Annual Report 2013

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

The Johns Hopkins University Applied Physics Laboratory

A University Affiliated Research Center

University Affiliated Research Centers are independent, nonprofit organizations that conduct essential research, development, and systems engineering to support national security needs. The centers serve strategic national priorities, free from conflicts of interest or competition with commercial industry. Collaboration with leading research universities allows these organizations to provide the U.S. government with access to our nation's most highly skilled scientists, engineers, and analysts to tackle vital national security and scientific challenges.

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Director's Message

At the Johns Hopkins University Applied Physics Laboratory, we are dedicated to strengthening our nation through transformative innovation and trusted technical leadership in national security and space.

For more than 70 years, U.S. government sponsors have relied on us to play a vital role in conducting essential research, development, systems engineering, and analysis that supports national security priorities. Along the way, our staff members have routinely demonstrated incredible creativity and ingenuity, which has led to innovations in space exploration, medical breakthroughs, and other exciting advances in science and technology. Throughout our history, we have emphasized practical solutions and maintained our commitment to inspiring future generations of scientists, engineers, and analysts.

Today, in an era of constrained federal research and development funding, we are focused more than ever on our role as a national resource—delivering value, innovation, and cost-effective solutions to meet new and emerging sponsor needs. During the past year, we developed capabilities that will serve as the basis for future systems, applied novel ideas to increase the effectiveness of current systems, and creatively adapted technologies for new missions. In doing so, we helped better protect our nation's forward-deployed forces and helped counter threats that ranged from the global proliferation of high-technology weapons systems to cyber-technology systems intended to destabilize our economy and society.

We were extremely pleased this past year when the U.S. Naval Sea Systems Command (NAVSEA) renewed its long-standing sponsorship of the Laboratory through a five-year contract, with a five-year extension option, for research, development, engineering, and testing and evaluation performed for sponsors across the Department of Defense. We highly value the Navy's continuing commitment, and we remain honored by the trust that all of our sponsors place in us to support key national security and space exploration missions.

We stand ready to take on the complexities and uncertainties of the coming year, and we look forward to the opportunities to continue making critical contributions to critical national challenges.

Ralph Semmel

Air and Missile Defense

Protecting Our Nation from Evolving Global Aircraft, Missile, and Surface Threats

Since 1942, APL has applied systems engineering principles and created advanced technologies to help protect U.S. and Allied naval fleets and forward-deployed forces from air attack. Today, we continue to perform this vital mission in an increasingly dynamic and complex environment, as we evolve to address new and emerging threats posed by long-range ballistic missiles. We devise, develop, engineer, test, and evaluate solutions that address current and future air and missile defense needs. We apply our expertise to make current systems more effective, and we have adapted several technologies for new missions and developed novel technologies for future implementation.

Integrating Systems and Technologies to Enhance Air and Missile Defense Effectiveness: STANDARD Missile-6 Flight Testing and Navy Integrated Fire Control—Counter Air

During 2013, the Navy reached two important milestones in the advancement of fleet air defense capabilities. One involved the STANDARD Missile (SM) program and the achievement of Initial Operational Capability (IOC) for the SM-6, the extended-range surface-to-air missile being developed to provide the Navy surface fleet with enhanced protection against advanced aircraft and missile threats. As Technical Direction Agent for SM, APL also provided critical contributions to system performance prediction; flight test preparation, execution, and data analysis; and missile integration into the AEGIS Weapon System.

In addition, the Navy's Program Executive Office, Integrated Warfare Systems tasked the Laboratory to lead a series of test flights demonstrating the integration of the SM-6 with the Cooperative Engagement Capability, airborne platforms, and AEGIS to demonstrate Naval Integrated Fire Control—Counter Air (NIFC-CA) capability. NIFC-CA allows Navy ships to engage over-the-horizon threats, significantly enhancing survivability and expanding the ships' capability to address multiple targets at extended ranges in high-threat environments. This capability was successfully demonstrated during an over-the-horizon engagement by USS *Chancellorsville* (CG 62)—an AEGIS

NIFC-CA success: USS Chancellorsville *engages an over-the-horizon target with a STANDARD Missile-6.*

Baseline 9 cruiser—at the Naval Air Warfare Center Weapons Division, Point Mugu Sea Test Range, California. This test represented a key milestone and marks the beginning of a multiyear campaign during which APL will help the Navy bring NIFC-CA to full operational status.

Closing the Aegis Ballistic Missile Defense Fire Control Loop with Space-Based Track Data

As Technical Direction Agent for Aegis Ballistic Missile Defense (BMD), APL led the scenario development, orchestrated preflight Ballistic Missile Defense System predictive performance analysis, and supported the Missile Defense Agency's Flight Test Maritime-20 (FTM-20) in February 2013. During the test, a U.S. Navy ship located on the Pacific Missile Range Facility in Hawaii, and configured with the Aegis BMD 4.0.2 combat system and the STANDARD Missile-3 (SM-3) Block IA guided missile, successfully engaged and intercepted a medium-range ballistic missile target.

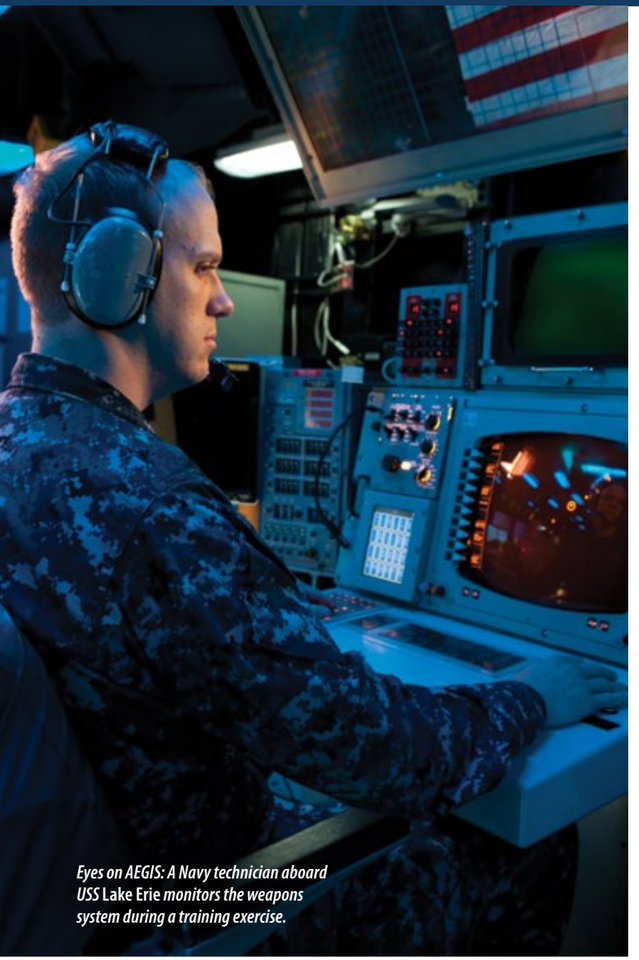
This was the first flight test mission that utilized Space Tracking and Surveillance System (STSS) satellite sensor data to enable the Aegis BMD fire control system to develop an engagement solution based on a space track and launch the SM-3. Subsequent to the SM-3 launch, the ship's AN/SPY-1 radar detected and tracked the target, and then provided the final handover to the SM-3 kinetic warhead, which successfully intercepted the target. As part of our role in the test, APL led the end-to-end analysis, providing engineering rigor and guidance to help analyze both digital and hardware-in-the-loop simulation results to predict overall preflight performance. This mission was critical in verifying the ability to use space-based sensor data to launch and guide the SM-3, further expanding the Aegis BMD System's engagement envelope.

