

APL AND THE U.S. NAVAL SERVICE: A PARTNERSHIP FOR THE FUTURE

Our world has undergone tremendous change in the past few years. The needs of the Navy and Marine Corps are evolving in response to the evolving threat and new warfare mission area priorities. The Applied Physics Laboratory is also changing, as it should; however, our commitment to our mission and to the Naval Service remains constant. We have significant and broad capabilities that we are applying in a wide variety of activities and programs, addressing both current requirements and those for the future. Our staff values the Laboratory's role as a steadfast and trusted partner with the Naval Service and is working vigorously to maintain that relationship.

INTRODUCTION

The Changing Environment

Today we are faced with a changed and changing world. The new international political system is radically different from that which shaped us in the past, and the implications for the defense establishment of the United States are profound. As an important element of that establishment, the future activities of APL must respond to changing requirements and opportunities.

In August 1990, as many of the changes in the former Soviet Union and Eastern Europe were taking shape and just as Iraq began its invasion of Kuwait, President Bush outlined a new defense strategy for the United States. That strategy, presented in a speech at the Aspen Institute, contained the following elements: smaller forces, not just uniformly reduced but restructured; continued emphasis on research and development; strategic deterrence and defense; forward presence; rapid response; readiness; and reconstitution. In the ensuing months, a National Security Strategy evolved that highlighted four principal elements: strategic deterrence and defense, forward presence, crisis response, and reconstitution.

A new President and a new Congress now preside as the world continues its hectic pace of change. Until the new administration completes its future years' defense budget, we cannot be certain of its priorities, or how they will fit with those of the Congress. From all that has been said or written by President Clinton and by Secretary of Defense Aspin, however, it seems clear that strategic deterrence and crisis response will continue to be emphasized.

The Changing Focus of the Naval Service

Within this evolving context, the Navy and Marine Corps in September 1992 issued a broad assessment of the future direction of our maritime forces. That signal event, . . . *From the Sea, Preparing the Naval Service for the 21st Century*,¹ was soon followed by a major restructuring of the offices of the Chief of Naval Operations

(CNO), and a redefinition of the warfare areas within which the Commanders-in-Chief and the CNO would set requirements to maintain a pronounced military advantage over any potential adversary. The thrust of these developments is that a major change is under way. There is a "fundamental shift away from open-ocean warfighting on the sea toward joint operations conducted from the sea."¹ The fundamental nature of this shift is well illustrated by the fact that long-familiar concepts such as anti-air warfare and anti-submarine warfare are being subsumed by newer terms or concepts such as joint littoral warfare and joint strike warfare.

. . . *From the Sea* described the intention to tightly integrate the naval forces into the National Security Strategy. "The new direction of the Navy and Marine Corps team, both active and reserve, is to provide the nation: Naval Expeditionary Forces, Shaped for Joint Operations, Operating Forward from the Sea, Tailored for National Needs."¹ At the same time that this new direction is set, there is a recognition of the continuing obligation of the Navy to "maintain a robust strategic deterrent by sending nuclear ballistic missile submarines to sea."¹ Also acknowledged is the need to explore other forms of conventional strategic deterrence, and in particular to examine naval capabilities that could contribute to theater missile defenses.

Four major operational capabilities were identified in . . . *From the Sea* as essential to successfully executing the new direction of the Navy and Marine Corps: command, control, and surveillance; battlespace dominance; power projection; and force sustainment. This article is intended to provide a description of APL in the context of these emerging elements of the new National Security Strategy. The sections that follow discuss the Laboratory's specific capabilities and activities, show how they have evolved, and describe how they flow smoothly into the new National Security Strategy and the new directions for our combined Naval Service.

APL'S MAJOR CAPABILITIES

The Applied Physics Laboratory possesses a remarkable breadth of capabilities and has been involved to an extraordinary extent in the long-term research and development of major Navy systems. The scope of its efforts extends across several areas of science and technology, includes many different warfare elements, and involves many types of activities, from basic research to full-scale operational system testing.

