8450 megahertz). The need for higher quality data in a constrained bandwidth further complicates matters, because it requires even greater power, which in turn increases the potential for out-of-band interference. This is true not only for the instrument data at X band, but also for broadcast data in L band.

NOAA has asked Aerospace to determine the feasibility and risk of integrating the core technologies into an end-to-end concept design that will meet system requirements. Accordingly, Aerospace has organized NOAA’s communications engineering efforts along three principal lines: spectrum management and regulatory issues, analysis of specific core technologies, and development of an end-to-end communications testbed to verify feasibility.

Spectrum management is a complex issue with far-reaching implications. Before the communications architecture can be developed, NOAA must find available bandwidth and reserve it through the National Telecommunications and Information Administration. This process takes years and requires planners to know which spacecraft contending for the same spectrum will be in orbit during the GOES-R series time frame, which can run for 20 to 25 years from first launch, about 10 years from now. Spectrum has not yet been coordinated for the instrument data downlink and GOES rebroadcast uplink. Aerospace, with NOAA, is working to ensure that suitable X-band spectrum will be available and that interference levels in both L and X bands can be coordinated.

Aerospace has identified several core technologies that must be developed to support GOES-R requirements. These include bandwidth-efficient and power-efficient communications, forward error-correction coding and interleaving, L-band linearized amplifiers, filtering, synchronization, and commercial microelectronics suitable for use at the radiation levels of geostationary orbits. These technologies have been selected for investigation because they individually pose development risks and costs, and their interaction as part of a comprehensive system can have profound consequences with respect to data quality, data rate, control of out-of-band emissions, spacecraft mass and power levels, and compatibility with receiver system electronics. Thus, the main challenge is to integrate and test all these core technologies in an end-to-end system.

The communications testbed uses representative hardware and realistic channel conditions to help determine their cumulative effect on bit-error rate, out-of-band interference, and error containment. The testbed emulates end-to-end transmitter/receiver hardware and thus facilitates investigating potential alternatives for modulation and coding. It can migrate to PC-card implementation to serve as a pathfinder for the GOES rebroadcast receiver design. It can scale to instrument data rates to support all
GOES-R reference architecture. Satellites transmit raw instrument data directly to a processing station. The data are compressed and sent back to the satellites, which then relay the data using a wide-area broadcast. The NOAA Satellite Operations Facility (NSOF) will house mission management (MM), product generation (PG), product distribution (PD), and the Satellite Operations Control Center (SOCC). NSOF will receive telemetry and instrument data directly from the satellite but will not transmit to the satellites because of FCC restrictions. Commands will be issued by SOCC and sent to the Command and Data Acquisition Station (CDAS) for relay to the satellites. Likewise, the GOES Rebroadcast (GRB) data will be assembled at NSOF and sent to CDAS for uplink to the satellites. GOES-R will maintain a 30-day archive of environmental data products. As new products are generated, old products will be transmitted to the Comprehensive Large Array Data Stewardship System (CLASS). L0 refers to raw data sorted by instrument at full space-time resolution, L1b are calibrated and resampled data in engineering units, and L2+ are derived products (like the cloud cover pictures in nightly weather forecasts). Both L0 and L1b include metadata needed for further processing.
reasonable modulation candidates for the instrument data link. It can characterize bit-error-rate performance of commercially available codecs (coder/decoders). It can investigate bit-error-rate statistics and error patterns above and below a 10^-9 bit-error rate for compressed/decompressed instrument data rates, which could not be achieved in a reasonable time using simulation.

NOAA has expressed a desire for stringent bit-error-rate requirements for its compressed data streams, but the science and research community has not yet specified how many erroneous pixels can be allowed for the Advanced Baseline Imager and for the Hyperspectral Environmental Suite data in a single scan, picture, frame, or data block. Aerospace is working with the science and research community to determine what bit-error pattern is preferable to provide appropriate data quality after decompression.

Ground System
The GOES-R ground system needs to substantially increase communications bandwidth, data processing, and archiving capabilities. To complicate matters, if the GOES-R space-segment architecture is distributed (as proposed in the reference architecture), satellite operations will need to control twice as many satellites and manage shared orbital locations. Moreover, ground facilities will need to include a remote backup location, so its survival will not be threatened by the weather at primary sites.