Enhancing the AEGIS Combat System

APL engineers continued to play key roles in efforts to enhance current and future AEGIS Combat System capability to perform integrated anti-air warfare and ballistic missile defense. As Technical Direction Agent for the program, we worked alongside Navy program office and industry experts to help ensure the successful introduction of Baseline 9, the first ships to field the state-of-the-art integrated air and missile defense capability, into the fleet.

We applied our systems engineering expertise and institutional knowledge to enhance development of the Aegis BMD 5.0 Capability Upgrade and 5.1 systems,

USS Lake Erie *sends a STANDARD Missile-3 Block IA toward its target during FTM-20.*



Eyes on AEGIS: A Navy technician aboard USS Lake Erie *monitors the weapons system during a training exercise.*

planned for integration into future AEGIS baselines, helping to advance that system through its system design reviews. APL engineers played a key role in developing and allocating system requirements to help guide industry weapon system and missile contractors. Aegis BMD 5.1 will introduce the advanced SM-3 Block IIA missile, for which we have provided systems engineering leadership during the cooperative U.S./Japanese development program. We also contributed to the development of the system's radar discrimination architecture to address a more complex set of threats, continuing our contributions to system discrimination, innovative architectures, and future system concepts.

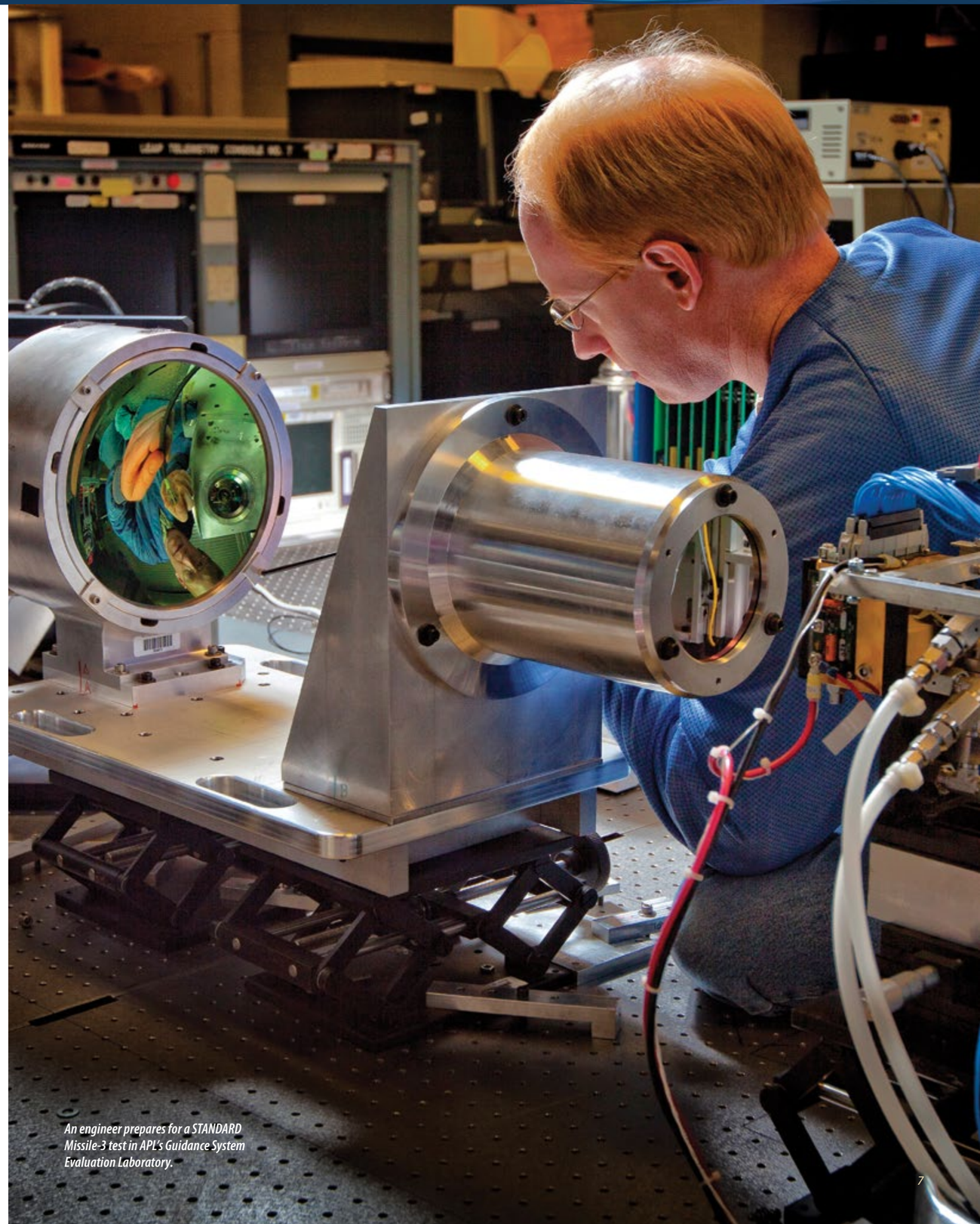
Delivering Next-Generation Electronic Warfare Protection

APL has been tasked by the Program Executive Office, Integrated Warfare Systems to work with the Naval Research Laboratory to develop concepts of employment and top-level system requirements for the Advanced Off-board Electronic Warfare (AOEW) system acquisition. As part of the effort, APL has been asked to lead the definition of system requirements for the coordinated tactical employment of AOEW and other EW assets to support effective "soft kill" engagement of anti-ship cruise and ballistic missiles. We will be leveraging our combined experience in EW systems development, autonomous systems technology, and engagement control systems to deliver the next generation of EW capabilities to the surface Navy.

Developing a Common "Kill Vehicle" for Ballistic Missile Defense

As part of an effort to develop advanced technologies to defend against enemy ballistic missiles, the Missile Defense Agency's (MDA's) Advanced Technology Directorate tasked APL to lead in defining a common kill vehicle (CKV) architecture and investigate potential cost savings and performance improvements associated with common component technologies for upgrades and new development.

An upcoming concept exploration phase will define system and subsystem technology guidelines for follow-on risk reduction and technology development. The Laboratory team worked collaboratively with MDA's Directorate for Engineering, the Ground-Based Midcourse Defense program, and the Aegis Ballistic Missile Defense program to establish a system context, and test parameters, for analyzing cost and performance trade-offs between current technologies and a potential CKV configuration. Within the resulting framework, our engineers generated system concepts for improved unitary kill vehicles for the Ground-Based Interceptor and began exploring concepts for advanced kill vehicle architectures.



