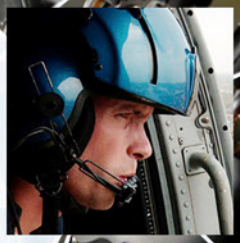
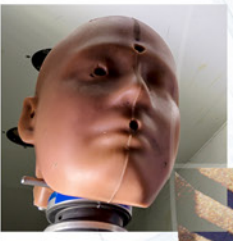
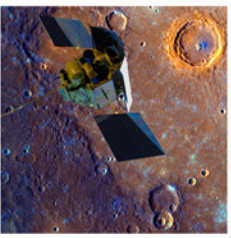
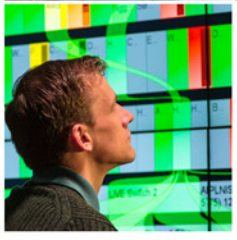
2014
Annual Report





APL JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

About The Johns Hopkins University Applied Physics Laboratory

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.

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Director's Message

We live in a world that is witnessing an incredible transformation at least partially driven by the diffusion of advanced technologies across the globe and their application by people and groups with competing goals and ideologies. As a result, the threats to our nation's security are more complex than ever before, and the technological advantage our military has enjoyed for decades is being challenged.

Here at the Johns Hopkins University Applied Physics Laboratory, our scientists and engineers are identifying and seeking solutions to these challenges, and we are applying our expertise across a broad spectrum of research fields, analyzing, harnessing, and exploiting emerging technologies to keep our nation safe.

During the past year, we made critical contributions to the challenges facing our sponsors in areas ranging from under the sea to space, and we have developed autonomous capabilities that can offset the asymmetric advantages of potential adversaries. We applied our technical knowledge and domain expertise to create new concepts and prototypes to enhance our military forces' ability to operate in contested areas of the world, and we adapted existing technology platforms to provide cost-effective solutions to meet new mission requirements. Many of these contributions are highlighted in this report. Others remain among the Laboratory's silent contributions to the security of our nation and its citizens.

Scientists and researchers working in other areas of the Laboratory advanced the frontiers of science, developing concepts and technologies to expand our knowledge of our solar system and space weather, breaking new ground in their pioneering efforts to apply brain–computer interface technology, and mentoring the next generation of American scientists and engineers through our internship and STEM outreach programs.

As we enter our 73rd year of service to the nation, we are more than ever focused on our role as a national resource—delivering innovative technologies and solutions to meet new and emerging sponsor needs.

We approach the complexities and missions of the coming year with confidence in our capabilities as we embrace the opportunity to make critical contributions to critical national challenges.

Ralph Semmel

APL provided key design and analysis before, during, and after the successful first flight test involving components of the Aegis Ashore system. The Aegis Weapon System fired a Standard Missile-3 Block IB guided missile from a land-based Vertical Launch System. (Missile Defense Agency)

Aegis Ashore

New Applications for Proven Technologies

As early as the mid-1980s, the U.S. Navy believed its Aegis Combat System could play a vital role in defending the United States and forward-deployed forces against ballistic missile attacks. Even as Patriot Missile batteries were being deployed 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.

That led to an experimentation and demonstration program to mature naval exoatmospheric Ballistic Missile Defense (BMD) capabilities—first with the Terrier Lightweight Exo-Atmospheric Projectile (LEAP) missile and then with the Aegis LEAP Interceptor (ALI). The program's efforts culminated on January 25, 2002, with the first successful Standard Missile-3 (SM-3) intercept of a ballistic missile target during Flight Mission-2 (FM-2), marking the dawn of a new era for the U.S. Navy.

To meet a presidential directive for fielding initial missile defense of the United States, Aegis BMD began fielding in 2004 to provide the Ballistic Missile Defense System (BMDS) with the capability to detect and track long-range ballistic missiles threatening U.S. territory. Since then, five Ticonderoga-class cruisers and 25 Arleigh Burke-class destroyers have been modified to serve as sea-based short- and medium-range ballistic missile defense platforms, armed with a combination of the Aegis Weapon System and SM-2 Block IV and SM-3 Block IA and IB missiles. These ships, currently serving in the Pacific and European theaters, provide our nation with the ability to intercept ballistic missiles before or after they reenter the atmosphere, to defend forward-based U.S. interests and allies.

As the Missile Defense Agency's (MDA's) Technical Direction Agent (TDA) for the Aegis BMD program, APL has played a key role in developing and validating the capabilities of these systems in 34 Aegis BMD flight test missions during the past 14 years.

In 2009, the director of MDA and the Aegis BMD program director tasked APL to colead an analysis of alternatives (AoA) study to develop a land-based concept that leveraged the SM-3 missile for defense against short- and medium-range ballistic missiles. The AoA recommendation to essentially move the Aegis system ashore was embraced by MDA. Subsequently, the recommended system architecture became a central component of a Presidential Directive on September 17, 2009, announcing the Phased Adaptive Approach (PAA)—an evolutionary ballistic missile defense system architecture comprising an Aegis BMD combat system, adapted to land, to be deployed in Romania by 2015 (PAA Phase II) and in Poland by 2018 (PAA Phase III). This new land-based instantiation of Aegis BMD became known as Aegis Ashore.

Expertise at the Ready

From 2010 to 2013, MDA counted on APL to perform the necessary TDA engineering functions to ensure the successful systems engineering and testing of the land adaptations required to make Aegis Ashore a reality. These functions included requirements development, performance evaluations, and systems engineering for hardware integration and testing at the land-based test site.

By 2014, the Aegis Ashore Missile Defense Test Complex (AAMDTC) had been built at the Pacific Missile Range Facility (PMRF) in Kauai, Hawaii, and was ready for testing during Aegis Ashore Control Test Vehicle-01 (AACTV-01). The AAMDTC was configured with Aegis Weapon System Baseline 9 (BMD 5.0) and an SM-3 Block IB to successfully engage a dynamic test target (simulated target) in AACTV-01.

As reflected in the AAMDTC, a key element of Aegis Ashore is that the SM-3 Vertical Launch System (VLS) is located miles away from the weapon system deckhouse housing the SPY-1 radar, a significant departure from a ship configuration. APL led the scenario development, orchestrated high-fidelity Aegis Ashore predictive performance analysis, conducted debris analysis for range safety, determined acceptable launch windows to avoid orbiting satellites, and supported AACTV-01 test execution.

System Success

On May 20, 2014, AACTV-01 was successfully conducted. It verified Aegis Ashore's ability to launch, control, establish uplink/downlink communication with, and provide guidance commands and target information to the SM-3 Block IB.

The land launch presented unique range safety challenges that APL helped resolve. These solutions included development of a novel algorithm for verifying the missile telemetry track to improve range safety situational awareness.

After the mission, APL experts began examining missile telemetry and weapon system data from PMRF to verify that performance matched preflight predictions. This was a crucial step toward demonstrating that we understand the combat system well enough to confidently deploy it to Romania. Initial results supported quick-look reviews at the test range, while more extensive analyses continued at APL until the final mission data review months after the test.

The lessons learned from AACTV-01 are now being applied to the first Aegis Ashore intercept mission at PMRF in 2015, named Flight Test Operational (FTO)-02 Event 1, which will demonstrate the full PAA architecture, including the addition of the land-based AN/TPY-2 radar and communication elements. As this "graduation test" incorporates a broader scope of BMDS functionality than AACTV-01, APL engineers and scientists are participating in leadership roles on multielement working groups across MDA. APL is evaluating Aegis Ashore performance by running high-fidelity models and conducting hardware-in-the-loop testing that incorporate the full PAA architecture. This combination of modeling and testing will provide the highest confidence to MDA leadership that all FTO-02 Event 1 test objectives can be achieved.

By incorporating proven, effective, and reliable technology, Aegis Ashore has evolved from a concept to a reality. It is a system that will strengthen our nation's ability to defend our allies from the threat of hostile ballistic missile attacks.

APL will continue to provide PAA Phase II performance evaluations to MDA to ensure effective introduction of this key BMD capability into the hands of the warfighter. Likewise, APL will play a key role in the development of the PAA Phase III system, including the next-generation weapon system (BMD 5.1) and missile (SM-3 Block IIA) to further extend U.S. capability to protect allies and forces around the world against the ever-increasing ballistic missile threat.

We lead the technical direction, testing, and evaluation of the revolutionary Naval Integrated Fire Control – Counter Air (NIFC-CA) system. During a three-day test in June 2014, NIFC-CA conducted the longest surface-to-air engagement in naval history, using a Standard Missile fired from the USS John Paul Jones, shown here launching an SM-6 during that event. (U.S. Navy)

Air and Missile Defense

Since 1942, APL has 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 advanced long-range ballistic and cruise 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.

Naval Integrated Fire Control – Counter Air (NIFC-CA)

NIFC-CA is a system of systems designed to extend the ship-borne theater air and cruise missile defense battlespace beyond the existing stand-alone capability of surface ship-controlled air-defense weapons. NIFC-CA leverages Standard Missile-6 (SM-6), the Aegis Weapon System, the Cooperative Engagement Capability (CEC), and cooperating sensors to provide an over-the-horizon engagement capability. APL led the execution of testing and evaluation of the NIFC-CA effects chain for Increment 1. Our leadership in testing, Technical Direction Agent (TDA) roles with the Standard Missile, Aegis, and CEC program offices, and systems engineering contributions enabled closing the fire control

loop through a series of successful tests in 2014. Increment 1 reached initial operational capability in March 2015 with the deployment of the USS Theodore Roosevelt Strike Group. APL significantly contributed to the longest surface-to-air engagement in naval history. This historical test of NIFC-CA, in June 2014, highlighted the value and enormous capability the program brings to our warfighters.

In 2014, we were designated by the Program Executive Office for Integrated Warfare Systems as lead for systems engineering activities supporting the next increment of NIFC-CA. Our unique position enables effective development through leveraging TDA roles and capitalizing on the existing close relationships with industry and government partners. The Laboratory's trusted technical advisor role across these programs creates a world-class, multipartner systems engineering organization focused on improving the NIFC-CA effects chain and transitioning this new capability to our warfighters.

Surface Electronic Warfare Improvement Program Successfully Installed

APL worked with the Naval Sea Systems Command (NAVSEA) to complete installation and operational testing of the next-generation shipboard electronic surveillance system, the Surface Electronic Warfare Improvement Program (SEWIP) Block 2, on board the USS Bainbridge (DDG-96). In addition, APL is leading the engineering design, algorithm development, and prototyping for the Soft Kill Coordinator (SKC), which provides direction and scheduling for onboard and offboard soft kill weapons. Playing a critical role in the development of the next-generation decoys slated for 2020, APL is working collaboratively with the Naval Research Laboratory to deliver the surface electronic warfare testbed that will be used to support capability assessments and tactical employment for electronic warfare systems.

Evolved Sea Sparrow Missile (ESSM) Block 2 Development

APL is playing a key role in the development of the ESSM Block 2 with a dual mode active/semi-active radio frequency (RF) seeker. ESSM is a short-range RF-guided missile being developed by a 12-member-nation consortium to provide self-defense capability for the ships of the U.S. and consortium member navies. Within the U.S. Navy, the new missile provides the outer layer of defense against anti-ship cruise missile threats for our aircraft carriers and amphibious ships and an inner layer of defense for ships equipped with the Aegis Combat System. We performed key missile design analyses, focusing on the radome, seeker antenna, and autopilot design, and we continue to lead the effort for integration of the missile into the U.S. and consortium navy combat systems. Our expanded role also includes collaborating with the Commander of Operational Test and Evaluation Forces to develop a plan for operational testing.

Affordable APL-Developed Target Flies on Aegis Ballistic Missile Defense (BMD) Flight Test Mission-22 (FTM-22)

APL engineers played a critical role in the development of the Terrier-Terrier-Oriole-E (TTO-E) target vehicle that was successfully intercepted by the Aegis BMD weapon system in October 2013 at the Pacific Missile Range Facility in Hawaii. We conceived, designed, and fabricated the separating nose tip of this target, which was the object to be intercepted. This critical flight test for the Aegis BMD program was an initial operational test and evaluation event and a prerequisite for a Standard Missile-3 Block IB production decision. The Missile Defense Agency leveraged concepts developed by APL for affordable targets used in fleet training exercises and adopted the TTO-E for use in FTM-22 after determining that it met its criteria for threat representation. APL developed an imaging sensor, thermal instrumentation, and an inflatable instrumentation boom that were also part of the TTO-E target configuration. The success of the TTO-E during FTM-22 led to its use in future flight tests and to the development and prototyping of additional follow-on nose tip designs.

Space Layer Options Study Defines Path for Missile Defense Layer

During 2014, APL served as technical lead for a critical analysis to define a path to a working missile defense space layer, designed to field a constellation of satellites to track ballistic missiles during their post-burnout, midcourse phase of flight. The Space Layer Options Study, sponsored by the Missile Defense Agency (MDA) with participation by the Air Force and six government-funded research centers, developed a variety of space architectures that can be quickly fielded with existing technology for a moderate investment and low cost risk. These architectures provide key near-term benefits to the Ballistic Missile Defense System in their initial configuration and can be incrementally grown into larger, more robust constellations. Senior leaders in MDA, the Air Force, and the Office of the Secretary of Defense praised the groundbreaking APL-led study. We are now working with MDA to further refine the space system concepts and inform an appropriate acquisition approach.

