
CRITICAL CONTRIBUTIONS
TO
CRITICAL CHALLENGES
1942
RISK
DEFINING INNOVATIONS
J H U
A P L
TRUSTED & RESEARCH DEVELOPMENT
TRANSIT
TREASURED NATIONAL RESOURCE
UNQUESTIONABLE INTEGRITY
CREATING DEFINING INNOVATIONS SINCE
1942
GAME-CHANGING IMPACT
RADIO PROXIMITY FU
WORLD ★ CLASS
EXPERTISE
PHASED ARRAY RADAR
EMBRACE
RISK
75 YEARS
THE JOHNS HOPKINS APPLIED PHYSICS LABORATORY
ANNUAL REPORT 2017
GAME CHANGING
IMPACT
TOMAHAWK
TRUSTED SERVICE TO OUR
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DEFINING INNOVATIONS
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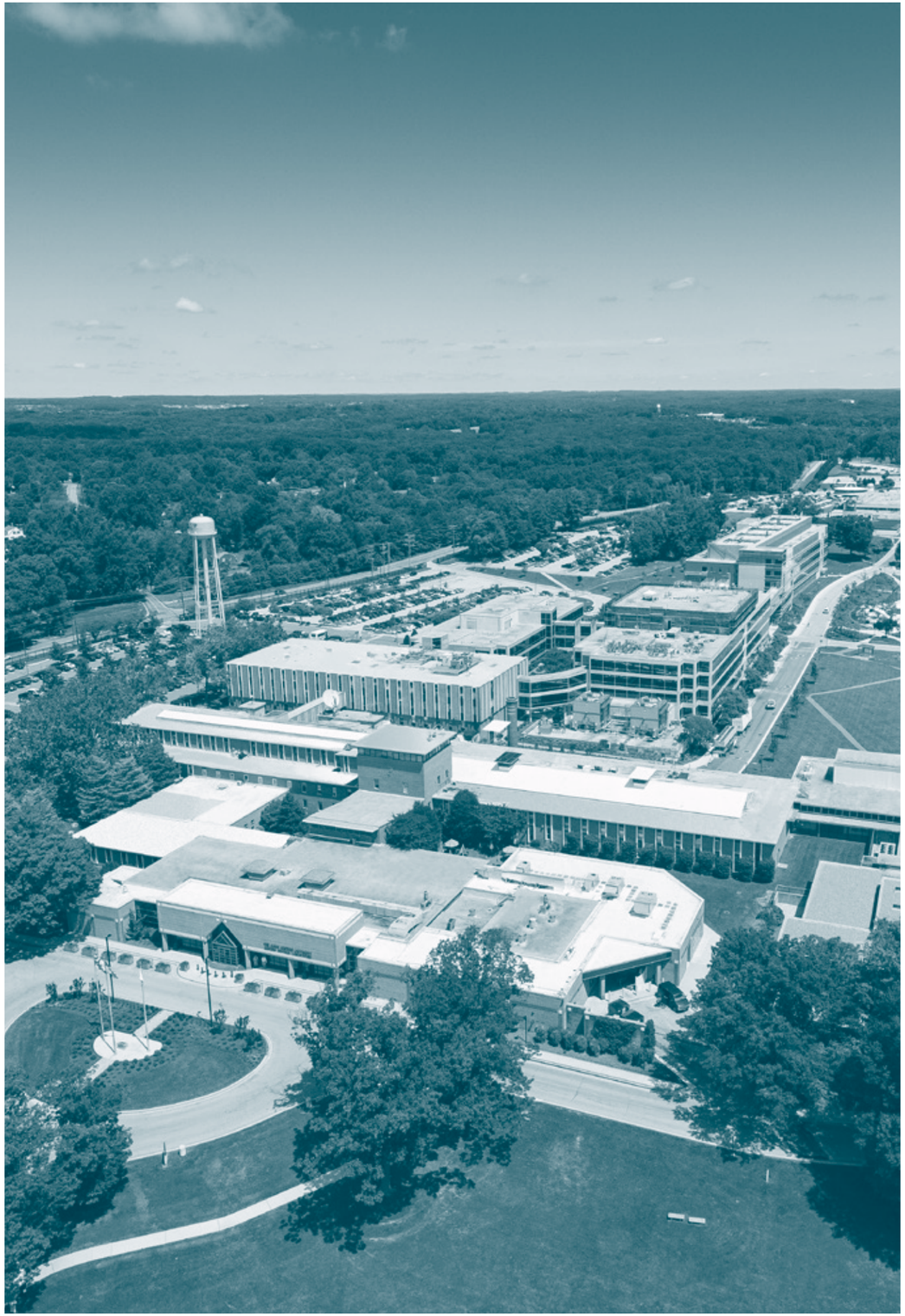

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The Johns Hopkins University Applied Physics Laboratory is a university affiliated research center that develops solutions to critical national challenges through the innovative application of science and technology. Our scientists, engineers, and analysts serve as trusted advisors to government, developing capabilities and ensuring the reliability of complex technology programs that strengthen the security of our nation and advance the frontiers of science and space exploration.

DIRECTOR'S MESSAGE

In 1942, APL's first director, Merle Tuve, and a small group of colleagues set out to speed the Allied victory in World War II. Their ambition was to create a proximity fuze that would effectively defeat the aerial bombardment of our forces in the Pacific. While the idea had been discussed broadly, it was not until Tuve and his small band of engineers tackled the problem that the proximity fuze became a real solution.

Members of Tuve's group actually deployed operationally, as commissioned officers, to help field the fuze. They observed that while the fuze performed as required, the gun system hampered its effectiveness. Without prompting, the APL team took on the urgent task to develop a better gun aiming device called a director. The system comprising the fuze and director proved to be a resounding success both at sea and onshore and did, indeed, hasten the end of the war. And with the creation of that system, APL began its journey in becoming the world-class systems engineering institution we treasure today.

This founding story of APL highlights the first of many incredible achievements that the Laboratory can look back on as we celebrate our 75th anniversary. In fact, APL has made thousands of critical contributions to our nation's most critical challenges since our founding in 1942. Including the proximity fuze, nine of those contributions are what we characterize as defining innovations—game-changing developments that have profoundly advanced science, engineering, and national security capabilities. In this year's annual report, we touch upon the stories of these remarkable advances while also exploring contributions made more recently, some of which might even become future defining innovations.

Significantly, our contributions today are as strong as they have ever been. Given the rapid pace of global technological change and scientific discovery, they are also markedly more varied. Our strength and our resilience in the face of such unprecedented change can be attributed to one constant: our amazing people. Since our humble first days in a suburban Maryland used car garage, our staff members have pushed the boundaries of knowledge and brought together technologies that have served the nation in a myriad of ways. Moreover, we remain driven by our belief, as Tuve once said, that "our moral responsibility goes all the way to the final battle use … it is our job to achieve the end result." We also recognize that throughout our history, our greatest achievements have been enabled and accelerated by our government, industry, and academic partners. More than ever, the Laboratory thrives as part of a dynamic, global science and technology ecosystem, and we are working to further cultivate that ecosystem and our centrality within it. To create the next generation of defining innovations that ensure our nation's preeminence, we must continue to envision bold solutions and connect emerging science and technology in new and potentially disruptive ways.

Clearly, our purpose and spirit were present from the start, but our ethos and culture grow stronger every day. Indeed, together as a team, we will continue to be bold, do great things, and make the world a better place!

USS *Helena* was the first user of the fuze in combat, 1943. (U.S. Navy)

75 Years of Critical Contributions

AIR AND MISSILE DEFENSE

World-Class Expertise in Protecting the Nation and Our Allies from Air and Missile Threats

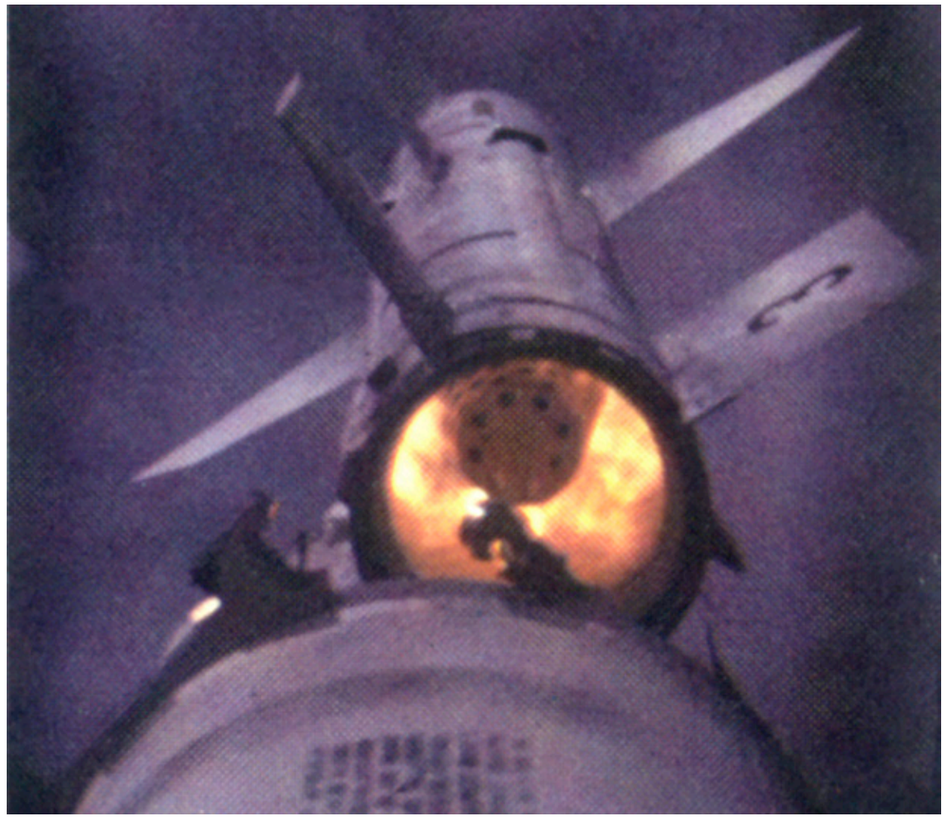
Less than four months after the Japanese attack on Pearl Harbor, APL was established to perfect and field one of America's most closely guarded wartime secrets—the radio proximity fuze. Called the VT fuze to protect its true capability, the device was a complex system of miniaturized electronics packed into the tip of anti-aircraft shells that were rugged enough to survive the 20,000-g force of being fired from a naval gun and sensitive enough to detonate a shell in close proximity to fast-moving enemy aircraft.

When it was fielded, the fuze cut the number of anti-aircraft shells required to down an enemy aircraft from an average of 2,400 to just a few. More than 23 million fuzes were produced for U.S. and Allied forces during the war, dramatically increasing the effectiveness of air defenses in the Pacific and playing a vital role in the Battle of the Bulge in Europe. The radio proximity fuze was later judged by historians as one of the three most important developments of the war—along with radar and the atomic bomb.

From that start, APL's deep, world-class expertise in air and missile defense began to take shape. Even as the radio proximity fuze was being fielded, others at APL had set out to develop a guided missile that could strike enemy aircraft at a distance of 10–20 nautical miles. Within a year, they had conducted the first successful supersonic ramjet engine flight test, and they eventually developed the first generation of Navy surface-to-air guided missiles—Talos, Terrier, and Tartar.

TRACKING TARGETS

By the late 1950s, the air defense threat had become more challenging, and it was clear that the radar technology of the time was unable to detect, track, and guide U.S. surface-to-air missiles against multiple attacking enemy aircraft or missiles. To address this critical challenge, APL developed a prototype "phased array" radar system for the Navy as well as key enabling support systems.



An early Talos missile, circa 1951, separates from its booster rocket. (U.S. Navy)

The system was designed to provide the near-instantaneous scanning, tracking, and closed-loop guidance needed to defend against simultaneous aircraft and missile raids. Subsequent advances led to a prototype phase shifter—a key element of a phased array—along with the radar-beam control algorithms and software, and complex signal processing needed to discriminate real targets from environmental clutter and signal noise. By 1969, APL had built and tested a prototype phased array radar system known as AMFAR (advanced multi-function array radar). This system was the precursor to the AN/SPY-1, a key enabler of the Navy's Aegis Combat System.

APL's expertise evolved to meet the threat of highly advanced air and missile attacks against the nation's battle groups. In the 1980s, the U.S. Navy called on APL to develop a real-time sensor networking concept called the Cooperative Engagement Capability, which combined and integrated radar measurements from multiple ships into composite tracks that would be more accurate and persistent than tracks generated by individual ship radars. The system provided ships in a

USS *Albany*, the first all-guided missile cruiser, simultaneously fires Talos and Tartar missiles in a 1963 test. (U.S. Navy)

battle group with an identical radar-track picture of threats in intense hostile electronic jamming environments, allowing ships to fire and guide surface-to-air missiles against targets using data from the radar systems of other ships or aircraft, even when the firing ship's own radar could not detect or track the targets.

APL also played a major role in developing the Ship Self Defense System (SSDS), an automated combat-direction system that integrates sensors and weapons such as the Evolved Sea Sparrow Missile (ESSM), the Rolling Airframe Missile (RAM), and the Phalanx Close-In Weapon System (CIWS)—providing a cost-effective self-defense capability for aircraft carriers and amphibious landing vessels. APL developed the concepts and pioneered the use of commercial hardware and software components to achieve the Navy's first local area network (LAN)-based, distributed-processing combat system. The concepts were proven aboard USS *Whidbey Island* in 1993; SSDS is now installed or slated for installation on all aircraft carriers and amphibious warfare ships. As technical direction agent, APL continues to work closely with industry and Navy labs to integrate new phased array sensors and to integrate and coordinate electronic warfare capabilities.

BALLISTIC MISSILE DEFENSE

During the 1990–91 Persian Gulf War, Aegis-equipped warships in the region were able to detect and track Iraqi short-range Scud-B missile launches, leading to the realization that existing Navy ships and combat systems could be modified to provide a ballistic missile defense capability. A series of experiments in which APL served as the technical direction agent for the Navy's theater-wide program culminated in the first successful ballistic missile intercept by a Standard Missile-3 (SM-3) in January 2002 and marked the dawn of a new era for the U.S. Navy.

The AN/SPY-1 phased-array radar undergoes operational testing aboard USS *Norton Sound*, 1980. (U.S. Navy)

A 1983 demonstration of the Digital Data Converter, which forms the basis of the Cooperative Engagement Capability. (U.S. Navy)

Since then, APL has been named the Missile Defense Agency's technical direction agent for the Aegis Ballistic Missile Defense (BMD) program, and we have played a continuing and vital role in the development of this new capability. In 2009, APL co-led a study to develop a concept that leveraged the SM-3 missile for defense against short- and medium-range ballistic missiles. The study recommended essentially moving the shipboard Aegis Ballistic Missile Defense combat system ashore, using the proven system architecture as the central component of an evolutionary ballistic missile defense system, known as the Phased Adaptive Approach.

Today, APL's support of air and missile defense programs continues. AMFAR's legacy lives on in the AN/SPY-1 radar and its successor, the Air and Missile Defense Radar (AMDR), which is in development to provide the continuous radar coverage needed to defend the U.S. Navy and its allies. The Cooperative Engagement Capability is aboard more than 120 U.S. Navy ships and airborne early warning aircraft, providing the foundation for systems that today can engage threats well beyond the horizon. APL continues to serve as technical direction agent for the Navy's Standard Missile programs, which are the backbone of Navy air defenses, and the Aegis BMD, the nation's sea-based ballistic missile defense capability.

All of this contributes to our mission to advance the ability of our nation to defend itself and others against a range of missile and aircraft threats. And APL will continue to meet that critical mission through innovative, effective, and affordable solutions to its most difficult challenges.

First intercept flight test of the Aegis Ashore system, 2015. (Missile Defense Agency)

AIR AND MISSILE DEFENSE

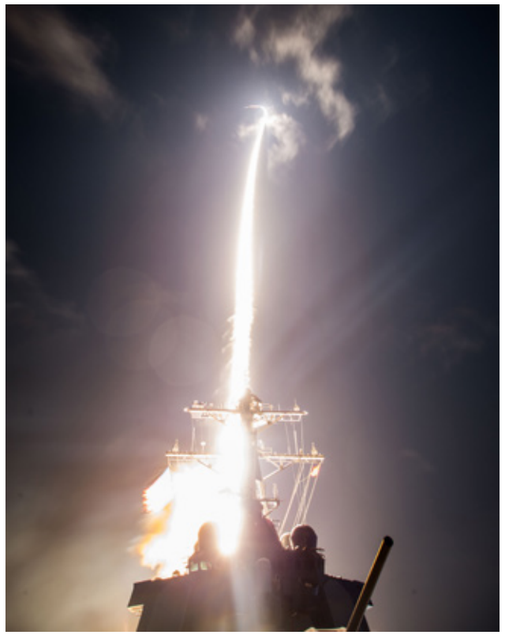
APL creates advanced technologies and capabilities to protect U.S. and allied fleets and deployed forces from air and missile attack. Performing this vital mission in an increasingly complex environment, we address new and emerging threats posed by advanced long-range ballistic and cruise missiles. We devise, develop, engineer, test, and evaluate solutions that address today's—and tomorrow's—air and missile defense needs, and we apply our expertise to make current systems more effective, adapt technologies for new missions, and develop novel technologies for future use.

VISHAL GIARE
Mission Area Executive

APL engineers successfully tested a powerful free-space optical communications system during the 2017 Trident Warrior Exercise.