An engineer prepares for a STANDARD Missile-3 test in APL's Guidance System Evaluation Laboratory.

Asymmetric Operations

Adapting Technologies to Meet Nontraditional Challenges

Today, nontraditional threats to the nation's security come in many varieties, driven by an ever-increasing number of interests. Domestically, they range from inexpensive, commercial off-the-shelf technologies capable of degrading or disrupting U.S. financial systems and infrastructure, to chemical, biological, and radiological attacks against U.S. citizens. International adversaries use these same devices to offset the modern capabilities of U.S. forces in the field. At APL, we creatively apply technology solutions to meet these new and emerging dangers. We define the threats; design practical, low-cost solutions; and develop prototypes that can be rapidly fielded to protect Americans and allies at home and abroad.

Hunting Malware at Its Source

APL researchers have developed a novel way to quickly identify malware by analyzing its code "DNA." The Department of Homeland Security's Office of Science and Technology selected our "Code DNA" technology as one of eight technologies for potential fielding through the department's Transition to Practice Program. This program seeks to identify and field promising cyber security technologies through appropriate commercialization channels. The technology—also named the Laboratory's Invention of the Year—is being tested by an independent agency before consideration for government pilot deployments.

Next-Generation Search Backpack

The Next-Generation Search Backpack project is a collaboration among APL, the Remote Sensing Laboratory, and the Department of Energy (DOE). Our principal role is system developer and producer of the first two prototypes with a goal to develop a production-ready radiation search backpack with directional gamma detection and nondirectional neutron capabilities. The APL-developed backpack will provide the basis for the long-haul principal search technology/platform for the National Nuclear Security Agency. The backpack is carried by DOE responders during missions to search for illicit nuclear materials or other radiological threats.

The new APL design departs significantly from earlier designs, specifically addressing weight, sensitivity, and power-consumption requirements while retaining a high level of functionality. The main architectural change is the adoption of a low-power embedded controller to replace miniature PCs, together with the "directionality" sensor improvements developed by APL. Size and weight improvements primarily focused on the packaging of the gamma sensor. The controller leverages a system developed and deployed by APL for a variety of low-power remote-sensing applications.

The Next-Generation Search Backpack is an efficient yet powerful tool for finding illicit nuclear materials or other radiological threats.

Cheap, disposable, and effective: ABLE reduces hearing loss and ear damage suffered by people exposed to an explosion.

ABLE Earplugs: Low-Cost Innovation Protects Hearing

Under APL's Ignition Grants program, APL researchers have developed a low-cost, disposable earplug to reduce the hearing loss and ear damage service members experience from explosive blasts. Called ABLE (for Anti-Blast Earplug), the devices allow wearers to hear normally until there is an explosion, when a tiny, lightweight ball inside the earplugs blocks sound waves, lessening their impact on the wearer.

The aim of the project is to allow wearers to hear normally before a blast and yet provide protection equal to that of traditional earplugs when a blast occurs. Using a device that mimics the effects of an explosion, researchers have measured ABLE's ability to allow normal hearing preblast and reduce pressure inside the ear when a blast occurs, and they determined that pressure is reduced by a factor of five. Researchers are hopeful that ABLE—which was named APL's Ignition Grant of the Year—will one day reduce the hearing loss experienced by the thousands of service members exposed to explosive blasts.

Harnessing the Power of Big Data and Surveillance Systems to Support Decision Making

The increasing volume and variety of available health data present significant and growing challenges to government decision makers who rely on these data. Traditional methods for identifying anomalies and visualizing data are no longer efficient given the vast number of available data types that must be monitored.

Under sponsorship from the Armed Forces Health Surveillance Center, APL has developed a disease-surveillance-processing engine that combines weighted evidence from all available data sources to provide fused alerts for severe conditions as they start to emerge. The technique enables the use of big data analytics for routine health monitoring without the burden of having to investigate lower-priority health anomalies. Also during the past year, we officially released our Suite for Automated Global Electronic bioSurveillance (SAGES) technology as open source, under Armed Forces Health Surveillance Center sponsorship.

Reducing Costs for Training Explosive-Detecting Dogs

APL has developed a reliable, low-cost, long-shelf-life training aid for agencies that use explosive-detecting dogs. The program's current emphasis is on development of training aids for powerful and sensitive homemade explosives. Ongoing laboratory analysis and field assessments have been positive, showing that APL's training aids are more affordable and more effective than commercial off-the-shelf aids; our team has also documented the manufacturing process and filed a patent. We are working with the Department of Homeland Security's Office of Science and Technology, which sponsors this work, to transfer this technology to the commercial market.

APL's realistic, low-cost training aids will help dogs sniff out dangerous, homemade explosives.

Force Projection

Extending and Ensuring Our Nation's Global Reach

As a nation whose future relies on global trade and market access, the Unites States requires the capability to project power around the world to protect vital national interests. For decades, APL has supported the U.S. Navy with systems engineering and technologies that strengthen its global reach and effectively deter adversaries who might threaten U.S. interests. APL's research and development programs range from those that enhance the capabilities of the nation's submarine fleet and the readiness of submarine-based ballistic missile systems to those designed to provide precision strike and engagement on a global scale.

Modernizing Mission Planning and Analysis for the U.S. Strategic Command

Among the highest priorities facing the U.S. Strategic Command's Joint Functional Component Command for Global Strike is the modernization of its mission threat planning and analysis system. New technologies and emerging threats have led to the need for an extensive redesign. Working alongside U.S. Strategic Command's mission planning and analysis system-modernization team, APL experts have developed a prototype of a sophisticated, automated, crisis action-planning process that integrates strike option and planning processes, including aim point and weapon assignment. System functionality also allows for the estimation of effects on targets and the mitigation of undesired consequences within specific confidence bounds.

APL is infusing technology with a "rank learning" algorithm that lightens the information load on Navy sonar operators.

Maritime Surveillance Systems: Advanced Surveillance Build (ASB) Pilot Program

APL is providing technical leadership for a pilot program to rapidly insert advanced technology into Maritime Surveillance Systems, modeled after the highly successful Submarine Force Advanced Processor Build (APB) modernization process. On a very compressed development timeline, we are leading program planning, system integration, two technology peer review working groups, and system testing and evaluation for the ASB Pilot Program.

Applying Technology to Enhance Navy Sonar Operations

APL is developing new tools to help Navy sonar operators manage the workload associated with increasingly sophisticated and sensitive systems. With funding provided by the Office of Naval Research Discovery and Invention program, we have developed a novel "rank learning" algorithm that prioritizes the wide range of acoustic contact signatures. Our Discounted Cumulative Margin Penalty Ranker merges state-of-the-art concepts from information retrieval research with large-margin techniques into a high-performance algorithm with excellent generalization properties. This ranking algorithm produced accurate results within a workload operators can manage. This technology is currently in transition to several Navy sonar processing systems.

The air-launched Long-Range Anti-Ship Missile (LRASM) allows U.S. forces to strike surface targets from outside an adversary's air defenses. Image courtesy of Lockheed Martin.