Air and Missile Defense Radar (AMDR)

APL provided systems engineering expertise and technical leadership to develop a transformational capability for the Navy: the next-generation multifunction array radar for the Aegis Combat System on future Arleigh Burke-class destroyers (DDG 51) Flight III. With more than 30 times the sensitivity of the AN/SPY-1, AMDR's active-element arrays and digital architecture will provide the unprecedented capability to counter raids of advanced air and ballistic missile threats. This significant increase will enable joint forces to maintain a forward presence and maneuver in complex theaters of operation. We also provided multidisciplinary expertise to assess contractor performance predictions, physical and functional design details, software development processes, and system verification methods. Additionally, our systems engineering expertise has resulted in the development of a robust system security architecture to address cyber threats. Our scientists and engineers are working closely with the Navy on this program, and we are conducting performance analyses and architecture studies to inform government decisions regarding fundamental engineering and capability choices.

Altered image of a U.S. Navy destroyer, used to illustrate installed components of the new, highly capable Air and Missile Defense Radar (AMDR). (Original photo: U.S. Navy)

Asymmetric Operations focuses on three challenges: the rise of non-state adversaries, the availability of weapons of mass destruction, and the emergence of cyberspace as a battlefield. By coordinating engineering expertise, data, and analysis, we provide the nation with solutions that improve security at home and abroad.

Countering Emerging Threats

New Technology for New Challenges

In October 2011, APL brought the Special Operations, Homeland Protection, and Cyber Operations mission areas together as the Asymmetric Operations Sector to address new national security challenges arising from three 21st-century phenomena: the emergence of cyberspace as a battlefield, the rise of non-state actors as a significant threat, and the ubiquitous access to news and information via social media and the Web. This latter phenomenon gives small groups disproportionate worldwide influence and access to technology expertise, especially about the fabrication of weapons of mass destruction (WMD). The threats that arise from these phenomena have characteristics that are substantially different from traditional threats.

First, they exploit a strategic vulnerability—that is, a vulnerability that is inherent in the nature of the United States, something that cannot be changed. For example, as the most cyber-dependent nation on Earth and the locus of the most valuable intellectual property, the United States has far more to lose from cyberattack than its adversaries do. Although a stronger cyber defense will limit the damage U.S. adversaries can inflict, the asymmetry in vulnerability will remain. Terrorists exploit the openness of American society and the value it attaches to privacy in order to carry out horrific acts of violence against innocent people. America cannot correct this asymmetric vulnerability without fundamentally changing its character.

Second, these threats are elusive—they present no visible, fixed target. Cyberspace is a prime example of a battlefield that ignores traditional notions of geography and physical boundaries. Less obviously, terrorists are not tied to a geographic location as much as to an ideology. The "center of gravity" for terrorism is in the minds and convictions of the people who support it. The production of WMD, particularly biological weapons, is no longer confined within either political or geographic boundaries. With its defenses designed to capture or defend territory, the United States needs new ways to address threats that are not rooted in geography.

Both the sponsorship and technology solutions for combating these new threats are highly diverse. APL has adapted and evolved to meet the nation's new national security research and development needs. For example, we have augmented our longtime expertise in traditional military communications with extensive knowledge of commercial networks and developed a competency in both cyber defense and exploitation. Competencies in cyber operations support multiple functions, such as intelligence gathering, locating terrorists, and protecting the nation's critical infrastructure. Our deep competency in radio frequency (RF) communications has proven particularly useful in cyber operations, in light of today's widespread use of commercial mobile communications and computing technology. This same RF expertise has also been taken in a completely new direction, to supply geolocation technology meeting difficult and stringent requirements for special operations use.

APL has also grown new expertise. For example, we have assembled a sizable group of scientific experts in radiological, chemical, and biological phenomenology, and added specialized infrastructure to support their research on combating WMD. This research supports both countering proliferation of these weapons and preventing their entry into the United States.

The expansion of APL's technological capabilities has broadened the roles we can provide to an increased sponsor base. We're building relationships with the special operations, intelligence, and homeland security communities that we have long enjoyed with the Navy. Each of these communities has a character that differs from our traditional sponsors.

APL directly supports U.S. special operations forces like the ones shown here as they prepare to board a UH-60 Black Hawk helicopter during a mission in Kunar province, Afghanistan. (U.S. Navy)

Accordingly, we have built the staff and facilities at the requisite level of clearance to engage with the intelligence community, we are adjusting to the rapid pace of development needed in the special operations community, and we are developing trusted relationships and a record of accomplishment with domestic agencies that play a key role in meeting asymmetric threats, such as the Transportation Security Administration and Customs and Border Protection.

Operations that address asymmetric threats are continuous and span the globe. For example, combating terrorism includes building a comprehensive intelligence picture of the plans and locations of multiple terrorist groups, disrupting the growth of terrorism through long-term engagements around the world, taking direct action, securing the nation's borders against terrorist infiltration, and developing a rapid domestic emergency response that blunts the impact of a terrorist attack on American soil. These activities, as well as those associated with combating WMD and cyberattack, cut across the sponsor and capability space of all three Asymmetric Operations mission areas.

The roles of the many organizations and agencies involved in managing these "new" asymmetric threats have yet to be conclusively defined. We have a rare opportunity to help shape national security strategy, drawing all of these disparate activities into a seamless operation with smooth handoffs among agencies that are involved in different ways, at different times, and in different regions. Ultimately, we aim to give the United States an enduring advantage in the fight against terrorism, WMD, and cyberattack.

Our Live data, Integration, Validation, and Experimentation (LIVE) Lab gives APL a powerful tool to evaluate cyber capabilities. In 2014, we hosted part of an Office of the Secretary of Defense project designed to improve the skills of our nation's cyber warriors.

Cyber Operations

We are helping to reshape intelligence and warfare around a new paradigm. APL's work broadens cyber efforts beyond point solutions, focusing on developing full-spectrum cyber solutions for key sponsor systems. Drawing from our disciplined systems engineering expertise, we are developing an agile cyber systems engineering methodology for continually changing cyber systems. APL is vigorously pursuing the science and technology needed for tomorrow's intelligence and full-spectrum cyber warfare systems.

Cyber Risk Assessments

In 2014, APL initiated the Nuclear Command, Control, and Communications (NC3) Cyber Risk Assessment (NCRA) project. Under the sponsorship of the Defense Information Systems Agency's Joint Systems Engineering and Integration Office, we lead a multifaceted team of government and industry experts in cybersecurity, systems engineering, and nuclear operations, all providing an in-depth, mission-focused look at nuclear-survivable NC3 systems. This team has already visited 13 NC3 locations and gathered data on six decision-making systems that support national leaders and military commanders during a national emergency. Over the next year, the team will assess 17 additional survivable systems used to direct, execute, and manage nuclear forces and will report to the Department of Defense's chief information officer on the cybersecurity of the nation's NC3 system.

Our researchers go into the field to work with personnel from U.S. Customs and Border Protection to help them better protect America from threats and illegal activities.

Joint Tactical Networks

APL serves as a technical advisor and interoperability standards profile developer on the Network Management Working Group established by the Department of Defense's chief information officer. The group is examining how joint tactical networks align and serve the changing needs and priorities of Joint Task Force mission commanders, addressing gaps in network efficiency, speed, and agility, and focusing on systems-level interoperability among the technologies used to manage and secure communications devices and networks, as well as information technology infrastructure and applications. We represented the group at Joint Users Interoperability Communications Exercise (JUICE) 2014, successfully exchanging information between a commercial off-the-shelf trouble-ticketing system and an open-source ticketing system.

Cyber ACEs

APL has been developing and coordinating agile systems engineering experiments known as Analytics Capabilities Exercises (ACEs), which provide an opportunity for engineers and scientists to dig into the requirements, architectures, and design decisions involved in integrating and adopting advanced cyber-protection technologies. Under a simulated malware attack, ACE 2 participants were challenged to quickly shift the advantage from attackers to system defenders. By leveraging our own "Code DNA" software, which locates malware variants through a fingerprint-matching technique, researchers sought to automate the task of evaluating multiple sources of threats—and cut the time needed to detect, analyze, and respond to malware from "months to milliseconds." Going forward, we will partner with government organizations to deploy ACE 2-motivated technologies, automation, and architecture to provide game-changing advances to malware detection and cyber system defense.

Cyber Warriors

When the Department of Defense holds a major exercise to train the nation's cyber warriors on how to best use the latest technologies, APL engineers and analysts are a critical part of the team. Our experts design, deploy, and support systems that provide new, graphical technologies to display, integrate, and store exercise data for analysis; support the participating teams in their own data analysis; and facilitate the briefs and reports that track and evaluate the success of each exercise. We were on board for Cyber Flag, hosted by U.S. Cyber Command at Nellis Air Force Base, Nevada, and Cyber Guard, a two-week exercise at the Federal Bureau of Investigation (FBI) Academy in Quantico, Virginia, focused on guarding the nation's critical infrastructure and key resources. We also hosted a segment of the five-part Project "C" (sponsored by the Office of the Secretary of Defense's Director of Operational Test & Evaluation) to evaluate cyber capabilities and improve initiatives and efficiency among people, processes, and tools.

Dagger

Mission success frequently depends on a complex web of interdependent activities, services, and systems, which makes it difficult to understand the impact on the overall mission when a component fails. APL researchers created the Dagger mission modeling and real-time assessment tool to organize and display mission dependencies, so that mission decision makers can plan, predict, execute, and respond quickly as real-time events force mission-critical decisions and reactions. Under sponsorship from Army Network Enterprise Technology Command (NETCOM), we used Dagger to map an Army mission's key cyber terrain and fuse results from cyber defensive analytics to present the mission impact of a cyberattack. The NETCOM Capstone featured Dagger's ability to give network defense service providers and cyber protection teams the situational awareness needed to actively defend the network and provide the commander with decision support to fight through an attack.

Homeland Protection

Our programs address a wide range of critical tactical and systems-level challenges related to border security, multimodal transportation security, safe and resilient infrastructure, cybersecurity, risk assessment and management, situational awareness of the threat environment, global health surveillance, and all-hazard national preparedness. The solutions we deliver for our sponsors reflect our deep understanding of operational realities and our close association with frontline security, law enforcement, and emergency response personnel.

Helping Protect and Defend the Nation's Borders and Coastline

APL is working closely with the U.S. Border Patrol (USBP) to help protect the nation's 6,000 miles of international border and 2,000 miles of coastline waters from illegal activities. USBP's mission spans a vast area with diverse and adaptive threats that create the continual need to evaluate and update their capabilities. APL has developed both the process and analytical tools to provide comprehensive mission analysis. These tools help USBP capture and articulate its needs and provide justifications, measures, and scenarios to help support and evaluate acquisition decisions.

A key part of this effort is achieved through a Capability Gap Analysis Process, a collaborative exercise that uses threat scenarios which participants discuss in detail and rate according to their current performance. The agents and other stakeholders collectively

represent a diverse set of expertise and experience levels, and their self-evaluation provides a solid foundation for a detailed analysis.

In combination with that analysis process, we developed a suite of analysis tools to help USBP visualize and analyze operational capability and performance. Called the Total Station View (TSV), it displays and quantifies various environmental, tactical, and technical elements of USBP operations, using physics-based models, process flow tools, and geospatial analysis methodologies to assess threat activity, system performance, and asset utilization. Together, these critical APL contributions are lending analytical rigor to strengthen border security.

Applied Technology Advances Aviation Security

Screening passengers and their baggage at airport security checkpoints and preventing access to restricted airport areas by unauthorized personnel are two of the most challenging issues facing aviation security today. Recent research, development, testing, and evaluation efforts for the Transportation Security Administration (TSA) are helping TSA maintain the technological edge needed to detect various threats while preserving passenger privacy and dignity during the screening process.

Our researchers conducted a technology study to improve TSA's approach for checkpoint technology development and acquisition planning. Open-source research was paired with insights collected from expert interviews with representatives from TSA, the Department of Homeland Security Science & Technology Directorate (DHS S&T), industry, academia, and national laboratories—resulting in a pair of comprehensive reports. The reports outlined potential technology development pathways for advanced imaging technology, carry-on baggage, explosives trace, and bottled liquid screening devices, and provided the most extensive look to date at potential checkpoint technology advancements.

We also conducted a cyber evaluation of a carry-on baggage screening system through a quick-turnaround test and evaluation activity that showcased the Lab's reverse engineering and cybersecurity evaluation expertise. The Laboratory also developed an interactive electronic database called the Augmentable Library of Chemicals, Explosives, and Materials for Homeland Security (ALCHEMY), which has become a core resource used by TSA to ensure appropriate selection, creation, and use of surrogate items approximating threats in their testing of explosives detection systems.

We also supported efforts to enable greater use of technology solutions in airport exit lanes where passengers egress from "sterile" into public areas. We developed technology selection guidelines and a set of Web-based, self-guided tools that allow airport operators to independently assess their technology needs and choose potential technology options based on unique physical configurations and the environment surrounding their exit lanes. These products were designed for airports of all sizes and were validated by industry and field users. The products currently have over 240 users representing more than 150 airports nationwide.

Applying Technology to Make Air Travel Safer

The Traffic Collision Avoidance System was developed in the 1970s in response to a series of tragic midair collisions. This system helps avoid collisions by tracking intruding aircraft using air-to-air transponder-based surveillance and issuing vertical guidance, in the form of cockpit visual and audio alarms generated via a complex set of heuristics. Our scientists and engineers have been contributing expertise to this system since 2004, and, more recently, they made a variety of contributions to the Federal Aviation Administration's funded research for a system known as the Airborne Collision Avoidance System Next Generation. This new system is being developed in response to the growth of air traffic worldwide and the changing nature of the airspace. The system is designed to adapt to the new airspace and improve safety, operational suitability, and acceptability (maintaining pilot trust in the system). The new system leverages novel surveillance inputs, including GPS-based Automatic Dependent Surveillance-Broadcast (ADS-B), and noncooperative sensors, such as those carried by some unmanned aerial systems, allowing the development of software specifically designed to account for unmanned aerial systems.