The Laboratory has developed a comprehensive understanding of most aspects of missile, radar, sonar, space, and submarine detection technology, and the characteristics and limitations unique to the shipboard operating environment. The technical staff of APL includes specialists in the specific scientific and engineering disciplines embodied in all these diverse areas, as well as systems engineers who can direct teams engaged in the development of complex combat and even multiple-ship systems. Further, the Laboratory has a proven capability not only in research and development, but also in the resolution of problems related to the production of systems, to the introduction of equipment into the fleet, to maintenance, and to logistics. The unique capabilities of APL stem from the body of knowledge, experience, data, and facilities established through more than a half century of highly diversified work solving problems for the Navy and other defense organizations.

THE CHARACTER OF THE APPLIED PHYSICS LABORATORY

In bringing its talents to bear on the many diverse problems encountered in meeting Navy operational needs, APL's efforts have been distinguished by the following special characteristics:

1. Applying scientific methods to the technical evaluation of operational systems. The orientation toward formulating and analyzing critical experiments to obtain basic understanding of detailed system performance is associated with the general spirit of critical inquiry derived in part from APL's association with the University.

2. Orienting research to achieving practical military objectives, with the general policy of coupling research activities closely with applications, to obtain products of direct applicability to Navy and defense needs.

3. Integrating systems composed of multiple, complex ordnance devices involving diverse disciplines. The Laboratory has attracted and trained versatile key project leaders who can understand the complex technology involved and make the compromises necessary to obtain a practical and balanced approach, leading to a product specification.

4. Following the development of complex technical programs from concept to operational deployment.

THE PARTNERSHIP

The following sections are organized principally along the lines of the new joint warfare mission areas. They describe the needs of the Naval Service in these areas, and APL's capabilities and activities aimed at helping the Navy and Marines meet those needs.

Joint Littoral Warfare

One of the principal consequences of the new operating environment is renewed emphasis on enabling the application of joint power in littoral areas. In support of this emphasis, APL brings a broad base of expertise applicable to multiple warfare areas.

Anti-Air Warfare

Anti-air warfare continues to be an essential element for achieving and retaining air superiority in the littoral battlespace. APL is preeminent in this field, having pioneered the Bumblebee Program and most subsequent Navy surface-to-air missile and weapon systems. The Laboratory has a deep understanding of all aspects of these systems, including the nature of the current and potential threat to the fleet, the problems of the operational environment, and the requirements of safety, maintenance, and logistics.

The Laboratory has developed several areas of competence relevant to anti-air warfare during the many years of its involvement in these programs. Specific areas have included propulsion, aerodynamics, guidance and control, signal processing, simulation, system analysis, and system engineering. Emphasis among these diverse elements has shifted over time at APL as needs have changed and as other laboratories and industry have developed complementary capabilities. The Laboratory has evolved a capacity for evaluating interactions and interfaces between the systems and subsystems in modern warships, both surface and submarine. That capability enables APL to assist the Navy in optimizing ship system performance and in analyzing fleet problems relating to ship design, advancing weapon technology, and the changing threat.

In addition, APL has developed an exceptional ability to solve sophisticated radar problems, specifically those involved in the automatic detection and tracking of air targets in adverse environments. Work at APL in advanced radar technology led to significant contributions to the Aegis Program, and the Laboratory continues to develop new systems, equipment, and computer programs to upgrade Aegis. Advanced concepts and technologies for surface ship combat systems of the future, beyond the Aegis era, are also being developed at APL.

Ship Self-Defense

The proliferation of fast, low-altitude, small cruise missiles that can be launched from aircraft, land, and watercraft against all ships supporting littoral warfare has become an important issue. The Navy's approach is to combine synergistically the elements of existing self-defense systems to provide significant improvements in the near term, while laying the foundation for more robust future approaches as necessary. Netting sensors, control systems, and weapons on a local area network is the concept for providing immediate improvement, and will allow future upgrades to occur. Because of its extensive experience in all aspects of this problem, APL is heavily involved as technical direction agent (TDA) to the cogni-

zant Navy office and as TDA and design agent for various parts of the solutions.

Tactical Ballistic Missile Defense

Naval forces must also provide defense against cruise missiles and tactical ballistic missiles within the entire amphibious objective area during littoral operations. This requirement necessitates further upgrades of area defense systems to counter threat advances (e.g., reduced observables, higher speeds, and altitudes) over a larger defended area than was previously required. The building blocks for the future rest with Aegis and Standard Missile, two systems for which APL has historically maintained a lead role.