Long-Range Anti-Ship Missile (LRASM)

LRASM is a jointly led program funded by the Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) to develop and demonstrate a long-range anti-ship missile capability against advanced enemy air-defense systems that deny access of U.S. airborne and surface-ship combatants. LRASM is a stealthy cruise missile derived from the JASSM-ER, upgraded with new avionics and algorithms to meet this urgent operational need identified by the U.S. Navy.

Since the inception of the LRASM program in 2008, APL has led the multiorganizational government assessment team. Team members have worked closely with DARPA, ONR, and contractors to develop and test LRASM in both air and surface-ship launch configurations. In addition to leading the team, we have contributed significantly to the missile's guidance, sensor, and survivability-related technologies. During the second half of 2013, we supported two successful end-to-end overwater flight tests that demonstrated LRASM's ability to detect, discriminate, and engage moving surface-ship targets from ranges exceeding 200 nautical miles. Recently, the Department of Defense directed the U.S. Navy to transition the DARPA/ONR demonstration LRASM into a tactical program of record. APL is working with DARPA and the U.S. Navy to make this transition.

EMAPS technology allows operators to map areas and confined spaces that GPS cannot "see."

EMAPS Technology "Sees" Where GPS Cannot

APL engineers have developed via the Ignition Grants Initiative a portable system that can be used to automatically create annotated physical maps of locations where GPS is not available, such as in underground areas and on ships. The Enhanced Mapping and Positioning System (EMAPS) uses a combination of 360-degree photo capability with light detection and ranging (LIDAR) sensors to create a map while an operator walks through an area wearing the unit in a backpack.

The system improves on algorithms once developed for robots—which are not practical for all environments—and has a built-in allowance for walking and other normal human movement. Designed mainly to detect and map environmental threats on ships and in other GPS-limited locations, EMAPS' novel algorithms also associate critical environmental data, such as radiation or radio frequency signal levels, with map locations.

Exploiting the Capabilities of Digital Radio Frequency Memory (DRFM)

DRFM technology is a key enabler for deceptive electronic attacks against modern radars, and it presents a significant challenge for electronic protection of friendly radars. The technology works by recording radar pulses, and then modulating and replaying them with high fidelity to generate false targets and other waveforms that deceive, distract, or saturate adversary radars. The proliferation of this technology is leading to increasingly sophisticated and capable systems that present opportunities and challenges for APL sponsors.

To address this need, APL is developing concepts, techniques, and tactics to harness and defend against this technology. One promising approach is the use of a novel "super pipeline" architecture that potentially provides significant performance improvements over existing DRFM architectures. In another approach, we are developing advanced DRFM electronic support capabilities to enable operation in a dense signal environment, improve tracking of a signal of interest, and increase electronic attack effectiveness. The developed concepts are being evaluated for both offensive and defensive airborne and surface electronic warfare applications.

Offensive Capabilities for Anti-Access/Area-Denial Environments

Potential adversaries are developing and deploying anti-access/area-denial (A2/AD) capabilities designed to limit access to the global commons and keep U.S. forces out of specific operating areas. These new threats present myriad challenges to conventional operations because of their long-range strike capability, diverse sensor networks, and integrated command and control systems designed for operation in complex, dynamic environments.

To meet this challenge, APL is funding the development of technologies and techniques to increase the ability of U.S. forces to operate in these potentially contested areas. Among the approaches are technologies that allow coordinated, swarming unmanned aerial system attacks on adversary A2/AD capabilities and the deployment of large numbers of inexpensive systems that add complexity to an adversary's network and targeting systems. We are also investigating the application of electronic warfare and cyber operations to disrupt adversary operations, and improved threat system modeling to assess the impacts of data fusion and automated decision-making algorithms in a networked adversary system.

Ensuring the Security of the Navy's Nuclear Assets

APL is working jointly with the Navy, Marine Corps, and Coast Guard to improve the security of the Navy's nuclear assets. We developed and implemented a methodology to analyze entire security systems—including barriers, sensors, vehicles, weapons, and personnel tactics—and identified the components that make these systems most effective against potential adversary attacks. The Navy is using this essential information to craft a risk-mitigation strategy.

The Navy counts on APL expertise to strengthen the security of its nuclear assets.

Space

Expanding the Frontiers of Space Science and Engineering

Over the past five decades, APL has designed, developed, and launched 68 spacecraft and more than 150 space instruments—focusing on the disciplined application of space physics and planetary science to advance knowledge and the use of space to the benefit of humankind while supporting national objectives. We develop innovative, low-cost concepts, technologies, and implementation strategies to expand the frontiers of space science and engineering, and to support national security objectives and provide tactical advantages to forward-deployed forces.

Into the Radiation Belts

After just one year in orbit, NASA's twin Van Allen Probes—built by and operated from APL—are fundamentally restructuring our understanding of the Van Allen radiation belts above our planet. Despite 55 years of study, there is much left to investigate about the radiation belts. Within a few short days after launch, the mission had answered one long-standing question about the acceleration of particles in the belts, and it revealed that the outer belt can split into two separate belts. Building on this first year of discovery and operations, the science teams of the Van Allen Probes (formerly named the Radiation Belt Storm Probes) are looking forward to unlocking further mysteries and advancing our knowledge of particle physics and the dynamics of space plasmas, as well as determining how to better protect space-based technology and people in space.

Approaching Pluto

Seven years after launch, the intrepid, APL-designed New Horizons spacecraft is close enough to take its first photos of Pluto and its largest moon, Charon. With arrival at the Pluto system less than two years away, the New Horizons science and engineering teams are ensuring every moment in the encounter is spent wisely.

In July, the flight sequence for close approach to Pluto was loaded aboard New Horizons and executed exactly as it will occur in 2015—an indication that the spacecraft and team will perform as designed. Later that month, the team sponsored a science conference at APL to review everything known about Pluto and its satellites, and their origin and evolution, and to hear informed scientific predictions about what New Horizons will find.

Durable Cubesats

APL's first pair of cubesats lifted to orbit aboard a Minotaur I rocket from Wallops Flight Facility, Virginia, in November 2013, as part of the U.S. Air Force ORS-3 mission. These innovative shoebox-sized satellites represent a new capability for the military and intelligence and science communities—a small satellite that can get to space inexpensively and be durable enough for long-term use. Because they cost relatively little to build, launch, and operate, cubesats are popular among university researchers looking to study the space just above Earth. The APL versions are destined for more technically demanding projects, including technology demonstrations of flight readiness; hence, they are designed to more demanding standards than a "typical" cubesat.

The APL cubesat draws from five decades of APL experience in building rugged spacecraft for harsh environments near and far from Earth—and from the Laboratory's deep, unique understanding of spacecraft, aerospace engineering, and applied engineering techniques. The satellites have all the subsystems of a standard orbiter—command and data handling, communications, navigation, power, and payload—scaled to fit into a 13- by 4- by 4-inch package that weighs less than 11 pounds. APL's next cubesat builds are currently under task order for both civil and national security sponsors.

About the size of a shoebox, cubesats provide an innovative and cost-effective way to carry a variety of payloads into space.