Our work has included significant inputs to the design details of the surveillance and threat logic and culminated in late 2014, when we led a Federal Aviation Administration-sponsored proof-of-concept flight test of the system at NASA's Armstrong Flight Research Center at Edwards Air Force Base, California. The flight test demonstrated for the first time the system's automatic response capability, which represents a significant milestone toward the eventual integration of unmanned aerial systems into the national airspace.

Portable Radiation Detection

Since 2006, we have worked alongside the Domestic Nuclear Detection Office in the Department of Homeland Security to improve radiation detection through the use of portable systems, mobile mounted systems, and stationary systems such as portal systems used at ports of entry.

As initial portal systems are nearing the end of their 10-year life cycle, we began work on the Polyvinyl Toluene Portal Improvement Project, a passive scanning radiation system designed to provide cost-effective and efficient solutions. The new system has an analysis algorithm that exploits the characteristics of potential threat radiation sources. As portals are crossed, radiation sensor panels detect any radiation and send the information to a supervisory computer for agents to read. Our contribution to the system has been improving algorithms and test efficiency. We proposed an optimization of the current algorithm that yields similar or better performance compared to the baseline algorithm, significantly decreases false-alarm rates, and requires no change to the existing hardware.

Testing threat materials against proposed algorithms can be challenging in an operational environment. We have worked with the sponsor to design surrogate objects that can be taken into an operational environment and represent the actual threat. This reduces costs by eliminating the need to test each newly developed algorithm in the field and makes testing realistic. We established an algorithm testbed to run various algorithms or modifications to current algorithms in software, to evaluate the algorithms' performance. This analysis can be done quickly (and the resulting data can be used for selection purposes) compared with testing all candidate algorithms in the field.

APL is guiding transition of the Tactical Operational (TACOP) LIDAR system (shown here) and other intelligence, surveillance, and reconnaissance Quick Reaction Capabilities to a formal program of record as part of EMARSS for the U.S. Army.

The EMAPS unit has collected more than 100 hours of mapping data from a wide array of GPS-denied environments—including ships (pictured), underground storage facilities, buildings, and Army training areas—and APL's main campus.

Special Operations

We create and enable asymmetric capabilities for the special operations community through objective technical direction, emerging technologies, and quick-response capabilities and solutions. These include raising situational awareness through high-precision, countermeasure-resistant tailored technology for intelligence, surveillance, and reconnaissance. We provide increased capabilities for their military information support operations and counterproliferation of weapons of mass destruction core activities.

Advancing the Knowledge Base of EMARSS

We led the effort to deliver a major study of 12 Quick Reaction Capability (QRC) manned intelligence, surveillance, and reconnaissance (ISR) aircraft and their systems to the Army's Program Executive Office (PEO) Intelligence Electronic Warfare and Sensors (IEW&S) Program Manager for Sensors, Aerial Intelligence (PM SAI). The study detailed a recommended configuration for aircraft that are cycling home from Afghanistan and are destined to be part of the Enhanced Medium Altitude Reconnaissance and Surveillance System (EMARSS), and informed future acquisition strategy. The team delivered a comprehensive analysis, with multiple reconfiguration potentials, and program recommendations that added value and content beyond the sponsor's scope. The study, which was included in the Army's annual report to Congress, has now served as reference material for the government's industry solicitation and has proven invaluable as the EMARSS acquisition strategy unfolds.

EMAPS: Mapping with a Backpack

APL engineers have developed a portable mapping system carried in a backpack—the Enhanced Mapping and Positioning System (EMAPS)—which can automatically create annotated physical maps in places where GPS is not available, such as in underground areas and on ships. Produced for the Defense Threat Reduction Agency (DTRA), EMAPS uses a combination of lasers and sensors to capture a floor-plan-style map of the area traversed, and it creates 360-degree photos and sensor readings of that area. In 2014, a dozen new interested sponsors reached out to EMAPS developers, and the technology was also featured in the Discovery Channel series "Brave New World with Stephen Hawking," which airs in the United States and the United Kingdom.

Stacking the CARDS

Under the sponsorship of the Defense Threat Reduction Agency (DTRA) Counter WMD Technology Department, we developed an operational prototype of a flying wing/multirotor hybrid platform called the Chemical, Biological, Radioactive, and Nuclear Defense (CBRN) Air-droppable Remotely Deployed System, or CARDS. The platform was designed to be dropped from an altitude of up to 60,000 feet, cruise to a delivery point, change to vertical takeoff and landing (VTOL) mode, land within a small target area, and depart after performing the mission. The CARDS platform was developed after an extensive analysis of alternatives. The system was successfully evaluated during drop tests that demonstrated autonomous air-drop, transitional flight, and precision emplacement capabilities. The precision landing portion of the mission has been tested successfully, and the platform will presently carry a payload of about five pounds.

Force Projection

Force Projection develops, delivers, and improves broad capabilities for the Navy, Air Force, and other services as they defend our nation's security around the globe. Shown here is the USS Theodore Roosevelt, leading ships from Carrier Strike Group 12 during a maneuvering exercise. (U.S. Navy)

Enabling Mission Success

Innovation and Solutions for the Warfighter

The nation's military forces are tasked with projecting power and influence around the globe to protect and defend American interests, often against increasingly sophisticated threats that range from anti-access/area denial technologies to air defense-confusing surface-to-air missiles to global-reach nuclear capabilities.

Keeping pace with these threats in an era of decreasing defense budgets drives the need for new thinking and innovation that includes the creative application of existing technologies. As a trusted technical advisor to sponsors, Force Projection leads a number of initiatives to develop new operational capabilities for mission success.

Fundamental to our approach is an increasing challenge to understand the operational problems with the user in mind. Each year, sector staff members work alongside warfighters from all services—at sea and in the field—to help us better understand their operational requirements, environments, and current technology applications. These engagements allow our experts to develop and apply technical solutions with a focus on three significant warfighter challenges.

Enabling Maritime Dominance in Contested Environments

Our Sea Control Mission Area delivers systems and technologies in support of U.S. Navy and joint service missions. We provide sponsors with the means to defeat undersea threats and deliver essential capabilities to project military power on, under, and above the sea. Our history of broad scientific and engineering expertise, combined with our ability to rapidly develop and test prototype systems, allows us to conduct extensive, complex research and development operations. APL has made many key undersea warfare contributions; Sea Control has broadened the scope of our programs. Today, these include development and fielding of innovative, effective solutions to provide global access for U.S. naval forces and to deny adversaries the effective use of the maritime domain.

Our contributions are focused in four key areas: enhanced maritime domain situational awareness, kinetic and non-kinetic effects to deter aggressors and de-escalate hostilities, force survivability against near-peer threats, and effective and affordable rapid prototyping and modernization. As an example, APL brought together the submarine, surface ship, and surveillance systems communities—as well as the Theater Undersea Warfare Commander (TUSWC)—for the AxB Watch Section Task Analysis, which examined how information flows between platforms and commands.

We have also developed new, affordable means for American ballistic missile submarines to maintain their stealth advantage in an increasingly sophisticated and networked undersea domain by developing comprehensive evidence-based metrics to improve submarine security patrol behavior.

In the past year, in partnership with Navy Warfare Centers, we rapidly developed the Mine Hunting Unmanned Surface Vehicle (MHUSV) system in response to an urgent operational need, and we repurposed an existing land-based surveillance platform to support multiple maritime uses. Our expertise in cyber has improved defense for Virginia-class submarines, and a collaborative team of engineers from across the mission area invented a cost-effective way to provide testing of advanced environmental sensors while in use. The system is now being expanded across additional submarine types.

APL developed requirements and performed systems integration for LightningSim, a low-cost F-35 Lightning II flight trainer that uses commercial off-the-shelf components that can provide up to 75 percent of human system interface training.

Precision Strike

We provide high-quality technical leadership and problem resolution in the conception, design, development, integration, and employment of detection and targeting, command and control, and engagement capabilities used for the projection of military effects appropriate to furthering national goals. Our efforts also include tactical aircraft, ship, and submarine programs as well as development of better technologies for tactical surveillance and targeting.

Low-Cost Flight Trainer

We have been instrumental in developing requirements and conducting systems integration for LightningSim, a low-cost flight simulator for the F-35 Lightning II program. Using commercial off-the-shelf components, we have used equipment that closely resembles the actual cockpit architecture to a high enough fidelity that as much as 75 percent of training on the human system interface can be accomplished without the need for costly live flight. The low-cost trainer is cost effective not only for the Department of Defense (DoD) but also for international partners who do not have access to trainers in their countries and must therefore travel to costly facilities in the United States. We are currently supporting the partners' simulator integration at facilities in their home countries.

Delivering Offensive Power Against Capable Adversaries

APL's Precision Strike Mission Area provides technologies and systems to support warfighter air-dominance and land-attack missions against peer adversaries and asymmetric threats. We deliver solutions associated with the challenges of detecting, targeting, and precisely engaging threats using both kinetic and non-kinetic means, while operating in contested anti-access/area denial environments. Our efforts are organized around platforms, weapons, and electronic attack systems with significant supporting elements in the areas of modeling, simulation, and analysis (M&SA); technology development; and prototyping.

In addressing precision strike challenges, we have developed and applied an overarching analytical framework that enables quantitative assessments of end-to-end system capabilities at the engineering, engagement, and mission levels for operations against highly integrated adversary defense systems. This analytical framework supports assessment of technology needs and development of new system requirements, and provides insight into operational tactics, techniques, and procedures.

We support development, acquisition, and operations of major platform and weapons systems, including the F-35 Lightning II, P-8A Poseidon, EA-18G Growler, MQ-4C Triton, Next Generation Jammer, Tomahawk Weapon System, and the Long-Range Anti-Ship Missile (LRASM). We also develop technologies and prototype systems for application to next-generation capabilities in areas such as autonomy; coordinated vehicle control; hypersonics; electromagnetic railgun; electronic warfare; data fusion; and vehicle guidance, navigation, and control.

Through combinations of innovative technology development, system acquisition, and resilient end-to-end integration, we aim to provide assured offensive strike capabilities that enable warfighter mission success in the highly contested and asymmetrical environments of today and into the future.

Realizing the Nation's Future Strategic Deterrent

One of the critical challenges faced by military leaders and policy makers is ensuring the continued readiness of the nation's strategic nuclear assets. The Strategic Deterrence Mission Area has served as a trusted advisor to the Navy's Fleet Ballistic Missile system program for more than 50 years. APL is now rising to the challenge of redefining strategic deterrence from the legacy nuclear-only mission to a broader set of responses to current and future national security challenges. Our goal is to provide technical leadership to ensure the long-term viability of our nation's strategic deterrence forces.

We work to achieve this goal primarily through our trusted agent support to the U.S. Navy's Strategic Systems Programs. As trusted agents, we analyze data collected during Demonstration and Shakedown Operations, Follow-On Commander's Evaluation Tests, and deterrent patrols to evaluate the operational accuracy, readiness, and reliability of the deployed Trident II Strategic Weapons System (SWS). We apply this knowledge to systems engineering and integration of new concepts, system alterations, and upgrades to the Trident II SWS to ensure its viable sustainment through 2080. We are expanding our role with the Air Force to include similar efforts on Air Force/Navy commonality, operational evaluation of the Minuteman III, and concept development for the next-generation Ground-Based Strategic Deterrent.

Our activities also include end-to-end systems engineering—from mission planning through battle damage assessment—and concept development and technology demonstration for Conventional Prompt Global Strike capabilities, emerging missions, and submarine payloads integration. Sponsors for these latter activities include the Air Force; Army; Defense Advanced Research Projects Agency; Navy; U.S. Strategic Command; and Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. We also collaborate with other government laboratories and agencies, including Charles Stark Draper Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories, and the Naval Surface Weapons Centers.

Through research, testing, and analysis, APL delivers solutions to maximize the effectiveness of our undersea warfare operations across a variety of platforms. Here, the Virginia-class USS Minnesota is shown during precommissioning sea trials. (U.S. Navy, courtesy of Huntington Ingalls Industries)

Increasing Intelligence-Gathering Affordability

The intelligence process used in our nation's defense has evolved along with the capabilities to gather information. As those capabilities multiply, there are challenges to processing the data. We completed a Task, Collect, Process, Exploit, Disseminate (TCPED) study on concepts based on two types of intelligence, surveillance, and reconnaissance (ISR) systems: a current, traditional system and a near-future, networked system of ISR systems. We used a model-based systems engineering approach to design for affordability, and the small study team rapidly developed an ISR network model that enabled efficient exploration of both the current and future concepts. Proofs of concept were created virtually and then rapidly prototyped, which provided preliminary verification of the concepts. Modeling and analysis of cost and ISR performance showed the near-future, networked system offered reduced operational cost, reduced asset requirements, and increasingly better performance with increased battlespace complexity. Key technology benefits within the netted ISR concept included cognitive command of ISR, collaborative sensor management, autonomous platform control, and multiple intelligence data fusion.

Swarming Offensive Systems

Weapon swarms challenge adversary capabilities to understand and effectively respond to the threat because they cannot accurately assess raid size or make out and address all of the weapons in time. Low-cost swarms offer the potential to impose an asymmetric cost on the adversary. We are developing technologies to enable low-cost swarming for precision strike. These developments include low-cost sensors/stimulators, algorithms for cooperative control, and swarming effectiveness analysis tools.