In light of these challenges, satellite operations need substantial automation along with integrated logistics support. GOES already employs substantial automation in product generation, but GOES-R may need virtually complete automation for this task.

Working with the program office and other contractors, Aerospace developed a GOES-R concept of operations to provide guidance for the program definition and risk reduction phase. As envisioned in this operational concept, the NOAA Satellite Operations Facility in Suitland, Maryland, will house mission management, product generation, and the Satellite Operations Control Center. It will receive telemetry and rebroadcast products directly from the satellite, but will not transmit the processed data uplink or bus commands to the satellites because of FCC restrictions. Commands will be generated at the Satellite Operations Control Center and relayed to a Command and Data Acquisition Station at Wallops, Virginia, for upload to the satellites. Likewise, GOES rebroadcast data will be assembled at Suitland and sent to Wallops for satellite upload, along with additional service data.

GOES-R will maintain a 30-day archive of raw data records and a 3-day archive of reconstructed unprocessed instrument data at full space-time resolution with supplemental information to be used in subsequent processing appended (Level 0). GOES-R will generate nearly 16 terabytes per day of meteorological and environmental (Level 2+) products. All calibrated instrument data and selected products are kept in permanent storage as part of the Comprehensive Large Array Data Stewardship System, known as CLASS. About 1 terabyte per day of data will be sent to CLASS.

Conclusion
The GOES-R system will transition to operations around 2014, with the first launch planned for late in 2012. The GOES-R satellite series will operate for more than 16 years, providing regional environmental imagery and specialized meteorological, climatic, terrestrial, oceanographic, and solar-geophysical data. GOES-R will support a wide variety of end users such as National Weather Service, Federal Aviation Administration, Environmental Protection Agency, and Department of Homeland Security. GOES-R products will be useful to much of America’s industry, including agribusiness, transportation, and construction.

Aerospace participation in research, source selection, and program office activities has been instrumental in identifying difficult issues facing the GOES-R system. Aerospace’s continued support in the upcoming acquisition phase can help ensure that the final architecture will be both feasible and powerful enough to meet the diverse user requirements. Aerospace expertise and continued involvement should enable NOAA to provide an improved geostationary weather and environmental sensing capability that can serve up to 2030.
Ultracold Molecules

In recent years, the scientific community has begun to recognize the potential of ultracold molecules (at temperatures less than 1 millikelvin). The manipulation of such molecules could lead to new advances in chemistry while paving the way for novel frequency standards, high-precision spectroscopy, and quantum computation and cryptography. Aerospace has significant expertise in laser-based cooling of atoms; however, molecules have more complex internal energy structures, and are therefore much harder to cool directly using a direct laser. To overcome this difficulty, Aerospace has been exploring new physical concepts and techniques. Initial efforts have yielded promising results.

For example, Aerospace achieved the simultaneous laser cooling and trapping of both rubidium (Rb) and cesium (Cs) atoms in a dual-species magneto-optical trap (dual MOT). According to He Wang of the Photonics Technology Department, the dual MOT employs the same technology that Aerospace uses to make cold-cesium atomic clocks. It uses laser beams at two different wavelengths and an inhomogeneous magnetic field to trap a cloud of two atomic species in a tiny volume of about 1 cubic millimeter. The two species are then mixed and simultaneously cooled to an extremely low temperature of about 100 microkelvin, at which point they could form ultracold diatomic molecules.

In the course of this research, Aerospace scientists first constructed the basic lab apparatus and performed a theoretical analysis, which served as the guide to the experiment. Next, they developed a two-photon ionization time-of-flight mass spectrometer and demonstrated the production of ultracold RbCs molecules, Rb dimers, and Cs dimers in the dual MOT. According to Wang, the direct detection of ultracold heteronuclear molecules in the lab represented a breakthrough in the field. “The experimental demonstration of three cold-molecule species places Aerospace among only a few laboratories in the world to have prepared microkelvin molecular samples in the laboratory,” Wang said.