Voyager 1 Reaches Interstellar Space

NASA's Voyager 1 spacecraft, carrying the APL-built Low Energy Charged Particle (LECP) instrument, became the first human-made object to venture into interstellar space. Voyager 1 first detected the pressure of interstellar space on the heliosphere, the bubble of charged particles surrounding the sun that reaches far beyond the outer planets, in 2004. Data from 2013 confirmed that Voyager 1 has been traveling for about one year through the plasma, or ionized gas, present in the space between the stars. Voyager is in interstellar space, a transitional region immediately outside the solar bubble, where some effects from our sun are still evident.

Space-Based Weather Technology Responds to Growing Need

Multi-Spectral Imaging System

APL is capitalizing on our heritage of infrared instruments to develop a compact, space-based weather sensor for U.S. operational needs. The Multi-Spectral Imaging System, or MSIS, will provide a weather-sensing capability to the U.S. Air Force that illustrates our responsiveness to growing cost consciousness in every sector of government. We have made the sensor smaller, lighter, and less power-hungry, yet versatile enough to observe terrestrial weather in wavelengths spanning the visible through infrared. Such sensors are more adaptable to fly on smaller platforms and more affordable for the government. An aircraft test flight in November 2013 demonstrated the sensor and its capabilities to distinguish different types of clouds.

Special Sensor Ultraviolet Spectrographic Imager

We are reinventing our Special Sensor Ultraviolet Spectrographic Imager (SSUSI), currently flying on Defense Meteorological Satellite Program orbiters, to provide the U.S. Air Force with a new generation of weather-sensing capabilities. Our sensor design based on the SSUSI platform, called SSUSI Lite, will observe the near-Earth environs in the far ultraviolet range. True to its name, the new sensor design is robust and versatile, and can be deployed at a lower cost with reduced schedule, power, and mass constraints. SSUSI Lite also offers new capabilities, such as better information to forward-deployed personnel and enhancements for space communications.

APL's first cubesats head to orbit on November 19, 2013.

National Security Analysis

Bringing Focus to Future Concepts and Strategies

In addition to developing technologies, APL assesses emerging technologies, warfighting concepts, and future national security concepts, strategies, and policies. We conduct assessments and analyses for organizations across the Department of Defense and other federal agencies to provide them with strategic insights on issues ranging from life-cycle system and program cost assessments to analytical models and gaming simulations to support strategic choices and decision making.

Supporting Efforts for Homeland Security to Strengthen Infrastructure Resiliency

As part of a broad-based effort to call attention to the importance of resiliency in the face of natural or man-made disasters, APL conducted a multidisciplinary study to assess the state of critical infrastructure and key national resources. The study informed efforts by Department of Homeland Security, Federal Emergency Management Agency, and White House policymakers and contributed to the development of a critical infrastructure resiliency policy, Presidential Policy Directive 21 (PPD-21), "Critical Infrastructure Security and Resilience." The lessons and findings are also covered in the book *Beyond the Storms: Strengthening Homeland Security and Disaster Management to Achieve Resilience.*

In the book Beyond the Storms, *APL homeland and national security advisor Dane Egli covers the resilience and security of the nation's critical infrastructure.*

Combating Extremism, Radicalism, and Piracy Near the Horn of Africa

More than 100 subject-matter experts, representing the whole of U.S. government agencies, gathered together for the sixth cycle of an exercise designed to share perspectives on violent extremist organizations operating on the Horn of Africa and to discuss and validate methods to address their threats and capabilities. The series of training exercises was funded by the U.S. Army Asymmetric Warfare Group and developed to support U.S. Africa Command and U.S. Army Africa. During the multiplayer "Red versus Blue" exercise, experts assessed the validity of various courses of action to thwart violent extremist organizations, radicalization, and piracy by those operating within Somalia, Djibouti, northern Kenya, and the Ogaden region of western Ethiopia.

APL analysts pore over data and input during an exercise to explore threats to stability and peace in the Horn of Africa.

Phantom Signal: National and Nuclear Voice Conferencing Testing and Measurement

APL is assessing secure voice conferencing systems used for critical national and nuclear missions. The challenge required new analysis approaches and techniques appropriate to the missions' operational environments. APL, working with the Department of Defense Chief Information Officer and the White House Military Office, established and standardized a repeatable method for objective, quantitative characterization of the end-to-end performance of national and nuclear command, control, and communications decision-making systems.

Phantom Signal tests in live environments have led to changes to systems and to procedures that improve the robustness and performance of mission operations. Testing and measurement activities and results are driving incremental improvement and longer-term modernization across multiple components of these critical systems.

Increasing the Efficiency of Navy Clinical Labs

In response to critical budgeting pressures, APL applied our medical systems engineering expertise to reengineer the laboratory analysis process and redesign the distribution of testing facilities used by the Naval Hospital Pensacola, Florida, and its supporting clinics. Geographic volume and cost analysis drove consolidation of tests and right-sizing capabilities at remote sites. The redesigned system achieved increased volume discounts from vendors, recaptured workload for the Department of Defense at a lower cost, eliminated underutilized equipment, and reduced personnel costs. This effort resulted in savings of nearly $1 million per year, freeing critical medical resources for alternative deployment. We are expanding the work to four additional hospitals and their clinics and, in conjunction with Navy officials, are exploring a path to expand this effort Navy-wide.

Research and Exploratory Development

Creating the Technologies of Tomorrow and Beyond

Even as APL focuses on our sponsors' current national security and space engineering challenges, we pursue and invest significantly in research and technology development efforts to provide future capabilities and technologies. This aspect of the Laboratory's research and development supports and drives future thinking in all other program areas.

New Quantum Algorithm Could Improve Future Stealth Technologies

APL researchers have devised a breakthrough quantum algorithm for solving big, linear systems of equations that could be used to calculate complex measurements such as radar cross-sections, an ability integral to the development of radar stealth technology, among many other applications.

Building on pioneering work in quantum algorithm design by Peter Shor and later by MIT researchers who developed the Quantum Linear Systems Algorithm (QLSA), APL researchers overcame vexing challenges to apply theory to real-world application. They demonstrated the applicability of the algorithm by showing how to encode the problem of calculating the electromagnetic scattering cross-section, also known as radar cross-section, which has become increasingly important to the military.

APL researchers have shown that these calculations could be done much faster and could model much more complex objects than would be possible using even the most powerful classical supercomputers. The work was funded by the Intelligence Advanced Research Projects Activity under its Quantum Computer Science program, which explores questions related to the computational resources required to run quantum algorithms on realistic quantum computers.

This inexpensive sensor, developed by APL, can warn of impending fires in lithium-ion batteries.