Tactical Hypersonic Strike

We serve as a technical advisor on tactical hypersonic strike weapon research programs utilizing both airbreathing propulsion and boost-glide technologies. Our contributions include operations analysis, conceptual design, and detailed independent analysis to help the government evaluate contractor weapon designs. We have also continued our technical advisory role in the Railgun Program and assisted the government in the areas of mission analysis, projectile testing and evaluation, and architecture development. Additionally, we have executed independent research and development activities focused on low-cost sensors for high-speed flight platforms and on computational modeling and simulation for hypersonic boost-glide systems.

T-45 Goshawk Trainer Sustainability

For more than eight years, we have been supporting the requirements and sustainment engineering areas of the Naval Air Systems Command's undergraduate flight training program. Our main objective has been to provide independent technical evaluations and analyses that can inform decision makers of efficiencies in engineering choices regarding the sustainability and supportability of the T-45 training aircraft. We have also used data furnished by the government to capture and document the current and updated processes that support the government-selected sustainment approach processes supporting the jet. Over the last four years, we have been instrumental in supporting decisions affecting the recapitalization of a large portion of the T-45 fleet. Our analysis, captured in a document called the *Sustainment Systems Engineering Guide Book* (SSEGB), was developed to be a living document that will guide current and new government staff through complex logistical procedures.

Sea Control

We support U.S. Navy and joint service missions, delivering essential capabilities to project military power on, under, and above the seas. APL has a significant record of key contributions to critical undersea warfare challenges and has more recently broadened the scope of our contributions to include developing and fielding innovative, effective solutions to provide global access for U.S. naval forces and to deny adversaries the effective use of the maritime domain. Our contributions are focused in four key areas: enhanced maritime domain situational awareness, kinetic and non-kinetic effects to deter aggressors and de-escalate hostilities, force survivability against near-peer threats, and effective and affordable rapid prototyping and modernization.

Increasing Innovation and Affordability Through Commonality

We have focused on applying successes in one arena to compatible other disciplines in order to maximize the value of lessons learned and solutions. Tactical Advancements for the Next Generation (TANG), designed to increase the speed and utility of technology deployment on submarines, expanded to a surface vessel TANG focused on surface anti-submarine warfare (ASW) challenges. More than 30 junior officers and operators

generated innovative capabilities to feed the Navy's advanced development process. Concepts generated during the Surface TANG Forum will be implemented in AN/SQQ-89 surface ship sonar over the next several builds.

Warfighting performance is threatened by the cost of developing and fielding capabilities. The Advanced Build (AxB) program addresses these challenges by driving the submarine, surface, and Integrated Undersea Surveillance System (IUSS) ASW systems to employ common technologies across a variety of platforms. AxB Watch Section Task Analysis was the first event to assess ASW systems across multiple platforms in a joint ASW scenario. The event brought together the submarine (APB), surface ship (ACB), and surveillance (ASB) systems along with the Theater Undersea Warfare Commander (TUSWC) in a synthetic environment to examine gaps in information flow between platforms and commands. Stakeholders/decision makers were able to see how the systems support working the ASW problem through the prism of a common scenario. Training, employment, setup, workarounds, decision methodologies, and strategies (pursuing vs. reacting) were all in plain view, first hand, and in real time. Analysis will focus on the strengths and weaknesses of each system and the system of systems, and whether situational awareness at the theater level is greater than the sum of the individual participants. Lessons learned and best practices for design and development were shared across communities.

Rapid Development of Mine Hunting Unmanned Surface Vehicle (MHUSV) for Fifth Fleet

We supported the Unmanned Maritime Systems Program Office (PMS-406) in the development of the MHUSV. The system was developed in response to a Fifth Fleet Urgent Operational Needs Statement (UONS), requesting a USV-based, day-night mine hunting capability. The MHUSV design leveraged existing Navy equipment and expertise at Naval Undersea Warfare Center Newport (Rhode Island), Naval Surface Warfare Center (NSWC) Panama City (Florida), and NSWC Carderock (Maryland). The first two systems were developed and delivered within 18 months of the UONS, and two additional MHUSVs will be delivered in 2015. APL developed hardware subsystems and operational documentation in support of this project, in addition to providing trusted program execution assistance to PMS-406.

Achieving Ground Surveillance Cost Efficiencies

The Persistent Ground Surveillance System (PGSS) program was initiated to provide a lower-cost, persistent intelligence, surveillance, and reconnaissance (ISR) solution to protect forward operating bases in Afghanistan. Lowering the cost was achieved in several ways, including government management, competition, and an APL-designed common modular gondola system.

Recently, the PGSS systems have been retrograded out of theater. Now, there is an ongoing effort to reuse the systems to support several Department of Defense (DoD) initiatives. First is the DoD's increasing focus on the Pacific region. Also, core PGSS technologies and designs are supporting an ongoing long-term demonstration for Customs and Border Patrol (CBP). In addition, the DoD is actively pursuing exportable configurations of both existing PGSS systems, as well as new configurations.

Increasing Our Impact for the Fleet

American fleet ballistic missile submarines (SSBNs) have operated essentially unopposed and undetected since the end of the Cold War. However, technology advances and proliferation have encroached on this primary mission. Our SSBN Operations Characterization team has developed a rapid but thorough analysis process and feedback initiative. The team developed a detailed and comprehensive "report card" of individual patrol behavior. In 2014, the team conducted 35 in-person reviews with commanders and crew, resulting in improved overall mission effectiveness and efficiency of each patrol and generating positive feedback from fleet operators. Additionally, as a member of the Navy's Anti-Submarine Warfare (ASW) Mobile Training Team, APL engages the fleet by providing ASW training on the latest surface ship sonar systems by subject-matter experts. And we facilitate hands-on training to Office of Naval Intelligence Acoustic Intelligence Specialists (ACINTs) through sessions that replay data from real-world submarine missions, focusing on recognition and optimal system employment, which in turn is passed on from the ACINTs to the submarine crews they support underway.

Applying Cyber Expertise to Defend Virginia-Class Submarines

For the past few decades, Navy platforms—including submarines—have leveraged digital processing systems to add enhanced warfighting capability, improve performance, and reduce costs. These gains incur a potential susceptibility to cyberattack and other processing system failures that must be managed, just like damage from corrosion, vibration, or kinetic attack is managed. In a joint effort, our Force Projection and Asymmetric Operations sectors invested internally to develop an understanding of operational dependence on digital processing systems and networks, and devise strategies to efficiently mitigate potential liability. Our preliminary strategy for managing these risks resonated with the Virginia-class submarine program office at the Naval Sea Systems Command, and the team has been commissioned to propose an integrated scheme to ensure that these submarines remain fully operational when faced with a malignant cyber environment.

Developing a Cost-Efficient Environmental Measurement Tool for Submarines

In June 2013, a group of APL engineers came together with the goal of reducing the cost of collecting environmental measurements during submarine at-sea testing. These environmental measurements play a critical role in understanding how the local environment affects sonar, radar, and optical sensor performance, and they allow submariners to best employ organic sensors and effectively evaluate their vulnerability to threats. The team initiated a grassroots effort, leveraging disparate capabilities across multiple projects and technical groups to acquire this data more efficiently. Force Projection used internal funds to design and build what became known as Hydrate, a flexible backbone of environmental sensors, data collection equipment, and analysis and display software. The team then convinced the sponsor to undertake an at-sea test (called Pelagos) of the system on board a Los Angeles-class attach submarine (SSN). The test was an unqualified success and demonstrated a reusable, low-cost option to collect data during sea tests, establishing Hydrate as a development platform to evaluate advanced sensors and displays for their tactical potential. We have been requested to provide proposals to design, fabricate, and deploy an SSBN version and a Virginia-class SSN version.

Since the inception of the U.S. Navy's Fleet Ballistic Missile program in 1956, APL has provided technical and analytical guidance and evaluation to the Navy for these critical strategic deterrents. (U.S. Navy)

Strategic Deterrence

For more than 50 years, we have made vital contributions to the U.S. Navy's Fleet Ballistic Missile program. We are rising to the challenge of redefining strategic systems from the legacy nuclear mission to a broad set of responses to current and future national security challenges. Our mission area demonstrates unequaled expertise in system development, testing, and evaluation, and we are applying that knowledge to the newly expanded roles of strategic systems in the Department of Defense.

Improved Decision Making for USSTRATCOM Mission Planning

As part of our long-standing support of the mission of the U.S. Strategic Command (USSTRATCOM) in its stewardship of the nation's strategic capabilities, we have continued development of a rapid strike mission planning capability prototype. New enhancements provide better collaborative decision-making processes, supported by multiple and integrated courses of action, and deliver measures of effectiveness with confidence assessments, where applicable. This prototype capability has been recently demonstrated to both the service and acquisition communities as a tool to enable prompt strikes against time-critical targets.

Developing Tests to Create Trusted Electronics

In collaboration with Naval Surface Warfare Center Crane Division, APL is helping the U.S. Navy protect their supply chain of electronic parts and assemblies from being contaminated by counterfeit and maliciously manipulated parts. We are developing a new approach incorporating risk-based analyses to determine what tests should be conducted on these parts and assemblies and how many should be tested. This approach takes into account the architecture of the system, the robustness of the supply chain, and quantifiable confidence in various underlying parameters.

Finding Undiscovered Trends in Weapons Systems' "Big Data"

Applying the tenets of Big Data that are also being applied to various other Department of Defense, National Institutes of Health, and Department of Homeland Security problems, including tracking potential terrorists, we are helping Strategic Systems Programs (SSP) get a handle on their diverse data collected over several years from several subcontractors in both digital and handwritten forms. The primary goal is to give the director of SSP, branch heads, and mid-level managers a dashboard view of the status of the entire U.S. Navy nuclear deterrence enterprise. A secondary goal is to discover previously undetected connections between diverse data streams that might be able to be used to focus future research and development efforts at SSP.

A New Submarine GPS Antenna for Rough Seas

To allow for more consistent reception of GPS data at speed and depth, we have developed a more advanced GPS antenna to be incorporated into the trailing wire antenna deployed by submarines from the AN/BRR-6 towed buoy. The new antenna assembly includes components to allow for GPS reception in high sea states by incorporating a frictionless connection between the primary wire and the antenna elements. These roll-invariant components maintain the overall buoyancy of the antenna and the upward orientation of the GPS elements while allowing the trailing wire to twist and turn in the prevailing currents and waves.

Cost Savings Through Risk–Benefit Analysis of System Requirements

In 2011, the U.S. Navy's Strategic Systems Programs established a program plan to address key risk areas. Most efforts to date have examined the Strategic Weapon System (SWS) architecture to discover opportunities to maintain demonstrated performance at reduced cost. We approached the problem from a different viewpoint than other researchers, hypothesizing that costs could be reduced by relaxing select system requirements. The Laboratory developed the Requirement Affordability Analysis, a process that evaluates changes in system performance and cost savings that might accrue from relaxed requirements. Input and data from multiple stakeholders were crucial in the process, as was APL expertise in analysis and systems. Several options were ultimately generated, with one providing both increased performance and cost savings. Although the test cases examined high-level SWS requirements, the process is scalable and can be extended to requirements that affect the system, subsystem, and component levels.

The effects of space weather—caused by solar storms and coronal mass ejections—on our critical technologies are of increasing concern to civilian and military stakeholders. APL is working to provide more data on these phenomena, in hopes of increasing our ability to predict and mitigate their effects.

Space Weather Watchers

Integrating Data and Analysis to Weather the Storms

From power grids to satellites, space weather affects civilian and military systems alike. The highest levels of government take space weather seriously. The Executive Office of the President receives updates on space weather activity, the Office of Science and Technology Policy formed an interagency working group to address threats from space weather, and the National Risk Assessment on Space Weather was executed in support of a presidential policy directive on emergency preparedness.

Yet only a fraction of the research resulting from government investments is being used to improve space weather forecasting and develop operational tools. The United States currently cannot accurately predict and deal with severe space weather events that could have crippling societal and national security effects and implications.

That's why APL's Space Exploration Sector works with civilian and military stakeholders on ideas and algorithms tailored to space weather challenges—a response to geomagnetic storms, for example, or working around disruptions to satellite communications. We're creating tools that integrate data from multiple sources into single, clear visualizations and fusing information from existing sources with new research to relate space weather and societal impacts. Along with space weather experts who are also integrating related data, we are providing decision makers with relevant and timely information in a rapidly evolving environment.

Space Weather: Why We Care

Space weather happens when storms from the sun react with Earth's magnetosphere. Studying space weather is important because solar storms can affect the technology we depend on every day. The same energy and radiation from solar flares and coronal mass ejections that bring us the colorful, dazzling northern and southern lights can also harm astronauts in space, damage sensitive electronics on satellites, interrupt radio signals, and knock out electrical systems.

Operational Effects

In the early morning of March 4, 2002, military officers in Bagram, Afghanistan, desperately radioed a Chinook helicopter headed for the snowcapped peak of Takur Ghar. On board were 21 men, deployed to rescue a team of Navy SEALs pinned down on the ridge dividing the Upper and Lower Shahikot valleys. The message was urgent: Do not land on the peak. The mountaintop was under enemy control.

The rescue team never got the message. Just after daybreak, the Chinook crash-landed on the peak under heavy enemy fire, and three men were killed in the ensuing firefight.

In 2014, APL researchers offered evidence that radio operators may have been thwarted by a little-known source of radio interference called plasma bubbles—wispy clouds of electrically charged gas particles that form after dark in the upper atmosphere. They can't be seen, but they can bend and disperse radio waves, interfering with communications.