Looking beyond the Navy's lower-tier capability in anti-tactical ballistic missiles, APL has been working closely with the Ballistic Missile Defense Office (BMDO; formerly the Strategic Defense Initiative Office, SDIO) and the Navy's Strategic Systems Project Office to define overall weapon system concepts that provide theater-wide defense against ballistic missiles. That work includes the definition of feasible upgrades to the AN/SPY radar; the utility and ability to use off-board sensors such as the Stereo Defense Support Program to aid in early warning and detection; the battle management/command, control, and communications architecture required to support such a system; and the evaluation of various BMDO interceptor concepts such as Theater High Altitude Area Defense, and Standard Missile with Lightweight Exoatmospheric Projectile. A full Theater Missile Defense capability will allow the Naval Service to expand its littoral role to protect population centers and other high-value assets.

Combat System Integration and Networking

A key to successful joint operations in the littoral area will be the linking together of sensors from many platforms, including systems such as Patriot and Airborne Warning and Control System aircraft. By so doing, a coherent air picture can be developed that will be remarkably immune to electronic countermeasures and various natural environmental limitations (such as sea and land clutter), and that will provide for better target identification than has been previously available. The requirements for linking sensors together include achieving accuracies sufficient to allow one platform's weapons to be fired using another platform's sensor data. In this way, it will be possible to have truly coordinated firepower, applying the best resources to defeat sophisticated enemy threats and to maintain battlespace dominance. Additionally, even self-defense systems will benefit by allowing the more timely use of electronic warfare elements whose effectiveness greatly depends on early deployment. The Laboratory is TDA for two programs: Force Anti-Air Warfare Coordination Technology and the Cooperative Engagement Capability (CEC), which have developed the requirements, concepts, and equipment for a netted sensor capability. In addition, APL is the design agent for the two major CEC compo-

nents: the Data Distribution System and the Cooperative Engagement Processor.

Command, Control, and Communications

Seamless command, control, and communications will be essential for effective operations in the complex sea-air-land battlespace of the littoral. The Laboratory's long recognition of the critical role of information dissemination among friendly forces is reflected in its continued development of advanced graphics and displays, man-machine interfaces, and information management techniques. These are applied to the presentation of tactical command data and other command decision-support systems aboard both Aegis and other combatants. In a related area, the Laboratory is a leader in the application of advanced computing, networking, and open-architecture techniques to combat system engineering.

Also important in littoral warfare is the use of communications systems that deny enemy forces information on the intent and plans of our expeditionary forces. The Laboratory serves as technical agent to the Navy Security Group in the engineering assessment, test, and evaluation of all command, control, and communications systems planned for introduction into the fleet. The Navy Security Group serves as the executive agent in management and oversight of the Navy Vulnerability Assessment Program. Recent major accomplishments under this activity include laboratory and at-sea tests of several radio systems that would operate in the littoral region and that offer substantial protection to the users. The results of the tests have been used to verify the resistance of the systems to jamming and signal intercept, and to suggest design changes, where necessary, to meet the required levels of performance.

Torpedo and Mine Defense

Battlespace dominance must extend under the sea as well. Diesel and other nonnuclear-powered submarines can pose a serious threat to our ability to dominate the littoral areas, and torpedoes and mines are difficult weapons to counter. The dedicated staff at APL has an enormous body of knowledge on the detection of quiet submarines and other underwater objects. This expertise has been gained through many years of experience working on the SSBN Security Program, the Integrated Undersea Surveillance System, and other related efforts, and extends from conventional passive acoustics, through some of the latest developments in active acoustics, to all forms of nonacoustic detection and localization. The latter includes magnetics, optics, infrared, radar, contaminants, and hydrodynamics. These capabilities are being brought to bear in counter-weapon and counter-platform initiatives.

The Laboratory is also supporting the development of mine search systems, including the Submarine Off-board Mine Search System. These systems will further enhance the ability of the submarine to dominate the battlespace, finding routes for joint amphibious operations without divulging the route to be used.