Optical Communications at Sea

We successfully demonstrated a high-bandwidth free-space optical (FSO) communications system between two moving ships, proving operational utility of FSO technology in the maritime environment. APL is the first organization to successfully operate such high-capacity FSO capability—up to 10 gigabits per second—on the move, on ships at sea, and in challenging near-shore environments. Lab engineers demonstrated this APL innovation—which is smaller and lighter and uses far less energy than similar FSO systems—at the 2017 Trident Warrior Exercise.



A Standard Missile-3 is launched from USS *John Paul Jones* in the first live-fire intercept using the new SM-3 Block IIA guided missile. (Missile Defense Agency)

Standard Missile-3: The Next Generation

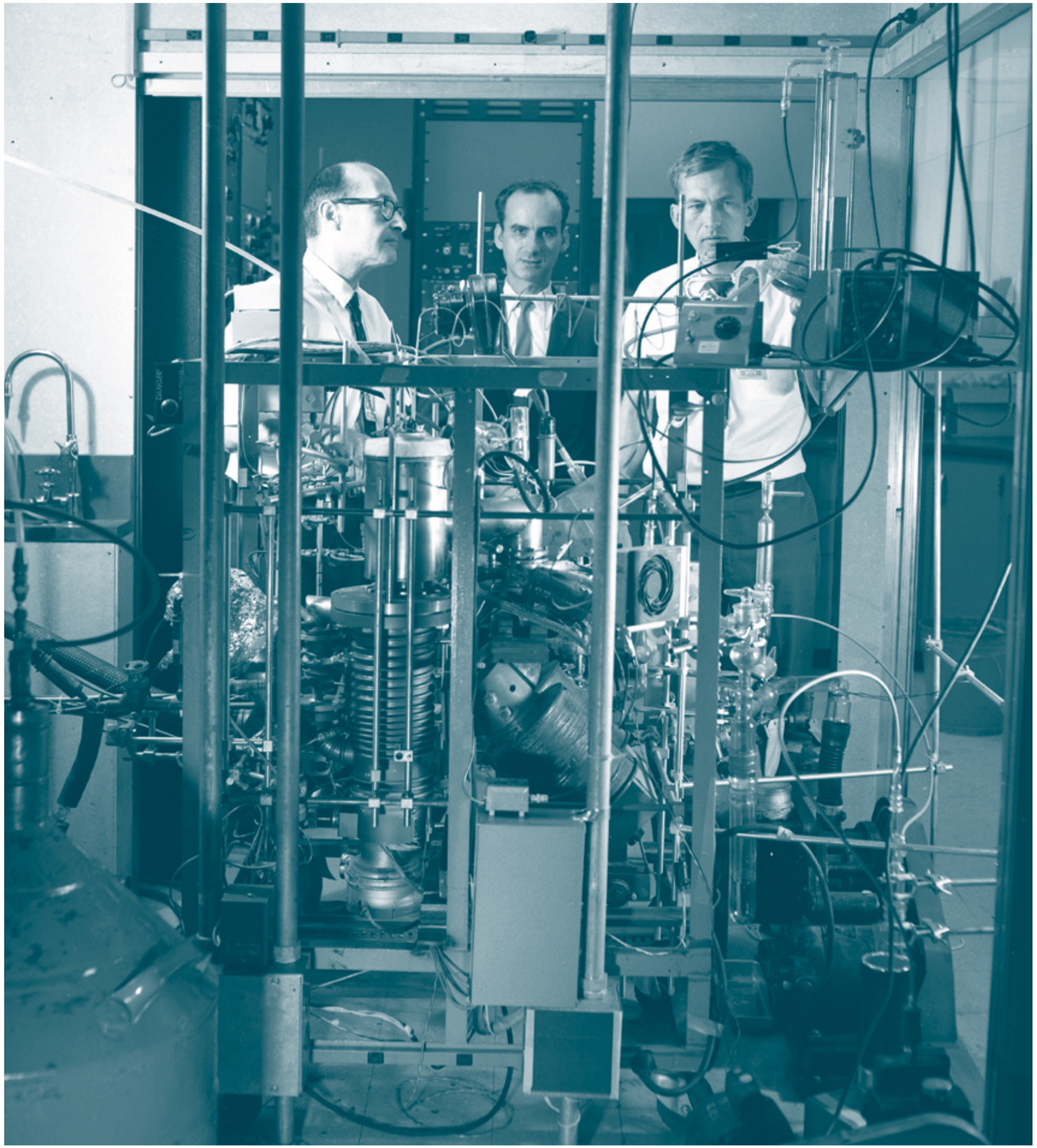
APL, in cooperation with the U.S. Missile Defense Agency (MDA), the Japan Ministry of Defense, and U.S. Navy sailors aboard USS *John Paul Jones*, completed the first live-fire intercept using the new Standard Missile-3 (SM-3) Block IIA guided missile during a February 2017 flight test in Hawaii. APL led key "end-to-end" system-level performance analysis in collaboration with the government–industry team for the SM-3 Block IIA missile, cooperatively developed by the United States and Japan. APL's high-fidelity modeling and simulation of the weapon and missile system provided key performance predictions to plan and safely execute this complex test on the flight test range. The missile, designed to be fired from Aegis ships and Aegis Ashore sites, is capable of countering more advanced and longer-range threats than the deployed SM-3 Block IB.

Test Target Prototyping

A cross-APL team of engineers, working with the Missile Defense Agency's (MDA's) Target and Countermeasures Directorate and other government and industry partners, develops cost-effective solutions for MDA to support live-fire testing of interceptors, sensors, and fire control systems. The team is currently developing two surrogate target vehicles. The first has successfully flown on three MDA tests (the latest being SFTM-02) and is part of a technology transfer activity to an industry partner; the second, being developed for a first flight in fiscal year 2019, is undergoing signature characterization.

Testing Air and Missile Defense Radar

APL teamed with industry and the Above Water Sensors Directorate of Program Executive Office Integrated Warfare Systems on two successful tests of the AN/SPY-6(V), a wideband digital beam-forming sensor known as the Air and Missile Defense Radar. The tests, held at the Pacific Missile Range Facility in April and July, put the system up against Aegis Readiness Assessment Vehicle (ARAV) targets, acting as an adversary ballistic missile surrogate. APL engineers led development of ARAV target and scenario requirements; developed, built, and tested key hardware on the targets, including infrared and visible cameras; and were part of the government–industry team evaluating the data from each flight test. The AN/SPY-6(V) will be integrated on DDG 51 Flight III combatants to enable next-generation integrated air and missile defense capabilities.



Modulated molecular beam mass spectrometer, used to study chemical reactions, circa 1953.

75 Years of Critical Contributions

ASYMMETRIC OPERATIONS

Game-Changing Impact in Countering New and Unconventional Threats

The events of September 11, 2001, brought asymmetric threats against the nation into dramatic focus. While APL had developed solutions to novel threats for decades, the unique nature of those threats, and the new technologies to address them, have grown dramatically. What's more, the need for technologies that serve the special operations community, those engaged in protecting our homeland, and our interests in cyberspace has also grown markedly. And as the technologies and threats have changed over time, so too have APL's expertise and contributions.

SUPPORTING COUNTERTERRORISM ABROAD

Since the 1990s, APL has worked with defense and security agencies to counter terrorist activities abroad. The challenges facing the military, and especially special forces, mirror the urgency that surrounded APL's development of the proximity fuze in the early years of World War II—staff members are focused on the critical need for operationally relevant solutions that leverage the best technologies available in integrated and deployable systems.

From sensors and communications devices to intelligence and reconnaissance tools, our contributions to special operations draw from advancements in all of our technical disciplines. For example, in 2011, responding to the operational imperative to secure new, smaller forward-operating bases in Afghanistan, experts from across the Lab (led by APL's Force Projection Sector) designed, prototyped, and deployed the Persistent Ground Surveillance System, a portable, low-cost aerostat with sensors to keep watch over the bases. In just seven months, this inexpensive "eye in the sky" was deployed and being hailed a game-changer by leaders in the field.

Around 2008, APL's decades-long experience in communications and electronic warfare proved critical in countering the threat of radio-controlled improvised explosive devices (IEDs) in Iraq and Afghanistan. Working for both the Navy and the Marine Corps, the Lab led the development of electronic jamming techniques and continues to tackle this critical challenge.

In a different context, APL's broad, long-standing expertise in light detection and ranging (LIDAR) proved useful to operations in dense forests in the early 2000s. Our focus on LIDAR research began in the early 1990s and evolved into technology that allowed overhead reconnaissance of objects through dense foliage, leading to critical discoveries.

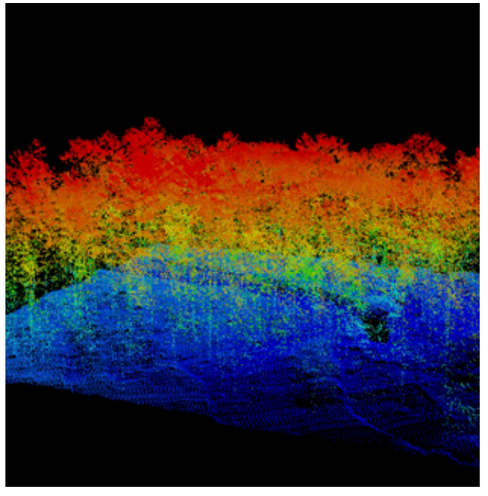
APL has applied its broad expertise to benefit Special Operations Forces for decades in their counterterrorism efforts. (U.S. Navy)

Finally, the Lab's technical expertise in chemical and biological sensing has led to novel assets for deployed forces, such as molecularly imprinted polymer sensors, backpack radiological mapping systems, a mobile detection laboratory, a leave-behind drop sensor for maritime searches, and rapid, handheld biosensors.

SECURING THE HOMELAND

As the Lab has witnessed the proliferation of advanced technologies on the battlefield—from missiles to chemicals to computer code—it has also recognized and developed ways to counter the evolving threats to the homeland. Drawing on decades of work, cross-Laboratory teams have developed innovative approaches for the Transportation Security Administration to screen for dangerous materials, including development of prototype radiological and nuclear detection systems. The urgent need for better hazardous-agent-detection tools led to compact mass spectrometers in the early 2000s and later, specialized on-site facilities such as the Chemical and Biological Test and Evaluation Center. APL researchers have even developed next-generation sensors by using gene sequencing and protein biomarkers.

As the biological threats to the world evolved, APL also invested resources in discovering ways to detect and track early exposure to biothreats in real time through disease surveillance. The Biosurveillance Portal developed at APL monitored, analyzed, and modeled the spread of health-related concerns across the globe and enabled communication and real-time collaboration by U.S. government agencies, public health officers, clinicians, and law enforcement personnel.



Researchers test a sensor element of the foliage-penetrating LIDAR technology, which became operational in 2010. A LIDAR image is at right.

The Laboratory's core competency in systems engineering has proven very useful for homeland defense over the years. For U.S. Customs and Border Patrol, APL played a key role in identifying systems requirements and the integration standards necessary for the agency to make smart acquisition investments. We also developed a suite of analytical tools, called Total Station View, to help agents visualize and analyze system performance.

REVEALING CYBER TERRAIN

Cyber tools and technologies rapidly evolved to become a critical contribution from the Laboratory after 9/11. By 2005, the Lab was helping sponsors apply rapidly advancing information technologies to some of their toughest, and newest, intelligence and warfighting challenges. APL helped to develop concepts ranging from critical Department of Defense networks, such as the Global Information Grid, to visualization tools that supported cyber operations.

The urgent need for better hazardous-agent-detection tools led to compact mass spectrometers (pictured) in the early 2000s, and later, facilities such as the Chemical and Biological Test and Evaluation Center.

As the military adopted network-centric communications technologies in the early days, APL developed methods to evaluate trade-offs between risks and system capabilities—increasingly important as attacks on U.S. networks and data grew. Our work to assist sponsors in assessing their systems and cyber vulnerabilities has developed over the years across many different applications, from conducting a highly realistic cyber experiment aboard a commissioned Navy ship to developing remote monitoring and control equipment for the Army.

Recognizing Laboratory systems are constantly under attack, APL's Information Technology Services Department and Cyber Operations Mission Area partnered in 2009 to make the Lab's own internal network a test and evaluation environment for cybersecurity. One result was the creation of the LIVE (Live data, Integration, Validation, and Experimentation) Lab, which monitors and applies new tools and visualization techniques to APL network data.

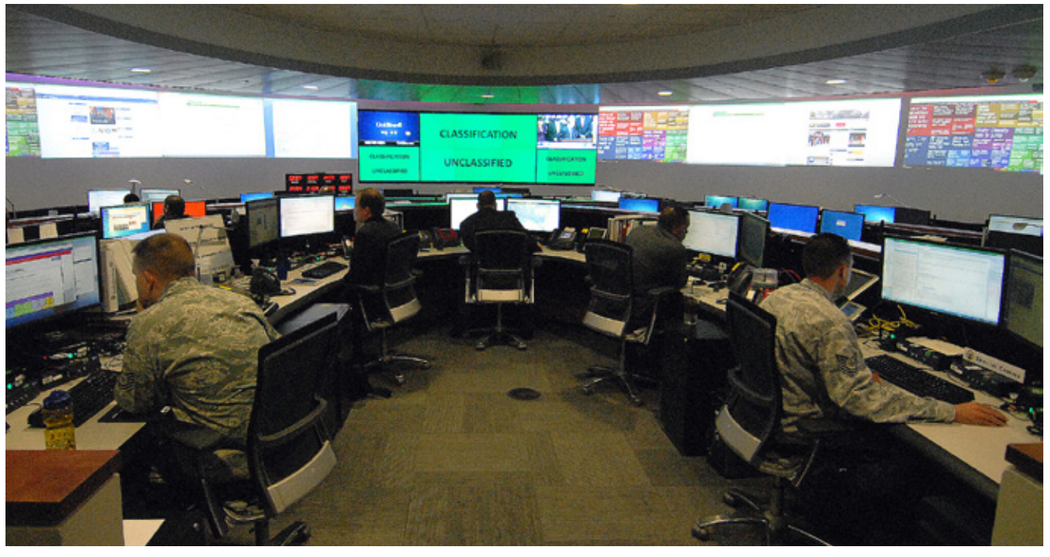
Talented APL engineers, scientists, and researchers continue to collaborate to break new ground and bring the best technological and analytical efforts to defeat all threats to the nation, at home or abroad, in real and virtual worlds.

The Live data, Integration, Validation, and Experimentation (LIVE) Lab has become APL's nerve center for developing solutions to continually evolving cyber threats.

CYBER OPERATIONS

APL is shaping the future of warfare through cyber operations, focusing on assuring critical Department of Defense missions, delivering key solutions to enable intelligence and military operations, and developing the systems that underpin novel operational capabilities in cyberspace and across the electromagnetic spectrum.

RAY YUAN
Mission Area Executive



APL's continuing work for the Defense Information Systems Agency includes research into long-range networking solutions for military platforms. (DISA)

Visible Light Communications

For the Defense Information Systems Agency (DISA), APL is developing mission concepts and integrating operational prototypes of visible light communications capabilities in the Department of Defense—helping DISA enhance data security and alleviate demands on the limited radio frequency (RF) spectrum. Our continuing work includes prototype secure implementations of light fidelity (Li-Fi) networks in enterprise workspaces and research into long-range networking solutions for military platforms.

Detecting Malware

Using different types of powerful analytics, the APL-developed REnigma tool enables cyber analysts to quickly review malware. REnigma's Virtual Machine Record and Replay capability records detected malware and allows an analyst to evaluate it in greater detail than previously possible. The technology provides an isolated environment where code can be executed without interfering with a network, and where malware samples can be detonated in a safe place. The typically time-consuming and often expensive recovery process after a malware attack can now be done more efficiently and cost-effectively. The technology will soon be commercially available to medium and large organizations that generally need malware analysis, such as banks and government agencies.

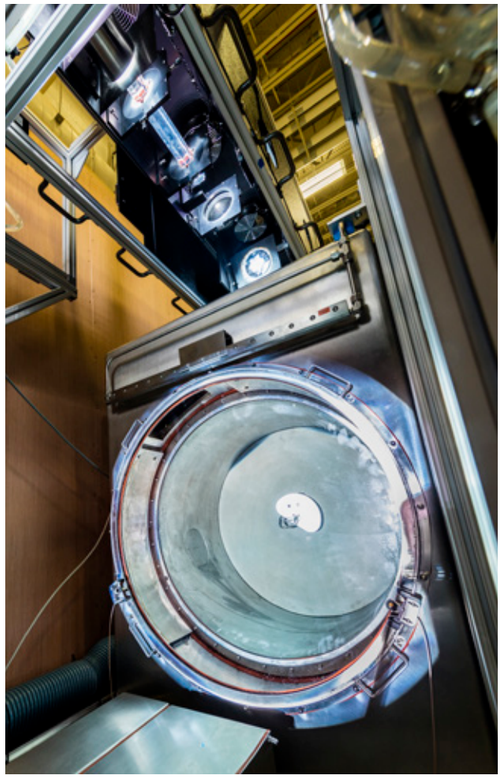
Integrated Adaptive Cyber Defense (IACD)

APL conceptualized, prototyped, and published a framework enabling the integration and automation of diverse cybersecurity solutions to dramatically increase the speed and scale of cyber defense. Our contributions include development of reference architectures and implementations adoptable by commercial companies; creation of IACD playbooks enabling business-level management of cyber-defense technology solutions; and establishment of Integrated Cyber, a multiday, multicommunity forum for the advancement of automation in cybersecurity. In fall 2017, the Financial Services Information Sharing and Analysis Center (FS-ISAC) partnered with APL to operationalize IACD in the financial sector. APL will serve as a trusted technical advisor to multiple financial institutions and the FS-ISAC in the adoption and expansion of IACD services.