The APL team looked at data from the Global Ultraviolet Imager instrument aboard the Earth-orbiting Thermosphere, Ionosphere, Mesosphere Energetics and Dynamics (TIMED) spacecraft, both of which were built by APL for NASA to study the composition and dynamics of the upper atmosphere. TIMED happened to fly over the battlefield at about the right time. APL researchers developed a technique to transform the two-dimensional TIMED

images into three-dimensional representations of plasma bubbles—and in doing so were able to show that there was indeed a plasma bubble between the ill-fated Chinook and the communications satellite. This new model shows the electron-depleted regions of the atmosphere where radio-wave interference, known as scintillation, is most likely to occur.

The plasma bubble present during the battle of Takur Ghar was probably not large enough to disturb radio communications by itself, but it likely contributed to the radio interference caused by the complex terrain in the area. The APL model could be used to minimize the impacts of plasma bubbles by detecting and predicting their movement for several hours after they form. By identifying these turbulent bubbles and their paths in real time, soldiers may be able to predict when and where they could experience radio interference and adapt by using a different radio frequency or some other means of communication.

New Tools

Our network of real-time or near-real-time data sources includes spacecraft, instruments, and research groups: Advanced Composition Explorer (ACE), Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE), and the SuperMAG collaboration, as well as space weather data from the Van Allen Probes. We provide online access to these data through advanced visualization tools and use them to generate indices and shape geophysical models—such as state-of-the-art models of Earth's heliosphere, magnetosphere, and ionosphere.

In addition to real-time capabilities, APL offers supporting data from assets such as the Defense Meteorological Satellite Program (DMSP) and years of historical data.

A Space Weather Network

A sampling of assets APL leverages to study space weather:

- By compiling data from magnetometers on 70 Earth-orbiting Iridium satellites, AMPERE provides global continuous monitoring of high-latitude currents that drive space weather. AMPERE can be used to provide advanced warning of large geo-magnetic storms.
- Super Dual Auroral Radar Network (SuperDARN) includes 32 over-the-horizon, high-frequency (HF) Doppler radars that measure plasma convection and high-latitude HF radio. The radar measurements drive climatological models for estimating ionospheric activity.
- Special Sensor Ultraviolet Spectrographic Imagers (SSUSI), flying on four DMSP spacecraft, provide the Air Force Weather Agency with more than two dozen products tailored to the space weather community. SSUSI makes important measurements concerning daily operations—measurements that are also crucial to understanding ionosphere/atmosphere coupling.
- SuperMAG will be a global collaboration of more than 300 magnetometer stations. The National Science Foundation is funding this effort to provide access to data from all available worldwide real-time magnetometers and continuous monitoring of the global ionosphere.

Artist rendering of NASA's New Horizons spacecraft encountering Pluto and its largest moon, Charon, in summer 2015. (APL/SwRI)

Civil Space

We make critical contributions to the missions of our major sponsor, NASA, to meet the challenges of space science. The 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.

New Horizons Reaches Pluto's Doorstep

After a voyage of nearly nine years and three billion miles—the farthest any space mission has ever traveled to reach its primary target—NASA's New Horizons spacecraft spent 2014 preparing for its long-awaited summer 2015 encounter with Pluto. Since launching on January 19, 2006, the APL-built and -operated New Horizons had spent 1,873 days—about two-thirds of its flight time—in hibernation, a technique the team employed to save wear and tear on spacecraft components and reduce the risk of system failures. The final wake-up, on December 6, signaled the end of New Horizons crossing the vast realm of interplanetary space to the very frontier of the solar system, and the beginning of the mission's primary objective: the exploration of Pluto and its moons.

Van Allen Probes Cover the Radiation Belts

The second full year of operations for this twin-spacecraft mission provided a number of discoveries about and new insights into the Van Allen radiation belts that surround our planet. The Van Allen Probes launched in August 2012, and NASA declared "mission success" in March 2014, just one-and-a-half years into the probes' two-year primary mission. Researchers from institutions across the nation have used Van Allen Probes data to learn why particles in the belts are accelerated to nearly the speed of light. In addition, new structures within the belts, dubbed "zebra stripes," were detected—although their existence was thought to be impossible. The spacecraft, guided by APL flight controllers through the highly energized particles in the belts, are also delivering real-time space-weather data, accessible to researchers and the public through newly enhanced web tools.

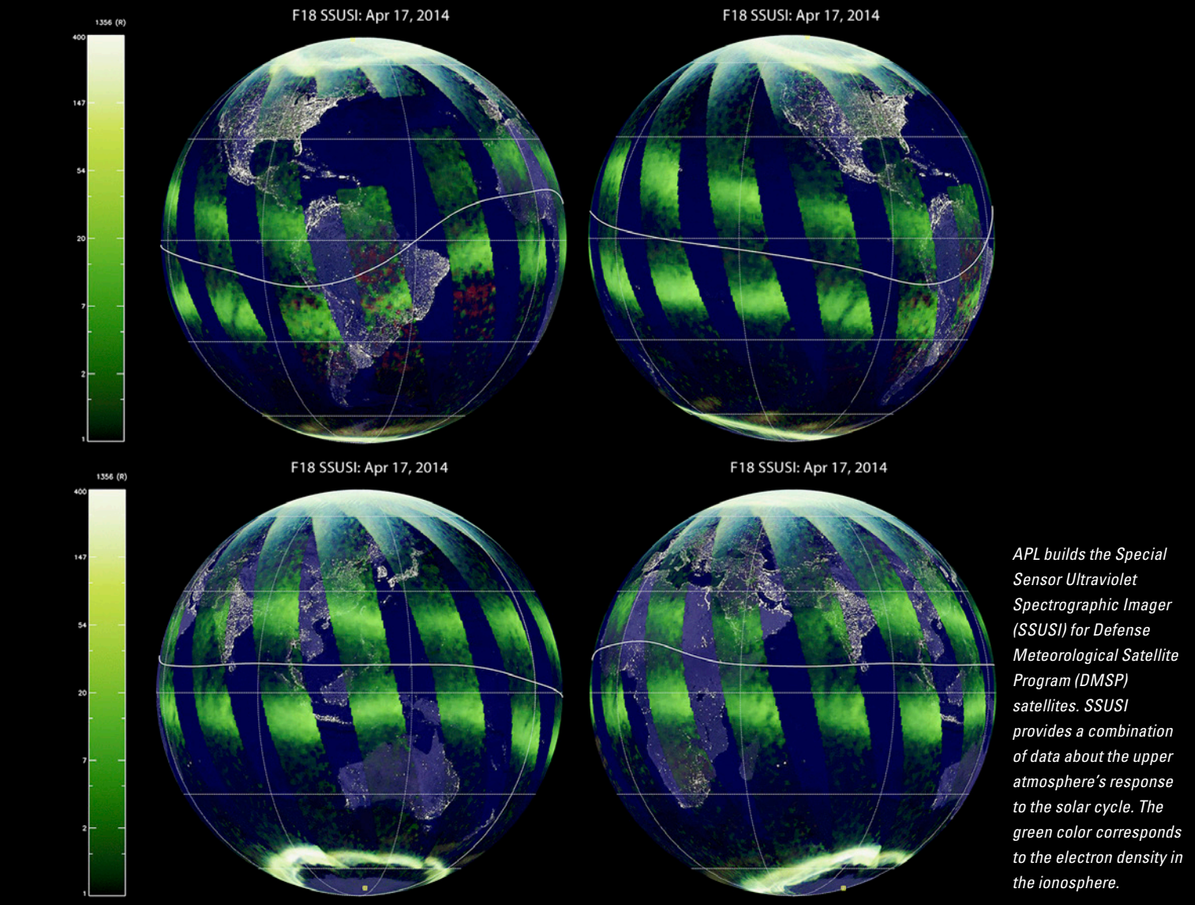
Rapid-Response Balloon Observatory Images a Comet

When the comet Siding Spring was discovered in 2013, researchers had no existing ability to study it from a space-based observatory, and there was neither time nor funding to create a dedicated spacecraft mission. In response to a call from NASA for a way to study this comet, APL proposed the Balloon Observation Platform for Planetary Science (BOPPS), a high-altitude, stratospheric balloon mission. BOPPS lifted off from NASA's Columbia Scientific Balloon Facility at Fort Sumner, New Mexico, in September 2014. Developed as an affordable, rapid-response means to perform high-level planetary science, BOPPS became the first balloon mission to capture images of a comet. During its 17-hour flight, the telescope and instruments made visible and infrared observations of Siding Spring, the comet PANSTARRS, the asteroid Ceres, and the double star Castor.

MESSENGER Completes Mercury Mission

The MErcury Surface, Space ENvironment, Geochemistry, and Ranging (MESSENGER) spacecraft ended 2014 literally running on fumes. After more than 10 years traveling in space—and nearly four of those orbiting Mercury—the spacecraft had expended most of its propellant and was on course to crash into the planet's surface at the end of March 2015. But clever APL engineers devised a way to use the pressurization gas in the spacecraft's propulsion system to propel MESSENGER for another month, allowing scientists to collect even more data about the planet closest to the sun. The technique added just a bit more time to a mission that continues to reshape our view of the innermost planet, delivering new close-up views of Mercury's cratered surface in 2014, including the first optical images of ice and other frozen volatile materials within permanently shadowed craters near the planet's north pole. MESSENGER impacted Mercury on April 30, 2015.

A composite of 29 images taken during the September 25, 2014, launch of the APL-built Balloon Observation Platform for Planetary Science (BOPPS), a rapid-response, high-altitude, stratospheric balloon mission. BOPPS captured the first images of a comet (Siding Spring) ever taken from a stratospheric balloon.



APL builds the Special Sensor Ultraviolet Spectrographic Imager (SSUSI) for Defense Meteorological Satellite Program (DMSP) satellites. SSUSI provides a combination of data about the upper atmosphere's response to the solar cycle. The green color corresponds to the electron density in the ionosphere.

National Security Space

Our programs focus on space solutions to critical military problems. Significant experience in both civilian and national security space programs is leveraged to develop and conduct innovative experimental missions, build space instruments, and produce new applications to meet warfighter needs.

Special Sensor Ultraviolet Spectrographic Imager (SSUSI)

The fourth of five APL-built SSUSI instruments was launched on a Defense Meteorological Satellite Program (DMSP) Block 5D-3 satellite in April 2014. After several months of checkout, the instrument is now complementing data from the other SSUSI instruments. Flying in a nearly polar, sun-synchronous orbit, each SSUSI instrument remotely measures ultraviolet (UV) emissions in five different wavelength bands from Earth's upper atmosphere. Since 2003, the APL SSUSI program has provided essential information about Earth's ionosphere and its response to the sun. The UV images and derived environmental data give the U.S. Air Force near-real-time information that can be used in a number of applications, such as maintenance of high-frequency communication links and related systems. The remaining SSUSI instruments could be ready for launch as early as 2016.

Small Satellites, Big Utility

Since launch on November 19, 2013, the APL-built Multimission Bus Demonstration (MBD)/Vector CubeSat and payload have performed exceptionally well, with our team supporting more than 1,800 communication passes and executing more than 550 payload operations. Mission performance has exceeded both requirements and expectations. Since the completion of the formal testing, the sponsor has continued to exercise the small satellite—and characterize its capabilities—from its ground system in Virginia Beach. A government evaluation team completed its formal testing campaign on the one-year anniversary of launch, fulfilling MBD/Vector's lifetime goal, and is now preparing a final report. The spacecraft reentered Earth's atmosphere in April 2015.

Space-Based Interceptor Assessments

After cancellation of the Precision Tracking Space System program in the president's FY 2014 budget, the Missile Defense Agency asked APL to be the technical lead for a Space Layer Options Study to assess missile defense needs and develop potential technical solutions. The one-year study brought to light an innovative solution using a hosted payload network that could address a need mentioned in the FY 2014 National Defense Authorization Act to improve kill assessment for the ground-based midcourse defense (GMD) system interceptors. Kill assessment messages provide data on the success or failure of an intercept and the confidence in the assessment and would ultimately be used for inventory management of the precious GMD interceptors. Using more than a decade of fundamental research and sensor design, we are developing and deploying an experimental network of sensors to provide observations, analysis, and command and control to support system kill assessment declarations on operationally relevant timelines. The sensors will be deployed on a host constellation during 2016 and 2017 to support Aegis Ballistic Missile Defense and GMD tests.

APL analyzed how U.S. and partner nation troops can more effectively align in today's complex environments. Here, U.S. soldiers demonstrate room-clearing procedures to Ukrainian troops. (U.S. Army)

National Security Analysis

The National Security Analysis Mission Area combines technical knowledge with analysis to find tomorrow's solutions to national security, space, and health challenges. Our studies inform and assist leaders in government policy, planning, and acquisition.

Leveraging Observations of Regionally Aligned Forces

In recent years, the Army has introduced a new strategy for managing forces that partners troops with nations within a region to provide combatant commanders with trained and ready troops who can be called upon to conduct military-to-military engagements, participate in exercises, or train and advise units preparing to serve as peacekeepers. The idea is that having units linked to specific parts of the globe will foster alliances, deter conflict, and provide important training opportunities for U.S. troops.

In 2014, APL researchers conducted a qualitative analysis of select Asymmetric Warfare Group (AWG) Tactical Trip Reports (TTRs) to determine how the AWG—the "operational arm" of U.S. Army Training and Doctrine Command—supported the regionally aligned forces (RAF) concept. The report highlighted the AWG's efforts and presented major and minor findings, with associated implications, best practices, lessons, insights, trends, and recommendations.