Researchers conducted further experiments geared toward enhancing the cold-molecule production rate and observed strong photoassociative resonance of ultracold Cs molecules. A higher production rate will benefit applications requiring higher signal-to-noise ratio and higher signal intensity, Wang said.

Heteronuclear cold molecules like RbCs have multiple frequency ranges in microwave, terahertz, and optical frequencies. In contrast, cold atoms like Cs only have frequencies in the microwave and optical ranges. Thus, just as laser-cooled atoms and ions form the basis for ultraprecise microwave and optical frequency standards, vibrational transitions in ultracold molecules could form the basis of terahertz frequency standards. In addition, Wang said, ultracold heteronuclear molecules like RbCs are electric dipoles, which allows them to be manipulated as the qubits (quantum bits) in quantum computing applications. Atoms do not have this dipole property.

Researchers are now implementing a laser-based dipole-force trap to store cold molecules long enough to allow more useful observation. “If the cold molecules formed in the dual MOT are not trapped, they will drift away within one hundredth of a second, leaving no time to study or probe them,” Wang explained. “A cold-molecule trap can store cold molecules for a few seconds—long enough to complete the measurements.”

Testing Ultrafast Circuits for Space Applications

Spacecraft electronics must operate in an extremely harsh environment. The constant bombardment of heavy ions and space particles can affect the performance of electronic components and lead to temporary or permanent failure. Aerospace has been testing the space-worthiness of circuits containing silicon-germanium heterojunction bipolar transistors (SiGe HBTs), which are expected to play an important role in advanced electronic systems for space. Potential applications include analog-to-digital converters operating at sampling rates in the 1–15 gigahertz range as well as digital logic circuits with data rates beyond 10 gigabits per second.

SiGe HBTs are potentially sensitive to total ionizing dose from protons as well as electrons, explained Donald Romeo, Senior Engineering Specialist in the Digital and Integrated Circuit Electronics Department. Ionizing radiation is primarily a surface effect, which can damage majority-carrier field-effect transistors, such as those used for CMOS; HBTs are bulk minority-carrier devices and are therefore largely immune to the effects of ionizing radiation within the device. Still, radiation can cause leakage paths between devices.

To study this technology, Aerospace designed testable logic circuits operating at gigabit-per-second rates using an in-house–designed custom digital logic cell family, which was used to implement the circuitry on a die fabricated by a wafer foundry using commercial 0.35-micron feature-size technology. More than 150 samples of the test die were supplied.
In addition, the research team used customized software to develop a high-speed circuit board containing the digital test device within a surface-mount package. Edge-mount connectors provided radio-frequency input and output signals. These boards are still being used to support accelerated radio-frequency life testing at elevated temperatures.

“Our forte is the ability to design special test circuits which will reveal the effects of aging and radiation damage well before ultimate failure,” said Romeo. The sort of test data acquired from these special test circuits and test structures are not generally available from wafer foundry operations for the state-of-the-art fabrication technologies, he said. “From our testing, which monitors several critical parameters, we can generate parameter-shift trend lines to extrapolate the mean time to failure for the on-orbit environment,” he said.

Among the circuits tested was a SiGe HBT “flight-like” maximum-length binary sequence circuit; Aerospace verified its operation up to 5 gigahertz (the test-fixture limit). Researchers also demonstrated logic-element gate-delay times of 18 picoseconds with a circuit containing a serial connection of 101 logic gates, which predicts the feasibility of radiation-hardened digital logic for operation beyond 10 gigahertz. The preliminary results derived from the accelerated life testing have demonstrated an estimated service life beyond 100,000 hours. Total-dose testing with gamma rays at Aerospace showed no change in performance at 500 kilorads (Si), and proton testing at UC Davis showed no increase in bit-error rate after 1.5 megarads (Si) when operating up to 5 gigahertz.

Glass Micromachines

Aerospace has developed a novel process for making microelectromechanical systems (MEMS) from silicon dioxide and implanting them on or within a silicon substrate.