HOMELAND PROTECTION

APL addresses a wide range of critical tactical and systems-level challenges related to border security, transportation security, cyber and physical security of critical infrastructure, resiliency and assured operations, integrated information for enhanced decision support, and emergency response systems. The solutions we deliver for our sponsors reflect our deep understanding of operational realities, built through close association with frontline security, law enforcement, and emergency response entities.

JOSE LATIMER
Mission Area Executive



APL's Rotating Drum System offers unprecedented aerosol research capabilities.

Biological Threat Analysis

APL is developing innovative ways to evaluate biological threats in a natural environment. The APL-designed and -built Rotating Drum System provides unprecedented aerosol research capabilities. With its continuously rotating drum, the system suspends aerosol particles for up to 24 hours so researchers can study biological viability due to environmental factors; while in suspension, the particles are exposed to ozone, simulated sunlight, and hydrothermal conditions resembling those in different regions of the continental United States. This is a capability unavailable anywhere else.

Situational Awareness for First Responders

Under the direction of the Department of Homeland Security Science and Technology Directorate, APL partnered with the New York City Police Department's Emergency Service Unit in April 2017 to field-test and evaluate a commercial Mobile Ad-hoc Networking (MANET) system. The MANET system comprises several components, including smartphone-based tactical awareness software, a wireless smart radio system, a tablet, GPS capabilities, antennas, and audio and video "plug and play." MANET field tests are aimed at providing local, state, and federal law enforcement with situational awareness tools similar to what frontline military forces use, but adapted to meet specific requirements of first responders.

Senior Leader Helicopter Communications

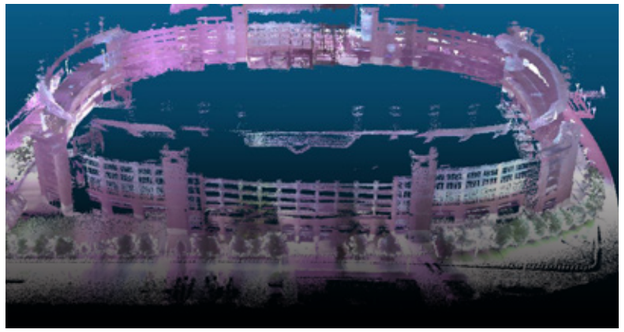
APL is working with the Navy to enhance communications on the senior leader helicopter fleet. We took part in the tests that led to acquisition of an advanced broadband line-of-sight system and engineered the classified wireless mobility system used by a senior leader communications support organization. Using that system as a model, APL integrated a suite of equipment and mobile devices for the Navy test lab and helicopter, and validated the use of wireless devices for secure voice, video, and email during flight. We also designed and configured a smaller Wi-Fi system that was tested on board and will integrate the components for permanent installation on the in-service fleet.

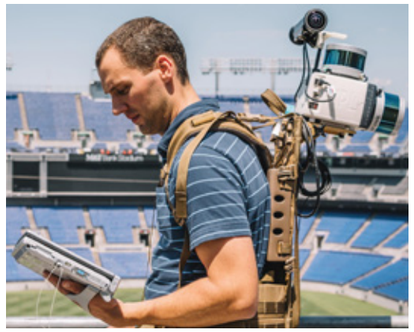
APL is working with the Navy to enhance communications on the senior leader helicopter fleet. (U.S. Marine Corps)

SPECIAL OPERATIONS

APL creates and enables asymmetric capabilities for the special operations community through objective technical expertise, development of emerging technologies, and quick-response solutions. These include raising situational awareness through high-precision, countermeasure-resistant tailored technology for intelligence, surveillance, and reconnaissance. We also provide increased capabilities for military information support operations and counterproliferation of weapons of mass destruction.

PAUL LEFEBVRE
Mission Area Executive





Technology enhancements to EMAPS—tested over the past year in locations such as M&T Bank Stadium in Baltimore—have substantially improved an operator's ability to visualize GPS-denied spaces.

Enhanced Mapping and Positioning System (EMAPS)

We continue to strengthen EMAPS, a portable mapping system carried in a backpack, for the Department of Defense's Chemical and Biological Defense Program. Using sensors and lasers, EMAPS creates annotated maps in spaces where GPS is not available, such as underground or on ships. EMAPS captures a floor plan of the area the user traverses as well as 360-degree photos; the system's novel algorithms associate critical sensor data, such as radiation and radio frequency signal levels, with map locations. We also added high-performance light detection and ranging (LIDAR) to the system and upgraded the software to process this data into a coordinate system—substantially improving the operator's ability to visualize GPS-denied spaces.

An APL-developed, cost-effective multifunctional water-purification membrane could reduce the military's reliance on bottled water in combat and humanitarian operations. (U.S. Air Force)

Pure Water

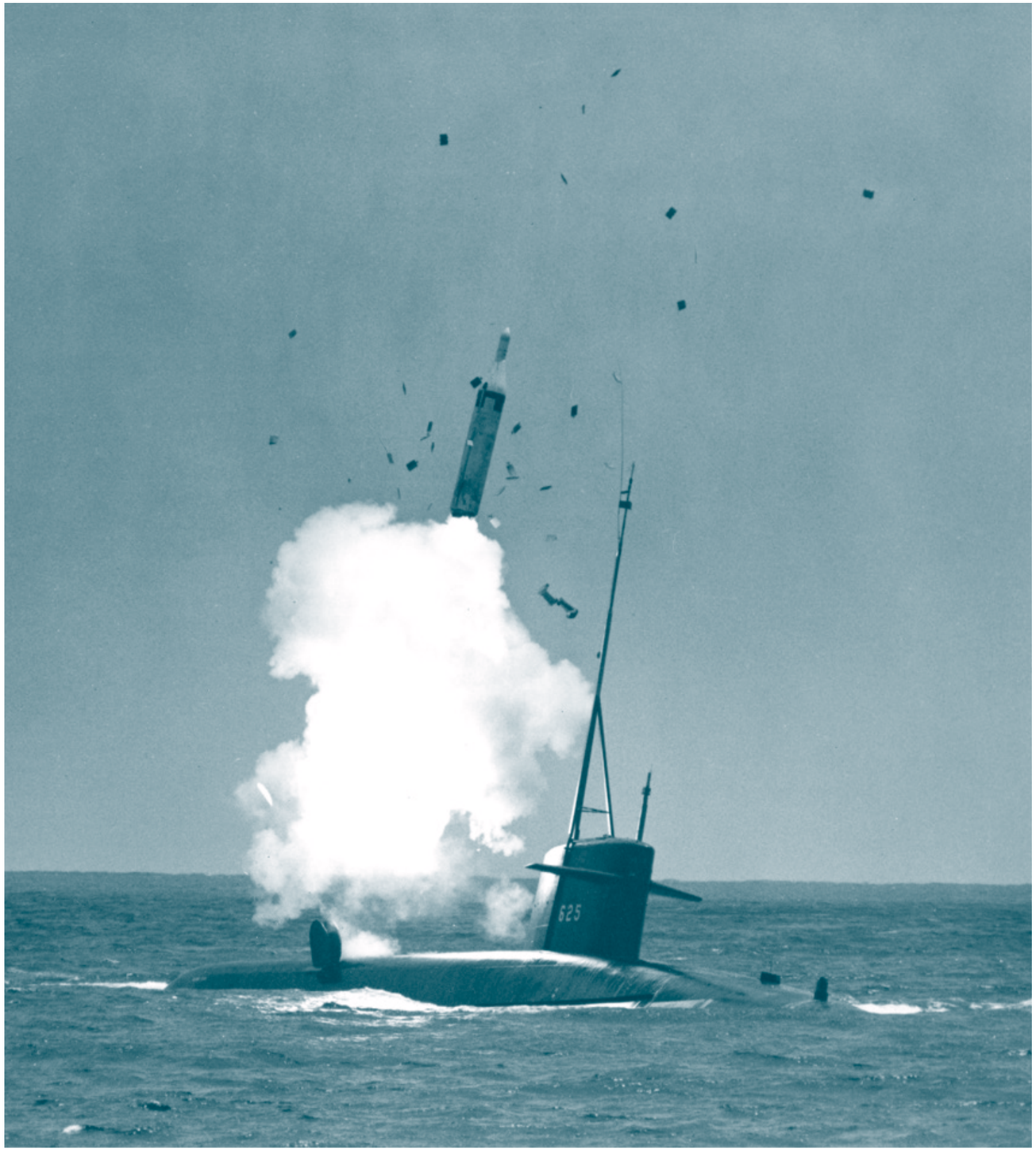
Potable water is a vital resource in a combat mission or during a natural disaster. Currently, the Department of Defense meets the demand by providing costly bottled water and using complex water purification units—but filters and bottled water have their limitations and drawbacks. APL researchers have developed a cost-effective, multifunctional water-purification membrane that can remove pathogens and toxic heavy metals such as lead, arsenic, mercury, and cadmium as well as provide fouling resistance. The technology, named an APL Invention of the Year, has potential military, civilian, and commercial applications.

Better Options for Data Analytics

The open-architecture tool we developed for U.S. Special Operations Command's Science and Technology Directorate limits dependence on a single vendor and enables the command to evaluate data analysis and visualization tools against defined data and interfaces. Most vendors prefer to provide the government with a full package of data, analytics, and visualization solutions. To support its specific missions, the government has to force vendors to provide analytics that it can separate from the data. Further, great power can be achieved by defining the interface between analytics to leverage a group of analytics to support a specific mission model.

Mobile Communications

Special Operations Forces (SOF) continue to rely on APL expertise to understand the communications technology landscape, inform requirements development, and identify options for mobile communications capabilities across a variety of operational scenarios. Our experts conducted technical exchanges, hosted two large workshops and seminars, and created and disseminated a comprehensive electronic survey to characterize detailed requirements and available capabilities. From these activities, APL helped identify key capability gaps, develop mobile communications requirements, and plan technology and acquisition programs to address one of SOF's most pressing needs.



A rare surface test launch of a Polaris missile, 1964. (U.S. Navy)

75 Years of Critical Contributions

FORCE PROJECTION

Trusted Technical Leadership in Strategic Deterrence, Sea Control, and Precision Strike

APL's development and deployment of the radio proximity fuze during World War II laid the groundwork for many of the Laboratory's critical contributions in the following years. Along with technology developments were capabilities to provide significant warfighting advantages and assure global access for the Navy and other military forces.

Today, these critical missions comprise the focus of the Lab's Force Projection Sector and its three mission areas: Strategic Deterrence, Sea Control, and Precision Strike. And more than ever, APL takes seriously its strong reputation and proven ability to deliver insight, data, and technical advice to our nation's military leaders by assessing system performance through detailed analysis, modeling, and testing—and by fielding prototype systems to prove operational concepts.

MISSION ASSURANCE, MISSILE ACCURACY

APL contributions to strategic deterrence date to the early days of the Cold War. As the nation sought to rapidly develop its nuclear strike capabilities, the Lab's proven ability to develop and evaluate complex, high-speed missile systems was essential to tackling what promised to be an enormous engineering challenge.

When the Navy began developing submarine-launched ballistic missiles in the late 1950s, it turned to APL for our expertise to shape what evolved into the Polaris system. Working under a demanding schedule, APL and government and industry partners developed this capability within three years, culminating with the successful launch of the first Polaris missile from USS *George Washington* in July 1960.

Soon after, in a separate and equally significant advancement, APL scientists and engineers created Transit—the world's first global satellite navigation system. Transit provided unprecedentedly accurate navigation for the Navy's Polaris submarine force, while becoming the precursor to the modern Global Positioning System.

APL's decades of groundbreaking undersea research and development provided the foundation for the powerful long-range towed arrays in use throughout the U.S. Navy today.

As the Navy evolved to the Trident missile system, the Lab further contributed to the accuracy of submarine-launched ballistic missiles by developing SATRACK. This missile-borne instrumentation package combines GPS data with missile flight-test telemetry and detailed error-estimation models to assess a test missile's accuracy. SATRACK models can also be used to predict the accuracy of a missile flown along an untested tactical trajectory anywhere in the world.

These advancements cut in half the number of flight tests required to precisely estimate weapon system accuracy, saving billions of dollars. More significant, APL's critical contributions enabled the Navy to successfully deploy Trident II with an unparalleled level of accuracy that still ensures U.S. Strategic Command is able to fulfill its mission.

These capabilities form the foundation for our work, and today we continue to provide systems engineering expertise to the Navy's strategic systems office, perform strategic weapons system evaluation, and experiment with flight-test cost-reduction approaches—and we are beginning to provide similar contributions to the U.S. Air Force.

MARITIME STRENGTH AND SECURITY

APL has long played an essential role in protecting the nation's maritime superiority. In the late 1960s, the Navy called upon APL to lead an effort to ensure the survivability of the nuclear-armed submarine force; the Lab took an innovative approach that first required the development of ocean physics expertise to spot potential vulnerabilities and opportunities for the U.S. fleet. Over the years, APL scientists and engineers have conducted more than 200 tests at sea and more than 190 tactical exercises to strengthen the stealth of U.S. submarines.

When experiments with long-line towed sonar arrays in the 1980s failed to detect threat submarines at expected ranges, APL developed the tests, prototypes, models, and analyses needed to unlock the

A 1990s APL/Navy program to incorporate advanced, commercially available technology during the construction or overhaul of submarines fundamentally changed the Navy's acquisition processes for submarine sonars and combat systems—and saved our nation billions of dollars. (U.S. Navy)

potential of this revolutionary technology. Our groundbreaking undersea research and development provided the foundation for the powerful long-range towed arrays the U.S. Navy uses today aboard submarines, surface combatants, and surveillance platforms—and also guided the stealth design requirements for multiple generations of U.S. submarines.

More recently, the Lab has helped ensure the Navy's undersea advantage during an era of increasingly quiet threat submarines. In 1996, the Navy embarked on a major initiative to incorporate the most advanced commercially available technology during the construction or overhaul of each submarine. Doing so required profound changes in the way the service traditionally developed, procured, and certified submarine technology and operational procedures. Through its partnerships and leadership, APL developed processes to quickly understand each new technology and its impact on system performance at sea, contributing to improvements in sonar, tactical control, instantaneous ranging, and information integration.

With APL's leadership, the Acoustic Rapid Commercial Off-the-Shelf Insertion program has transformed the Navy's submarine technology acquisition process into an agile and innovative enterprise that has modernized critical weapon systems at substantially reduced costs.

Our deep technical and operational knowledge in undersea warfare underpins our current emphasis in wide area anti-submarine warfare, building the future force of integrated manned and unmanned systems, generating maritime situational awareness, and providing assured survivability for naval forces in contested environments.

READY TO STRIKE

Another area in which APL has played a key role for the Navy is precision strike, through both electronic and kinetic means. In the early 1970s—on the basis of APL's legacy of developing high-speed missile systems—the Navy sought the Lab's help to develop a guidance system for its Harpoon and Tomahawk cruise missiles that could travel long distances and strike targets. When greater accuracy was needed for the Tomahawk, APL developed the algorithms needed to apply technology that compared images taken by an onboard camera to scenes stored in the missile computer—a game-changing advancement known as terrain contour mapping.

Since the U.S. Navy lost its first aircraft to a surface-to-air missile system in the skies over Vietnam, APL has played a key role in the development of tactics and electronic countermeasures to deal with the threat of foreign air defense systems. Working with naval aviation and industry partners, APL designed and developed prototypes of systems to support the Navy EA-6B Prowler as well as its successor, the EA-18 Growler—electronic warfare aircraft equipped to suppress enemy defenses in support of U.S. and allied operations.

APL continues to be deeply involved in Navy electronic warfare operations through its work with the Jammer Technique Optimization (JATO) group. This consortium of military, government, and independent research and development organizations provides engineering, development, and test support to evaluate, validate, and operate radar and communications jamming techniques. Among JATO's more recent successes is APL's development of a jamming capability for the U.S. Marine Corps to defeat the use of improvised explosive devices in Iraq.

While the technologies are much more advanced and the threats much different than what Lab engineers and scientists faced in the days of the VT fuze, their successors maintain that deep dedication to revolutionize the nation's approach to warfare—increasing operational impact with a focus on electromagnetic dominance, asymmetric weapons (including hypersonic strike), and end-to-end capabilities that enable the success of our warfighters in ever more complex environments.

APL has designed and developed systems to support the Navy EA-6B Prowler as well as its successor, the EA-18 Growler (pictured)—electronic warfare aircraft equipped to suppress enemy defenses in support of U.S. and allied operations. (U.S. Navy)

APL's critical contributions have enabled the Navy to successfully deploy Trident II and achieve an unparalleled level of accuracy that ensures U.S. Strategic Command can fulfill its mission. (U.S. Navy)

APL's game-changing terrain contour mapping and digital scene matching technologies have ensured greater accuracy for the Tomahawk weapons system. (U.S. Navy)

PRECISION STRIKE

APL's critical precision strike contributions address tactical aircraft, kinetic and non-kinetic weapon systems, and end-to-end capability development and demonstration. Our work spans research and development of technologies supporting emerging capabilities, technical support to major acquisition programs, and close interaction with the warfighters who use these capabilities. Our experts address integrated strike development of end-to-end solutions from detection through engagement, electronic attack development of non-kinetic capabilities, and advanced development aimed at experimentation and prototyping.