APL researchers reviewed 315 TTRs, 15 of which contained data relevant to RAF operations. A number of best practices stressed the importance of understanding U.S. embassy operations, specifically the roles and functions of country team members, such as defense attachés, as well as how these embassy resources relate to a RAF unit's mission.

The analysis also underscored the importance of all soldiers understanding their role as U.S. representatives in a foreign country. In addition, the Operational Advisors (OAs) either provided observations on or provided guidance concerning the importance of RAF leadership's early communications with the country team and the defense attachés to facilitate greater mission understanding and scoping.

The research results emphasized the critical role that the AWG plays in furthering the concept of a force filled with geographical experts in hopes that steady relationships with other nations can help prevent future conflicts. As the OAs continue their activities as global operational scouts and as the AWG matures its regionally aligned squadron construct, it affords the group a unique opportunity to provide regionally tailored and culturally focused support to the RAF.

Delivering Impactful Analysis to Policy and Decision Makers

To further address the needs of policy and decision makers, APL continues to invest internal funds in the analysis of challenges and opportunities that may be just over the horizon or are of particular relevance to the defense community. Included in that analysis in 2014 was an examination of the nation's nuclear deterrent and the consequences of the decisions being made, as well as decisions that have been avoided. This analysis of the strategic consequences of maintaining the nation's current course or pursuing an alternative is making an impact on this critical issue.

Opportunities and challenges in the realm of autonomous systems formed another part of APL's analysis in 2014. While ideas for potential autonomous systems have proliferated, this analysis offered practical considerations for decision makers making nearer-term investments. The analysis included a review of national and international legal and ethical norms, as well as domestic public opinion, which should inform research and development, as well as policy efforts.

Finally, with sustained budget pressures and the uncertainty of sequester, APL explored ways for the nation to maintain its technological edge in national defense. Drawing on an analysis of previous budget downturns and major acquisition programs, researchers have sketched an option to preserve gains in our research and development programs and a process for selecting and managing suitable technologies which could be put "on the shelf" for future use, should the need arise.

To further the impact of APL analysis and research, Assistant Director Christine Fox developed a new publication series and initiated the APL Senior Fellows program. Under the Fellows program, the Lab has welcomed four new Senior Fellows, including former U.S. European Command (EUCOM) Commander, Admiral Jim Stavridis; former Undersecretary for Defense for Policy, Dr. Jim Miller; former director of the Clandestine Information Technology Office at the Central Intelligence Agency, Mr. Jim Gosler; and former Chairman of the Department of Homeland Security Science and Technology Advisory Committee, Dr. Phil DePoy.

Joint Force Development

Future scenarios allow organizations to explore multiple potential futures, generate robust strategies, and examine early warning signs to understand how the future is unfolding. Our broad expertise in air and missile defense, force projection, and military analysis enables us to assist military leaders with preparing for future challenges.

Last year, Joint Force Development asked APL to organize three future seminars that examined science and technology, human geography, and world order. The events were held in March, June, and September 2014, respectively. Participants in the seminars included a mix of personnel from the Office of the Secretary of Defense, the Joint Staff, Military Services, and Combatant Commands, as well as the Department of Defense (DoD), government laboratories, academia, and industry.

The seminars examine the operational impact of a wide variety of changes occurring in the world by posing focused, future military challenges that describe how evolving security conditions might challenge U.S. approaches to the successful use of military force and then suggesting potential new operational approaches and sets of potential future capabilities to address those conditions.

The results will be used to postulate the nature of future conflicts and the implications for future military forces. They will be also used to develop a comprehensive understanding of the future operating environment in order to identify and prioritize the most pressing future military challenges for the United States. Finally, the results of the seminars will guide Joint Staff and DoD concept development activities that, in turn, could drive future force structure, experimentation, and investments.

National Security and Emergency Preparedness Communications

In 2012, after President Obama signed an executive order granting the Department of Homeland Security wide-ranging responsibility to ensure that private networks and broadcast facilities operate properly in the case of national emergency, the Department of Defense Chief Information Officer (DoD CIO) asked APL to provide technical support to the Executive Committee (ExCom). ExCom, cochaired by the DoD CIO and established by the executive order, was tasked with overseeing the development, testing, implementation, and sustainment of national security and emergency preparedness (NS/EP) communications that are directly responsive to the national security needs of the president, vice president, and senior national leadership.

APL provided technical advice to inform national-level strategies and to develop the technical and operational requirements for NS/EP communications, with a focus on improved performance and resilience. The operational and technical requirements will allow the ExCom to establish a national-level requirements baseline for NS/EP communications and information services, to support investment that will improve situational understanding and decision making for national leadership in all operational environments and locations, including mobile.

These requirements will directly impact a wide range of ongoing modernization activities that will support national-level capabilities in times of need. This year, continued engineering efforts focus on developing effective priority services to ensure that all essential communications—public, sensitive unclassified, and classified—are available at all times and under all circumstances.

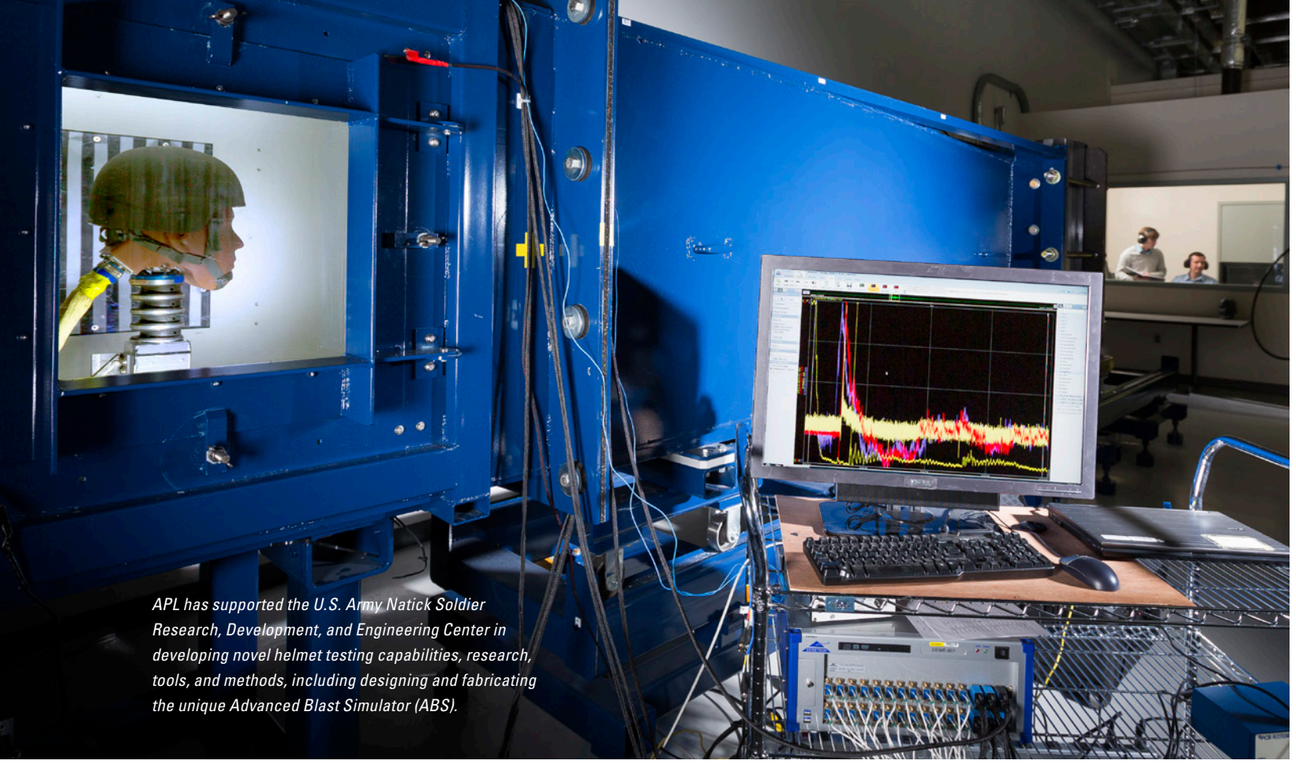
The Modular Prosthetic Limb (MPL) has led to groundbreaking developments in many related fields. To utilize the best controller for the MPL—the mind—a brain–computer interface (BCI) was developed that allows a person to perform many dexterous tasks. (UPMC/University of Pittsburgh Schools of the Health Sciences)

Research and Exploratory Development

We merge science, technology, and systems engineering to provide highly innovative, affordable, and timely solutions to critical national challenges. We support other APL mission areas in cross-enterprise initiatives of vital importance to the nation and the Laboratory by making technology breakthroughs and transitioning solutions to our sponsors. Our basic and applied research and technology development provides the foundation for many forward-looking internal and sponsored programs and initiatives.

Advanced Brain–Computer Interface

Developed by APL for the Defense Advanced Research Projects Agency (DARPA), the revolutionary Modular Prosthetic Limb (MPL) allows users to control a highly advanced prosthetic arm and hand using anything from muscle control to eye tracking. The most ambitious of those involves utilizing the best controller we know—the human brain. This method uses a brain–computer interface (BCI)—where brain activity is interpreted and commands are then sent to the MPL. This technique has already been demonstrated with great success by a team from the University of Pittsburgh, where the direct connection from brain to machine provided for direct control of the MPL.



APL has supported the U.S. Army Natick Soldier Research, Development, and Engineering Center in developing novel helmet testing capabilities, research, tools, and methods, including designing and fabricating the unique Advanced Blast Simulator (ABS).

Protecting Warfighters with Improved Personal Protective Equipment

Helmet systems protect the nation's troops from blast, ballistic, and impact threats. APL has supported the U.S. Army in developing novel testing capabilities, research tools, and methods for assessing the efficacy of helmets in mitigating traumatic blast injuries. The Biomechanics & Injury Mitigation Systems (BIMS) Program initiated this effort by designing and fabricating an Advanced Blast Simulator (ABS). The ABS is a unique system that permits large-scale simulation of blast waves in a laboratory setting. This system can now recreate precise, repeatable blast wave pressure profiles matched to explosives testing.

APL will now begin the development and testing of next-generation physical human surrogate systems representing various regions of the human body (e.g., head, torso), determining the ability of these systems to assess risk of injury due to blast loading. These surrogates will then be used to evaluate the performance of personal protective equipment (PPE) under operationally relevant dynamic loading conditions. The combination of new test capabilities and human surrogate systems permits the development of standardized test methods that have previously been unattainable. Ultimately, the objective of this project is to inform the future design approach to PPE and to improve the protection of U.S. troops.

Testing the Safety of Autonomous Systems in Complex Environments

Autonomous systems respond to unpredictable change by devising a course of action. But developers cannot be sure that the autonomous decisions will achieve objectives set by human supervisors and not produce unacceptable unintended consequences. Autonomous systems are particularly challenging because test range personnel cannot possibly identify all interactions between the autonomous system and the natural world. APL developed the Safe Testing of Autonomy in Complex, Interactive Environments (TACE), a test infrastructure that combines synthetic and actual forces to produce a realistic, real-time, interactive autonomous vehicle test environment. TACE, sponsored by the Department of Defense Test Resource Management Center, also provides safe testing assurances via onboard safety monitoring.

Current unmanned aerial vehicle (UAV) testing and evaluation technologies are essentially platform-centric and do not address the advent of autonomous behaviors, where responses and decisions driven by "human behaviors" will be replaced by "machine behaviors." In many cases, an "operator-in-the-loop" machine-implemented autonomy is capable of executing highly complex and near-real-time actions that are faster than human responses.

During training, humans learn how to contribute to the success of the mission and the commander's intent. An autonomous UAV is also capable of learning and modifying its behavior. Thus, the autonomy response space represents an intractable possible number of closed-form solutions in terms of description or testing. Simulations with sophisticated mathematical and statistical analyses will be used, but the final challenge will be to actually perform LIVE/SAFE tests, where the UAV can be virtually stimulated over a wide and rich set of environmental and sensory inputs while its behavior is recorded for comparison to simulated results.

There are two critical aspects to conducting such a test sequence: safety override must be maintained at all times and there must be minimal "impact" to the system under test (SUT) and range infrastructure. APL's TACE provides test monitoring hardware and software that use mathematically rigorous techniques to prevent unsafe autonomous UAV operations and actions, while providing complex and interactive live, virtual, constructive test environments to stimulate UAVs so that their response and performance can be observed, recorded, and compared to pretest simulations.

In 2014, APL successfully demonstrated the ability to allow autonomous searching and tracking within a specified test area, and a "watchdog" function successfully overrode unsafe behaviors of the SUT. In 2015, APL will migrate TACE to a military-relevant ScanEagle for testing at Yuma Proving Ground in Arizona.

Seeing in Perfect HARMONIE

HARMONIE—Hybrid Augmented Reality Multimodal Operation Neural Integration Environment—has continued to build upon research by APL under the Defense Advanced Research Projects Agency's Revolutionizing Prosthetics Program. As part of that effort, researchers investigated a number of different ways to move the Modular Prosthetic Limb and were able to achieve impressive control, but they discovered that the user had to remain very focused on the tasks at hand, which was mentally taxing. The idea behind the new system is to combine elements of computer vision (to identify objects and their locations), autonomous manipulation (to move the arm toward the desired object and grasp it), and a user interface (to tell the limb what to actually do with the object).

To that end, APL has received $4 million from the Mann Fund to develop a next-generation retinal prosthesis system. Working with Second Sight Medical Products, Inc., which develops, manufactures, and markets implantable visual prosthetics, the Laboratory will develop a system that includes sensor-equipped glasses that can identify potential obstacles, doorways, hallways, and household objects and their relative positions, as well as hardware that projects the information into the retinal prosthesis, bypassing damaged rods and cones in the retina.

