THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

2018 ANNUAL REPORT

CRITICAL
CONTRIBUTIONS
TO
CRITICAL
CHALLENGES

CONTENTS

DIRECTOR'S MESSAGE

APL is home to a gifted staff with thousands of different technical and analytical skills, extensive experience with a broad array of applications, and access to hundreds of unique laboratories. While this powerful combination is often transparent to our partners, it fuels the unique collaborations that lead to our critical contributions to our nation's challenges as well as the defining innovations that have been among APL's greatest achievements.

We set a very high bar for what we consider a defining innovation. Over our 75-year history, only nine accomplishments have been given this prestigious designation. They represent game-changing developments that have profoundly impacted society by advancing science, engineering, and national security capabilities. While each of the nine is unique, they, like so many of our critical contributions, share a common ingredient: teamwork. They happened because great scientists, engineers, and analysts—enabled by top-notch administrative professionals and support staff—collaborated within the Lab and with our external partners. So while we may not know what our next defining innovation might be, we do have a good idea of how it will come about.

To thrive amid rapid change, APL must continue to recruit and develop world-class expertise in established and emerging disciplines, responding to today's needs while anticipating tomorrow's challenges. We must, in the words of Nobel laureate Albert Szent-Györgyi, "see what everybody else has seen and think what nobody has thought" so that we might find unique ways to combine novel science and technology to benefit our nation—whether that be in military operations, cyber, homeland protection, space exploration, or health care.

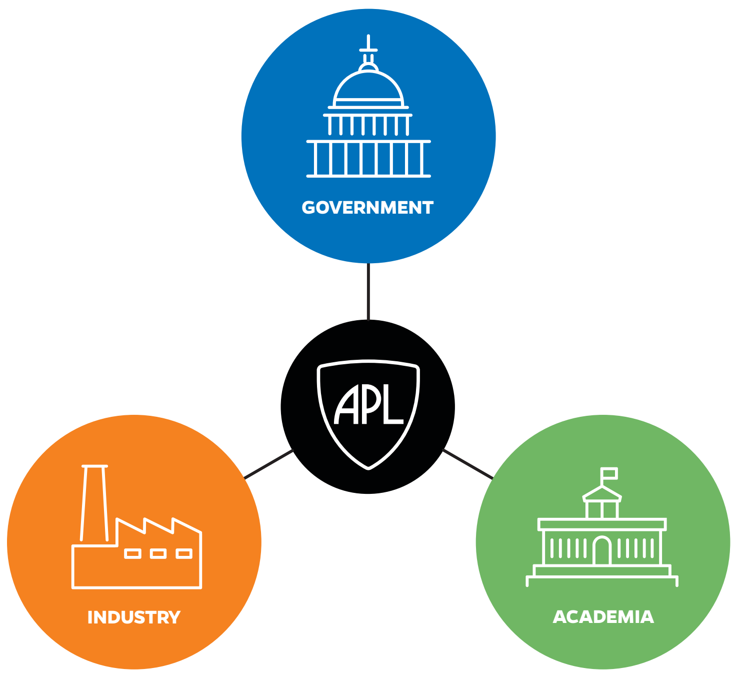
This Annual Report highlights some of our many critical contributions and, as important, the teams that made those contributions. Each section focuses on a significant cross-enterprise effort. The stories are by no means all-inclusive of the many projects, technologies, and innovations we are pursuing across our mission areas, but they give a sense of the breadth and depth of APL's technical expertise and the unique ways in which our talent comes together to solve challenges that are particularly important to our nation.

I often cite a proverb that says "none of us is as smart as all of us." These are words that APL lives by. We thrive on teamwork, and the synergy we achieve by working as a team cannot be underestimated. As we have long known at APL, it is the team that transforms great ideas into reality.

ABOUT UARCS

University Affiliated Research Centers (UARCs) are not-for-profit entities sponsored and primarily funded by the U.S. government to address technical needs that cannot be met as effectively by existing government or contractor resources. These organizations typically assist government agencies with scientific research and development, studies and analyses, and systems engineering and integration by bringing together the expertise of government, industry, and academia to solve complex technical problems in the public interest.

—Department of Defense UARC Engagement Guide



Our long-term strategic relationships with sponsors are characterized by:

- Responsiveness to evolving sponsor requirements
- Comprehensive knowledge of sponsor requirements and problems
- Broad access to information, including proprietary data
- Broad corporate knowledge
- Independence and objectivity
- Quick response capability
- Current operational experience
- Freedom from real and/or perceived conflicts of interest

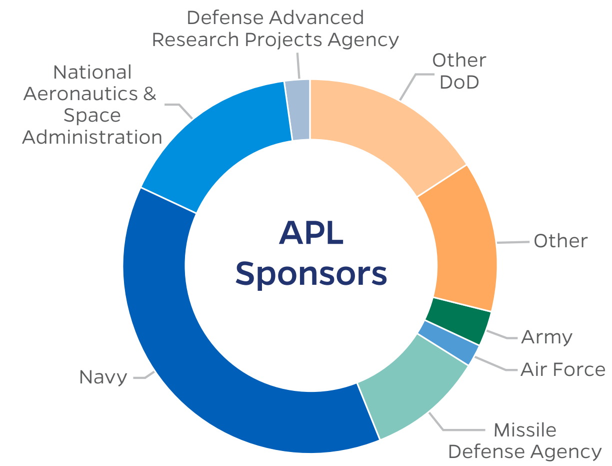
As a UARC, APL is a division of Johns Hopkins University. This is a relationship we hold dear and one that helps to enable our objective and independent work.