Technology to Improve the Safety of Lithium-Ion Batteries

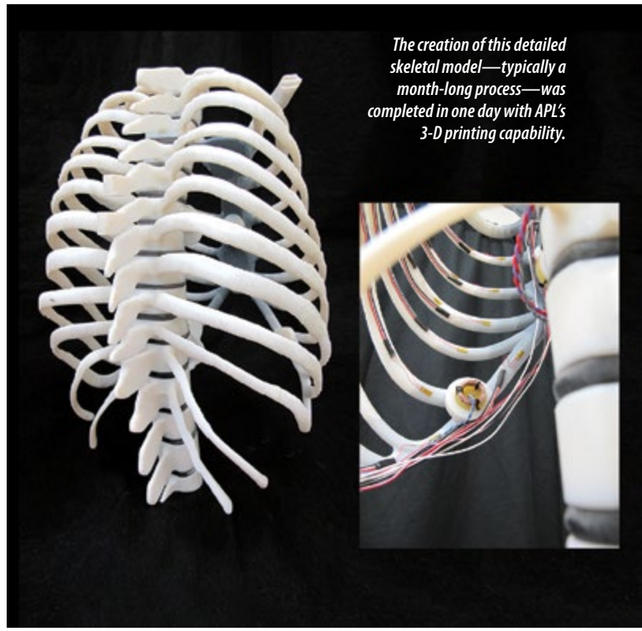
APL has refined technology that could improve the safety of lithium-ion batteries. These power sources, born in 1991, have become an important energy-storage technology. The rechargeable batteries are, arguably, the backbone of the wireless revolution of handheld devices. However, they sometimes generate enough heat to start fires in a process known as thermal runaway. For example, short circuits between the two electrodes in a battery cell can heat the electrodes, potentially triggering chemical reactions that quickly generate more heat until the electrolyte—which contains organic solvents—bursts into flame.

In 2011, we developed an inexpensive sensor capable of warning of impending catastrophic failure in lithium-ion batteries. The sensor was based on the discovery of an intrinsic relationship between the internal temperature of lithium-ion cells and an easily measured electrical parameter of the cell. Although sensing temperature increases was helpful, during the past two years, we have focused on precisely measuring heat while charging and discharging, which helps battery users in several ways. Users can cool the battery through forced convective heat transfer when heat generation reaches a specified point, and they can also save costs associated with cooling by choosing the duration of cooling.

Applying 3-D Printing to Improve Personnel Protection Technologies

APL is employing advanced additive manufacturing processes to print biofidelic human surrogate models. These models are being used by the Department of Defense to evaluate the impact of various weapons on service personnel. Traditionally, a detailed skeleton, including ribs, spine, and sternum, was handmade via mold and casting processes that could take as long as a month. Newer 3-D printing capability allows engineers to prototype the skeletal system within a day.

The additive manufacturing allows optimal materials to replicate the bone materials determined most representative of the human skeleton. Ultimately, this new fabrication approach will reduce production time and costs while increasing product controls. These advantages will help transition these surrogate systems from research platforms to more robust and repeatable test devices that can be used by the military community to evaluate the effects of various weapons systems.

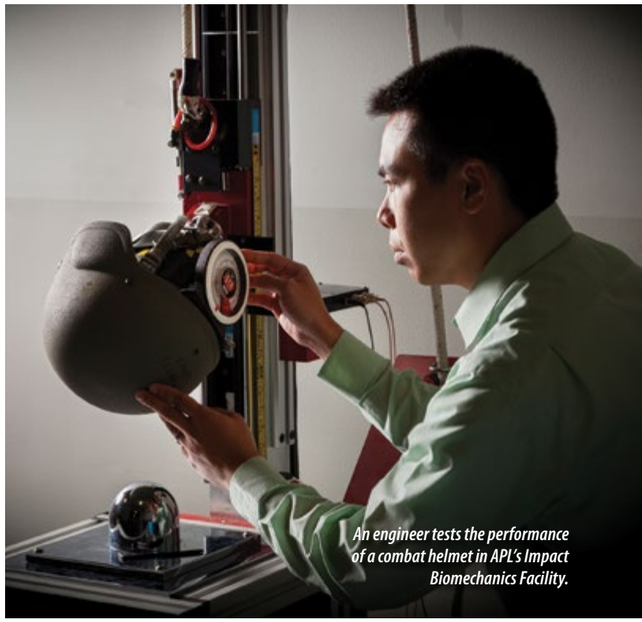


The creation of this detailed skeletal model—typically a month-long process—was completed in one day with APL's 3-D printing capability.

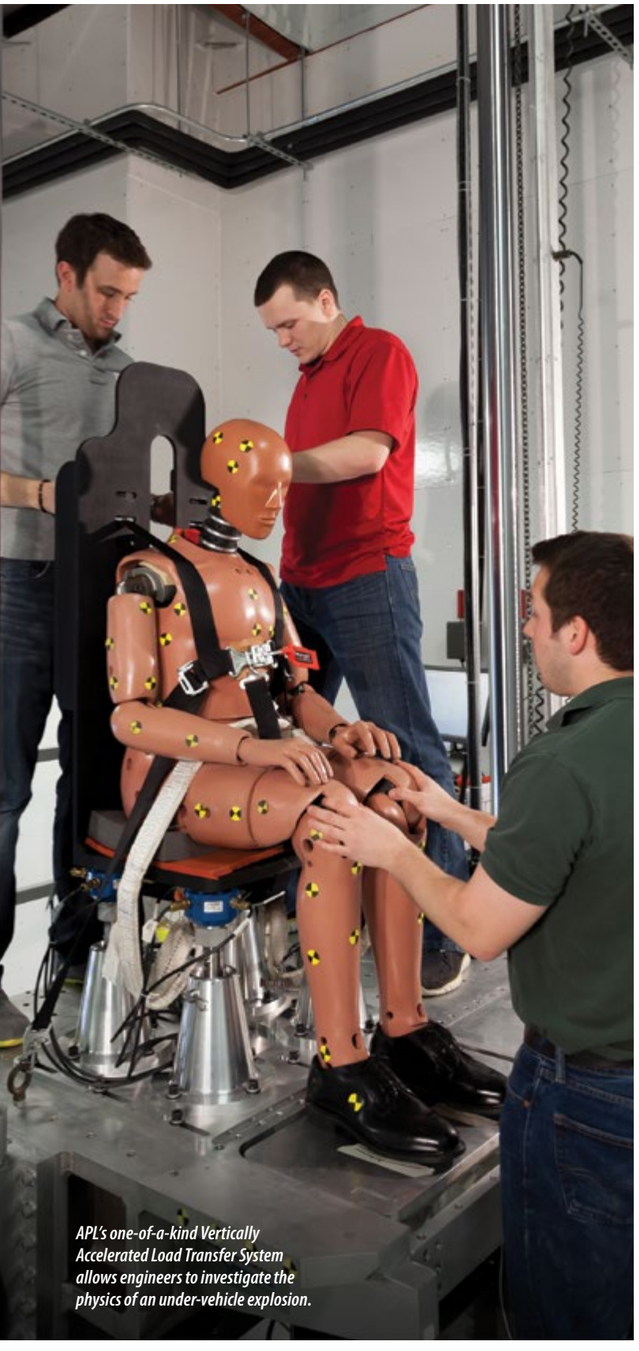
Developing "SMART" Helmets to Protect U.S. Marines

APL engineers and scientists have developed a comprehensive approach to helmet performance metrics for the Marine Corps called SMART-TE (Suspension Materials and Retention Technology Test and Evaluation). The approach includes new methods for determining the efficacy of helmet protection, comfort, and retention. This compilation of new evaluation methods has been employed for use on multiple existing and prospective helmet technologies.