Warfare Analysis and Assessment

Joint littoral warfare spans several of the former warfare areas. In approaching the problem of integrating those elements into a cohesive whole, new ways are needed to assess capabilities and lay the groundwork for the future. The Laboratory performs a wide range of naval warfare analysis and assessment functions associated with requirements analysis, such as technical intelligence analysis, threat assessment, scenario development, concept development for system employment, systems and operational analyses, computer model building, and database building and maintenance. Both APL's Warfare Analysis Laboratory and computer-simulation-supported analyses are employed to determine the military utility and estimated performance of weapon and combat system concepts. Such analyses include joint mission area assessments; cost and operational effectiveness analyses; major Navy and Department of Defense studies; and, as part of APL's system engineering role, critical experiments and test and evaluation programs.

Joint Strike Warfare

Application of power projection from the sea requires mobility, flexibility, and technology to amass forces rapidly and generate high-intensity, precise offensive power. Carrier and cruise missile firepower are critical components of the theater commander's ability to apply sustained, high-volume, effective ordnance on an enemy's military forces and support infrastructure.

Through its preeminence in missile systems engineering, APL has contributed to the development of cruise missiles and their applications to strike warfare. The Laboratory's contributions span initial concepts in the late 1940s and 1950s, through the development of the antiship Harpoon and the Standoff Land-Attack Missile, to the deployment of the long-range Tomahawk missile, in both land-attack and anti-ship variants. Special areas of APL contributions, starting in the late 1960s, included threat analyses, technology evaluations, and preparation of missile and system design studies, as well as particularly important critical experiments on radar seekers. Throughout the Harpoon Program, the Laboratory played a major role in the design and development of guidance and countermeasure systems. In the Tomahawk Program, APL recommended the original application of the terrain contour matching guidance concept. Later, in 1982, the Laboratory was designated as TDA for cruise missiles, making APL responsible for the development of requirements, assessment of performance, identification of problem areas and associated potential solutions, detailed effectiveness analyses, and concept development and prototyping of advanced systems.

Tomahawk Baseline Improvement Program

The Laboratory invented concepts used in the new Digital Scene Matching Area Correlator (DSMAC IIA), which will be deployed in 1993. Use of APL's Mission Planning Laboratory has provided DSMAC algorithms and critical parameters for scene selection in the new Digital Imagery Work Station and has supported validation of

algorithms in the Tomahawk Mission Planning System Upgrade. The Navigation and Guidance Integration Laboratory has supported extensive testing of the Global Positioning System capability on Block III Tomahawk. Similar tests of the navigation and guidance packages of the Tomahawk Baseline Improvement Program (TBIP) are being prepared. The Laboratory is currently leading three of the critical TBIP risk reduction teams and is providing technical support for the TBIP cost and operational effectiveness analysis. Further, APL designed, built, and operates high-power modular jammers for testing antiship missiles and performs a detailed accuracy analysis of all Tomahawk flights.

Precision Strike Architecture

Another element of the Laboratory's commitment to enhancing joint strike warfare is reflected in its support of the Precision Strike Architecture Study, a new program still in its formative stage. The study is jointly sponsored by the Director, Defense Research and Engineering, and the Joint Chiefs of Staff. The objective of the study is to develop a plan for evolving the nation's precision strike capability (sensors, weapons, communications, etc.). The plan should support decisions concerning near-term changes (e.g., tactics), mid-term improvements (acquisition programs), and far-term benefits (advanced technology development and demonstrations). A consortium of a dozen laboratories and not-for-profit organizations has been formed to conduct the study, and APL has been tasked to integrate its efforts. This activity is an example of the Laboratory's unique ability to coordinate and lead a widely diverse, jointly sponsored group of organizations to address multiservice war-fighting needs.

Joint Surveillance

Providing timely and accurate indications and warning, target acquisition and identification, and tracking and sorting in complex and noisy environments is crucial to effective planning and execution of expected naval and joint force engagements. The Laboratory's extensive capabilities in sensors, signal and data processing, and simulation and modeling have for years been applied to this important area.

Over-the-Horizon Targeting

For more than a decade, APL has assisted the Space and Naval Warfare Systems Command (SPAWAR) and its predecessor, NAVALEX, in conducting the Navy Over-the-Horizon Targeting (OTH-T) Program, and more recently in conducting the Joint OTH-T Program. The Laboratory has participated in various tests and fleet exercises, including a recent series of tests to develop joint service coordination and interoperability of surveillance assets. Work has also included the development of a high-fidelity, wide-area surveillance sensor and data fusion model, used for estimating the expected tactical picture quality (as opposed to using ground truth) in simulated tactical situations.