The HARMONIE system has been deployed in clinical settings at Caltech and Johns Hopkins Medicine and is undergoing additional testing as part of an internally funded project, the Clinical Evaluation of Emerging Rehabilitative Technologies.

A new "self-healing" paint additive, developed by APL in partnership with the Office of Naval Research, allows scratches in vehicle paint to scar and heal, which would help prevent corrosion.

Self-Healing Paint

Corrosion of infrastructure and equipment costs the Department of Defense an estimated $22.5 billion per year. APL has developed a new additive that could help military vehicles heal like human skin and avoid costly maintenance as a result of corrosion. Developed in partnership with the Office of Naval Research, polyfibroblast allows scratches forming in vehicle paint to scar and heal before the effects of corrosion ever reach the metal beneath.

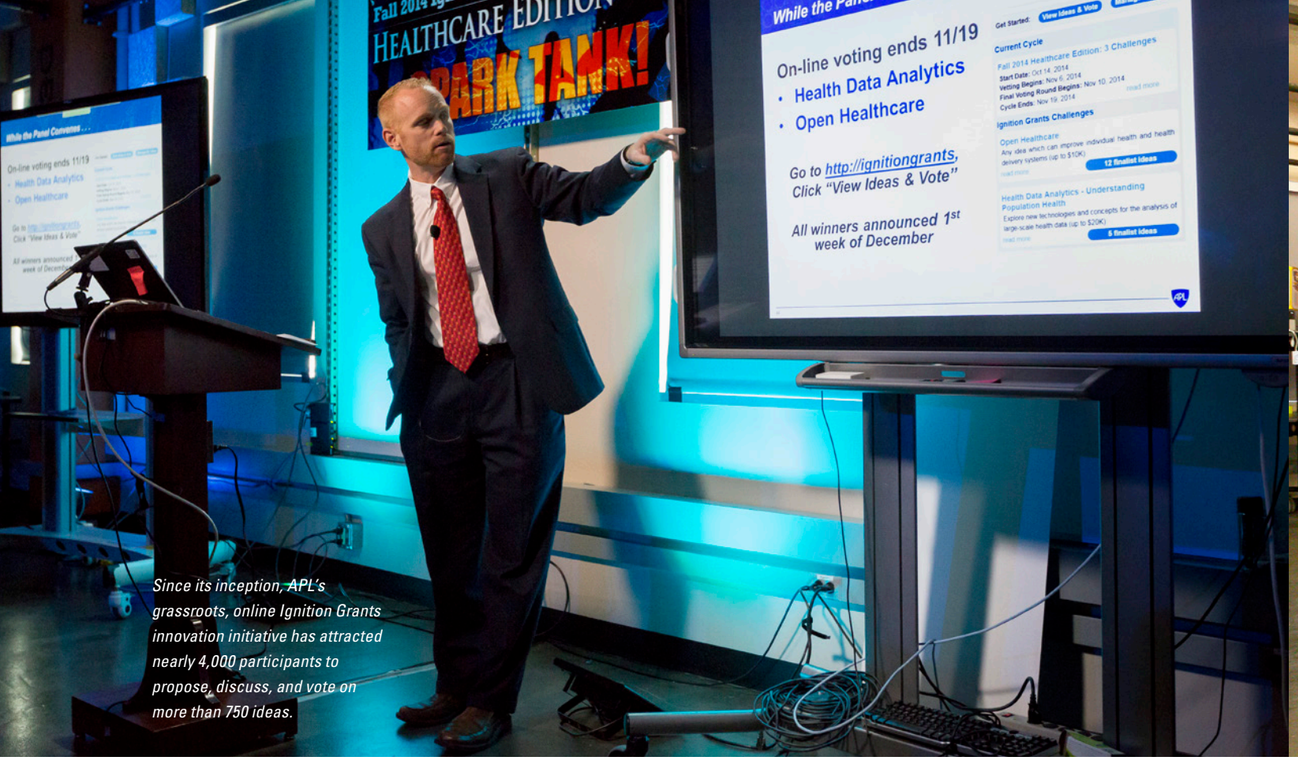
Polyfibroblast is a powder that can be added to commercial off-the-shelf paint primers. It is made up of microscopic polymer spheres filled with an oily liquid. When scratched, resin from the broken capsules forms a waxy, water-repellent coating across the exposed steel that protects against corrosion. While many self-healing paints are designed solely for cosmetic purposes, polyfibroblast is being engineered specifically for tactical vehicles used in a variety of harsh environments. The primer has been tested on tactical ground vehicles at Aberdeen Proving Ground, Maryland, and the Marine Corps Base Camp Lejeune in North Carolina. Plans are to implement it on a wide scale.

APL is now researching formulas that will allow the polyfibroblast to be added to other primers, like those used for aircraft and ships, and is working on a touch-up version that will not require a vehicle to be sprayed in its entirety. We are also taking measurements that will make it possible to write a specification that can be added to the qualified products database, which would enable the government to purchase and use the paint on its vehicles.

APL, in collaboration with Harvard University, developed a droplet-based Rapid Acceleration of Laboratory Evolution (oRACLE) Chip that will allow researchers to drastically reduce the time it takes to mimic the natural evolution of a virus in a laboratory setting.

Prophecy

APL, in collaboration with Harvard University, developed a device for the Defense Advanced Research Projects Agency (DARPA) that will allow researchers in the lab to drastically reduce the time it takes to mimic the natural evolution of a virus. Developed for DARPA's Prophecy pathogen defeat program, the tool—a droplet-based Rapid Acceleration of Laboratory Evolution (oRACLE) Chip—can potentially improve the nation's ability to interdict emerging diseases and can also be applied to addressing the challenges of bacterial drug resistance, food safety, and biological weapons defense. Applying APL's expertise in systems biology, optics, and biological assay development and Harvard's prowess in microfluidics (a technology characterized by the engineered manipulation of fluids at the submillimeter scale), scientists applied droplet-based microfluidics to segregate and propagate a viral population as individual viral lineages, simultaneously performing millions of in vitro evolutionary bottlenecking experiments. The genomes of the evolving viral populations in each segregated lineage can be sequenced individually to determine mutations that enable viruses to evade evolutionary stresses, such as a drug or antibody. The oRACLE Chip allows scientists to quickly propagate millions of parallel passages of a virus over several generations in a short timescale—automating work that would have taken years to perform by hand into just hours. Evolving millions of independent viral lineages may allow the device to predict evolutionary mutations in advance of their occurrence. Such experiments not only enable quantification of the risk that a particular antiviral drug will fail and when, but also produce the actual future viruses, providing the targets for development of new drugs and enabling a proactive approach to interdicting an emerging threat.



Since its inception, APL's grassroots, online Ignition Grants innovation initiative has attracted nearly 4,000 participants to propose, discuss, and vote on more than 750 ideas.

Our new innovation center—four anchor spaces collectively known as Central Spark—opened in April 2014 and has become one of the most popular centers of collaboration and creativity at APL.

A Culture of Innovation

APL was built on a foundation of innovative and creative thinking and the ability to translate those ideas into effective technical solutions. Over the past several years, we have focused on enhancing the Laboratory's culture of innovation through a series of coordinated, enterprise-level initiatives. Today, these "innovation experiments" have increased collaboration, resulted in more numerous inventions and disclosures, and provided sponsors with new and exciting potential avenues of exploration for their programs.

Ignition Grants

The first of our current generation of innovation initiatives—Ignition Grants—is a grassroots, online initiative. Any staff member can submit one or more new ideas and then improve the ideas via crowdsourcing. Staff members then vote online for the ideas they think should receive grants. These grants provide seed funding for a staff member or small team to work on an idea or produce a proposal, analysis, or early laboratory prototype. To date, Ignition Grants have attracted nearly 4,000 participants who proposed, discussed, and voted on more than 750 ideas.

Although the original Ignition Grants cycle was open for any ideas, subsequent cycles have added a "wicked problem" engineering challenge category, sometimes to address a critical real-world sponsor challenge. For more sensitive challenges, Ignition Grants voting narrows the entries to a set of semifinalists, and final selections occur during an hour-long "Spark Tank" session. During the session, a panel of experts provides insights and answers audience questions, and then the audience votes on the winners.

In the first year of Ignition Grants, the annual number of APL invention disclosures increased 80 percent, and that level has remained steady to this day. Johns Hopkins University recently announced a university-wide program called Idea Lab, patterned directly after Ignition Grants.

Tech Splash Videos

To help share expertise, accomplishments, and capabilities across the organization, we developed a video series called Tech Splash in 2013. These short, sometimes edgy videos highlight information and ideas that might be useful in multiple domains across the Laboratory. Edited and produced in-house, the three- to five-minute videos are viewed on our intranet, and some are shared externally on the APL YouTube channel. Late last year, a video released through Tech Splash featured Les Baugh, a double amputee who operated—for the first time in history—two neurologically controlled APL-built prosthetic arms. The video has received more than 2.3 million YouTube views.

Central Spark

Our new innovation center, called Central Spark, was created from an Ignition Grant proposal. It opened in April 2014 and has become one of the most popular centers of collaboration and creativity at APL. Conceived, designed, and managed by staff members, Central Spark consists of four anchor spaces. First is Design Central, a design thinking area that also includes gaming, modeling and simulation, and software app prototyping. Next is Maker Central, a maker space featuring modular electronics and 3-D printers for staff members to use to physically explore ideas and designs. Academy Central provides a space for teaching about topics of interest. Finally, Media Central allows staff members to make videos to increase and enhance sharing of technical knowledge. In the first several days after opening its doors, close to 3,000 people visited Central Spark. Sponsors and stakeholders have been very engaged by the facility and its potential, and a number of inventions and concepts developed for sponsors are the direct result of this innovation center.

Facilities and Capabilities

Guidance System Evaluation Laboratory

The Guidance System Evaluation Laboratory (GSEL) creates a virtual flight environment for the evaluation of missile subsystems, including the homing seeker, guidance system and interfaces for propulsion, flight control actuators, and combat system. Prior to live-fire test exercises, GSEL engineers verify missile launch-to-intercept functionality and characterize performance of selected subsystems. GSEL includes infrared and radar sources to represent target environments and background scenes of varying complexity.

LIVE Lab

Our Live data, Integration, Validation, and Experimentation (LIVE) Lab uses APL's own complex internal computer network as a base to study how data move and to study the ways that outside users, both benign and harmful, attempt to connect to our network. Other networks, both real and simulated, are also studied. Researchers have developed new tools to discover clandestine attempts to access data, as well as new methods to assess the effectiveness of security and offensive cyber operations.

Facilities and Capabilities

Collaborative Analysis Centers

These unique facilities, located at APL's main campus in Laurel, Maryland, and in Crystal City, Virginia, provide our sponsors with capabilities in applying modeling, simulation, and gaming expertise to studying future needs; recommending requirements to meet those needs; and evaluating alternative solutions. The Collaborative Analysis Centers (CACs) feature electronic seminar support workstations running groupware, large projection screens, 3-D scenario modeling and visualization, extensive information/database access and network capability, and multilevel security. Traditionally, the CACs have been used to conduct military simulations. Today, they are also used to explore a broad range of challenges.

Mechanical Fabrication and Engineered Materials

The wide variety of engineering needs at APL—from rapid-response prototypes that address immediate needs in the field to years-long spacecraft design and fabrication—requires a dedicated and talented team that can respond to innovative ideas and turn them into effective devices. Our comprehensive fabrication facilities deliver hardware systems through a wide variety of equipment and services, including complex machining and assembly, reverse engineering, additive manufacturing, and other unique fabrication capabilities.

APL's Invention of the Year was awarded to the oRACLE Chip (p. 45), a new way to quickly predict the evolution of viruses, which can speed the development time for vaccines.

Technology Transfer

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

Our innovation and technology transfer initiatives increased invention disclosures by 12 percent from FY 2013, including increases in disclosures for biomedical technologies and for space and environmental sensors.

License agreements increased from 40 to 77, continuing a trend fueled by increased focus on our culture of discovery and invention. Six start-up companies were formed last year, bringing the total number of spinoffs since FY 2000 to 34. Two of these companies are NexGen Forensic Science, based on a technology that can identify individuals at a crime scene, and Articu-Tech, which explores the science and technology behind mobile devices.

Technology Partnerships

Several of these new businesses are a direct result of our relationships with the Maryland Technology Development Corporation (TEDCO) and the Maryland Center for Entrepreneurship (MCE). In May 2014, MCE launched monthly technology reviews of APL technologies to determine their readiness for commercialization and to stimulate interest among reviewers. Four potential APL start-ups have since been offered free six-month membership to MCE's interactive entrepreneurial community.

Following strategic discussions between OTT, MCE, and TEDCO, the latter group committed to facilitating the Maryland Innovation Initiative (MII) process for APL start-ups, which could generate $100,000 in development funding. In addition, TEDCO Capital Partners will facilitate the venture funds process.

Internal Development Efforts

In FY 2014, OTT funded five projects selected to further develop technology that benefits both our government sponsors and commercial needs. One project, the Aerosol Indicator for Self-Use (ALIS), used the Lab's newly established Central Spark facility to develop a socially networked, app-based air-quality monitor. A start-up company was formed around this technology, and an established organization focused on home-care products for asthmatic patients is interested in ALIS.

Another research project improved the rolling resistance and wet traction balance of tires and tank tracks by using high-aspect-ratio fillers. Currently, several large automotive device firms have expressed interest in this work.