As explained by Meg Abraham of the Aerospace Center for Microtechnology, the new process entails placing a mask over a silicon wafer and firing oxygen ions at it. The ions pass through the mask and burrow into the wafer to varying depths, based on their acceleration energy. When the wafer is annealed at a high temperature, the oxygen and silicon combine to form a glass-like silicon dioxide, which shrinks in the process. The technique can therefore produce nanoscale devices using the comparatively inexpensive microscale masks common in most silicon processing.

These devices can range in size from tens of microns down to the tens of nanometers. “As far as we can tell,” said Abraham, “the lower limit of the device scale is defined by the ability of the material to remain structurally viable.” The devices can be released after processing or packaging via laser-assisted chemical etching. This aspect makes them easy to integrate with electronics, because the etch releases only the devices, conserving the rest of the silicon for other uses.

Traditionally, MEMS are manufactured by growing successive layers of material and patterning them via photolithography and wet etching, Abraham explained; however, these layers tend to be uneven over large areas. Also, in trying to produce very thin layers—on the order of a few hundred nanometers—the process can result in discontinuous layers. Furthermore, said Abraham, the wet etch processes are hard to control. “All these problems make the traditional methods hard to scale down to the nanometer level,” she said.

Traditional MEMS are also fabricated from silicon—but this material is not always a good choice for electro-optical and optical devices because it does not transmit light in some important areas.
wavelengths. Silicon dioxide, the chemical compound found most frequently in glass, would be more useful in these applications, said Abraham. But MEMS manufacturers have not found many effective ways to release the glassy MEMS component without destroying the rest of the silicon wafer, which is needed for both structural support and for microelectronics. The Aerospace technique overcomes this difficulty.

The process can be used to make a host of devices, Abraham said. For example, Aerospace has shown that efficient radio-frequency microreceivers could be fabricated if they were constructed in integrated arrays; the Aerospace MEMS technique could enable this construction. Other potential applications include optical ring resonators, which could be used in integrated electro-optics or to generate Raman spectra for spectrometers; electromechanical ring resonators, which are commonly used as radio-frequency filters for cellular technology; on-chip fiber optics, which could lead to improved optical communications in both terrestrial and space environments; and on-chip bioassay microlabs, which could be useful in national defense and crime investigation as well as in medical diagnostics.

Data Fusion and Satellite Observation

The correlation of data from satellite sensors and ground-based monitors can yield significant insights into phenomena occurring near or on Earth’s surface. Aerospace is investigating how data from defense satellite sensors can augment data from weather satellites, nuclear-event sensors, imagery assets, ground-based infrasonic and seismic arrays, ground-based cameras, and other recording and monitoring devices. According to Dee Pack, director of the Remote Sensing Department, this work could enhance missions such as early detection and long-term monitoring of serious fires, early warning of volcanic-ash plumes that can threaten jet aircraft, and reduction of false alarms concerning atmospheric nuclear detonations.

For example, in one recent study, Aerospace helped analyze data obtained from satellites and ground-based systems to characterize a large meteor that exploded over Park Forest, Illinois, on March 27, 2003. “These large meteors are of concern to the Department of Defense due to their ability to mimic nuclear events,” Pack said. These meteor events occur 50–60 times per year globally and are the single largest source of false alarms for infrasonic nuclear monitoring stations operated by the Comprehensive Test Ban Treaty organization, he said.

Working with Sandia National Laboratory, Aerospace correlated data from visible-light satellite sensors and video recordings from ground-based cameras to generate light curves. These indicated that the total energy release of the meteor was equivalent to a 0.34 kiloton nuclear event. An accurate trajectory was generated from measurements taken by infrared satellite sensors that scanned the emissive track of the meteor as it passed through the atmosphere. The trajectory was used to derive an initial velocity of roughly 20 kilometers per second, decelerating to 14 kilometers per second at lower altitude. The calculated velocity and total kinetic energy were then used to derive the meteor’s initial mass, which was estimated at 7.8 tons. The mass calculation, in turn, was used to obtain a diameter estimate of 1.6 meters.