DAVID VANWIE
Mission Area Executive

On assignment aboard USS *Ronald Reagan*, APL technical staff members gained first-hand knowledge of fleet critical challenges. (U.S. Navy)

Deployed with the Fleet

In 2017, APL staff members deployed on U.S. Navy Commander, Task Force 70 (CTF-70) patrols aboard the carrier USS *Ronald Reagan*—an assignment that allowed our engineers to experience the fleet's challenges and operational workflows, and gather important data to feed future analyses and technology demonstrations in operationally relevant environments. In the first tour—focused on the electromagnetic posture of the battle group—APL staff members quickly developed and deployed custom equipment to provide unique data-collection capabilities that led to improved fleet tactics, techniques, and procedures.

APL work to test and validate precision targeting systems—like the one integrated into the Army's M1200 Armored Knight vehicle—is ensuring that ground forces can rapidly and accurately provide GPS locations of battlefield targets.

Next Generation Jammer

Strongly leveraging APL's technical expertise, the Navy's Next Generation Jammer (NGJ) Mid-Band (Increment 1) program entered the engineering and manufacturing development phase. We have been part of the NGJ team since initial concept development in 2001—playing a key role in the evolution of this initiative to equip warfighters of all services with state-of-the-art technology to address emerging electronic warfare gaps.

Precision Targeting

Working to ensure that ground forces can rapidly and accurately provide GPS locations of battlefield targets, APL performed design analyses and developed procedures that resulted in the successful testing of the Joint Effects Targeting System (JETS) and improvements to the system's precision geolocation capability. JETS, now set for initial operation in 2018, will be the first handheld precision-targeting system that includes all-weather geolocation using a miniature inertial navigation system (INS) as well as the ability to use a night or day celestial compass—for which APL conducted design trades and developed specifications. We worked on an even smaller microelectromechanical systems-based INS for the Office of Naval Research and the U.S. Marine Corps, devising ways for seamless integration into a deployed Marine targeting system. We also led an effort to measure data suitable to validate error estimates provided by a targeting system integrated onto the Army's M1200 Armored Knight vehicle.

Modeling Warfighter Decision-Making

Working with technical consultants and the Navy fighter aircraft community, we created a pilot-behavior model for air-to-air combat. Combined with new tactics and employment modes in BRAWLER—an accepted engagement-level modeling and simulation environment for air-to-air combat—the model allows analysts and decision-makers to study the impact of human performance on air-to-air engagements and overall mission effectiveness. Specifically, we can inject unusual responses into simulations that previously had reflected only "by the book" execution. The model, and its application to engagement-level simulation, marks the importance of operators as the critical element in system designs.

SEA CONTROL

APL supports U.S. Navy and joint service missions, delivering essential capabilities to project military power on, under, and above the seas. We focus on four key areas to revolutionize maritime superiority: maritime domain situational awareness, kinetic and non-kinetic effects to deter aggressors and deescalate hostilities, force survivability against near-peer threats, and effective and affordable rapid prototyping and modernization. We develop and field innovative solutions that maintain global access for U.S. naval forces and deny adversaries use of the maritime domain.

CHRISTOPHER WATKINS
Mission Area Executive

An APL/Naval Air Warfare Center demonstration of swarming unmanned surface vehicles illustrated capabilities the Navy can use to address a range of operational challenges.

Swarming Unmanned Surface Vehicles

APL, in collaboration with the Naval Air Warfare Center Port Hueneme Weapons Division, led a swarming unmanned surface vehicle demonstration of advanced multivehicle autonomy at tactically relevant speeds. We developed a "plug and play" kit that converts any Navy high-speed maneuverable surface boat into an autonomous, unmanned vehicle—as well as the autonomy control segments to enable a six-vehicle, open-water demonstration at speeds faster than 40 knots. The demonstration included tactical situations such as bad-actor engagement and coordinated attack scenarios—illustrating a potential leap-ahead capability the Navy can use to address a range of operational challenges.

APL programs ensure our nation's submarines stay hidden in the face of new technology, changing mission requirements, and increasingly sophisticated adversaries. (U.S. Navy)

Submarine Survivability Program

The SSN/SSGN survivability program ensures our submarines stay hidden regardless of new technology, changing mission requirements, and increasingly sophisticated adversaries. We take a fundamental physics approach to understanding submarine detection and counterdetection by developing detailed models validated with full-scale sea tests. This year's studies, analyses, and sea tests improved our understanding of the physics of submarine stealth, allowing submarine operators to develop better tactical guidance and allowing the resourcing and acquisition communities to establish requirements—and ultimately to shape designs of the next-generation fast-attack submarine.

Integrated Undersea Surveillance Systems

We are solving critical challenges for the Navy's undersea surveillance community, making contributions such as active and passive sonar processing algorithms for inclusion in the Advanced Surveillance Build tactical sonar modernization program. We provided direction for both U.S. and allied platforms to complete initial operational test and evaluation for the Surveillance Towed Array Sensor System (SURTASS), and developed modular, quick-reaction, mobile surveillance system capabilities to extend SURTASS presence worldwide. Our laboratory-based fleet operator watch section testing characterized new tactical sonar functionality and capabilities, and included developmental concepts of employment.

Unmanned Surface Vessel Perception

International regulations for preventing collisions at sea require vessels to operate within certain distances based on the visual identification of other vessels. We have applied machine-learning techniques to teach autonomous vessel-piloting systems how to identify and then safely respond to other ships. Our team compiled an extensive database of images at diverse aspects, ranges, and environmental conditions, and used this data to design and demonstrate a vessel-recognition system accurate enough to meet international requirements for safe passage of vessels.

STRATEGIC DETERRENCE

Building on five decades of vital contributions to the U.S. Navy's Fleet Ballistic Missile program, APL is transforming strategic systems from their legacy nuclear mission to a broad set of responses to current and future national security challenges. We demonstrate expertise in system development, testing, and evaluation for the SSBN mission and are applying that knowledge to the critical, newly expanded roles of strategic systems in our nation's defense.

STEPHEN LEWIA
Mission Area Executive

APL's quick analyses and simulations were critical to the success of this Air Force Minuteman III operational test at Vandenberg Air Force Base, California, in September 2016. (U.S. Air Force)

Dynamic Simulation

With the clock ticking down to the first Minuteman III test flight to feature a miniature analog translator (MAT)—developed and built by APL to replace the obsolete full signal translator (FST) used for real-time range tracking and GPS signal data on prior test flights—qualification tests identified a need to change a configuration file in the MAT ground equipment. Short on time, and with no FSTs available to replace the new technology for the test flight, APL integrated the MAT into an existing hardware-in-the-loop simulation suite and added the missing processing components to create a full end-to-end simulation for various flight conditions. The Air Force then used this data to show with high confidence that the system would perform within specs, and the GT-219 missile flew successfully—and on time.

Rapid Prototyping

We improved on training aids by rapidly and cost-effectively prototyping an interactive pressurization valve for missile tube launcher training. The actual valve is expensive, pneumatically actuated, cast iron and stainless steel; ours was modeled with computer-aided-design tools and 3-D printed in plastic. We then equipped it with motors and sensors and linked the valve to an existing computer simulation of the launch system. This device demonstrated APL's ability to provide effective, low-cost alternatives to traditional trainer mock-ups.

APL is using the commercially developed Wave Glider to demonstrate how quickly the Navy can field new sensor systems.

Ground-Based Strategic Deterrent

APL has a significant evaluation role in the Air Force program to replace the aging Minuteman III system. Building on our deep experience as an independent evaluator of the Trident II system, we provided critical information that will help program leads determine the feasibility of the ground-based strategic deterrent's ambitious accuracy threshold with currently available technology. Our research showed that an effective combination of models and flight-test instrumentation would help the Air Force meet U.S. Strategic Command accuracy evaluation goals in just 11 tests—a significant savings over the 30 tests needed with a traditional approach—and we provided similar advice concerning instrument and test requirements to meet Strategic Command's reliability evaluation goals.

Wave Glider Demonstration

For the first time, we used the commercially developed Wave Glider to demonstrate how quickly the Navy can field new sensor systems. A significant operational challenge was to hold Wave Glider's position in the Gulf Stream, where currents can exceed five knots and potentially override the glider's top speed of about two knots. In a set of successful tests, Wave Glider spent more than six hours in a planned area—a milestone in proving the glider can perform missions that include communication, submarine position localization, and data collection in a broad range of ocean environments.

Engineers move Transit 1B, APL's second satellite, to its launch vehicle in 1960.

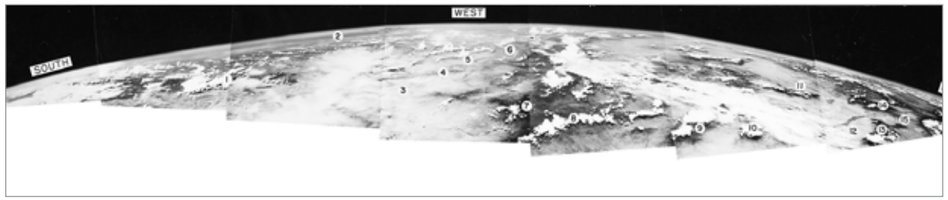
75 Years of Critical Contributions

SPACE EXPLORATION

Boldly Opening New Frontiers of Science and Engineering

By the time APL established its Space Division on Christmas Eve 1959, Lab engineers and scientists had already been expanding the world's knowledge of space to increase scientific knowledge and ensure national security.

In the 1940s, physicist James Van Allen and colleagues instrumented captured German V-2 rockets with sensors and cameras and fired them into the skies. With the experiment, the Lab captured the first photos of Earth from space and illuminated data on the cosmic ray particles that bombard our planet.



First view of the curvature of Earth from space, provided by an APL camera aboard a V-2 rocket in 1948.

Just over a decade later, young physicists William Guier and George Weiffenbach followed the Doppler shift in radio signals transmitted by Sputnik and used them to determine the orbit of the Soviet satellite as it flew over the APL campus. Then by reversing their calculations—using the satellite to pinpoint the location of something on Earth, rather than tracking the spacecraft from the ground—they laid the foundation for Transit, the world's first satellite navigation system, which vastly improved the ability of American submarines to accurately determine their positions around the globe.

APL's space science and engineering programs have long thrived on "impossible" challenges. Through the design and construction of 69 spacecraft and more than 150 specialized instruments, our drive to gather knowledge has been fueled by perseverance. APL's first satellite, Transit 1A, never made it to orbit, but engineers squeezed enough data from its short 1959 flight to apply to the next several launches. Transit 2A performed well enough for the Navy to continue funding additional experimental Transit spacecraft, and APL staff members produced a series of Transit satellites. The spacecraft entered service as the Navy Navigation Satellite System in 1964; four years later, an operational constellation of satellites and on-orbit spares was in place.

KNOWLEDGE ON THE EDGE

Over the decades, APL has delivered big with low costs—from data on the shape of the Earth, the heights of the oceans, the sun–Earth connection, ice on Mercury, the boundaries of the solar system, and the astrophysical characteristics of the universe.

Space shuttle program costs in the 1970s and 1980s pressurized funding for NASA's planetary science missions, which at the time typically cost more than $1 billion each. Convinced we could design, build, and operate spacecraft well below that threshold, we proposed a generation of ambitious, low-cost planetary missions. In our first opportunity to prove the viability of this defining innovation, APL developed the Near Earth Asteroid Rendezvous (NEAR) mission, the first to orbit an asteroid. APL built the spacecraft more rapidly (26 months) and less expensively (25 percent less than estimated) than had ever been attempted for a planetary mission, and it was a stunning success. After a year of orbiting the asteroid Eros, in February 2001, APL engineers softly landed NEAR on the asteroid—where it continued to transmit data back to Earth for more than two weeks.

George Weiffenbach, Frank McClure, and William Guier—who invented the concept of satellite navigation—study a map showing Transit satellite orbit passes in 1961.

NEAR's success cemented APL's reputation as a national leader in low-cost planetary exploration and inspired NASA not only to continue the Discovery program—which led to APL's MESSENGER Mercury orbiter, launched in 2004—but also to create the New Frontiers program, with New Horizons, which launched in 2006 and completed a historic flyby of Pluto in 2015, as its first mission.

Today's space work is just as exciting and important as APL's earliest programs. The Van Allen Probes are studying the donut-shaped swarms of charged particles surrounding Earth known as the Van Allen belts, named for Van Allen—who discovered the belts in the course of his pioneering research—and delivering data that will be critical to spacecraft and human survival in near-Earth space.

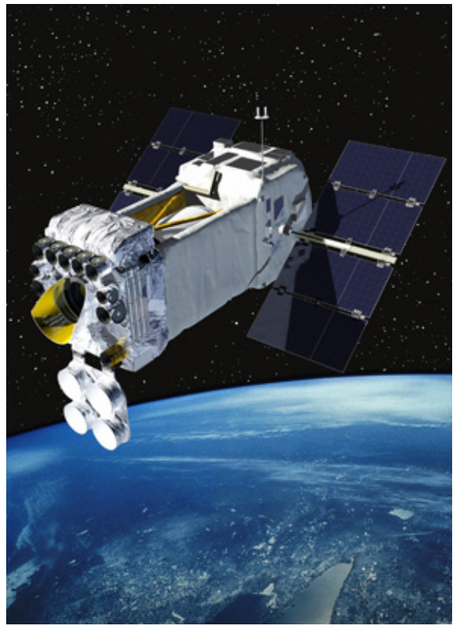
Work is also under way on Parker Solar Probe, set to launch in 2018. The probe will plunge through the sun's atmosphere, seven times closer to the surface than any spacecraft before it, sending back data that scientists have sought for more than six decades. The spacecraft will face brutal heat and radiation, being exposed to 475 times the solar irradiance experienced on Earth. This NASA mission of exploration will provide humanity with the first-ever close-up view of a star and improve our ability to forecast solar flares and major space-weather events that impact life on Earth.

OPERATIONAL IMPACT

APL has also demonstrated the tactical value of knowing conditions in space, especially those that can affect communications and satellite operations. Military commanders and field operators have long blamed communications outages on faulty equipment, even when the cause could have been space weather. The Lab has responded by designing instruments that will improve the military's ability to track and someday forecast space weather—a capability that will also be important to the nation's economy as it depends more and more on space-based assets.

We are also contributing to the nation's ability to defend the homeland and regional interests against ballistic missile threats from the ultimate vantage point. A legacy that began in the 1980s with the Delta series of space-based missile-detection missions continues today with networks of APL-designed and -developed sensors that, when hosted on commercial satellites, will be able to detect when an interceptor impacts a ballistic missile threat.

Parker Solar Probe, the first mission to explore the corona of the sun, is scheduled to launch in 2018.



Launched in 1996, the Midcourse Space Experiment, the largest satellite ever built at APL, was key to the development of U.S. missile defense.

APL's New Horizons spacecraft flew by Pluto in July 2015.

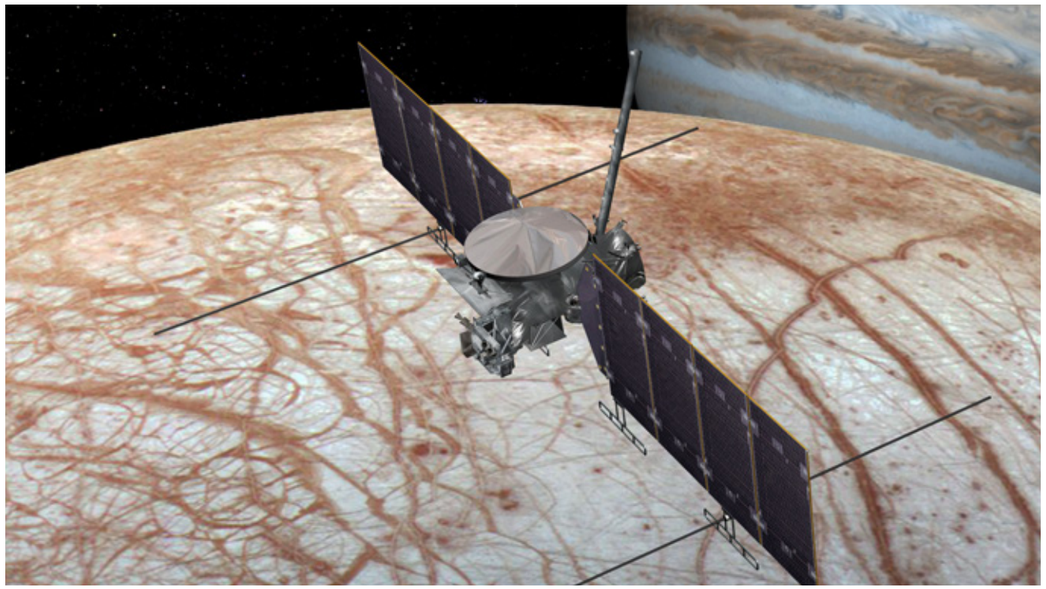
Our heritage also runs through APL's tremendous capability and credibility in other areas of physics that directly apply to warfighters and scientists. The Lab continues to develop low-cost CubeSats, some designed to be secondary payloads on launches of larger satellites. These small satellites represent a new capability particularly for the military: agile spacecraft that can not only be launched quickly and inexpensively, but also survive the space environment for long-term use.

Whether helping humankind reach new worlds or making discoveries about how space weather affects life on our own planet, APL is positioned to tackle tomorrow's space challenges. And for that, the Lab's space scientists and engineers owe a nod to the past—the effective mission management, systems engineering, and culture of creativity that have always defined APL.