To promote adoption of these new protocols, APL has been asked to introduce and train government and industry laboratories in their use. In this program, called Improved Helmet Suspension System (IHSS), we will participate as the lead test organization, providing test protocol (fitting, blunt impact, ballistic impact, and stability and retention) guidance and support, verifying test results from government and industry test labs, testing and evaluating innovative new helmet systems, and integrating and analyzing test data from all test organizations. We will also continue to expand and enhance the existing set of protocols to include new threat levels, operational scenarios, and injury-related metrics.



An engineer tests the performance of a combat helmet in APL's Impact Biomechanics Facility.



APL's one-of-a-kind Vertically Accelerated Load Transfer System allows engineers to investigate the physics of an under-vehicle explosion.

Protecting Personnel from Under-Body Explosive Devices

Explosions beneath vehicles (or under-body blasts) emerged as a major threat to military vehicles and their passengers during the wars in Iraq and Afghanistan. The force created by these blasts impacts the vehicle and is transferred to passengers, resulting in significant injuries and deaths. To better understand and enhance protection against these blasts, APL experts are exploring the physics of these extreme events in partnership with military medical researchers.

Our team has developed the Vertically Accelerated Load Transfer System (VALTS), a novel way to simulate the effects of a wide variety of these blasts. This experimental system offers the unique capability of replicating an improvised explosive device blast event on a vehicle, but in a laboratory setting.

Applying Advanced Technology to Map the Human Brain

Through APL-funded research to reverse-engineer cortical microcircuits, APL and Johns Hopkins University have become leaders in the large-scale systems engineering required to manage and exploit new and emerging brain-mapping data. These joint efforts have resulted in the creation of the largest online open-science repository for "connectomics" data. APL's specific contributions include the design and implementation of a standard markup language for electron microscopy connectomics data and an open-source and easily accessible interface to the Open Connectome Web services.

With additional funding through research grants from the National Institutes of Health and the National Science Foundation, APL and Johns Hopkins have continued to expand their research and presented their findings at a number of prestigious gatherings. In addition, APL leveraged the open-source toolkit to create a STEM challenge project sponsored by the Maryland Business Roundtable that enlisted approximately 2,000 Maryland high school students in crowd-sourced brain mapping research.

Technology Transfer

APL's Office of Technology Transfer (OTT) transforms Laboratory innovations into publicly available technologies that foster economic development. OTT helps launch start-up companies, issues licenses, and develops strategic partnerships aimed at translating APL innovations into commercially viable products that benefit society.

Technology Partnerships

APL and the Howard County Economic Development Authority (HCEDA) established a technology transfer partnership to bring APL innovations to the marketplace. Under an agreement signed in August, the Laboratory and county, through the Maryland Center for Entrepreneurship (MCE), seek to create companies and accelerate commercialization of targeted technologies developed at APL.

Together, APL and HCEDA will identify inventions they believe have the best chance of commercial success and match those technologies with MCE and other resources to accelerate commercialization. The initiative builds on the long relationship between the county and APL, creating a powerful coalition with a keen ability to form companies and transition innovative technologies to the community and broader marketplace.

> "The partnership provides the foundation to move Maryland into the future. The work being done at APL is fantastic, and we will now be able to provide the resources that help some groundbreaking developments turn into new businesses and jobs."
>
> Ken Ulman, Howard County Executive

Top Inventions

APL's **Invention of the Year**, "Code DNA," is a novel technique that creates a compressed DNA-type fingerprint of a binary that represents the various types of instructions found in its code, and then compares this fingerprint to those of known malware, exposing any similarities between the binary's code and code in malware. The **Government Purpose Innovation Award**—which recognizes an invention that has the potential to make a major impact in the defense community, and the nation—went to the "Airport Radar Counter-Terrorism Protection System," which can detect and locate the source of signals generated by radar-jamming devices.

HCEDA CEO Lawrence Twele and APL Director Ralph Semmel sign an agreement on a technology transfer partnership.

Exemplary Programs

APL received "exemplar" ratings in three key categories in the Institute for Defense Analyses report *Exemplar Practices for Department of Defense Technology Transfer.* Sponsored by the Assistant Secretary of Defense for Research and Engineering, who sees technology transfer as a driver of innovation in the Department of Defense and the economy, the report identifies and encourages the adoption of effective programs. APL received top rankings for its effective technology transfer office, researcher engagement, and well-managed intellectual property.

By the Numbers

Technology Transfer from October 2012 through September 2013

230	inventions disclosed
77	regular U.S., foreign, and provisional patent applications filed
16	U.S. patents issued
40	license agreements executed
4	companies created

University Collaboration

As a University Affiliated Research Center and division of Johns Hopkins University, APL has many exciting opportunities to make the world healthier, safer, and more secure. We team with our Johns Hopkins partners and experts in other specialized fields to address a wide array of challenges and missions for our sponsors. These interdisciplinary collaborations reach across the full spectrum of the Johns Hopkins University (JHU) and the Johns Hopkins Hospital, including the university's 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.

Higher Education

The Laboratory has a strong commitment to continuing education. Nearly 200 APL staff members teach engineering, applied science, technical management, and information technology courses within the JHU Whiting School's Engineering for Professionals (EP) program. APL professional staff members also serve as program chairs for eight of EP's 15 master's degree programs. These eight programs account for more than 85% of EP enrollments.

APL-Based EP Programs

Applied and Computational Mathematics, Applied Physics, Computer Science, Cybersecurity, Electrical and Computer Engineering, Information Systems Engineering, Systems Engineering, Technical Management

EP students can attend classes at APL, at the JHU Homewood campus, or at six other regional locations. In addition, companies and organizations across the nation have educational partnerships with JHU, particularly in systems engineering. Online education is a growing focus of the EP program, with approximately half of total course enrollments and 10 master's degree programs offered online.

APL Advanced Application Scholars Program

Developed for motivated, well-qualified Johns Hopkins undergraduate and graduate students in engineering, computer science, applied mathematics, and physics, the APL Advanced Application Scholars Program offers paid internships and placement for selected students at the Lab. Last year, approximately 14 students (from a field of about 80 applicants) earned roles in a variety of APL projects, including modeling and simulation; hardware and data systems design, testing, and evaluation; software design and development; and scientific research. Part-time employment during the academic year is also available to students.

Ph.D. Pathways

APL and the Whiting School of Engineering launched a partnership to promote further collaboration between the two Johns Hopkins divisions. The agreement widens a path for more Whiting School doctoral candidates to conduct their research at APL while offering flexibility for staff members seeking doctorates through the Whiting School.

Protecting and "Healing" Troops

Scientists from APL and the Johns Hopkins School of Medicine and Wilmer Eye Institute are working on lightweight, easy-to-apply materials to quickly repair or protect battlefield eye injuries. Sponsored by the U.S. Army Medical Research and Materiel Command, the project includes a cellulose adhesive bandage for mild abrasions, a gel-like reconstructive membrane for serious injuries that might require replacement of eye tissue, and a "glue" for sealing penetrating eye wounds that makes stitches obsolete.