While we have strict conflict of interest restrictions, our sponsors can include government offices and philanthropic organizations.

UARCs function broadly as trusted technical advisors to sponsors. When appropriate, and where no conflict of interest exists, they may compete for science and technology work on Broad Agency Announcements and Announcements of Opportunity.

The majority of our work comes from the Department of Defense (DoD) as sole-source (noncompetitive) funding under the Competition in Contracts Act (CICA), primarily, though not exclusively, Exemption 3.

ABOUT APL



APL's mission is to make critical contributions to critical challenges. As the nation's preeminent UARC, we have:

- Broad exposure to challenges facing a wide variety of sponsors
- A diversity of expertise and experience to address those challenges
- A track record of bringing together government, academia, and industry in solving complex challenges

Our access to numerous innovation ecosystems helps us in our work.

In 2018, we had:

- ~100 different government sponsors
- ~200 subcontracts to 74 different universities

Strategic Systems Test and Evaluation

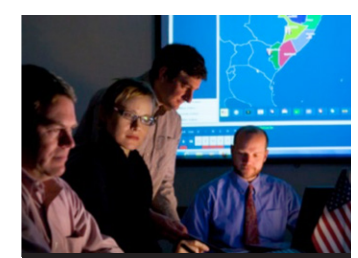
Submarine Security and Survivability

Space Science and Engineering

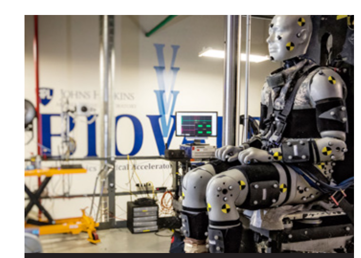
Combat Systems and Guided Missiles

Theater Air Defense and Power Projection

Cybersecurity and Big Data



Simulation, Modeling, and Operations Analysis

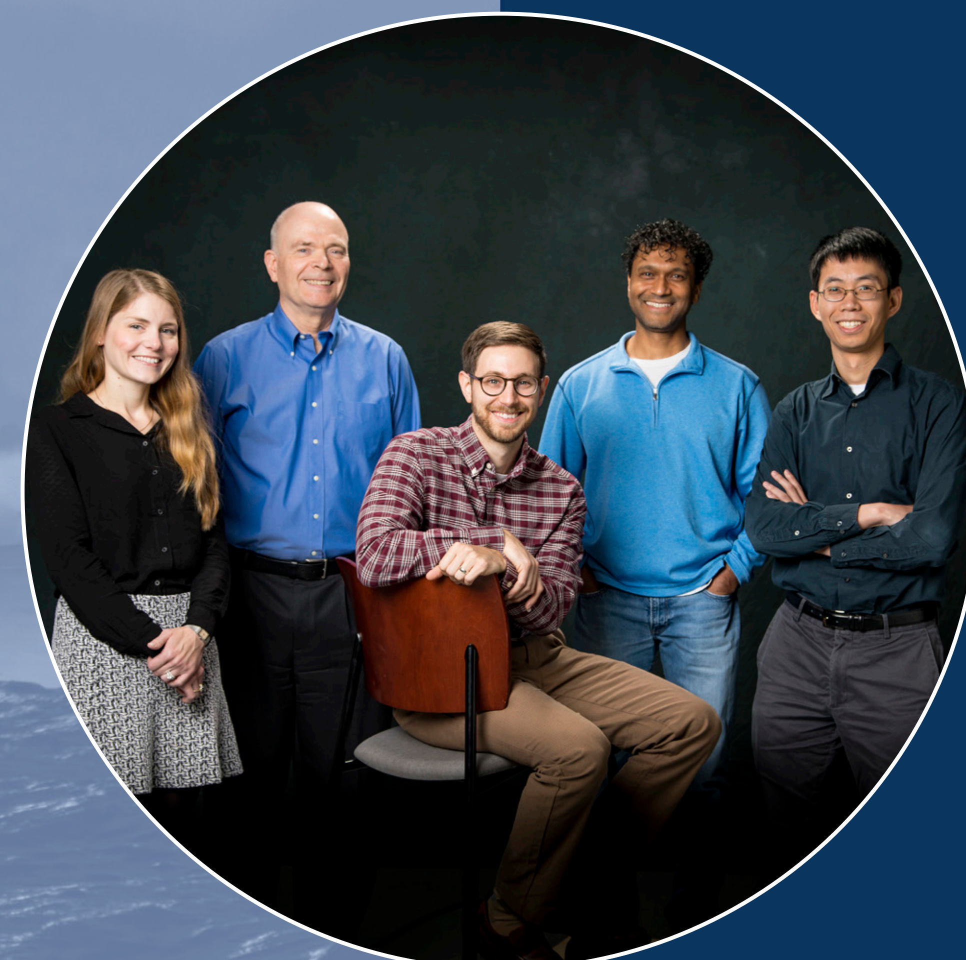


Mission-Related Research and Development

U.S. Navy

BOLD, NEXT-GENERATION INITIATIVES

APL is developing national security initiatives in each sector that have the potential for game-changing impact.