Teaming with Our Johns Hopkins Partners

The patent for a technology that monitors head impacts in contact sports, jointly developed by researchers at APL and the Whiting School of Engineering, was licensed to a Maryland-based start-up already selling products used in football, lacrosse, and hockey helmets.

In another joint effort assisted in part by the TEDCO MII Fund, a research team consisting of researchers from APL, the School of Medicine, the Whiting School, and Walter Reed National Military Medical Center has driven development of a workstation for cranio-maxillofacial surgical procedures. This technology has received a prize from The Abell Foundation, which recognizes innovative advances in translational research that have clear commercial potential.

Top Inventions

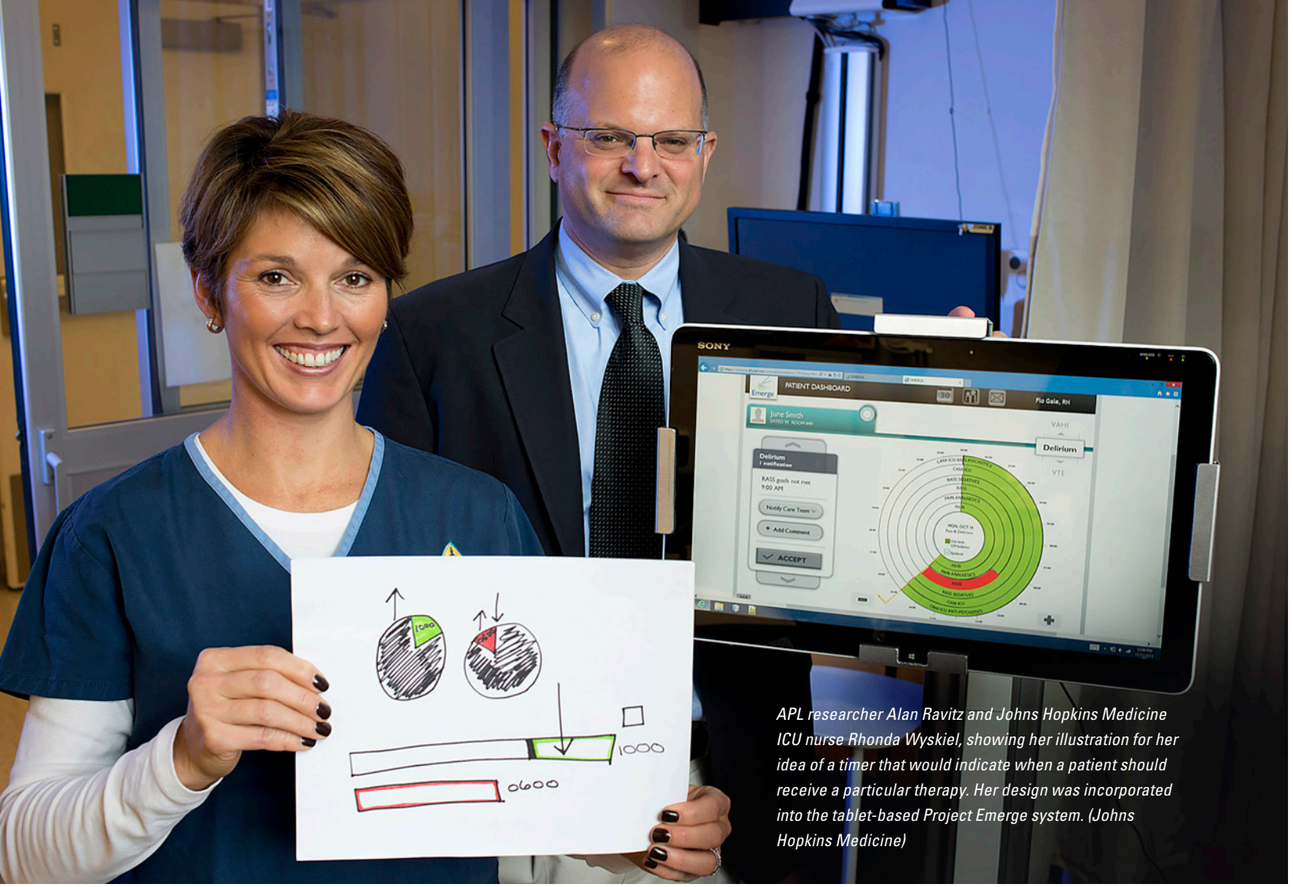
A method for quickly predicting the evolution of viruses was selected as the APL Invention of the Year. Existing vaccines are designed to protect against existing viruses, while vaccines for new strains take years to develop. The award-winning technology speeds up development and can predict new viruses before they exist.

The Government Purpose Innovation Award, for the invention that has the potential to make a major impact in the defense community and on the nation, was awarded for algorithms developed to perform geo-registration for aerial surveillance and reconnaissance without GPS assistance.

By the Numbers

Technology Transfer from October 2013 through September 2014

257	Inventions disclosed
95	Regular U.S., foreign, and provisional patent applications filed
29	U.S. patents issued
77	License agreements executed
6	Companies created



APL researcher Alan Ravitz and Johns Hopkins Medicine ICU nurse Rhonda Wyskiel, showing her illustration for her idea of a timer that would indicate when a patient should receive a particular therapy. Her design was incorporated into the tablet-based Project Emerge system. (Johns Hopkins Medicine)

University Collaboration

As a university affiliated research center and division of Johns Hopkins University (JHU), 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 JHU and the Johns Hopkins Hospital, including the university's Whiting School of Engineering, School of Medicine, Krieger School of Arts and Sciences, Nitze School of Advanced International Studies, Bloomberg School of Public Health, and Carey Business School.

Higher Education

The Laboratory has a strong commitment to continuing education. More than 170 APL staff members teach engineering, applied science, engineering management, 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 10 of EP's 19 master's degree programs. These 10 programs account for more than 85 percent of EP enrollments.

APL-Based EP Programs

Applied and Computational Mathematics, Applied Physics, Computer Science, Cybersecurity, Electrical and Computer Engineering, Engineering Management, Information Systems Engineering, Space 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 more than 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 majoring 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 continue their partnership of providing a path for more Whiting School doctoral candidates to conduct their research at APL while offering flexibility for APL staff members seeking doctorates through the Whiting School. APL and JHU are presently exploring how to further increase the number and types of opportunities and reduce real and perceived bureaucratic impediments.

Healthcare Program Area

The Laboratory created a new Healthcare Program Area in 2014 with focuses on eliminating preventable harm, illness, and injury to military members, and rapidly responding to health challenges facing the nation. The scientists and engineers in this program area continue to work closely with Johns Hopkins Medicine to solve national healthcare challenges.

APL engineers have teamed up with Johns Hopkins Armstrong Institute scientists and doctors on Project Emerge, developing a custom-made tablet computer aimed at reducing medical errors in intensive care units (ICUs). The Project Emerge team developed software that coordinates and integrates the data and information about each ICU patient. Using a tablet to access this information, healthcare workers can determine a patient's risk for preventable harms and receive recommendations on how to reduce the risk of a particular harm. Embedded alarms alert staff members to danger and remind them to perform certain tasks.

APL and the Armstrong Institute have also collaborated to design and evaluate a medication infusion pump prototype. The team has created a prototype interface that is integrated with other hospital information technology systems to meet many of the needs identified by medical clinicians.

Forty-one clinicians were introduced to the new pump user interface design and were then asked to perform several tasks in a simulated hospital environment, both in auto-programming and in manual programming modes. The test results have been published, and members of academia, business, and industry have been encouraged to further develop the infusion pump prototype.

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

During the 2013–14 academic year, 2,000 students participated in the 10 APL-based EP programs, accounting for 7,080 course enrollments. More than 700 master's degrees were conferred by EP during the 2013–14 academic year. Since 1968, more than 1,300 APL staff members (and more than 16,500 other students) have received master's degrees from these programs.

Tuesday afternoons at APL bring 20 middle and high school age young women to learn about software coding and engineering from Lab volunteers as part of the nationwide Girls Who Code initiative.

Community Involvement

APL continues to serve the nation by tackling the critical challenge of inspiring and training the next generation of scientists and engineers. In 2014, the Laboratory's science, technology, engineering, and mathematics (STEM) education and outreach programs reached more than 5,000 students and community residents.

Prepared for Success

APL's Student Program to Inspire, Relate and Enrich (ASPIRE) included 68 APL mentors guiding 94 high school juniors and seniors, all working on real Lab projects and most planning to study STEM subjects in college. Our College Prep Program—supporting academically talented students who have little or no exposure to the college application process—has "graduated" more than 120 students. Approximately 70 APL staff members gave 4,000 hours of volunteer time to support this program. More than 95 percent of program graduates are on track to earn a bachelor's degree, and more than 10 program alumni have interned at APL in the ASPIRE program.

In the Classroom and After School

A group of 20 local middle and high school girls spent Tuesday afternoons at APL learning both the science and art of computer coding from APL staff members as part of the Girls Who Code program. Girls Who Code is part of a national organization that works to inspire, educate and equip girls with the computing skills to pursue 21st century opportunities, with the ultimate goal of reaching gender parity in computing fields. This year, APL is also partnering with the Boys & Girls Club of Metropolitan Baltimore to offer an after-school math tutoring program to 18 middle school students. The program aims to increase the students' proficiency in math using tactile and computer based techniques. The group is meeting once each week for 10 weeks in the fall and 10 weeks in the spring.

Powerful Events

More than 700 parents and students attended the annual Girl Power event—learning first-hand about opportunities for women in STEM fields. Other events like robotics competitions and the UNITE teachers workshop brought many more to the Lab.

APL also participated in the USA Science & Engineering Festival in Washington, D.C. The event was attended by more than 200,000 K–12 students, parents, teachers, and STEM professionals. APL's STEM representatives guided students through a demonstration of simple "prosthetic hands," built using APL's 3-D printers. Students also had the opportunity to interact with the Modular Prosthetic Limb from the APL-led Defense Advanced Research Projects Agency (DARPA) Revolutionizing Prosthetics Program.

Nearly 200 parents attended the third annual STEMpowerment workshop, hearing from higher education institutions, nonprofit organizations, and industry and government representatives about STEM resources available to them and their students.

Maryland MESA Days Encourage STEM Success

APL's Maryland Mathematics, Engineering, and Science Achievement (MESA) program is designed to prepare pre-college students for academic and professional careers in STEM. Maryland MESA aims to increase the number of engineers, scientists, mathematicians, and related professionals and serves as a driving force in encouraging and assisting minorities and females in achieving success in these fields. The program provides services and programs to more than 2,500 students and 180 teachers from across central Maryland.

To the Moon

The Van Allen Probes and Solar Probe Plus space missions and CRISM instrument (in orbit around Mars) were the topics for this year's Space Academy. Now in its 15th 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.

Founded at APL in 1976, the Maryland Mathematics, Engineering, and Science Achievement (MESA) program provides information and programming to more than 2,500 students and 180 teachers across central Maryland, and participates in events like the USA Science & Engineering Festival in Washington, D.C.

Awards and Honors

Laboratory Awards

Left: Johns Hopkins University honored APL with a Green Blue Jay Award for its contributions to the university's sustainability efforts.

APL was named a top supporter of the nation's historically black engineering schools by *U.S. Black Engineer & Information Technology* magazine.

Right: Karla and Will Gray Roncal (center) of APL's College Prep Program, which helps high school students prepare for, apply to, and succeed in college, received the Howard County Volunteer of the Year award.

The Laboratory received the 2014 State Chair Above and Beyond Award, which recognizes employers whose programs exceed requirements of the Uniformed Services Employment and Reemployment Rights Act.

Staff Member Awards

Russ Gingras received the Navy's Superior Public Service Award, its second highest civilian honor.

Dawnielle Farrar-Gaines received a Women of Color Technical Innovation award.

Nykia Jackson received a Women of Color Technology Rising Star award.

Elishiah Miller received a national STAR Award from the Society of Hispanic Professional Engineers.

Jack Keane (center) received the Military Operations Research Society's Vance Wanner Memorial Award, the society's highest honor.

Daniel O'Shaughnessy was named the first recipient of the Heinlein Award, which recognizes space-tested technologies that can benefit commercial space activities.

Katy Carneal, Andrew Merkle, Mehran Armand, and other coauthors were awarded the Best Paper Award at the International Conference on Pattern Recognition Applications and Methods.

Jerry Vetter, Bill Kohri, and other coauthors received the Naval Research Laboratory's Alan Berman Research Publications Award.

The MErcury Surface Space Environment, Geochemistry and Ranging (MESSENGER) Project Team was awarded the National Space Society's 2014 Space Pioneer Award in the Science and Engineering Category.

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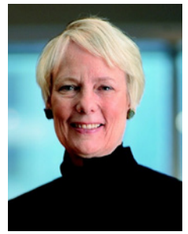

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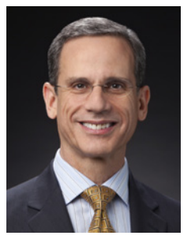

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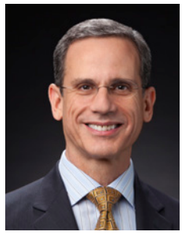
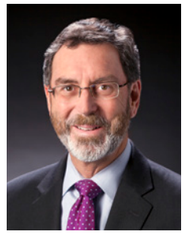
Leadership



Ralph Semmel
Director



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During the fiscal year that ended September 30, 2014, the Johns Hopkins University Applied Physics Laboratory recorded revenue from contracts and grants totaling $1.26 billion, compared with $1.16 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.

The Johns Hopkins University Applied Physics Laboratory

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