APL is working with the Department of Plastic and Reconstructive Surgery to develop and test a computerized, biomechanically based planning tool that would improve the quality and success of face transplants—especially for troops with severe battlefield injuries. Capitalizing on the Lab's expertise in developing navigation systems, computer models, robotic-assisted tools, and visualization devices, the team hopes to reduce the postoperative deformities many patients suffer that are due to differences between their own anatomy and the tissue donor's.

Better tools may help; for instance, surgeons align a patient's upper jaw with a donor's lower jaw, making it easier for the patient to chew and swallow. The team's work would also enable injured soldiers to regain their pretraumatic identity and facial harmony, allowing them a smoother transition back into family, work, social life, and even military service.

Ron Luman, APL chief of staff and chair of the Johns Hopkins Engineering for Professionals systems engineering program, congratulates a Whiting School graduate.

U.S. News and World Report named the Whiting School's EP program among the nation's best online graduate engineering programs.

During the 2012–2013 academic year, 2,850 students participated in the eight APL-based EP programs, accounting for 7,408 course enrollments. More than 600 master's degrees were conferred during the 2012–2013 academic year. Since 1968, more than 1,200 APL staff members (and over 16,000 other students) have received master's degrees from these programs.

Fellows and Grants

Under the Merle A. Tuve Fellowship, Amir Najmi will pursue an adjunct appointment at Johns Hopkins Medicine that involves mathematical characterization of the effects of mental activity on the termination of epileptic-like seizures that arise after cortical stimulation.

With a Diversity Innovation Grant from the Johns Hopkins Diversity Leadership Council—part of an initiative to support fresh ideas that foster diversity and inclusion among Johns Hopkins communities—Linda Kress-McDonald produced "It Gets Better," a video to encourage and support lesbian, gay, bisexual, and transgender youth who are struggling with or suffering because of their sexual orientation or gender identity.

The Johns Hopkins University Homewood campus

Awards and Honors

Laboratory Awards

APL received a Business Leadership Award from the Howard County Commission on Disability Issues for hiring Cameron D'Aquila and making him the first person placed by the Arc of Howard County at a desk job outside of the Arc offices.

APL received a Silver Award as a "Healthy Workplace" from the Healthy Howard initiative for being committed to improving employee health and wellness.

U.S. Black Engineer & Information Technology magazine included APL on its 2013 list of top supporters of the nation's historically black engineering schools.

Individual Awards

Tom Milam

was inducted into the Army's Psychological Operations Regiment as a distinguished/honorary member.

Mike Kutzer and Mehran Armand,

along with Johns Hopkins postdoctoral coauthors, were awarded Best Medical Robotics Paper at the 2013 IEEE International Conference on Robotics and Automation for "A Continuum Manipulator Made of Interlocking Fibers."

Tom Krimigis was honored in his native Greece for contributions to space science, physics, and exploration.

Team Cameron: APL staff helped Cameron D'Aquila (center) find a role in the workplace.

Jerry Krill

was inducted into the University of Maryland's A. James Clark School of Engineering Innovation Hall of Fame for his technical leadership in developing the Cooperative Engagement Capability sensor network system.

Jerry Vetter and Bill Kohri

(and other coauthors) received the Naval Research Laboratory's Alan Berman Research Publication Award for NRL's best published technical writing.

Katy Carneal, Andrew Merkle, and Mehran Armand

(and other coauthors) received a Best Paper Award at the International Conference on Pattern Recognition Applications and Methods.

Sam Seymour

was named 2013 Systems Engineer of the Year by the Chesapeake Chapter of the International Council on Systems Engineering.

Tom Krimigis

received a 2013 "Niki" (Victory) Award from the Athens Information Technology Education and Research Center in Greece for his pioneering contributions to space science, physics, and exploration.

Community Involvement

APL joins the nation in tackling the critical challenge of inspiring and training the next generation of scientists and engineers. In 2013, our Science, Technology, Engineering, and Mathematics (STEM) education and outreach programs reached nearly 3,500 students, parents, and teachers—thanks to 400 APL volunteers working in counties throughout Maryland.

Prepared for Success

APL's Student Program to Inspire, Relate & Enrich (ASPIRE) included 77 APL mentors guiding 96 high school students, all working on real Lab projects and most planning to study STEM subjects in college. Our College Prep Program—supporting academically talented students with little or no exposure to the college application process—"graduated" its 100th student last summer. Nine out of 10 APL College Prep Program graduates are pursuing STEM majors, and all are on track to earn a bachelor's degree.

On the Web

Combine five inquisitive teens with a patient teacher and you get *Fifth Period*, the creative bimonthly comic strip that headlines the Lab's revamped STEM website. Upgrades to the website made it easy for volunteers to view and register for opportunities online and for students, parents, and teachers to access a wide range of information and educational resources.

Powerful Events

A record 1,000 parents and students attended the seventh annual "Girl Power" event in March 2013—learning first-hand about opportunities for women in STEM fields. Nearly 300 parents attended the second annual Parent STEMpowerment Workshop in November, hearing from higher-education institutions, nonprofit organizations, and industry and government representatives about the STEM resources available to them and their students.

MESA Days

Maryland MESA (Mathematics, Engineering, Science Achievement) grew to serve more than 2,900 students across the state. Dedicated APL subject-matter experts assisted with

Maryland Mathematics, Engineering, Science, and Achievement students take part in "MESA Days" activities at APL.

competitions and content in programs ranging from biomedicine to rocketry.

In the Classroom

Through a pilot program with Howard County schools, APL tutors helped more than 50 middle-schoolers tackle algebra and pass the state's high school assessment exam. APL volunteers also developed content to give students hands-on experience in writing programs in the Python programming language. Four APL staff members worked to help 24 students at four Howard County middle schools as part of this effort.

To the Moon

Lunar science and Mars exploration were topics for this year's Space Academy. Now in its 14th year, the Space Academy series, sponsored by APL and Discovery Education, takes Maryland middle school students behind the scenes of space missions and introduces them to the people who conduct some of NASA's most exciting projects.

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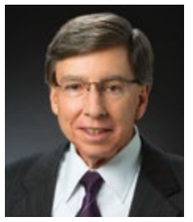

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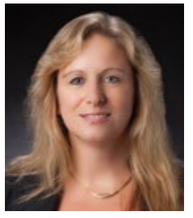

Aili Kujawa
Head, Human Resources
and Services

Michael Misumi
Head, Information
Technology Services;
Chief Information Officer

2013 Financial Statement

During the fiscal year that ended September 30, 2013, the Johns Hopkins University Applied Physics Laboratory recorded revenue from contracts and grants totaling $1.14 billion, compared with $1.08 billion for the previous fiscal year. 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.

About the Johns Hopkins University Applied Physics Laboratory

The Johns Hopkins University Applied Physics Laboratory strengthens our nation through transformative innovation and trusted technical leadership in national security and in space. For more than 70 years, APL has provided critical contributions to critical challenges with systems engineering and integration, technology research and development, and analysis. Our scientists, engineers, and analysts serve as trusted advisors and technical experts to the government, ensuring the reliability of complex technologies that safeguard our nation's security and advance the frontiers of space. We also maintain independent research and development programs that pioneer and explore emerging technologies and concepts to address future national priorities.

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