In laying the foundations for a transformational combat system, senior missile defense expert William Bath (second from left) oversaw a series of missile defense challenges that drew upon the diverse skills of experts across the Laboratory, including (from left) physicist Carrie Rogers, mathematician Jason Scott, computer scientist Anshu Saksena, and electrical engineer Nathanael Kuo.

FOUNDATIONS FOR THE TRANSFORMATIONAL COMBAT SYSTEM

For the past 75 years, the Laboratory has been instrumental in developing advanced capabilities to defend our forces and allies against aircraft and missile attacks.

That experience is proving more valuable today than ever before. Cruise and ballistic missiles are becoming more sophisticated, faster, and more maneuverable. Threats of large, coordinated, and combined raids of missiles, autonomous vehicles, and nonkinetic kill mechanisms present dangers to our forces that demand a comprehensive layered defeat strategy. More than an iteration of our current defense systems, the nation needs a game-changing shift in how we design combat systems in the future.

APL decided to take a radical approach to this challenge. Senior missile defense expert William “Jerry” Bath oversaw a series of missile defense challenges that drew upon the diverse skills of experts across the Laboratory, including physicist Carrie Rogers, electrical engineer Nathanael Kuo, mathematician Jason Scott, and computer scientist Anshu Saksena, and what emerged was a foundation for a new combat system that will ensure comprehensive defeat of all current and future air and missile threats.

For instance, the Navy employs a combination of electronic countermeasures that make incoming missiles miss and kinetic options that destroy incoming missiles. What’s the best way to coordinate those technologies to survive large, complex raids on ships?

Tomorrow’s active combat-management capabilities must include the robust use and control of electronic warfare (EW) techniques while ultimately fully integrating kinetic responses. We developed several concepts for EW and kinematic scheduling at both force and unit levels to maximize efficiency and effectiveness against large raids, and we are collaborating with other Navy laboratories to prototype weapons and countermeasure scheduling concepts for integration with the AEGIS Combat System.

Beyond complexity, countering speed is another challenge. Nations around the globe are focusing more attention on hypersonic systems, and potential adversaries are reportedly advancing programs to field hypersonic boost-glide weapons. These systems likely pose a significant threat within the next decade. APL has initiated a comprehensive evaluation of multilayered defenses against advanced hypersonic threats, including concepts to counter threats that possess a kinetic advantage and an approach for analyzing the combined effect of multiple defeat modalities.

In fact, our work in this area is already helping our sponsors. The Missile Defense Agency has used our new combat system concepts and end-to-end analysis techniques and tools in a Department of Defense Analysis of Alternatives on Hypersonic Defense to aid in developing a capability description for the next generation of hypersonic defense.

As we shape these foundational efforts, we also eye a future in which combat systems learn and evolve autonomously. In the time it takes innovations to make their way into the entire fleet—typically a decade or more—threats change and evolve, and new dangers arise. But what if a combat system could *adapt* to those threats? It’s our “mission impossible” that—thanks to APL’s growing leadership in autonomy and artificial intelligence—it might actually be *possible*, and we aim to show that defense systems, when faced with new threat weapons, can learn about the dangers those weapons pose and how to defeat them.

BOLD, NEXT-GENERATION INITIATIVES

LEADING AT HYPERSONIC SPEED

APL work in hypersonic technologies goes back half a century, when the Laboratory undertook a then-classified program in the 1960s to develop a family of supersonic combustion ramjet missiles.

Today—from basic researcher to technology developer to trusted advisor—our role in hypersonics is as critical as ever. APL engineers lead projects to advance the state of the art of guidance, navigation, and control of these vehicles; validate the tools used to predict boundary layer transition; and investigate new materials to withstand the thermal environment.

A main challenge in enabling hypersonic flight is developing robust guidance and control algorithms, primarily because the aerodynamic and propulsive models needed to shape these algorithms are difficult to characterize at such fast speeds. We are leveraging our experience in the development and analysis of guidance and control algorithms to aid in the development of multiple hypersonic weapons for the Department of Defense. We are also investigating advanced autopilot methods to compensate for uncertainty and to adapt to sudden and unexpected changes in aerodynamic characteristics.

In addition to augmenting our capabilities in tuning and analyzing state-of-the-art autopilot topologies, we are developing tools and techniques for assessing autopilot robustness to aerodynamic variations, as well as developing novel guidance methods to shape hypersonic trajectories.

The unique shape of hypersonic vehicles requires aerodynamic controls that differ significantly from the fins on conventional missiles. These control surfaces have unusual characteristics that vary significantly through flight, are very nonlinear in their effectiveness, and require high-speed autopilots to maintain control of the vehicle.

The development of hypersonic capabilities is one of the Pentagon’s highest technical priorities.

We have developed new guidance laws for these vehicles, and we are currently investigating a number of hypersonic vehicle designs as part of the Laboratory’s technical expertise role for multiple sponsors.

APL is working to advance three types of propulsion systems needed for hypersonic flight: a solid rocket motor, which is required for hypersonic missiles; a dual-mode ramjet (DMRJ) engine, which is a type of air-breathing propulsion system that is used on powered cruise missiles; and a turbine-based-combined-cycle engine that incorporates a conventional military turbofan engine for takeoff and low-speed acceleration and a DMRJ for high-speed flight.

With these advances, the Laboratory is also making significant discoveries in material science that will allow sustained hypersonic flight.