“Thorough study of these bolides is warranted so no confusion results should one explosively disintegrate at an inopportune time in a region where military tensions are high,” Pack said, adding, “Further analysis of the Park Forest event will add to our knowledge base of the infrared, visible, infrasonic, and seismic signatures of these extraordinary Earth-crossing objects and serve to train global observers to better recognize and characterize these naturally occurring huge explosive events.”


Patents


This waveguide device permits the selection of either linearly or circularly polarized signals in user terminals for commercial satellite systems. This capability allows a single terminal design to be interchangeably used for different satellite services. The ability to sequentially use different satellite services with a common terminal design avoids the cost of purchasing multiple terminals for each service. The waveguide design has low insertion loss for efficient operation and a high power-handling capability in comparison with conventional hybrid and switch combiners. Furthermore, the switch devices can be cascaded with appropriate waveguide transitions for simultaneous multiple frequency operation, for example, C- and Ku-band frequency commercial services.


Fluid-filled three-dimensional bodies or “machines” embedded in a polymeric matrix provide damping of vibroacoustic forces. The machines have an internal space that changes volume when the composite material is subjected to a predetermined force. The space is filled by a viscous and compression-resistant fluid that flows in or out in response to the volume changes. The fluid can also include bubbles of compressible fluid. The bubbles would act as a reservoir, expanding or contracting as the volume of the internal space changes. Arrays of long tubular or cylindrical bodies can be arranged in planes to achieve varying dampering profiles.


Designed for use with microsatellites, a conductive hinge made of a shape-memory alloy can be used for stowing and deploying solar panels. In its basic form, the hinge is made from a thin sheet of superelastic material such as nitinol (NiTi) that can be bent around an extremely small radius without breakage or permanent deformation. The hinge is used to connect thin-film solar-cell panels, which can be stacked on top of each other with minimal spacing. On orbit, the solar array is released and deployed (by the elastic energy stored in the hinge material) into a predetermined shape such as a PowerBox or PowerSphere. The hinge can be further adapted into a latch to lock the panels in place after deployment. Also, because the material is electrically conductive, the hinge can function as a power bus for routing current through multiple interconnected panels.


A quadrature demodulator for use in optical receivers mitigates the problem of phase shifting that can occur when portions of a signal are sent through separate optical fibers. The demodulator has an optical local oscillator that generates a weak pilot tone that is mixed with the large optical input signal. Thus, the pilot tone and input signal are exposed to the same environmental perturbations of the optical fibers. The pilot tone functions as a phase-shift reference, enabling the demodulator to maintain optical phase coherence between the separate in-phase (I) and quadrature (Q) optical channels. During homodyne demodulation, the pilot tone is routed through I- and Q-channel fibers and then mixed with the optical local oscillator to produce the error component for closed-loop control. The detected quadrature components of the unknown input signal can be used for coherent or incoherent optical receiver applications.


Photostructurable glass-ceramic materials can be used to make spacecraft support structures, insulated circuit substrates, multichip module supports, actuators, sensors, and thermal control systems. The materials can be inexpensively molded into any shape, machined to micron tolerances, metalized to form electronic structures, and assembled through fusion bonding. When tempered, the materials resist tension-induced fracture and function as electrical and thermal insulators; they are also transparent to visible and near-infrared light. The photostructurable glass-ceramic materials do not outgas chemicals, have zero porosity, can be handled using cleanroom protocols, and are amenable to
system integration using standard microelectronics fabrication techniques. This multifunctionality allows almost an entire integrated spacecraft to be fabricated from these materials.


This microfabrication technique can be used to form features of high and low aspect ratio in a photosensitive material such as photostructurable glass. The key to this technique corresponds to the fine control of the material exposure dose by a variable-intensity pulsed ultraviolet laser during direct-write patterning. The consequence is that differing etch rates can be achieved across the substrate without the need for protective etch masks. The method offers direct-write serial patterning with batch chemical processing and permits the fabrication of complex structures and features on a single wafer. Adjacent microstructures with aspect ratios ranging from 2:1 to 30:1 can be created. The variable exposure method enables the conversion of computer-assisted design patterns and corresponding laser irradiation information into microfabricated structures that retain precise feature sizes within predetermined dimensions. The method can be used in the fabrication of high-aspect-ratio mesoscale structures that require fine microscale features, for example, in complex fluidic devices or in far-infrared or terahertz devices.