CIVIL SPACE

APL makes critical contributions to NASA and international missions to meet the challenges of space science. Our work includes conducting research and space exploration; development and application of space science, engineering, and technology; and production of one-of-a-kind spacecraft, instruments, and subsystems.

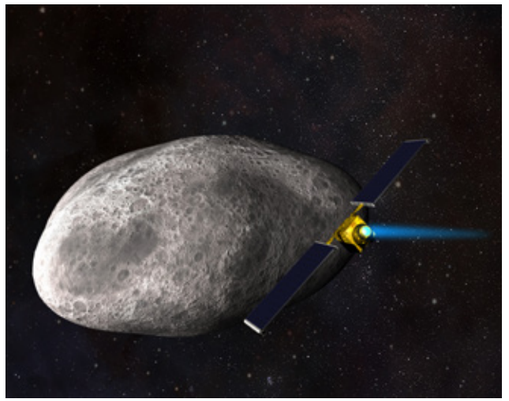
KURT LINDSTROM
Mission Area Executive



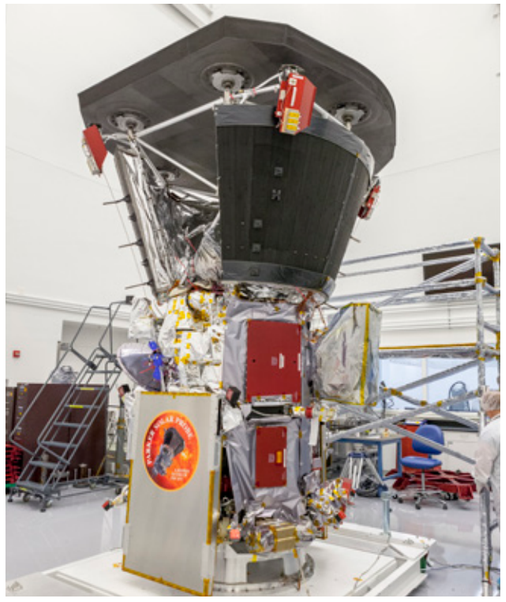
APL plays key leadership roles on, and will provide two science instruments for, NASA's mission to Jupiter's icy moon Europa. (NASA)

Destination: Europa

The search for life in the solar system beyond Earth gets a boost when NASA's Europa Clipper mission launches to explore under the icy crust of Jupiter's moon Europa in 2022. We play critical technical roles on the mission, which NASA's Jet Propulsion Laboratory leads in partnership with APL, and are contributing two science instruments: the Plasma Instrument for Magnetic Sounding, which scientists will use to determine the thickness of the ice that encases Europa as well as the depth and salinity of its ocean, and the Europa Imaging System, a high-resolution camera that will offer near-global and targeted coverage. NASA has also asked the JPL–APL team to study a Europa Lander concept for launch in 2024.



DART will determine how a spacecraft's impact on the smaller member of the binary asteroid Didymos—at more than four miles per second—will alter the binary's orbit.



APL engineers are completing testing and integration of Parker Solar Probe, on track for launch in summer 2018.

Honoring a Pioneer: *In May 2017, NASA renamed Solar Probe Plus to Parker Solar Probe, honoring legendary solar scientist Eugene Parker, whose theories fueled the key questions about the sun and led to the mission being first proposed in 1958.*

Targeting an Asteroid

The first-ever mission to demonstrate an asteroid deflection technique for planetary defense—NASA's Double Asteroid Redirection Test (DART)—moved into the preliminary design phase. Led by APL, DART would be NASA's first mission to demonstrate what's known as the kinetic impactor technique that involves striking an asteroid to shift its orbit and deflect it from Earth. DART's target is the binary asteroid Didymos, which will have distant approaches to Earth in 2022 and 2024.

Beyond Pluto

Two years after NASA's New Horizons spacecraft left Pluto and its moons in the rearview mirror—and revolutionized humankind's view of these small, dynamic worlds on the edge of our solar system—the APL-built and -operated probe is speeding deeper into the distant Kuiper Belt toward a flyby of an ancient Kuiper Belt object, named 2014 MU69, on New Year's Day 2019. When New Horizons flies by it, MU69 will be the most distant object ever explored by a spacecraft, more than a billion miles farther from our sun than Pluto. The team is already doing initial reconnaissance on MU69, using assets such as the Hubble Space Telescope to search for dust and other debris that might be hazardous to the passing spacecraft.

Touching the Sun

NASA's Parker Solar Probe spacecraft—designed and built at APL—is on track for a summer 2018 launch. Parker Solar Probe will travel closer to the sun than any satellite in history to make detailed observations of the magnetic field, plasma, and accelerated particles in the sun's corona, finally answering fundamental questions that have plagued scientists for decades—why is the corona hotter than the sun's surface, and why does solar wind exist? By making these measurements in the region where solar wind is created, and where the most hazardous solar energetic particles are energized, Parker Solar Probe will also improve our ability to characterize and forecast the dynamics of the heliosphere and the resulting effect on Earth's radiation environment. These effects influence space weather on Earth and in the orbital space where future explorers will live and work.

NATIONAL SECURITY SPACE

APL leverages significant experience in both civil and national security space programs, as well as other technical areas across the Lab, to develop and conduct innovative missions, build space instruments, and produce applications to meet warfighter needs.

PATRICK BINNING
Mission Area Executive

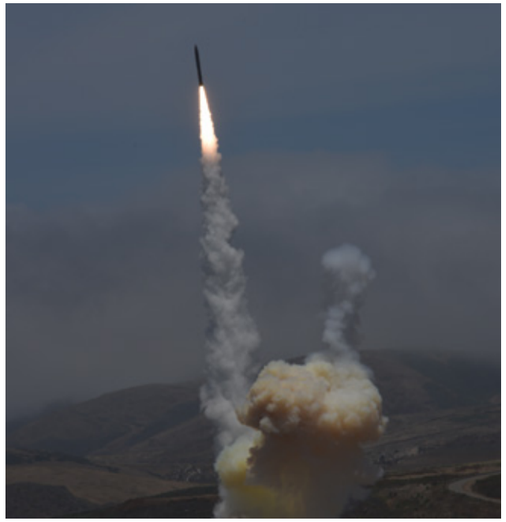
APL is working with the Army to develop and demonstrate the utility of small satellites to conduct multiple missions.

Resilient Satellite Communications (SATCOM)

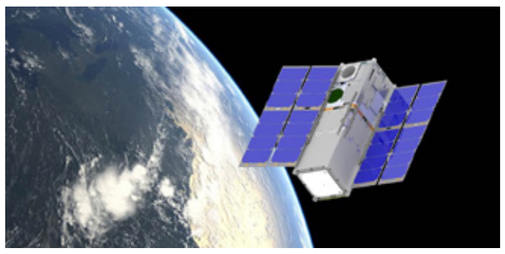
Under the Army Resilient Global On-the-Move SATCOM program, we supported the Space and Strategic Systems Directorate of the Army's Space and Missile Defense Command/Army Strategic Forces Command, exploring the utility of small satellites in carrying out multiple Army missions. APL provided system analysis and design expertise to develop high-level requirements for a production-ready small-satellite system that can undergo developmental testing and evaluation.

Space-Based Kill Assessment (SKA)

APL developed and tested the sensors for the Missile Defense Agency's SKA experiment—a network of small sensors, to be hosted on commercial satellites, that will be able to detect when an interceptor impacts a ballistic missile threat. SKA combines low-cost sensor capability with an opportunity for hosting sensors on commercial space platforms. With all flight hardware fabricated, tested, and delivered to the host for integration, the SKA system is expected to be on orbit in 2018—and to become a critical element in the nation's Ballistic Missile Defense System.



The Missile Defense Agency's SKA sensor will be able to detect when an interceptor, like that shown here, impacts a ballistic missile threat. (Missile Defense Agency)



With the CAT flight demonstration, APL will evaluate and validate technology performance in a 3U-sized CubeSat.

Space Weather Sensors

Knowing the distribution and direction of energetic charged particles along a spacecraft's trajectory is key to situational and satellite-health awareness; yet many missions resist flying particle sensors because the instruments can be heavy and expensive. We are developing a small, highly capable charged-particle sensor to deliver data that can help Air Force operators assess whether space weather conditions play a role in spacecraft anomalies. Building on APL's heritage of developing particle instruments for NASA missions, we produced a concept for a sensor that meets or exceeds Air Force requirements.

Space Security and Defense

APL provides expertise to the Space Security and Defense program, a joint Department of Defense/Office of the Director of National Intelligence organization focused on creating a more resilient and enduring national security space capability. The program's projects and activities center on identifying solutions to current space-protection needs with a practical approach to balancing near-term results with long-term acquisition, architecture, and strategic objectives.

CubeSat Signal Preprocessor Assessment and Test (CAT)

Set to deploy from the International Space Station in 2018, the APL-led CAT will demonstrate the performance of innovative signal-processing technology in a 3U (or triple) CubeSat. Capitalizing on our successful small-satellite Multimission Bus Demonstration, we conducted preliminary system engineering activities and subsystem analysis, and developed requirements for this upcoming test. We are also developing two CAT flight systems—one that integrates government payloads and another with commercially procured spacecraft platforms—and will lead mission operations.

APL analysts conduct battle simulations, 1961.

75 Years of Critical Contributions

NATIONAL SECURITY ANALYSIS

Defining Critical Challenges for the Nation's Leaders and Decision-Makers

In preparing for critical contributions to critical challenges, it is essential to understand the true challenges and ask the right questions. Since our earliest days, APL has played a role in uncovering the root causes of the nation's challenges and using analysis to formulate the most effective technological solutions.

From evaluating technology alternatives to identifying feasible policy options, the scientists, engineers, mathematicians, and political scientists working in APL's National Security Analysis Department (NSAD) have helped guide the Lab and sponsors on technology investments and their use. What distinguishes our analysis from others is our

unique understanding of operational needs, trusted agent status with the many entities—government and commercial—whose data can inform strong analysis, and connection to engineers who can realize the solutions the analysis department might identify.

Much of APL's analysis through the years has focused on weapons system requirements, design, and modification. In fact, among APL's first rigorous studies was an assessment of capabilities needed to defend the fleet against aircraft attacks by standoff weapons such as glide bombs and anti-ship missiles. Building on our experience in developing the radio proximity fuze in the early days of World War II, APL recommended that the Navy develop surface-to-air guided missiles, and the Lab subsequently developed the first generation of these missiles to meet the threat.

NAVAL INSIGHTS

Starting in the late 1950s, APL supported analyses ranging from naval roles in a conflict with the Soviet Union, to modeling and simulation of naval strike warfare, antisubmarine warfare, and anti-air warfare. In those early days, modeling was very difficult because of limitations in computing systems. As computers became more powerful, NSAD analysts pioneered new, effective methods that proved important in describing the complex interactions of events in naval tactics.

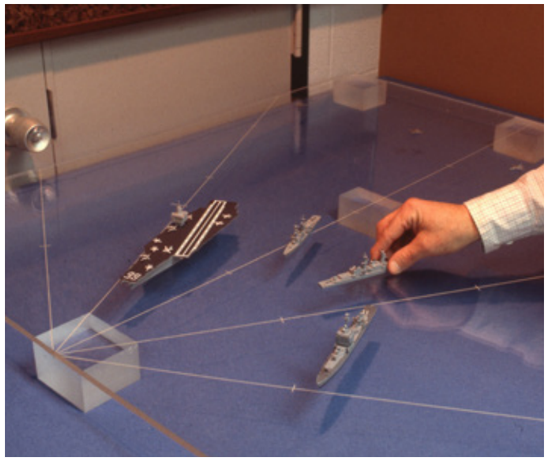
In the mid-1960s, on the basis of our guided missile system expertise, APL was asked to join an effort to analyze U.S. aircraft losses in Vietnam and develop tactics and techniques to counter North Vietnamese air defenses. APL was subsequently invited to help develop requirements and tactics for airborne jamming systems, including the Navy's EA-6B aircraft—a responsibility that continues today.

Since the 1970s, warfare analysis at APL has become increasingly diverse, broadening beyond naval insights to include those that apply to all elements of joint and national capability. Analysts with deep individual expertise have performed detailed technical analyses that range from enhancing the quality of systems designs, to determining how best to use them, and to establishing their overall effectiveness in potential scenarios.

DIVERSIFYING TOOLS AND APPROACHES

Over the years, APL has conducted warfare analyses to identify modifications for deployed weapon systems and to define requirements for next-generation systems. That work continues through physics-based analyses including system- and mission-level modeling. Additionally, APL has developed new analytic approaches to real-world operational and policy issues. These include case studies, historical reviews, event reconstructions, and wargaming. All of these analyses have the common element of deep technical underpinnings and an understanding of the operational and policy environment.

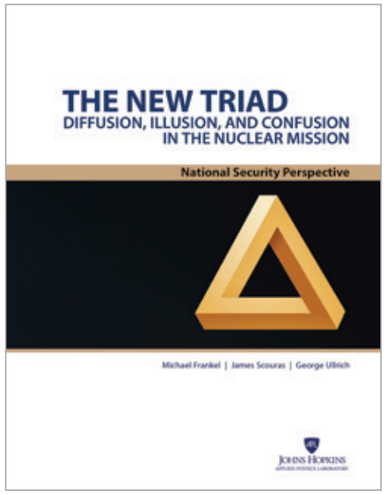
Recent APL studies have informed operational plans being developed by combatant commanders. They are also creating the basis for new policies spanning topics from lethal autonomous systems to assured space operations. Today, APL is helping government leaders grapple with the myriad of issues that span the intersection of technology and policy, combining rigorous analytic approaches with the Lab's extensive technical knowledge and experience.



Decades of national security analyses at APL have included (from left) computer-aided decision-making in the Battle Simulation Facility (1962); wargaming in the 1980s; and "crisis rooms" in the Warfare Analysis Lab during the 1990 Gulf War.

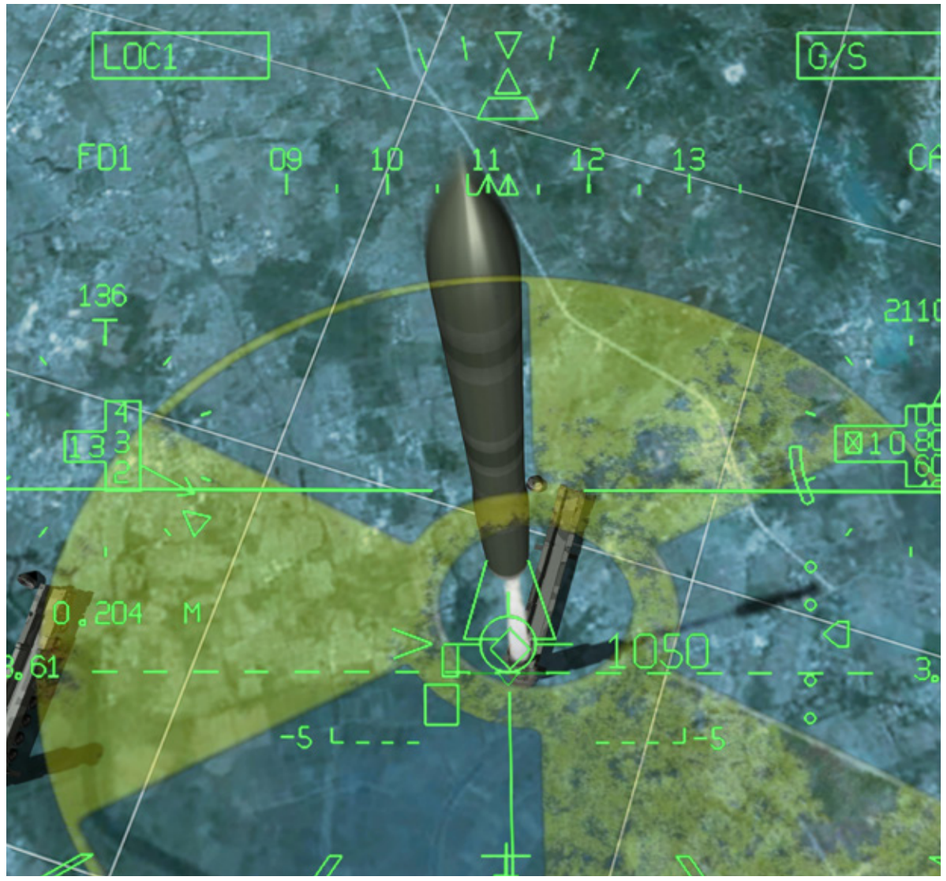
INDEPENDENTLY ASSESSING CHALLENGES AND OPPORTUNITIES

Parallel to its warfare analysis exercises and system-level analyses of alternatives, NSAD also has a history of undertaking internally funded studies that explore the impacts of current and emerging national security issues. Recent studies have looked in depth at the growing threat of and potential responses to cyber attacks on critical infrastructure, policy decisions concerning emerging technologies like artificial intelligence and nuclear weapons, and the threat posed by a resurgent and increasingly sophisticated Russia taking action in the "gray zone"—the area of conflict that stays just below the threshold of conventional warfare. Many of these studies are published and available for the public; others remain among the Lab's silent contributions to the security of our nation.



In 1995, the virtual environment of operation "Kernel Blitz" in the Warfare Analysis Laboratory combined live action with pioneering testing of computer technology.