The fundamental challenge for materials in the hypersonic environment is thermal survivability, withstanding significant aerothermal and structural loads in flight. We have completed a three-year strategic internal research and development program focusing on high-risk areas for tactical hypersonic vehicles whose mass and volume constraints are particularly challenging.

Leveraging APL's groundbreaking work with the heat shield for Parker Solar Probe (launched in August 2018 to explore the sun), our materials research team has focused on protecting the leading edges and control surfaces of hypersonic vehicles. The team is also examining ways to fabricate these systems by using additive manufacturing processes.

APL is playing a leading role in developing and enabling the flight of first-generation hypersonic vehicles, but our vision is to play a critical role in transitioning hypersonic capabilities to operating forces. We also intend to define the vision and technological development needs for the second- and third-generation systems, and to begin exploring the complete utility of the hypersonics domain.

BOUNDARY LAYER TRANSITION

Brad Wheaton leads an APL team tackling a challenge that is critical to hypersonics: accurately predicting the state of the boundary layer, or the thin layer of air near the surface of these incredibly fast-moving vehicles.

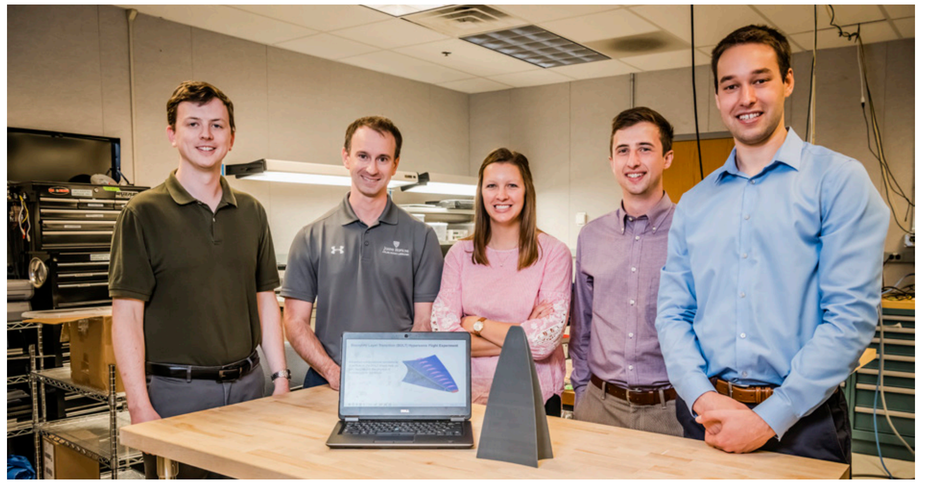
Hypersonic vehicles move fast—faster than five times the speed of sound, or Mach 5. Being able to pinpoint whether the air is laminar (moving in a smooth, straight line) or has transitioned to turbulent (swirling in eddies, with up to eight times the heat transfer) is critical for determining what materials to use when designing hypersonic aircraft and missiles.

Figuring out where boundary layer transition occurs also helps better predict vehicle controllability and aerodynamic drag. However, multiple factors—including vehicle shape, speed, and altitude—make identifying boundary layer transition extremely difficult.

Enter Wheaton and his team at APL. After being awarded a research grant from the Air Force Office of Scientific Research, the team set out to advance our knowledge of boundary layer transition physics through a series of experiments called BOLT.

BOLT builds on recent work to study transition in simple conical shapes and uses it to develop new physics-based transition prediction tools. The BOLT team set out to apply these state-of-the-art tools to a new, more complex geometry, where the physics of transition are not yet known.

To achieve this, the team is conducting computational analyses and wind-tunnel tests to characterize boundary layer transition on the geometry over the course of the next three years, culminating with a test experiment to measure boundary layer transition in hypersonic flight.



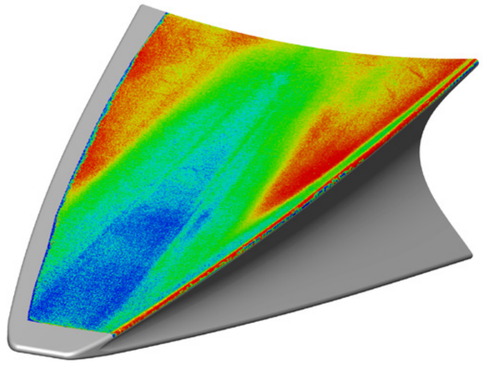
(From left) APL staff members Dennis Berridge and Brad Wheaton worked with interns Heather Kostak, Gregory McKiernan, and John Thome to analyze data and help design an experiment to predict the state of the thin layer of air near the surface of hypersonic vehicles.

With BOLT, Wheaton and fellow APLers Dennis Berridge and Thomas Wolf lead a diverse multiorganizational team that includes some of the nation's top academic, commercial, and government research groups, including the University of Minnesota, Purdue University, Texas A&M University, CUBRC, NASA Langley, the Air Force Research Laboratory, and VirtusAero. They are also supported by Air and Missile Defense Sector staff members who are predicting in-flight temperatures during the experiment, and the Research and Exploratory Development Department's Advanced Mechanical Fabrication Group and machine shop, where wind-tunnel models and the flight experiment hardware are being built.

The BOLT effort also features graduate students from around the country, several of whom joined APL as summer interns to analyze data and help design the flight experiment. The interns also had an opportunity to work on other hypersonic programs to see firsthand how scientific knowledge can be used to design real-world systems.