Data-aided synchronizers are used to track the symbol timing and carrier phase of a continuous phase modulation (CPM) signal in the presence of noise. These digital synchronizers are suitable for use in Gaussian minimum shift keying (GMSK) communications systems. Data-aided tracking is applied in two forms. In the first, the timing error of the received CPM signal is extracted from the principal Laurent amplitude modulation component by an early and late gating operation, followed by a multiplication of the data decision, which removes the data modulation in the error signal. In the second form, the phase error of the received CPM signal is extracted by a cross-correlation operation, with the data decision produced by a serial data demodulator. In each case, the resulting error signal is tracked by a second-order digital loop operating at the symbol rate.


Using code-division multiple-access (CDMA) protocols, this networked communication system can transmit command and telemetry data between a spacecraft orbiting a planet and a number of mobile landers or rovers on the planet’s surface. When several landers come within the beamwidth of the spacecraft antenna, they can all receive communication simultaneously. The downlink transmitter has a quadrature component that carries a pilot code for coarse acquisition and an in-phase component that carries a Walsh-Hadamard code and a PN code for fine acquisition. The downlink subsystem uses direct-sequence spread-spectrum signaling and amplitude modulation. The uplink subsystem uses spread-spectrum signaling and phase modulation. Characterized by reduced mass, size, and power consumption, the system provides reliable operation despite fading and multipath effects caused by variable surface terrain and atmospheric interference.


To reduce the risk of a spacecraft or aircraft colliding with another object, this method first screens out objects that present no risk. For those that could possibly collide, the method then determines whether the distance between the two objects at their closest approach will be less than a critical amount. If so, conjunction determinations are performed using high-fidelity time-stepped trajectory propagation. When conjunction is indicated, the method then determines the collision probability based on an error covariance matrix that is transformed to an encounter frame by rotation and scaling. A contour integration method can then efficiently compute collision conflict probability. When the probability exceeds a certain threshold, the method determines an avoidance maneuver, optimized in terms of direction, magnitude, and time. For each value of time before anticipated conjunction, a gradient method determines the optimal direction, and a numerical search method determines the optimal magnitude.


Designed for economical testing of DC-to-DC power converters and similar electronic devices, this system provides direct testing power to a system under test at a significant level above the net input power drawn from the utility grid or the input power source. The system uses at least an efficient DC-DC converter serving as a controllable electronic load that absorbs the output power from the system under test and feeds it back into the main input, rather than flushing it out to the power grid or letting it fully dissipate as heat, as occurs in conventional electronic loads. Stability can be improved by means of transient stabilizers inserted in the feedback path. Undervoltage and overvoltage limiters can be included for additional stability and reliability, and an active power-factor correction AC-to-DC converter can be inserted to improve power quality and efficiency of power transferred from the utility grid.


This patent describes a method and system for sequentially inflating the cells in an inflatable structure by means of electronic control and power lines integrated into the walls of each cell. A microelectromechanical system (MEMS) capable of generating inflation gas is placed inside each cell. The MEMS contains all of the associated electronics for controlling the release of gas in small increments and determining the resultant pressure change in the inflatable structure. The control electronics can execute a preprogrammed inflation sequence and communicate status along with any measured parameters to a central processor. The MEMS devices would operate using direct current and control lines supplied from a spacecraft bus. Various types of gas generators can be used, such as cellular containment evaporation gas generators and laser ablation gas generators.
An Overview of Meteorological Satellites

Leslie O. Belsma of Space Support Division supports both the DMSP and NPOESS program offices. She also manages an Internal Research and Development project to demonstrate the use of satellite data to improve high-resolution weather forecasting in support of air-quality and homeland-security applications. She promotes the use of satellite data for air-quality applications through presentations to the civil-air quality community. A retired Air Force weather officer with an M.S. in aeronomy from the University of Michigan, she joined Aerospace in 1999 (leslie.o.belsma@aero.org).