Along with APL's Research and Exploratory Development Department, NSAD continues to serve as the headlights of the Lab, assessing emerging technologies and challenges that can be transformed into opportunities and capabilities. In the past two years, while maintaining our in-depth warfare analysis expertise, APL has significantly expanded our policy analysis capabilities. The addition of Senior Fellows, former senior government officials with significant expertise on a wide range of defense policy and technology issues, is strengthening our insights and ensuring that APL continues to probe the most critical challenges facing our nation.



Ranging from air defenses and mobile platforms to terrorists and long-range missile systems, time-critical targets are diverse and complex threats. APL analyses have identified, quantified, and prioritized opportunities to address time-critical targets across multiple domains.

NATIONAL SECURITY ANALYSIS

APL is framing the challenges that shape defining innovations to ensure our nation's preeminence in the 21st century. We combine technical knowledge with analysis to find tomorrow's solutions to national security, space, and health challenges. Our analysis informs senior decision-makers across the government on national policy, technology, acquisition, exercises and experimentation, and complex current and future operations.

PRESTON DUNLAP
Mission Area Executive

Partnering with the Undersecretary of Defense for Acquisition, Technology and Logistics, APL designed and hosted a space wargame for more than 20 of America's most senior national security leaders.

Engaging Senior Decision-Makers

APL partnered with the Undersecretary of Defense for Acquisition, Technology and Logistics to design and execute a space wargame based on a rigorous analytical framework. Twenty-two of America's most senior national security leaders, including the Deputy National Security Advisor, the Deputy Secretary of Defense, the Secretary of the Air Force, and multiple combatant commanders, gathered at APL to explore responses to scenarios that threatened U.S. space-based assets, culminating a yearlong analysis and planning effort. Our physics-based technical analysis was an excellent foundation for the exercise, designed for participants to understand strengths and weaknesses of future architecture options, identify the value of enhanced capabilities, and identify implications when faced with challenges in space.

Countering Anti-Access, Area-Denial Threats

APL is an established, critical partner of the Office of the Secretary of Defense Strategic Capabilities Office, which provides lower-cost, strategic alternatives for shaping and countering emerging threats. Since 2012 we have provided the office with physics-based analytic assessments regarding the feasibility, survivability, and military utility of more than 40 concepts—most recently on projects including long-range strike capabilities and teaming of manned and unmanned systems—and ensured the technical validity of program proposals. APL has served as a technical lead, lead systems integrator, and technical direction agent and has guided rapid fielding and prototyping of systems as well as testing and evaluation.

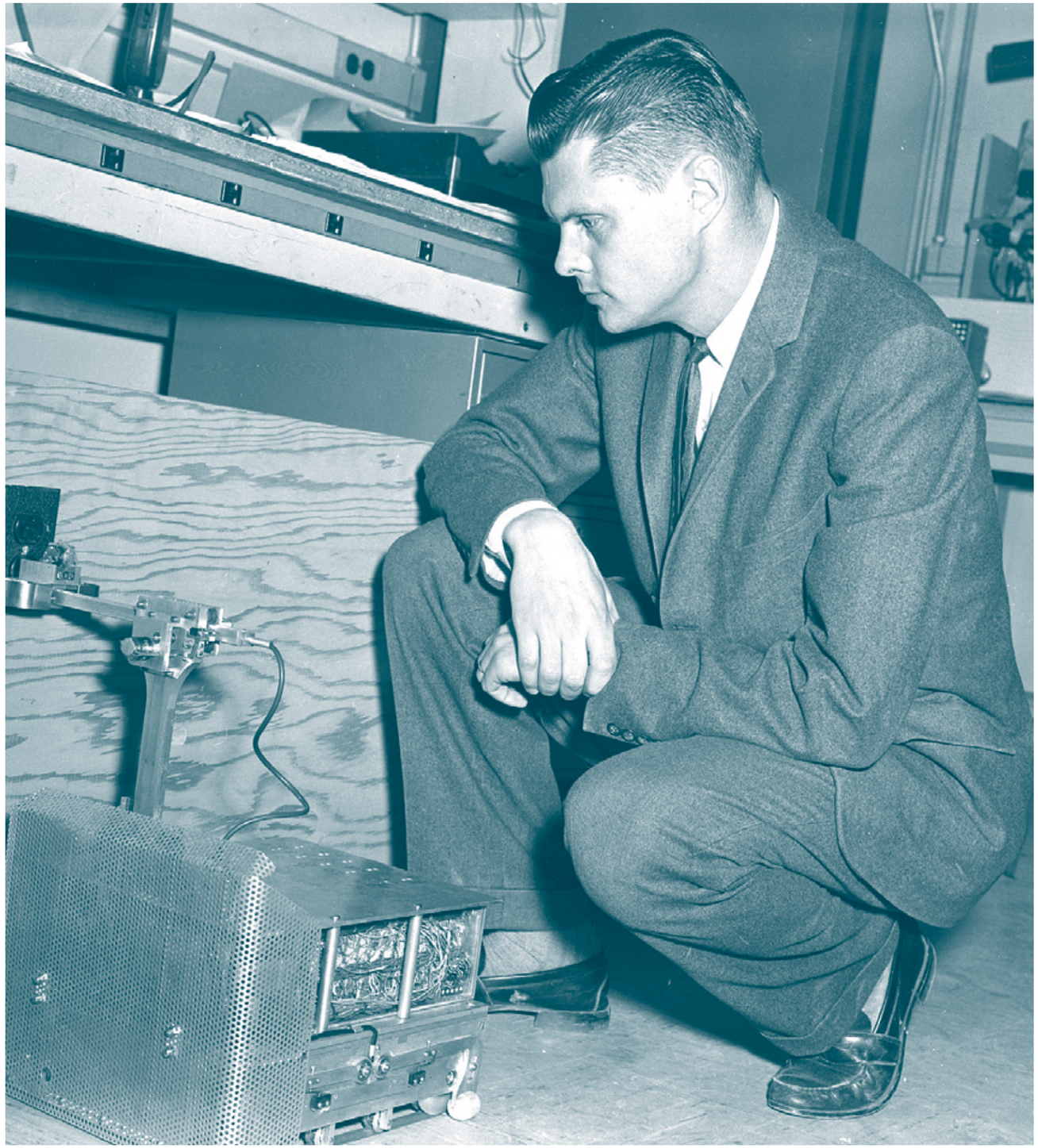
Shaping the *Joint Future Operating Environment*

On behalf of the chairman of the Joint Chiefs of Staff, APL led development of the *Joint Future Operating Environment*, which lays the foundation for force development across the services. The document provides a vision for a security environment that requires innovative approaches to U.S. military operations—and we designed and executed a series of workshops to discern the nature and aspects of that future environment. We also played a central role in the research, analysis, development, and writing of *Joint Operating Environment 2035*, a key publication that will provide guidance for how future Joint Forces develop.

APL provides physics-based analytic assessments regarding the feasibility, survivability, and military utility of strategic-defense concepts. (U.S. Air Force)

Ensuring Resilient Enabling Capabilities in Denied Environments

On behalf of the Office of the Secretary of Defense, APL is merging technical capabilities with acquisition strategy to mitigate adversary threats to Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) in the maritime, terrestrial, air, space, and cyber domains. The latest example is Pacific Pilot, which established a proven testing regime and results that offer the Department of Defense (DoD) new pathways to support the warfighter. The convergence of integrated networks enabling protected, resilient, and redundant pathways will provide a ubiquitous means to support global operations across the range of military operations. This network will also extend services to the tactical edge and provision remote management where necessary. Inclusion of enhanced program protection and security measures will ensure a robust and enduring capability for DoD and the government.



Ferdinand, APL's first "automaton," searches for power in 1962.

75 Years of Critical Contributions

RESEARCH AND EXPLORATORY DEVELOPMENT

Taking Risks to Realize Great Visions and Tackle Tomorrow's Challenges

APL formed its research center in the spring of 1947 to provide long-term focus on fundamental science and engineering that may have great impact for the nation.

Most emblematic of the process and achievements of the Lab's research department is the story of how it initiated the age of satellite navigation, something that would become a defining innovation for the world. Frank McClure was chairman of the Lab's research programs in 1957 when he learned a pair of young APL engineers had tracked Sputnik by following the Doppler effect of the chirping Soviet satellite as it passed overhead. McClure, who was working on the Navy's Polaris strategic submarine program, realized that reversing the orbit equation calculated by the young engineers might allow for the location of a submarine in the world's oceans—meaning that since you could determine a satellite's location from the ground, it might also be possible to determine your position on the ground if you knew where the satellite was in space.

Shaping the concept of satellite navigation in the late 1950s, APL Research Center Chair Frank McClure (center) and colleagues helped the nation tackle a range of military and scientific challenges.

With that, a major Navy dilemma—the worldwide navigation of Polaris submarines—was about to be solved. The game-changing invention of satellite navigation has since had global impact, and it expanded the Lab's expertise in space and undersea systems and directly precipitated the formation of APL's Space Division in 1959.

This culture of exploration and collaboration has held steady over years of research and development innovation at APL. From the beginning, experts in diverse technical fields have explored ways to combine technologies and apply their knowledge and ideas to a wide variety of applications. They have helped sponsors that range from federal, to state, and even to city governments solve critical challenges—from automated mass transit concepts for the federal Urban Mass Transportation Agency, to combustion research for firefighters under the umbrella of the National Science Foundation, to harbor traffic-control studies for the city of San Francisco, to clean-air turbulence and weather radar investigations for the Federal Aviation Administration.

An APL/Johns Hopkins Medicine collaborative biomedical program launched in the 1960s yielded several important breakthroughs, such as the rechargeable pacemaker.

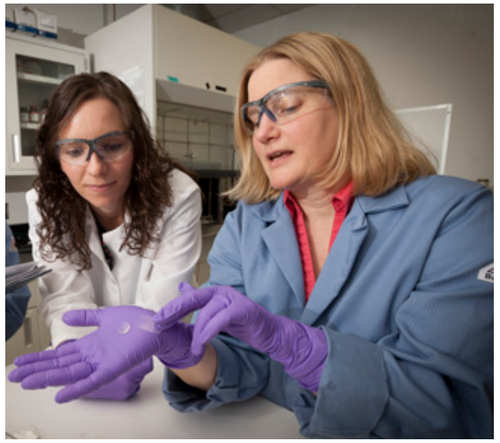
COLLABORATING FOR IMPACT

Collaboration has been key to our research successes, whether it be working across the Lab—such as to create satellite navigation—or with research organizations across the country. One example of external collaboration, among many, has been the national effort to help the world understand the biomechanics of human injury in an "underbody blast," or when an explosive is detonated underneath a vehicle. APL has led a diverse research team comprising the top biomechanics researchers in the country as part of the Warrior Injury Assessment Manikin (WIAMan) project for the U.S. Army. APL launched its Biomechanics and Injury Mitigation Systems (BIMS) program in 2007 to develop experimental and computational tools for modeling the human body, realistically simulating events that may inflict injury and determining the efficacy of existing and novel injury mitigation strategies. The team's work and collaborations have dramatically increased the knowledge of injury biomechanics and precipitated some of the most advanced test systems in the world.

Similarly, in 2006, on behalf of the Defense Advanced Research Projects Agency (DARPA), the Lab took leadership of a national effort to develop revolutionary advances in prosthetic limb technology that would restore full motor and sensory capability to upper-extremity amputees. The intricate inner workings of the arm created under the Revolutionizing Prosthetics program reflect the latest developments in human–machine interfaces.

The Lab also has substantial collaborations closer to home. APL and Johns Hopkins launched a collaborative biomedical program in 1965, and in the past decade we have dedicated significantly more resources to revolutionizing health care. In the early days, APL's research guided such lifesaving innovations as implantable cardiac defibrillators, a control system for heart pacemakers, and medicine delivery systems that were the forbearer to insulin pumps. More recently, the Lab has been applying its unique expertise in systems engineering and data analysis to everything from intensive care unit (ICU) operations to precision medicine.

In 2012, APL and Johns Hopkins Medicine developed the EMERGE system, which integrates data and information about each ICU patient to create a more holistic picture of the patient's well-being and to improve system interoperability. At least one in every five of the estimated four million patients treated in ICUs each year is harmed during their hospital stay, largely because of human errors and a lack of interoperability between the myriad of systems in an ICU. The APL–Hopkins approach was unique in its focus on addressing that challenge systematically.



Quick healing, lasting recovery: APL researchers focus on healing warfighters both on the battlefield—with inventions such as the Eye PATCH corneal bandage (left)—and when they return—with programs such as the revolutionary Modular Prosthetic Limb.

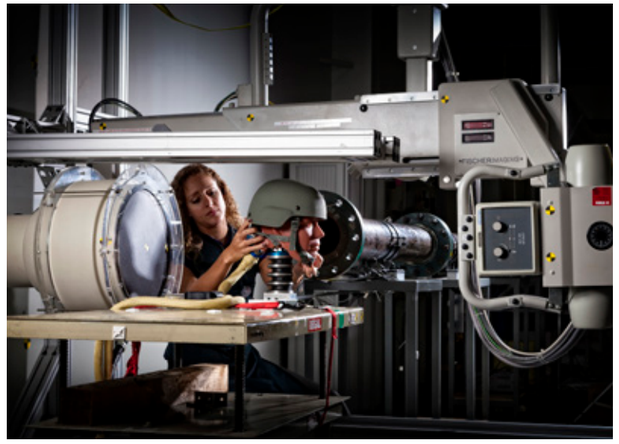
THE PACE OF DISCOVERY

While the possibilities for the fusion of Hopkins' expertise in engineering and medicine are exciting, so too are incredible possibilities opening up with our recent advances in robotics, machine learning, computer science, materials science, quantum physics, and advanced fabrication, among others.

APL's experience with unmanned systems, robotics, and autonomy stretches back to the early 1960s, when researchers created "the Hopkins Beast" and "Ferdinand," the first beloved APL robots, known then as "automatons." Since those early days, APL has been building, testing, and evolving robotic and autonomous systems at sea, on the ground, in the air, in deep space, and even in cyberspace—from neurally integrated devices in prosthetics patients to the New Horizons spacecraft speeding to the outer reaches of our solar system.

More recent advances, especially those in the commercial sector, have opened up new horizons for human–machine teaming. As a consequence, the Lab created the Intelligent Systems Center in 2016, which brings together experts in robotics, autonomy, neuroscience, and information science to accelerate multidisciplinary opportunities for these systems in solving the nation's critical challenges. This center is a state-of-the-art, flexible-space facility with laboratories for hardware and software development, modular test platforms, and unmanned vehicle test areas.

The pace of scientific discovery around the world is stretching the bounds of imagination, but the Lab's dedication to understanding the latest developments and finding novel ways to apply them to the nation's critical challenges is proving more essential every day.



APL systems engineering expertise fuels the Biomechanics and Injury Mitigation Systems program to develop realistic models of the human body and define strategies and technologies to protect U.S. service members.

In APL's mock intensive care unit (ICU), engineers test tools and methods for improving efficiency and connectivity between ICU systems.

NATIONAL HEALTH

APL aims to revolutionize health through science and engineering. We focus on programs to predict and prevent illness, injury, and disease; rapidly detect and respond to changes in health status; restore and sustain health; and improve overall health and human performance—leveraging expertise from across Johns Hopkins and the Laboratory to develop solutions that advance health and health care solutions for civilian, military, and veteran populations worldwide.

SEZIN PALMER
Mission Area Executive

APL is developing environmental risk assessment tools that can be readily integrated into the Nett Warrior combat situational awareness platform. (U.S. Army)

Army Environmental Health Research

APL and the U.S. Army Center for Environmental Health Research are developing capabilities to detect, assess, and prevent effects from exposure to toxic materials—focusing especially on ways to prevent acute and chronic health effects through new biological technologies. To this end, APL is enabling the development of novel technological solutions, including models for host–microbiome interaction, novel capabilities to detect coliform bacteria in water systems, and environmental risk assessment tools that can be readily integrated into the Nett Warrior combat situational awareness platform—in addition to executing personalized medicine initiatives related to pulmonary and environmental health.

Health Surveillance

APL's leadership in electronic disease surveillance, both at home and abroad, is making a difference on the front lines of protecting the health of a population. Many state and local health departments have employed APL's Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE). With the U.S. Centers for Disease Control and Prevention adopting ESSENCE as an analysis and visualization tool for the National Syndromic Surveillance Program—and using it to track developing situations from the opioid crisis to Zika outbreaks—we are laying the groundwork for a fully integrated national surveillance picture. Internationally, with our Suite for Automated Global Electronic bioSurveillance (SAGES), nations with limited resources are gaining capacity to conduct disease surveillance—a capability critical to providing early warnings for their populations as well as enhancing the safety of forward-deployed U.S. military personnel.

Mapping the Brain for Machine Learning

APL leads several test and evaluation efforts for the Intelligence Advanced Research Projects Activity's Machine Intelligence from Cortical Networks (MICrONs) project, launched to develop state-of-the-art machine learning capabilities by modeling how the brain processes information. APL has developed a novel cloud-based capability for storing, accessing, and processing petabytes (millions of gigabytes) of neuroanatomical data—the Block and Object Storage Service—that enables researchers from across the nation to conduct large-scale neuroscience inquiries. Additionally, APL scientists oversee the processing of data collected from targeted neuroscience experiments and evaluate the performance of various algorithms to automate identification of neural connections. The technologies that APL developed under MICrONS are already being leveraged by the broader research community and serve as a foundation for our future BRAIN initiative work and similar programs with global reach.