Wheaton hopes the cross-collaborative BOLT experiments will help APL and the greater hypersonics community gain important knowledge the community can use to improve prediction of boundary layer transition on future hypersonic vehicles.

BOLT is an example of APL's role as a trusted partner between academia and research and the government to turn research and scientific concepts into reality.



Visualization of surface heat transfer using temperature-sensitive paint on a full-scale BOLT model in the CUBRC LENS II shock tunnel (Buffalo, NY). Regions of higher heating (orange/red) are due to boundary layer transition.

Members of the Parker Solar Probe team in the Space Environment Simulator at NASA's Goddard Space Flight Center. (From left) Curtis Wilkerson, Felipe Ruiz, Neal Bachtell, Betsy Congdon, Lee Hobson, Tony Ahan, Chip Delmar, and Daniel Eby.

EXPLORATION TO THE EXTREMES

From the sun to Earth and beyond—with the Parker Solar Probe, Double Asteroid Redirection Test (DART), and Dragonfly missions—APL is disrupting the future of space science and exploration.

HERE COMES THE SUN

When NASA's Parker Solar Probe began its first encounter with the sun's corona in late 2018—flying closer to our star than any other mission in history—Betsy Congdon was watching a little more intensely than the rest of the world.

For the better part of the past decade, Congdon led the team that designed, developed, and tested Parker's Thermal Protection System (TPS)—an eight-foot-diameter carbon–carbon foam shield that defends the spacecraft against the intense heat and energy of our star. Every instrument and system on the APL-built spacecraft (save for a special particle detector and four antennas) is hidden from the sun behind the breakthrough TPS as the probe fulfills its critical mission: explore the sun's outer atmosphere and make critical observations to answer decades-old questions about the physics of stars.

The TPS leads a list of innovations that turned a longtime scientific quest—predating NASA itself—into space exploration reality. When Parker Solar Probe is hurtling past the sun at some 430,000 miles an hour, it is 90 million miles from mission controllers on Earth—too far away to be "driven" by the team. This means that adjustments to how the spacecraft protects itself with the TPS must be handled by onboard guidance and control systems, which use new and effective autonomous software to allow the spacecraft to instantly alter its pointing. This autonomous capability (shaped by engineer Adrian Hill) is also critical to the operation of the spacecraft's solar arrays, which must be constantly adjusted for optimal angle as Parker Solar Probe travels through the sun's harsh, superheated corona.

Veteran space-environment expert Carl "Jack" Ercol designed a revolutionary water-cooling system that keeps those solar arrays at peak performance, even in extremely hostile conditions that other missions have never operated in before. When flying around the sun, the solar arrays receive 25 times more solar energy than they would orbiting Earth, and while the temperature on the TPS reaches more than 2,500°F, the cooling system keep the arrays at a nominal temperature of 250°F.

Parker Solar Probe is one of the most autonomous systems ever flown. That autonomy, along with the new cooling system and TPS—which, to Congdon's expectations, kept the spacecraft's critical systems operating near room temperature during that first solar pass—is crucial to ensuring the probe can perform the never-before-possible science investigations at the sun that will answer questions scientists have had for more than 60 years about our star and its corona.

(Right) On to the sun: Parker Solar Probe lifts off on a Delta VI Heavy from Cape Canaveral Air Force Station, Florida, in the predawn hours of August 12, 2018.

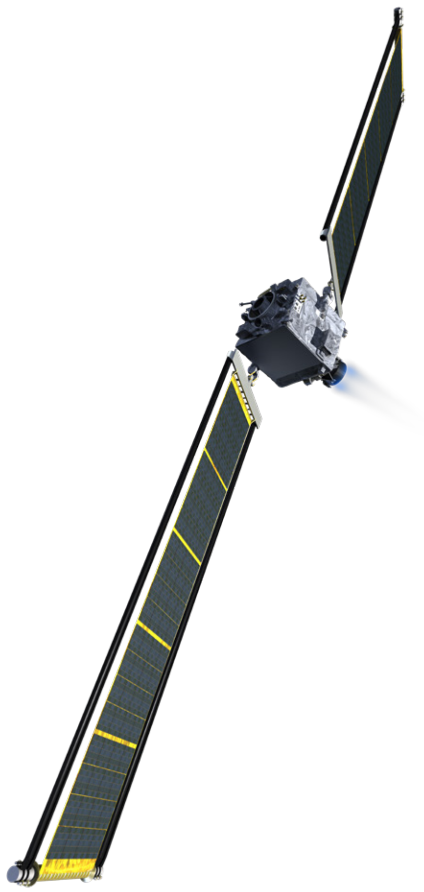
Parker Solar Probe Team

EXPLORATION TO THE EXTREMES

MAKING AN IMPACT

For decades, Andy Cheng and Andy Rivkin have studied the composition, chemistry, and construction of asteroids, but never how to knock one of these large space rocks off course.