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The Near Real Time Processing Effort

Jim O’Neal is Senior Project Engineer in Civil and Commercial Operations, currently assigned to NOAA/NESDIS. Before joining Aerospace in 2000, he served as program manager of NOAA’s Polar-orbiting Operational Environmental Satellite (POES) Program, and while in the Air Force, program manager of DMSP Block 6. He holds M.S. degrees in statistics and electrical engineering (jim.oneal@noaa.gov).

The NPOESS Preparatory Project: Architecture and Prototype Studies

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Samuel Gasster is Senior Engineering Specialist in the Computer Systems Research Department, where he specializes in grid computing technology for scientific and remote-sensing applications, high-performance computing applications, and data-modeling and data-management system development. He has worked at Aerospace for 15 years and has supported a wide range of defense and civilian programs and agencies, including DMSP, NPOESS, NASA, and NOAA. He was the sensor technical lead during the acquisition phase of the NPOESS Conical-scanning Microwave Imager/Sounder and provides algorithm and software performance evaluation support to the NPOESS program. He is also the CrIS Level 1 Science Team Lead for the NASA NPP Science Team. He has taught remote sensing and computer science at UCLA Extension and systems engineering at CalTech. He holds a Ph.D. in physics from the University of California, Berkeley (samuel.d.gasster@aero.org).

James Hecht is Senior Scientist in the Space Sciences Department. He has authored more than 60 refereed scientific papers since arriving at Aerospace in 1981. He specializes in optical remote sensing of the upper atmosphere, which has allowed him to study the aurora at –40° in February in Alaska and to develop experiments on atmospheric gravity waves in the heat of the desert sun in Alice Springs, Australia. He has performed basic research for both NASA and the National Science Foundation and supported DMSP, NPOESS, and BMDO. He holds a Ph.D. in physics from the University of California, Santa Barbara (james.h.hecht@aero.org).

NOAA's Move Toward an Enterprise Architecture

Constance Killion, Senior Project Engineer, is a member of the Silver Spring Program Office, Civil and Commercial Operations, supporting NOAA’s Office of Systems Development. She joined Aerospace in 1999 to support the National Security Space Architecture’s office, working primarily on the communications architecture, now known as Transformational Communications, and on the Space-based Radar Working Group. An assignment in the Reconnaissance Systems Division led her to NOAA, where she led the development of operational concepts for NOAA and NESDIS, and has been a primary author of NOAA’s Strategic Direction for the Integrated Global Environmental Observations and Data Management System. A retired naval officer, she spent four years at NASA, one working moon and Mars architectures and three as Chief of International Planning and Programs (constance.j.killion@aero.org).

Thomas C. Adang is Director of the Silver Spring Program Office in Civil and Commercial Operations. His office is supporting NOAA in the development of its future geostationary operational environmental satellite (GOES-R) and in the development and implementation of an integrated Earth-observation and data-management system architecture. He joined Aerospace in 2000 after 27 years of active military service in the Marine Corps and Air Force in the fields of tactical communications, operational weather forecasting, and air and space operations. Upon joining Aerospace, he provided space systems engineering and architecture support as part of the National Systems Group’s Imagery Programs Division. He moved to Silver Spring to establish that office in 2002. He has a Ph.D. in atmospheric science and remote sensing from the University of Arizona (tom.adang@noaa.gov).

Going the Distance: GOES-R and the Future of U.S. Geostationary Environmental Satellites

Nathaniel E. Feldman is Senior Engineering Specialist in the Communications Architecture Department. Prior to joining Aerospace in 1981, he worked at Rand in systems analysis and in the exploratory design of microwave electronic systems; while there, his analyses of communication satellite architectures contributed to NASA's shift from passive to active satellites and to NASA’s and DOD’s shift from UHF and X band to much higher frequency bands. At Aerospace, he has examined jam resistance, covertness, signal-processing trade-offs, delays during day-to-day operations and in crises, and outages due to propagation effects. An Associate Fellow of AIAA and a Senior Member of IEEE, he received his M.S.E.E. from the University of California, Berkeley (nathaniel.e.feldman@aero.org).