The Laboratory also leads a surveillance working group for the multiwarfare analyses conducted by

SPAWAR 31. This working group is chartered to quantify the capabilities of surveillance assets against threats in scenarios of current interest to joint assessments, and in particular in support of ongoing surveillance assessments being conducted by the CNO's N87 office.

Remote Sensing

In support of space-based joint surveillance needs, APL carries out research involving remote sensing of the ocean and atmospheric propagation of microwave energy. Microwave radars based on satellites and aircraft are used for environmental monitoring and ocean surveillance. The environmental monitoring activities include observations of ocean winds and waves using imaging radars, and observations of the geoid using radar altimeters from satellites. In surveillance, microwave radars are used to detect wake patterns produced by surface ships, and research is under way to investigate the potential observability of submarine signatures. Research in this area also includes work on the propagation of microwave energy in a marine-ducting environment, a collaborative effort with other APL programs engaged in ship defense. This research involves investigating the effects of terrain and vegetation on the propagation of microwave signals between mobile land transmitters and satellites for communications purposes. Remote-sensing measurements have been made from various satellites including Seasat, Geosat, ERS-1, and the space shuttle, and these activities will continue by using microwave radars on upcoming ERS flights and on shuttle imaging radar missions. The Laboratory will also help to develop an operational radar altimeter for use by the Navy.

Space and Electronic Warfare and Intelligence

Joint force operations are critically dependent on the timely collection and dissemination of tactical information and the coordinated employment of modern electronic warfare assets. The Laboratory's expertise in the areas of satellite communications control systems, the man-machine interface, applications of expert systems to network planning, waveform engineering, the introduction of commercial standards to operational control systems, and related areas will be particularly valuable to the introduction of next-generation satellite communications.

Space and Electronic Warfare

The development of space and electronic warfare (SEW) and intelligence assets is a principal responsibility of SPAWAR. The Laboratory conducts systems engineering, analysis, and testing for the SEW Systems Engineer, SPAWAR 32, and has been designated as the design agent by the Command. Recently, APL provided technical expertise for Exercise Tandem Thrust, including participation in the development of demonstration and data-collection plans, on-site representation during the exercise, and preparation of the analytical report. In addition, APL assisted SPAWAR 32 in the initiation of a Joint Theater/Task Force Crisis Management demonstration program and conducted technical studies of data link requirements,

Copernicus common-message standards, and data compression technology.

The Laboratory's ongoing efforts as the SEW design agent include (1) participation in SEW-related fleet exercises, (2) development of SEW systems standards and interfaces, particularly common-message standards and data compression, (3) development and demonstration of improved logistics communications elements, (4) SEW analytical modeling, and (5) conduct of the necessary systems engineering to permit SEW/combat systems interoperability in specific areas of power projection and fleet defense.

Satellite Communication Control

The Laboratory undertook a major effort during the past ten years to provide technical evaluation and engineering prototype development support to the Army for satellite communications control and network management. That work has focused on ground-based control systems (both fixed and mobile) and terminals that support networks using the Defense Satellite Communications System (DSCS) and Milstar communications system. It has involved the specification of new control systems, development and demonstration of prototype systems for the ground mobile forces and selected fixed sites, and application of new expert-system-based technology to the network planning and management problem. A major super-high-frequency and extremely-high-frequency satellite communications facility has been established at the Laboratory with a fully operational DSCS and Milstar satellite terminal for use in testing over-the-satellite loop-back and end-to-end networks.

Intelligence Assessment

In the area of intelligence, APL maintains its current awareness of threat systems through a designated Scientific and Technical Intelligence Liaison Office and uses this information in warfare analysis seminars conducted in support of the Office of the CNO. Several technical intelligence programs are conducted for the Navy and for other agencies. The Laboratory also performs engineering development and testing to improve and help evolve the Air Force's EF-111A and EA-6B electronic warfare capabilities.