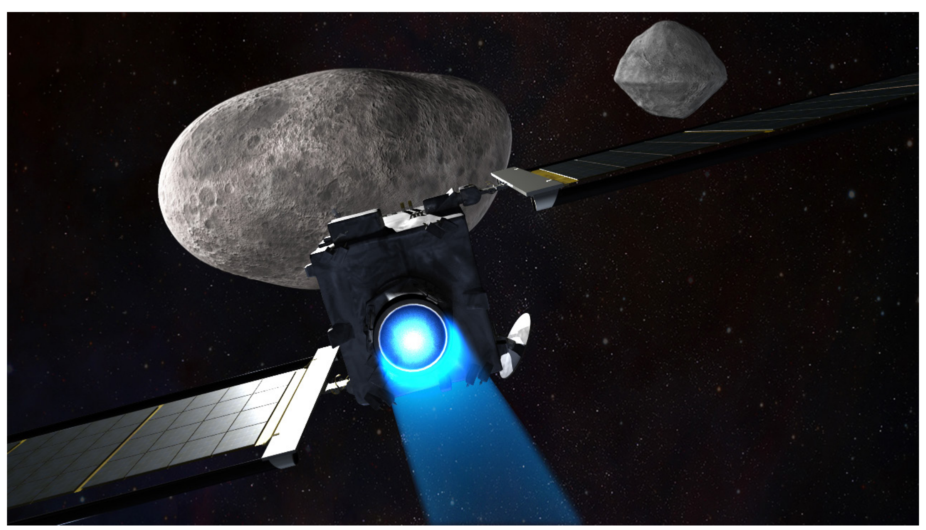
Yet that's just what the APL scientists aim to do as investigation co-leads on the Double Asteroid Redirection Test (DART). DART, which is being designed, built, and led by APL for NASA, is the first-ever mission to demonstrate an asteroid-deflection technique for planetary defense on a real asteroid. With planetary scientist Nancy Chabot as the mission's coordination lead, the spacecraft is scheduled to launch in June 2021.



DART will test what's known as the kinetic-impact technique—slamming into an asteroid to shift its orbit—and take a critical step in demonstrating we can protect our planet from a potential strike.

DART's target is the asteroid Didymos—Greek for "twin"—a binary system that consists of two bodies: Didymos A, which is about one-half mile in size, and a smaller asteroid in its orbit called Didymos B, measuring about 530 feet across. Led by Michelle Chen, the DART team has developed the autonomous SmartNav system, which would identify and distinguish between the two bodies at Didymos and then direct the spacecraft toward the smaller moon. To accurately navigate to the asteroid using onboard systems, the DART team is leveraging decades of missile guidance algorithms developed at APL. DART will fly to Didymos and use the APL-developed onboard autonomous targeting system to aim itself at Didymos B. Then, the refrigerator-sized spacecraft will strike the smaller body at a speed of approximately 3.7 miles per second, which is about nine times faster a bullet.

The kinetic-impact technique works by changing the speed of a threatening asteroid by a small fraction of its total velocity well before it is predicted to impact Earth so that over time, that small nudge will add up to a big shift in the asteroid's path, directing it away from Earth. Observatories on Earth will watch the impact and the resulting change in the orbit of Didymos B around Didymos A, allowing Cheng, Rivkin, and scientists around the world to better determine the capabilities of kinetic impact as an asteroid-mitigation strategy.



(Right) An artist's illustration of DART from behind the NASA Evolutionary Xenon Thruster-Commercial (NEXT-C) ion engine. (Above) With solar panels fully deployed, DART measures just under 60 feet across.

A TITAN PROPOSAL

Principal Investigator Zibi Turtle has assembled a squad of talented scientists and engineers to shape Dragonfly, the proposed rotorcraft lander expedition across Saturn's exotic moon Titan that's vying to become NASA's next New Frontiers mission.

Titan turns out to be the ideal location for such a voyage. The moon has such a thick atmosphere and such low gravity that a dual quadcopter could potentially cover up to hundreds of miles across the moon in just a couple of years. Designing a way to take advantage of that environment might be the most creative aspect of a mission aimed at a serious space challenge: getting a close view—and direct "taste"—of the complex organic compounds on Titan's surface that could hold the ingredients for life.

Titan is in many ways the most Earth-like world in the solar system and, as an "ocean world," one of NASA's top exploration targets. Larger than the planet Mercury and covered by a nitrogen atmosphere laden with organic smog, Titan's surface is partially hidden from view. Far from the sun, Titan is cold enough that methane plays the active role that water plays on Earth, serving as a condensable greenhouse gas, forming clouds and rain, and pooling on the surface as lakes and seas. Titan's carbon-rich surface is shaped not only by winds that sculpt drifts of aromatic organics into long, linear dunes but also by methane rivers and possible cryovolcanic eruptions of liquid water.

Designed to sample surface materials and determine compositions in different settings, the revolutionary Dragonfly concept offers the capability to explore diverse locations and characterize the habitability of Titan's environment, investigate the progression of prebiotic chemistry, and even search for chemical hints of water-based or hydrocarbon-based life.

Artist's rendering of the Dragonfly concept to explore Saturn's moon Titan.

CYBER ARCHITECTURES FOR MULTIPLE PLATFORMS

APL is developing and implementing revolutionary situational awareness capabilities across critical cyber platforms, from stronger resilience in Navy shipboard and national transportation screening systems to searching data for hints of a potential cyber attack.

An engineering team that includes (from left) Daniel Hedgecock, Bliss Carkhuff, Dane Fichter, and Leslie Cruz is taking a multipronged approach to a range of cyber threats, pioneering security and situational awareness capabilities for applications on specified vessel classes.