The Systems Approach to Saving Lives

APL's thought leaders are stirring discussions on the importance of taking a systems approach to health care. In articles published in the *Harvard Business Review* and in a paper being developed for the National Academy of Medicine, Lab and Johns Hopkins Medicine experts stress how devices must be designed to work together if the health industry is serious about saving lives and increasing productivity. The problem is that clinicians too often mold processes around the demands of multiple devices and disparate health information systems. By using systems engineering, we can integrate technologies and build hospitals and clinics that ensure consistently safe, high-quality, and efficient care.

Durable and Portable Therapeutics Production

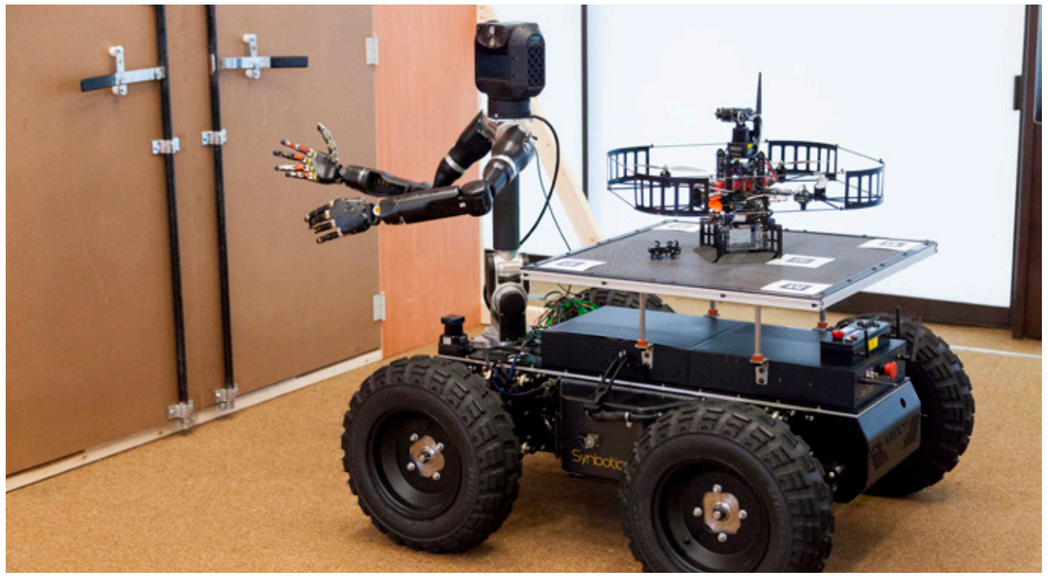
APL experts have made significant strides in developing methods for portable production of vaccines and other therapeutics, enabling production on demand in remote locations and during emergency outbreaks. Our method allows protein expression systems to withstand months of heat stress under atmospheric conditions. It efficiently produces proteins with reagents that can be easily stored and distributed under harsh conditions, overcoming many of the challenges associated with implementing novel therapeutics in remote areas.

Haitian Ministry of Health technicians enroll a schoolgirl for lymphatic filariasis and malaria testing; APL's SAGES tool can identify disease outbreaks in communities around the world before the outbreaks become impossible to control. (Centers for Disease Control and Prevention)

RESEARCH AND EXPLORATORY DEVELOPMENT

APL is creating a vibrant flow of research that seizes opportunities for technology breakthroughs and for transitioning innovative and timely solutions to our sponsors. Our basic and applied research and technology development provides the foundation for many internal and sponsored programs and initiatives.

ANDREW MERKLE
Mission Area Executive



APL's Bimanual Dexterous Robotic Platform—Robo Sally—is designed to remove human responders from life-threatening operations.

Robotic Teamwork

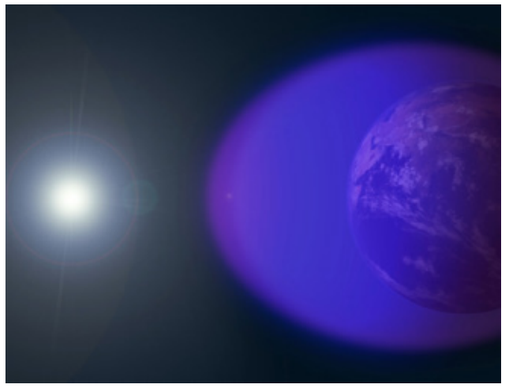
APL has developed novel intelligent systems technologies that enable a team of robots to autonomously observe, orient, decide, and act while interfacing with human "teammates" on critical applications. Using our marsupial team-planning algorithms, a lead robot can quarterback ground and air robots through a cluttered indoor space while relaying information about the surroundings—and even opening doors. Using APL-developed algorithms, these robots can offer descriptions of novel objects in their camera feed, such as "dangerous" or "electronic device." Integrating these technologies has allowed us to demonstrate high-level command of the robot team by a remote operator through goal indication in a previously unexplored area on a map and interfacing through voice queries for situational reports.

Solid-State Thermoelectric Technologies

Under the Defense Advanced Research Projects Agency's Materials for Transduction effort, we lead an industry–academia–Department of Defense team working on novel coolers integrated with nanoengineered materials. Building on state-of-the-art capabilities with thin-film thermoelectrics for near-room-temperature cooling, sensing, and harvesting energy, we also are leveraging capabilities for other advanced thermoelectric device applications—including the Operational Lightweight Intelligent Thermo Electric power source for mobile platforms as well as a project to reduce auxiliary power units by using natural heat sources in hypersonic platforms.

Autonomy Test and Evaluation

We are developing methods and procedures to ensure the safety and performance of autonomous systems. The Safe Testing of Autonomy in Complex, Interactive Environments (TACE) program provides two core testing and evaluation capabilities: first is a watchdog function consisting of onboard hardware and software that will take control of the test system should an action (like a change in climb rate or speed) violate the test parameters; second is a live-virtual-constructive environment in which the system's autonomy can be replicated in combinations of live and virtual agents interacting in complete, realistic consideration of each other. We transitioned TACE technologies to the Department of Defense's Atlantic Test Ranges and integrated with its range systems to enable safe transit of unmanned aerial systems to the ranges' offshore test airspace without need for chase aircraft. The full TACE complement of capabilities is currently being transitioned to the Air Force Test Center at Edwards Air Force Base to enable a small unmanned aerial system infrastructure to test autonomy technologies.



Under the HFGeo initiative, APL is using science to locate high-frequency targets refracted by the ionosphere, a layer of charged particles (shown in purple, not to scale) extending from about 50 to 360 miles above Earth. (NASA)

Ionosphere Modeling

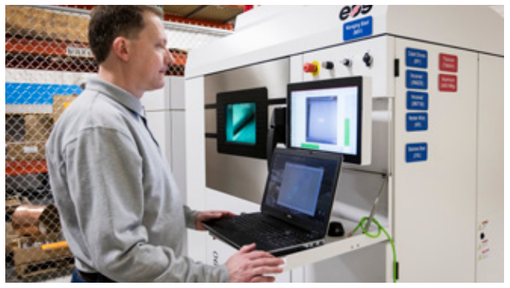
Under the Intelligence Advanced Research Projects Activity's HFGeo initiative, we are using science to accurately locate high-frequency targets refracted by the ionosphere. APL and project partner University of Bath developed techniques to analyze field-test data to estimate whether a "good" ionospheric model could meet program metrics—and based on analysis so far, it appears that it can. Furthermore, APL and Bath have developed research models that mitigate the effect of a dynamic ionosphere on angle-of-arrival observations exceeding program metrics.

LABS AND INNOVATION

Making critical contributions requires taking some risks, and risks (and experiments) are best taken in labs. Here are some of APL's notable research and collaboration spaces, as well as some programs that provide fuel for the innovative ideas born within.

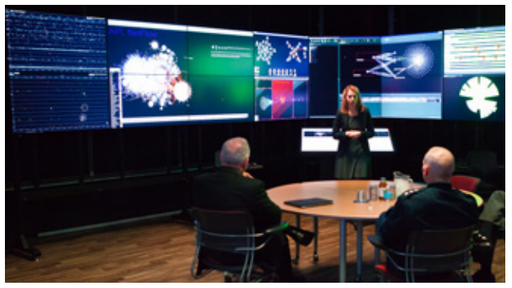
Intelligent Systems Center

The Intelligent Systems Center radically enhances our ability to develop machine and algorithm teammates for human operators. The center leverages APL's broad expertise across defense, intelligence, homeland protection, space exploration, and health care to fundamentally advance the employment of intelligent systems in real-world settings—and in ways that benefit the nation.



Engineered Materials Laboratory

Blending materials science with art, the Engineered Materials Laboratory produces highly customized hardware for a wide range of applications. Today, this facility is also advancing the state of the art in additive manufacturing.

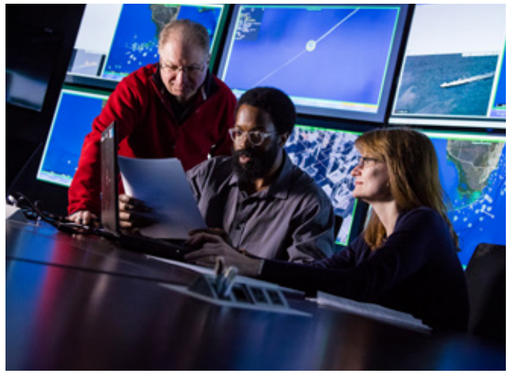


LIVE Lab

The Live data, Integration, Validation, and Experimentation (LIVE) Lab was created for researchers to visualize data on information networks and use automated pattern recognition to discover anomalies that indicate cyber attacks. LIVE Lab features a suite of tools to help cyber operators detect, understand, and respond to cyber attacks across many platforms and applications.

Experimental Communications Laboratory

The Experimental Communications Laboratory was established in the early 1980s to develop prototype communication systems for a variety of applications, including strategic command and control. It remains a primary space for APL's asymmetric operations work.



Combat Systems Evaluation and Minotaur Laboratories

The Combat Systems Evaluation Laboratory supports developers who prototype, test, and field solutions for combat identification, area air defense, time-sensitive targeting, and surface surveillance. The newly built Minotaur Laboratory adds to this capability by enabling engineers to participate in fleet exercises and operations, and to perform remote diagnostics of shipboard systems.

Mechanical Fabrication Facility

From the proximity fuze, to spacecraft, to prosthetic limbs, the mechanical fabrication facility has for decades provided prototypes and even spaceflight-qualified hardware required for the complex systems developed by APL.

Guidance System Evaluation Laboratory

The Guidance System Evaluation Laboratory (GSEL) has been a key resource for APL and the Navy throughout 50-plus years of Standard Missile (SM) evolution. GSEL provides the capability to assess hardware and software performance in realistic radio frequency and infrared signal environments driven by high-fidelity flight-simulation models.

Hydrodynamics Research Laboratory

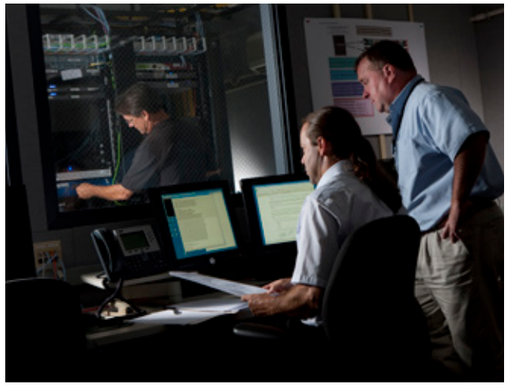
The Hydrodynamics Research Laboratory was established decades ago to help the Navy and other government sponsors understand the phenomenology behind hydrodynamics challenges—a critical mission that continues today.

Space Simulation and Vibration Test Labs

APL's Space Simulation Laboratory simulates the operating conditions of space, and the Vibration Test Laboratory performs structural qualification testing to ensure space systems can withstand the rigors of launch and operation. Our testing philosophy—test as you fly, fly as you test—has enabled the remarkable longevity of APL's planetary missions.

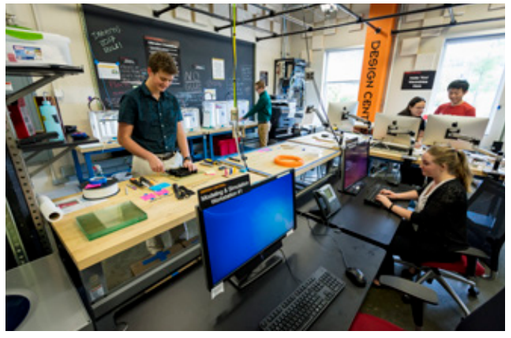
BIMS Laboratories

The Biomechanics and Injury Mitigation Systems (BIMS) Laboratories were established to support APL research on injuries from blunt trauma and automotive impacts. Since then, APL's injury assessment capabilities have grown to include armor performance assessments as well as research on blast wave effects and occupant safety in under-vehicle explosions.



Computing Center

The Frank T. McClure Computing Center, established in the mid-1950s, has evolved from a central mainframe computer to a vast network of computers. Today, our distributed computing facilities are solving scientific problems, simulating missile flights, and predicting weather conditions for missions across APL.



Central Spark

This center of innovation and collaboration is a true creative space, where staff members can discuss and explore ideas. Central Spark's four anchor spaces—Design Central, Maker Central, Academy Central, and Media Central—provide equipment, training, and, most importantly, freedom to try concepts and hypotheses across physical and digital domains.

Innovation Programs

Project Catalyst

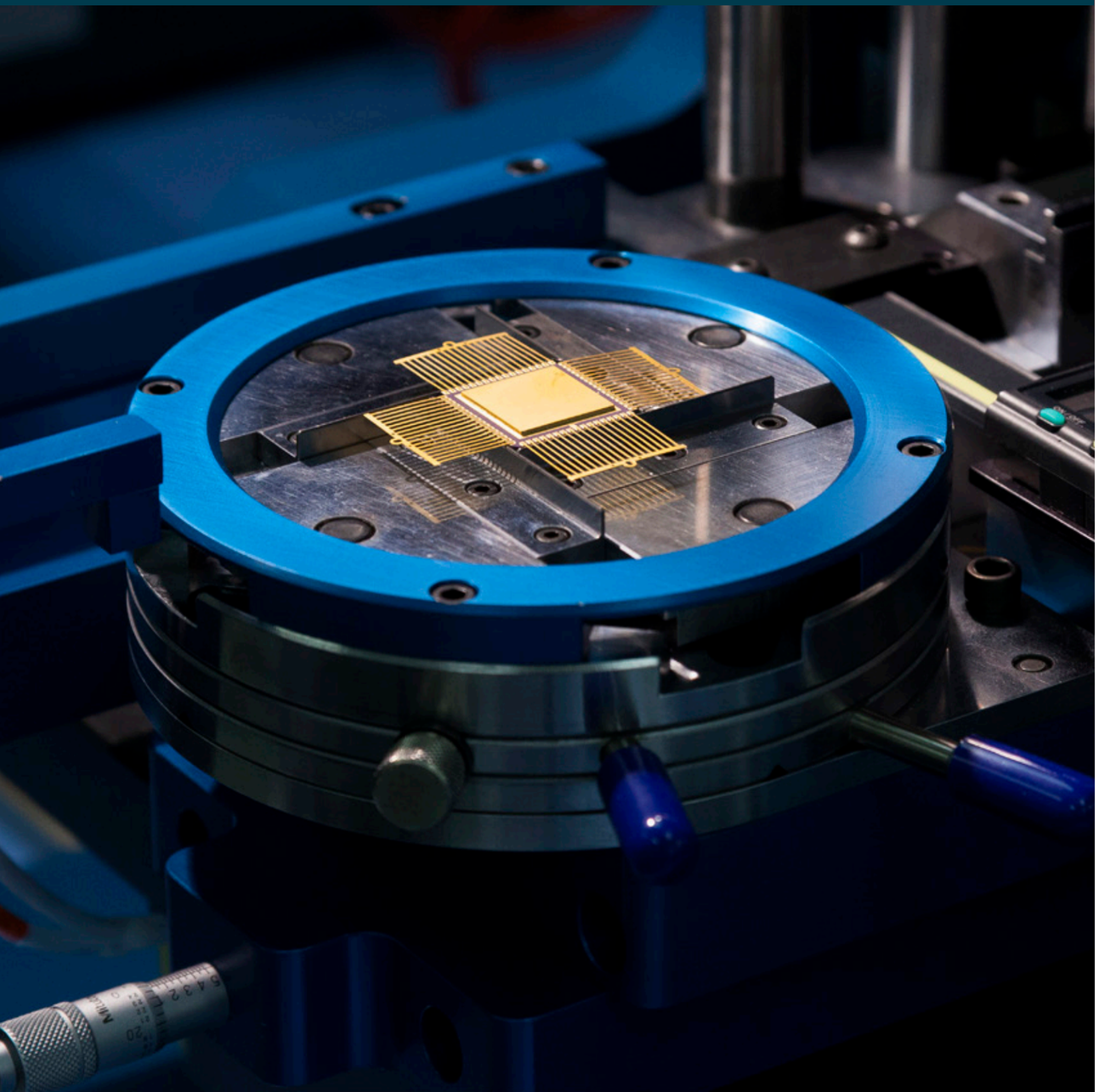
The Lab's Ignition Grants experiment, which provided funding to staff member-selected independent research projects, has delivered several innovations for our sponsors and created promising research avenues for many other concepts. Building on that success, Project Catalyst offers investments in high-risk, transformational ideas and technologies that could impact the future work of the Lab. The initiative includes the well-established Ignition Grants and two new awards: Combustion Grants, which provide more than twice the maximum level of funding of Ignition Grants; and Propulsion Grants, which are multiyear and could provide more than $1 million in funding. The Lab's goal is to inspire staff members to take technical risks, think bigger and bolder, and develop breakthroughs for our nation's key challenges.