Strategic Deterrence

Since 1957, APL has been a key partner in the Navy's submarine-launched ballistic missile program, starting with Polaris and continuing through Trident II. Significant contributions have been made in four major areas: weapons system reliability and accuracy; SSBN security; SSBN survivability; and SSBN command, control, and communications. Analysis of these areas on a patrol-by-patrol basis provides a comprehensive, continuous review of the weapons system performance, including the missile; the platform; and the command, control, and communications interface with the National Military Command System.

Fleet Ballistic Missile System Evaluation

The Laboratory has a unique and major role in support of the Fleet Ballistic Missile (FBM) Program. No other laboratory or contractor has the composite qualifications to carry out the required test, analysis, and evaluation effort, although a search for such an agency was made by the Navy in the early phases of the program. The unique qualifications that APL has brought to FBM weapons systems evaluation are long experience in all aspects of guided missile technology from research to production and test, special skills in systems testing and evaluation, a staff combining specialists in all relevant branches of science and engineering, a long acquaintance with Navy operational environmental problems, and a philosophy of teamwork within APL as well as with military and industrial organizations.

No other organization has APL's broad background and experience in FBM weapon system analysis and evaluation. Many organizations support the FBM program in carrying out predeployment analyses of subsystem components, but their efforts are primarily projections and theoretical studies undertaken on a one-time basis. The Laboratory provides the post-deployment operational analysis of all subsystems operating together as a system. That effort is not a one-time demonstration, but rather a continuing program to assess the readiness of the deployed system in its operating environment.

With a strong systems background and no particular responsibility for equipment development, APL is in the position of being able to make independent, objective recommendations to the Navy's Strategic Systems Project Office without bias. For this reason, private industry can work freely with APL and can exchange technical information without fear of competition or loss of a proprietary advantage. Further, APL has the computer capacity and the staff essential for the formulation and exercise of large-scale simulations. Assessment of FBM weapon system performance requires the use of such complex computer simulations and access to the large quantities of performance data accumulated over many years.

SSBN Security and Survivability

The Navy's SSBN Security Program evaluates whether new technologies and potentially important phenomena could render our FBM submarines vulnerable to detection and prosecution by adversaries of the United States. This program was initiated in 1969, with APL as the principal technical agent. The Laboratory has had the primary missions of (1) researching oceanographic concepts as they relate to submarine detection, (2) developing a progressively better understanding of the signals generated by submarines and the corresponding noise fields, (3) developing a wide range of experimental sensors, and (4) developing and evaluating tactics for use by the FBM submarine force.

In cooperation with the Navy research and development centers, other university laboratories, and industry, this activity requires that APL propose, plan, direct, and

conduct portions of projects deemed essential to the continued covert mobility of the FBM force. In addition to determining that no external threat was present during SSBN patrols over the years, APL, as lead laboratory for the SSBN Security Program, has developed techniques to ensure the future security of these platforms by identifying potential vulnerabilities and then recommending the necessary operational or engineering countermeasures. As a consequence of more than twenty-five years of intensive, focused research, APL possesses a scientific and engineering staff with a greater range and depth of understanding of all the various physical phenomena that could be involved in the detection of highly stealthy submarines than any other organization. Specific APL expertise in towed-array analysis has been of great value to submariners both in threat detection and in monitoring own-ship performance. The Laboratory's skills in acoustic processing have led to current initiatives in in-port security, ingress and egress procedures, and certain "continuity-of-operations" programs.

APL is also the lead laboratory for the Navy's SSBN Survivability Program. Countermeasures that may be needed to preserve the covert mobility of the FBM force of the future (as identified by the SSBN Security Program) are developed and tested to ensure their availability when and if they are needed. The strong overlap in the spectrum of knowledge, experience, and relations between this program and the SSBN Security Program makes APL uniquely qualified to lead these efforts. With the increased reliance on sea-based deterrence and the substantial reductions occurring in the size of the FBM force, these programs will become even more important.

Satellite Technology and Space Science

In space development programs, APL's initial capabilities were based on its background and experience in guided missile technology. This included first-hand knowledge of and the facilities for designing, building, and testing compact, complex electronic equipment able to survive environments peculiar to rocket launching and flight. Through this background, APL was able to achieve from the outset a remarkable record of reliability in space satellites and has one of the nation's most experienced and capable teams in satellite design and construction. The Laboratory has designed, constructed, and launched fifty-four satellites having varying missions and complexity, and has provided well over 100 different instruments deployed on other spacecraft. In that process, APL has learned to solve the problems of reliability, communications, data analysis, and the many other challenges of system operation in the space environment.