THE NAVY'S CYBER AWAKENING

There's more than one way to sink a ship. After years of fortifying the fleet against visible kinetic threats above and below the seas, the U.S. Navy is confronting a clear and present danger in a new realm: cyberattacks that could cripple a vessel and take down its operational systems.

Over the past decade, APL has helped the Navy address significant cyber challenges in its shipboard information technology and operational systems—an awakening that has spurred a sea change in how the Navy identifies, detects, and deflects cyber threats to the world's most advanced and powerful naval fleet.

It took a war game, nearly a decade ago, for the Navy to see that cyber threats were growing in scope and power, and experience just how hackers can quickly break into a vessel's computers and render its operational and weapons systems useless. This prompted a service-wide initiative to infuse cybersecurity thinking in all Navy programs and begin shaping a culture that considers dominance in the cyberdomain every bit as essential to victory as success in the skies or at sea.

As the organization that has served the Navy through nearly eight decades of strategic responses to evolving threats, APL responded swiftly to this newest challenge. The Lab is working with the Navy on a bold initiative to generate capabilities that will provide cyber situational awareness for hull, mechanical, and electrical systems afloat.

Program manager Steve Carder and an engineering team that includes Tony Webber, Leslie Cruz, and Brian Garofalo are taking a multipronged approach to a range of cyber threats, pioneering security and situational awareness capabilities for applications on specified vessel classes. One particular project focuses on developing software that collects data on numerous processes, analyzes that data, zeros in on abnormal system behaviors, and displays them quickly and clearly to the sailors who can act on them. This project included tailored visualization and state-of-the-art control system "fingerprinting" capabilities that were integrated seamlessly into existing Navy situational-awareness tools.

Long term, Carder's team is aiming beyond situational awareness toward full recovery from any targeted attacks on vessel systems—all part of APL's mission to help the Navy focus on response and recovery for end-to-end cyber resiliency.

Sailors stand watch in the Fleet Operations Center at the headquarters of U.S. Fleet Cyber Command/U.S. 10th Fleet. (U.S. Navy)

SECURE SYSTEMS

The "bad guys" in a cyber exercise typically know little about the systems they attack. They'll break into and disrupt a system, but they often can't say exactly how they achieved those effects or know what defenses might have stopped them—and that's information critical to shoring up the system's defenses.

But what if these "red teams" had the inside scoop on the systems ahead of time? It's not cheating—it's the idea behind System Security Profiling (SSP), a technique developed by the National Security Agency that APL is building on to supply sponsors with insights into protecting equipment they buy off the shelf.

APL provides sponsors with critical insights on protecting equipment they buy off the shelf—helping to improve the cybersecurity posture of critical systems.

Mike Hostetter, Gary Wright, and Adam Sawyer lead a team working with the Transportation Security Administration (TSA) to test airport-checkpoint screening systems and several commercial security solutions being procured by large mass transit and passenger rail authorities. SSP calls for specific, targeted investigations of a system's cyber weaknesses, leading to a 360-degree assessment of as many cyber weaknesses as possible in the shortest amount of time—and at lower cost.

The process includes identifying weak settings and gaps in a system's configuration; mapping a network in search of weak protocols, configurations, and access points; finding areas to exploit; planning and performing the attacks; identifying mitigation strategies; and reporting on the findings.

Source code and open-source information are key to planning the test. Source code analysis takes place in APL's Software Assurance Research and Applications (SARA) laboratory; the team gathering open-source information (also known as open-source intelligence gathering) uses an advanced and automated APL-developed process that leverages open-source and commercial off-the-shelf tools and expert human analysis.

The tests for TSA highlighted various areas for improvement, including those related to cyber hygiene, configuration, software, physical access, and networking. For each finding, APL provided specific technical details, along with one or more suggested mitigations. The findings, grouped in terms of estimated severity and potential impact to the mission, will go a long way toward improving the cybersecurity of the nation's transportation systems.

CYBER ARCHITECTURES FOR MULTIPLE PLATFORMS

THE CYBER "SMART AGENT"

Terror groups tend to follow the same pattern when executing an attack: they recruit participants, acquire and weaponize a pathogen, buy equipment and supplies, and devise a plan to pull off the attack. All of these activities leave a trail—evidence that they occurred—much of which shows up somewhere in a swelling sea of data available at multiple classification levels.

This is exactly why Joe Behling and his team of scientists and software engineers developed AGENT, a data-aggregating system that turns nuggets of information into actionable intelligence. Like an asymmetric smart agent, the platform combines technologies and processes and blends knowledge and data to give analysts—potentially across all agencies and services—unprecedented situational understanding of a threat.

AGENT works by leveraging machine-readable adversary knowledge models, such as the APL-developed Graph Semantic Framework (GRAPH-SF) database and analysis tool. GRAPH-SF itself is a valuable weapon in the fight against terror, the culmination of five years of Department of Defense–funded research to develop state-of-the-art graphs that characterize known processes for more than 40 agents used in weapons of mass destruction. This community-vetted knowledge store contains more than 15,000 objects and 75,000 individual terms, providing analysts with detailed information on people, places, and things associated with weapons of mass destruction.

AGENT is designed to be predictive and proactive, enabling the warfighter to tap the collective knowledge of operators and scientists to accomplish their mission with unprecedented precision and timeliness. The system's developers aim to transform the intelligence analytic process and pioneer ways to identify, locate, and neutralize bad actors intent on harming our nation and its allies.