Samuel Lim is Director of Business Development for the Electronic Systems Division (ESD). He is responsible for developing, expanding, and overseeing all of ESD civil and commercial new business activities. He began his career at Aerospace in 1988, first as a member of the technical staff in the Communications Systems Engineering Department, and later as a project engineer for MIL-SATCOM Advanced Programs. He left Aerospace in 1993 to work for Boeing Space and Communications and later for Hughes. He returned to Aerospace in 2002. He holds an M.B.A. and an M.S.E.E. in communications from UCLA (samuel.lim@aero.org).

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Kenneth D. Shere, Senior Project Engineer, provides system support to NOAA through the Silver Spring Program Office, Civil and Commercial Operations. He joined Aerospace in 1995. Particular areas of expertise include systems-of-systems architectures, ground-station acquisition, strategic planning, systems engineering, software engineering, source operations analysis, and proposal evaluation. He holds a Ph.D. in applied mathematics from the University of Illinois (kenneth.shere@noaa.gov).
High-resolution weather forecasts from meteorological models are essential to air-quality predictions, which have become a routine component of daily urban forecasts nationwide. In a region such as Los Angeles, a high-resolution model is necessary to represent the small-scale phenomena that influence dispersion of pollutants (or chemical or biological agents). In addition to charting regional scale winds, the model must accurately capture the circulation of sea and land breezes and the convectively driven upslope circulation in the surrounding mountains. The accuracy of fine-scale, limited-area forecast models depends, among other factors, on the quality of boundary and initial conditions supplied to the model; the number, distribution, and quality of atmospheric observations; and the methods used to analyze them.

Aerospace has been conducting research geared toward improving fine-scale, real-time weather predictions over the Los Angeles basin through the optimal assimilation of space-based and local weather observations. One result of this research is a system that automatically issues daily 36-hour forecasts and posts them on a publicly accessible Web site, www.aerospaceweather.com. Aerospace is making these forecasts available to demonstrate the benefits of satellite weather data for air-quality monitoring and emergency response planning. The forecasts contain hourly predictions extending through late afternoon of the following day.

A widely used weather prediction model known as MM5 has been configured to run with data assimilation and analysis software to automatically generate pseudo-operational daily weather forecasts at 5-kilometer resolution. The system analyzes operational data from the Air Force Weather Agency that includes surface weather reports and weather-balloon observations, aircraft reports, cloud-drift readings from geostationary satellites, and moisture and surface wind speed over oceans from the DMSP Special Sensor Microwave Imager. Additional buoy data are pulled from the National Buoy Data Center. Data are also automatically pulled from surface stations operated by the South Coast Air Quality Management District of California and the Bureau of Land Management as well as NOAA’s Forecast Systems Laboratory boundary layer profiler and ground-based GPS receiver networks. To make an acceptable forecast over a domain with significant ocean area, the MM5 model also requires fairly accurate measurements of sea surface temperature, which are obtained from the Navy via the Air Force Weather Agency.

Verification software was developed to compare the MM5 output to observations. The program can compare temperature, relative humidity, dew point, mixing ratio, total precipitable water, wind speed, and wind direction. It performs separate comparisons for sounding and surface-station data. Verification scatter plots for a given model run are posted to the Web site two days after that run. Individual time series of model forecasts and corresponding surface observations for a number of air-quality monitoring sites are also posted.

Work is still under way to establish a continual data-assimilation cycle and to assimilate additional data sources. Researchers also hope to complete background error statistics and to optimize the model configuration based on feedback from verification efforts. The MM5 system may also be coupled with a more sophisticated land-surface model and draw upon high-resolution sea surface temperature readings. Additional plans call for deploying a transportable lidar system to locations in the Los Angeles basin to verify MM5 model forecasts and using MM5 wind forecasts in a multiple-particle dispersion model developed at Aerospace to predict the path of a toxic release.

Particle dispersion simulation of a toxic plume release driven by MM5 winds over the Los Angeles area.

Scatter plots like this, plotting the observed temperature versus the predicted temperature, are used to validate and improve the forecast model.

Sample snapshot of the predicted rain and surface winds from the animated loops available for each forecast. A winter rainstorm is approaching Los Angeles.