Satellite Navigation

When Sputnik I was launched in 1957, APL scientists monitoring its radio-beacon transmissions developed two important concepts. First, techniques were derived to determine the satellite's ephemeris via precise measurements of the radio signals received from it. Second, a system concept was developed to use a satellite constellation for navigation on or near the Earth's surface. This

latter effort resulted in APL building the Navy Navigation Satellite System (Navsat or Transit).

In that era, development of a satellite navigation system was so radical that it required APL to become involved in the end-to-end development of all aspects of the system so that it would be operational for the Navy in the required time frame. This end-to-end development and quick-reaction capability became the paradigm for the Laboratory's approach to the development of future space-related programs. In addition, the development of technologies in the navigation area provided a base for supporting other needs. The Laboratory has become a valuable source for highly stable clocks for use in space missions, including various reconnaissance missions, NASA's Topex (ocean topography experiment) mission, and the Cassini mission to Saturn. APL is also one of only three laboratories in the United States that contribute to the international time standard.

Space Research and Instrumentation

The Laboratory is a world leader in Earth geodesy, in solar and planetary science, and in investigating the principles governing the flow of energy between the Earth and the Sun. One important phase of that work is the study of the effects of charged-particle activity on radio propagation. Scientists at APL discovered the intense field-aligned currents that are major contributors to the aurora and to various phenomena of radio propagation.

APL has built and deployed spacecraft instrument systems operating at infrared, visible, and ultraviolet wavelengths, as well as spaceborne radars and energetic particle detectors. The Laboratory's Hilat and Polar Bear satellites observed daytime auroral displays around the Earth's pole. Particle detectors on board the Voyager deep-space probes confirmed APL's theory that charged-particle bombardment was causing the blackened rings of Uranus. For five years, the Geosat radar altimeter, launched in 1985, made precise measurements of the height of the ocean surface while providing information for exact determination of the geoid. The Laboratory built one of the three satellites for the multinational Active Magnetospheric Particle Tracer Explorers Program, whose objective was to expand our knowledge of interactions between the solar-wind plasma and the Earth's magnetosphere. A particle detector was also launched on the Galileo (Jupiter orbiter) mission in 1989, and the Hopkins Ultraviolet Telescope, a collaborative effort between the Laboratory and the University's Center for Astrophysical Science, was flown aboard the shuttle in December 1990. The Hopkins Ultraviolet Telescope obtained exceptional data on several important astrophysical objects.

Strategic Defense

Shortly after the formal inception of the Strategic Defense Initiative (SDI), the Laboratory was asked to design an experiment to assess remote sensing alternatives for detecting signals from rocket plumes and hard-body targets.

SDI/Delta Missions

The space science and development activities of the Laboratory placed it in a unique position to provide new remote sensing options to SDI. The Hilat and Polar Bear satellite observations of the aurora proved that, even under stressing daytime conditions, ultraviolet radiation ($<4000 \text{ \AA}$) could reveal relatively weak signatures against the atmospheric background of the Earth. This finding suggested new instrument concepts for using short-wavelength radiation for the traditional SDI tasks of acquisition, tracking, and discrimination. On the basis of the new concepts, APL proposed and executed the three SDI/Delta missions: Delta 180 (Vector Sum), Delta 181 (Thrust Vector), and Delta 183 (Delta Star).

Lasting only a few hours, the Delta 180 mission demonstrated the autonomous interception of one thrusting rocket by another. One of the Delta 180 rockets carried several ultraviolet sensors, all of which discovered strong short-wavelength emissions emanating from the rocket plumes of both vehicles. The unexpected emissions resulted in new SDI initiatives in ultraviolet technology that led to the Delta 181 and Delta 183 missions.

The Delta 181 mission involved the observation of hard-body targets at close ranges as well as rocket plumes, and demonstrated the feasibility of using passive ultraviolet and visible sensors for remote sensing of a variety of likely strategic targets. In addition, Delta 181 sensors observed a rocket plume at operational ranges against the Earth-limb background.