Janney 2.0

Named for Stuart S. Janney Jr. and his son, Stuart S. Janney III—who both served as chair of APL's board of managers/trustees—Janney 2.0 encourages staff members to expand their networks and explore science and technologies emerging from unfamiliar national and international commercial and academic communities. Janney 2.0 provides staff members with several pathways to the international crossroads of ideas to encourage them to explore new concepts and technologies, visit new conferences, and plug in to a vibrant, international technology ecosystem. The initiative is an important component of APL's Centennial Vision, which envisions an organization widely recognized for its technical leadership and bold, once unimaginable solutions to the country's most complex national security and space exploration challenges.

TECHNOLOGY TRANSFER

APL seeks opportunities to transform our innovations into publicly available technologies. The Lab's Office of Technology Transfer (OTT) helps launch start-up companies, issues licenses, and develops strategic partnerships aimed at leveraging APL inventions for the broadest possible impact to benefit society.



Invention Disclosures

In fiscal year 2017, APL innovators filed a Lab-record 355 invention disclosures. More than a third of these disclosures were submitted by first-time inventors—highlighting our ongoing effort to create a climate of risk-taking, discovery, and thought leadership.

Supporting Start-Ups

Over the past two years, five companies were formed on the basis of APL technology. For example, with the involvement of InnovateTech Ventures—an organization that builds high-potential start-ups using patented technology developed at universities—we established Thermohalt Technologies, LLC, to license and commercialize the work done on APL's battery internal-temperature sensor. Gallant Technology, Inc. secured a license for technology we developed to improve the performance of bomb-sniffing dogs for the Department of Homeland Security.

Collaboration and Partnership

Our strong technology transfer partnership with Johns Hopkins continues, facilitated by regular strategy meetings between APL and Johns Hopkins Technology Ventures. Cooperative research between JHU and APL resulted in 22 invention disclosures from sectors and departments across the Lab, and OTT participates on the JHU Department of Medicine Innovation and Commercialization Steering Committee and in the Johns Hopkins Center for Bioengineering Innovation and Design. APL also continues to support local economic development, especially through collaboration with the Maryland Center for Entrepreneurship.

Commercial Technologies

APL's Instrumented Rail Inspection System (IRiS) provides reconnaissance for first responders during railway incidents. Funded by the Transportation Security Administration, APL worked with transit agencies to assess needs and design and build a prototype. Under an agreement with APL, the Harsco Corporation is evaluating the unmanned-vehicle technology for introduction to railway safety, security, and emergency operations—making IRiS a great example of the government funding development of a technology that could contribute to the safety and security of the nation's critical transportation infrastructure.

The government-funded, APL-developed IRiS could contribute to the safety and security of the nation's transportation infrastructure.

APL has a long-term commitment to bringing commercial technologies to government users; the Acoustic Rapid Commercial Off-the-Shelf Insertion program transformed the Navy's submarine technology acquisition process into an agile and innovative enterprise, for example, and our work with CubeSats and tools such as the Wave Glider enhance sponsor tests and operations.

Top Inventions

APL recognizes our top inventions and innovators each spring at the APL Achievement Awards. Our latest Invention of the Year honors went to a novel method of using nanoplatforms to control diagnostic drug delivery and therapeutic compounds that allow nanoparticle structures to perform better. Technology that mitigates failures associated with mechanically adhered coatings earned the Government Purpose Innovation Award.

Technology Transfer by the Numbers

Technology Transfer from October 2016 through September 2017

355	Inventions disclosed
93	Provisional patent applications filed
32	Nonprovisional patent applications filed
16	U.S. patents issued
78	License agreements executed
3	Companies created

UNIVERSITY COLLABORATION

As a university affiliated research center and division of Johns Hopkins, APL has many opportunities to make the world healthier, safer, and more secure. With our JHU partners, we address a wide array of challenges and missions; these interdisciplinary collaborations reach across the university and the Johns Hopkins Hospital, including the Whiting School of Engineering, the School of Medicine, the Krieger School of Arts and Sciences, the Nitze School of Advanced International Studies, the Bloomberg School of Public Health, and the Carey Business School.

Engineering for Professionals Programs

More than 180 APL staff members teach engineering, applied science, engineering management, technical management, and information technology courses within the Johns Hopkins Engineering for Professionals (EP) program. APL staff members also serve as chairs and vice chairs for 11 of EP's 20 master's degree programs.

Engineering for Professionals students can attend classes at APL, the Homewood campus, or four other regional locations—and about 80 percent of total course enrollments and 14 master's degree programs are also offered online. Companies and organizations across the nation also have educational partnerships with JHU. The 10 APL-based programs—applied and computational mathematics, applied physics, computer science, cybersecurity, electrical and computer engineering, engineering management, information systems engineering, space systems engineering, systems engineering, and technical management—account for more than 87 percent of EP enrollments.

During the 2016–17 academic year, more than 3,200 students participated in the 10 APL-based EP programs, accounting for approximately 7,200 course enrollments. EP conferred more than 665 master's degrees during the year. Since 1968, more than 1,450 APL staff members (and more than 17,400 other students) have received master's degrees from these programs.

Discovery Awards

APL scientists were among the Johns Hopkins researchers chosen for the second round of JHU Discovery Awards. The program, part of a $15 million commitment to cross-university, faculty-led research, attracted 167 proposals, from which 24 teams, each composed of members from at least two Johns Hopkins divisions, received awards. APL researchers were on two teams investigating hyperspectral imaging in human cancer and molecular signatures of malaria in breath.

Partnering for Health

Through APL's new National Heath Mission Area, we are teaming with Johns Hopkins Medicine, the Bloomberg School of Public Health, and the Whiting School of Engineering on an initiative to apply rigorous data analysis and systems engineering practices to the diagnosis and treatment of disease. The partnership leverages the medical and systems engineering expertise resident at the institutions to create a learning health system that will speed the translation of knowledge to practice in these and other key areas. Johns Hopkins Medicine has identified several similarly challenging conditions for which precision medicine centers of excellence will improve efficiencies and patient outcomes, while fostering new research and treatment platforms.

Space@Hopkins

APL is connecting with Johns Hopkins divisions, departments, and partners in a common pursuit of space research. Space@Hopkins highlights the wide scope of JHU's space-related activities to foster collaboration among university-affiliated researchers and provide access to new partnerships. Focusing on eight initial research fields, including heliophysics, planetary science, and spacecraft engineering, the work features collaborations with affiliates such as the Space Telescope Science Institute and NASA's Goddard Space Flight Center.

COMMUNITY INVOLVEMENT

The Lab's Science, Technology, Engineering, and Mathematics (STEM) education and outreach programs reach more than 3,500 students, parents, and teachers a year, thanks to the 300-plus APL volunteers working in counties throughout Maryland.

Maryland MESA

Founded at APL, Maryland Mathematics, Engineering, Science Achievement (MESA) is an extracurricular program for students in grades 3–12. Maryland MESA aims to increase the number of engineers, scientists, mathematicians, and related professionals at technical and management levels while encouraging and helping minorities and females to succeed in these fields. The program provides services and programs to 2,500 students and nearly 160 teachers.

APL's Student Program to Inspire, Relate and Enrich (ASPIRE)

For the 2016–17 school year and summer, ASPIRE placed 211 high school juniors and seniors recommended by their schools into one-on-one internships with 132 APL volunteers. Interns worked on sponsor and internal research and development projects and gained valuable skills and career experience.

College Prep Program

Seventeen students participated in APL's award-winning summer mentoring program that encourages high school students to apply to top colleges, pursue advanced degrees, and explore STEM careers. Most participants have little or no exposure to the college application process when they start the program, but with the help of 25 APL volunteers and additional members of the community, they quickly acquire tools to help them apply to college, excel in their studies, and pursue their dreams. More than 90 percent of the 170 program alumni are on track to earn a bachelor's degree, and many are pursuing advanced degrees.

Boys & Girls Clubs Math Tutoring

In 2017, we again partnered with the Boys & Girls Clubs of Metropolitan Baltimore to offer math tutoring. Lab volunteers met weekly with 20 students on the APL campus for 10 weeks, during sessions in the spring and fall, helping the students strengthen their core math skills.

Outreach

APL hosted the 11th annual "Girl Power" STEM expo in March, with more than 600 elementary through high school girls and their families visiting the daylong interactive event to learn about STEM education and careers. In April, more than 600 staff members' children came to campus for "Take Our Daughters and Sons to Work Day," touring the Lab and learning about STEM through a range of fun, interactive activities.

Internships

APL offers numerous opportunities for students through the **College Internship Program**. Summer internships are open to qualifying students; the students work with APL scientists and engineers, conducting research, developing leadership skills, and growing professionally. More than 375 students from 100 colleges and universities completed an internship or co-op at APL in FY 2017.

The **APL-NASA intern program** offers summer projects for rising sophomores through doctoral candidates interested in working on NASA missions or conducting space-related research.

The **National Consortium for Graduate Degrees for Minorities in Engineering (GEM)** encourages minority men and women to pursue graduate degrees in engineering and the natural sciences, and participate in internships at the graduate level at universities across the country.

The **APL Technology Leadership Scholars (ATLAS)** program, open to rising juniors or graduate students majoring in engineering, math, physics, or computer science from Historically Black Colleges and Universities, Hispanic-Serving Institutions, and Minority Institutions, included a record cohort of 32 students—most of whom will be eligible for full-time employment at APL by May 2018.

AWARDS AND HONORS

APL Director Ralph Semmel received a Maryland International Business Leadership Award from the World Trade Center Institute.

APL Chief of Staff Ron Luman (1) was named a Fellow of the International Council on Systems Engineering.

Fast Company (2) listed APL among the world's "Most Innovative" companies.

Baltimore Innovation Awards recognized Hal Weaver (3), project scientist for the New Horizons mission to Pluto, as "Scientist of the Year."

Tom Krimigis (4, center) received the NASA Distinguished Public Service Medal.

Jeff Chavis (5), Amir Matlock (6), Lanier Watkins (7), and Jarriel Cook (8) were honored with Black Engineer of the Year Awards. Chavis received a Professional Achievement – Industry award, Matlock and Watkins received Modern-Day Technology Leader awards, and Cook received an Emerald Honors Award in Research Leadership.

The Maryland Academy of Sciences recognized Brett Denevi (9, left) as an Outstanding Young Scientist and Robert Armiger (9, right) and Ryan Gardner (10) as Outstanding Young Engineers.

Sarah Flanigan and Justin Atchison earned grants from the Future Space Leaders Foundation to present at the 66th International Astronautical Congress in Jerusalem.

David Challener was recognized with the Trusted Computing Group's Distinguished Service Award.

Linda Butler earned an Excellence in Gifted and Talented Education School Award by the Maryland State Advisory Council on Gifted and Talented Education.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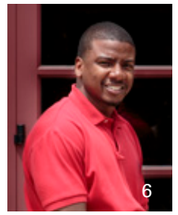
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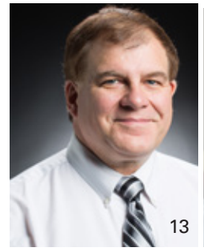
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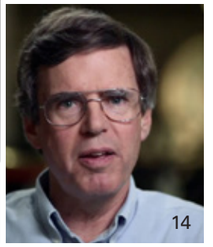
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The honors continued for the New Horizons mission team (11), including the *Aviation Week and Space Technology* Laureate for space exploration; the American Astronomical Society's Neil Armstrong Space Flight Achievement Award; the National Space Club and Foundation's Goddard Memorial Trophy; and the NASA Group Achievement Award.

APL was honored with an Above and Beyond Award for our extraordinary support for employees who serve in the National Guard and Reserve.

Dana Hurley was honored with the 2016 Michael J. Wargo Exploration Science Award.

Danielle Chou (12, left) and Eric Chang (not pictured) were honored with Diversity Recognition Awards from the JHU Diversity Leadership Council.

Space scientists Scott Murchie (13) and Barry Mauk (14) were named Fellows of the American Geophysical Union.

The Arc of Howard County selected APL for an Excellence in Employment award.

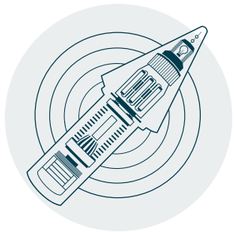
Tom Sokol received the Mid-Atlantic Section Engineer of the Year award from the American Institute of Aeronautics and Astronautics.

Natalie Hagan (15, left) received the Advocating Women in Engineering Award, and Cheryl Manning (right) was awarded the Fellow Grade honor by the Society of Women Engineers.

APL's Bradford Lapsansky (16, left) and Jaime Arribas Starkey-El (right) and earned honors for their NoverFlow, a device to help municipalities track dumpster loads, as part of the AT&T Mobile App Internet of Things Government Solutions Hackathon.

DEFINING INNOVATIONS

Among the Johns Hopkins University Applied Physics Laboratory's thousands of critical contributions to national security and space exploration are a number of defining innovations: game-changing breakthroughs in technology that have created inflection points in history. These revolutionary advances have ignited new engineering accomplishments globally, saved lives, and secured the United States against threats at home and abroad.

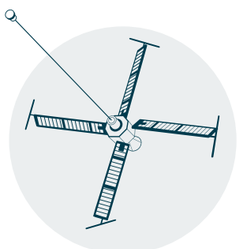


RADIO PROXIMITY FUZE

The Johns Hopkins University Applied Physics Laboratory was established in early 1942 to perfect and field one of America's most closely guarded secrets of World War II—the radio proximity fuze. The device was judged by historians as one of the three most important developments of the war, along with radar and the atomic bomb.

BIRTHPLACE OF U.S. NAVY SURFACE-TO-AIR MISSILES

APL's pioneering research to develop the first generation of Navy surface-to-air guided missiles in the 1940s laid the foundation for technologies and systems that continue to defend the Navy's fleet and provide the backbone of our nation's air and missile defense.



TRANSIT

APL created the world's first satellite navigation system to serve the Navy, especially the nation's ballistic missile submarine force. The forerunner of modern GPS, Transit provided essential capability to the U.S. Navy from 1964 until the 1990s.

AMFAR: NAVY PHASED ARRAY RADAR

APL designed, built, and demonstrated the prototype of the Navy's advanced, multifunction phased array radar to defend against multiple, simultaneous aircraft and missile attacks. This prototype served as the foundation for the SPY-1 series of phased array radars.

ADVANCED SONAR ARRAYS

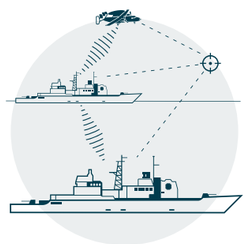
APL developed prototypes, experiments, and ocean physics and engineering models that unlocked the potential of towed sonar arrays. These groundbreaking developments enabled long-range towed arrays that revolutionized anti-submarine warfare and guided stealth designs for multiple generations of U.S. submarines.

SATRACK: BALLISTIC MISSILE TESTING

To ensure the accuracy of the Trident II submarine-launched ballistic missile, APL developed a transformational instrumentation system that confidently estimates missile accuracy anywhere in the world. SATRACK has saved the Navy billions of dollars in flight test costs and remains essential to our nation's nuclear deterrence strategy.

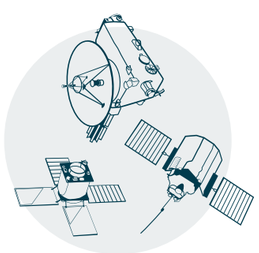
TOMAHAWK

APL developed the guidance and control technology for the Tomahawk cruise missile, making it the world's first long-range, precision-guided weapon. The guidance system allows Tomahawk to travel hundreds miles of over varied terrain and strike heavily defended targets with great accuracy.



COOPERATIVE ENGAGEMENT CAPABILITY

The Cooperative Engagement Capability (CEC), led by APL for the Navy, provided the first networked air defense for U.S. Navy ships and airborne early warning aircraft. CEC revolutionized naval battle group air defenses by enabling ships to engage aircraft and missiles not seen by their own radars using composite radar tracks created from the radars of ships within the battle group.



LOW-COST PLANETARY EXPLORATION

APL's revolutionary low-cost approach to planetary exploration, demonstrated first by the NEAR mission to the asteroid Eros, inspired NASA's Discovery and New Frontiers programs, and led to the highly successful MESSENGER mission to Mercury and New Horizons mission to Pluto.

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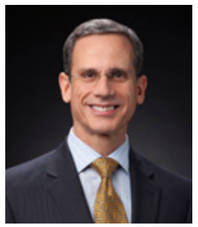

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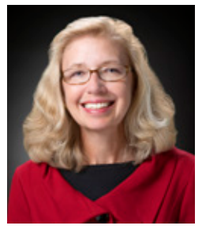

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During the fiscal year that ended September 30, 2017, the Johns Hopkins University Applied Physics Laboratory recorded revenue from contracts and grants totaling $1.45 billion. As a scientific and educational nonprofit organization, we reinvest proceeds from our contract research and development activities into programs, facilities, and capabilities that further our scientific and technology development mission.

The Johns Hopkins University Applied Physics Laboratory

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University affiliated research centers are independent, nonprofit organizations that conduct essential research, development, and systems engineering to strengthen our nation. The centers focus on strategic national priorities, free from conflicts of interest or competition with commercial industry. They provide the U.S. government with access to highly skilled scientists, engineers, and analysts to tackle vital national security and scientific challenges.

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