Lasting nine months, the Delta 183 mission used a suite of infrared, visible, and ultraviolet sensors to investigate various targets and backgrounds. The systems used on this mission had acquisition and tracking capabilities; spectacular measurements of "real-target" plumes and hard bodies occurred from what were essentially operational ranges. Delta 183 demonstrated the feasibility of a long-term functional surveillance station, such as that envisioned by the Brilliant Eyes concept. Significantly, the APL-built satellite required only nine months from concept to launch.

Midcourse Space Experiment

The three Delta missions have provided information to several SDI data centers currently used by SDI systems planners. In addition, APL investigators have analyzed the data and proposed several refinements in short-wavelength sensors. The refinements are embodied in the upcoming Midcourse Space Experiment (MSX), an ambitious multiyear mission to acquire data on strategic targets, Earth and celestial backgrounds, and the local contamination environment. MSX will demonstrate acquisition, tracking, discrimination, and surveillance functions crucial to SDI by using ultraviolet, visible, and infrared sensors. The satellite will rely to a considerable extent on an APL-developed short-wavelength instrument, that is, the ultraviolet and visible imaging and spectrographic imaging (UVISI) sensor system, for data processing and for tracking and pointing the satellite. The Laboratory's UVISI consists of four imagers (both wide and narrow field), five

spectrographic imagers, and a unique image processor that provides tracking data to the satellite's attitude system. The UVISI can observe targets or backgrounds at wavelengths from the far ultraviolet to the near infrared, and was designed, built, and calibrated at the Laboratory.

In addition to providing a key instrument on MSX, APL will supply the MSX spacecraft itself and will test and integrate the various other instruments. After launch of the satellite in 1994, APL will have primary charge of the ground and flight operations and will initiate on-board processing tasks related to the moment-to-moment operation of the satellite. The ground operations will use a 25-Mbit-per-second receiving station, the fastest of its kind in the world. The APL processing center on the ground will reformat this information, provide attitude and tracking information in addition to time references, and send the resulting data set to various SDI data centers and MSX investigative teams for analysis.

The Laboratory has two MSX investigative teams that will analyze data from the satellite: a short-wavelength terrestrial background team and a contamination team. The teams will reduce the data, provide high-level data products, compare their results with current models of the strategic scene, and develop their own models and interpretations. Their investigations will directly benefit SDI systems such as Brilliant Eyes/Pebbles and Theater Missile Defense, and will have ramifications for essentially all military space systems. In addition, UVISI observations will allow investigators the unique flexibility to pursue scientifically relevant topics such as global change, ozone depletion, and atmospheric composition.

SUMMARY

For more than fifty years, the Navy and other government sponsors have found APL to be invaluable in assisting them in the technical direction and evaluation of a broad range of research and development programs. APL has earned the confidence of both sponsors and industry and has been able to play a unique and positive role in expediting top-priority technical programs. The Laboratory has been able to perform this function by providing unbiased but expert assistance in resolving problems directly relevant to the development, test, and production of Navy systems.

At the beginning of the missile era, the limited funds available to develop and introduce missile technology required a concentration of expenditures at a single activity. The Laboratory was judged to be the best qualified for missile system implementation on naval ships, having already successfully demonstrated its scientific capabilities. In overcoming the difficulties associated with developing complex missile systems, APL became systems-oriented in its technical approach, in contrast to the technology-oriented approach characteristic of many defense laboratories. In the ensuing years, a few organizations have developed expertise comparable to APL's in isolated areas. No other organization, however, has the *broad range* of expertise found at The Johns Hopkins University Applied Physics Laboratory.

The Laboratory's primary dedication has been and will continue to be to programs sponsored by the Naval Service and the Department of Defense (DoD). APL has also been asked, however, to use its expertise in exploring vital research areas for federal civil agencies. Our major non-DoD work has been for NASA in the areas of space science and applications. But APL has also made significant contributions in such fields as biomedical engineering, transportation, energy, and the environment. Strong mutual benefits have been derived from these programs. Although APL is the largest Navy-sponsored university laboratory, it receives only 1.8% of the Navy's research, development, test, and evaluation resources. That modest investment has provided an invaluable resource that has served the country exceptionally well for more than fifty years. We look forward to continuing this mutually rewarding relationship for many years to come.

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