AGENT has been deployed operationally and can also be applied to threat areas such as terrorism, human trafficking, narcotics, and cyber.

The AGENT application leverages adversary knowledge models to follow the cyber trail left by terrorists planning an attack.

RESPONDING TO GROWING NATIONAL HEALTH CHALLENGES

APL is transforming health care by bringing significant new data analytics and systems engineering capability to the field of medicine that will enhance the nation's ability to predict, prevent, and detect illness and injury.

The multidisciplinary team uncovering the power of data analytics to transform health care includes (from left) Geoff Osier, Brant Chee, Caitlyn Bishop, and Will Gray Roncal.

PRECISION HEALTH AND MEDICINE

In 2017, APL and Johns Hopkins Medicine (JHM) forged a partnership to revolutionize disease diagnosis and treatment, laying a foundation for research and discovery as well as point-of-care decision-making to advance the state of precision medicine.

Precision medicine is an emerging approach to disease prevention and treatment that considers a person's unique behavioral, biological, social, and environmental determinants of health. A precise understanding of an individual's health determinants can be used keep them healthy or, when necessary, to treat them and help them quickly recover from illness or injury.

Key components of precision health and medicine include the ability to comb data found in familiar sources such as medical records and research studies as well as data from nontraditional sources such as advanced devices and wearable electronics. But the volume, variety, and velocity of this information far exceed the ability of researchers and systems to capitalize on the valuable insights potentially existing in the data.

To tackle the challenge, APL assembled a team of engineers and scientists that includes Brant Chee, a data scientist; Corban Rivera, a computer scientist; James Castle, a Unix system administration expert; Will Gray Roncal, an electrical engineer; Caitlyn Bishop, a mathematician; Perry Wilson, a cloud computing expert; and Derek Pryor, a software developer.

In collaboration with JHM, the team developed an information technology system that couples biomedical research and discovery with clinical decision-making in a continually learning precision medicine system. They designed an analytics platform that supports both precision medicine research and health care delivery as the basis for the learning health care ecosystem. Key elements of this platform include accessing electronic medical records, imaging, genomics, and many other health records; transforming and loading data from those systems into a "data commons"; and having appropriate security and access controls and a robust analytics framework.

The partnership builds on APL's expertise in data analytics and clinical and research precision medicine assets at Johns Hopkins. For several conditions, including multiple sclerosis and prostate cancer, JHM has launched precision medicine centers of excellence where these new technologies and measurement tools can be applied to greatly improve patient care.

APL is homing in on the technical and economic promise of precision medicine by asking the following questions: What investments are needed to achieve the envisioned learning health care system, including the underlying information technology and analytics infrastructure? What will be the resulting economic impact of being able to diagnosis sooner and more accurately? And what is required to apply the right therapy sooner and in just the right measure for a given individual?

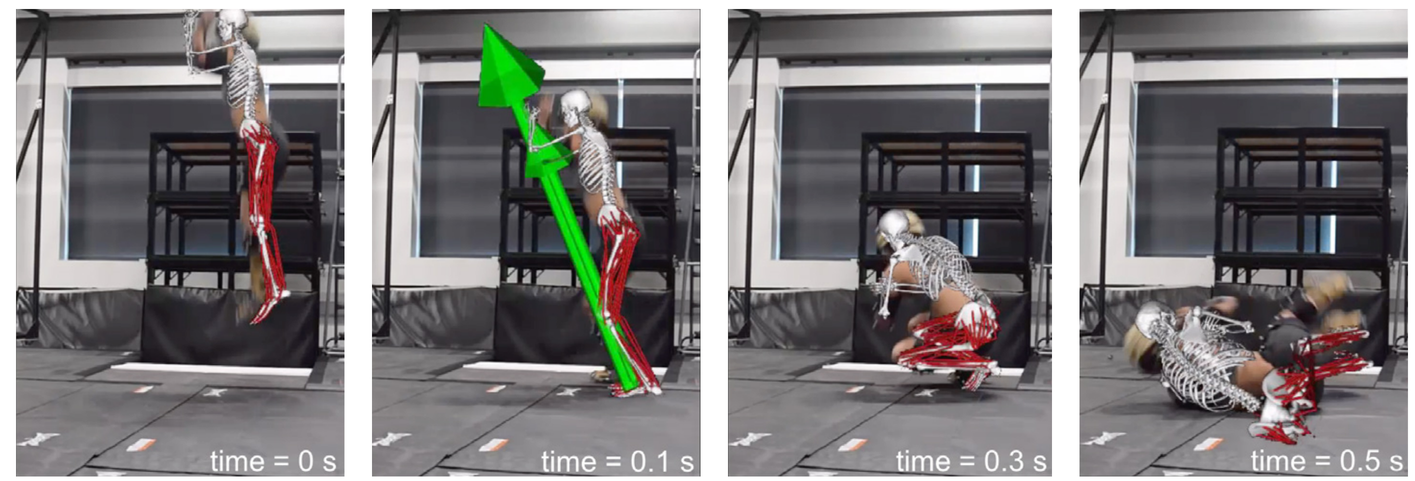
The APL research team is poised to capitalize on the initial implementation of this platform and is investing internal research and development funds in discovering pioneering solutions to further the precision health and medicine vision.

SAFER JUMPS

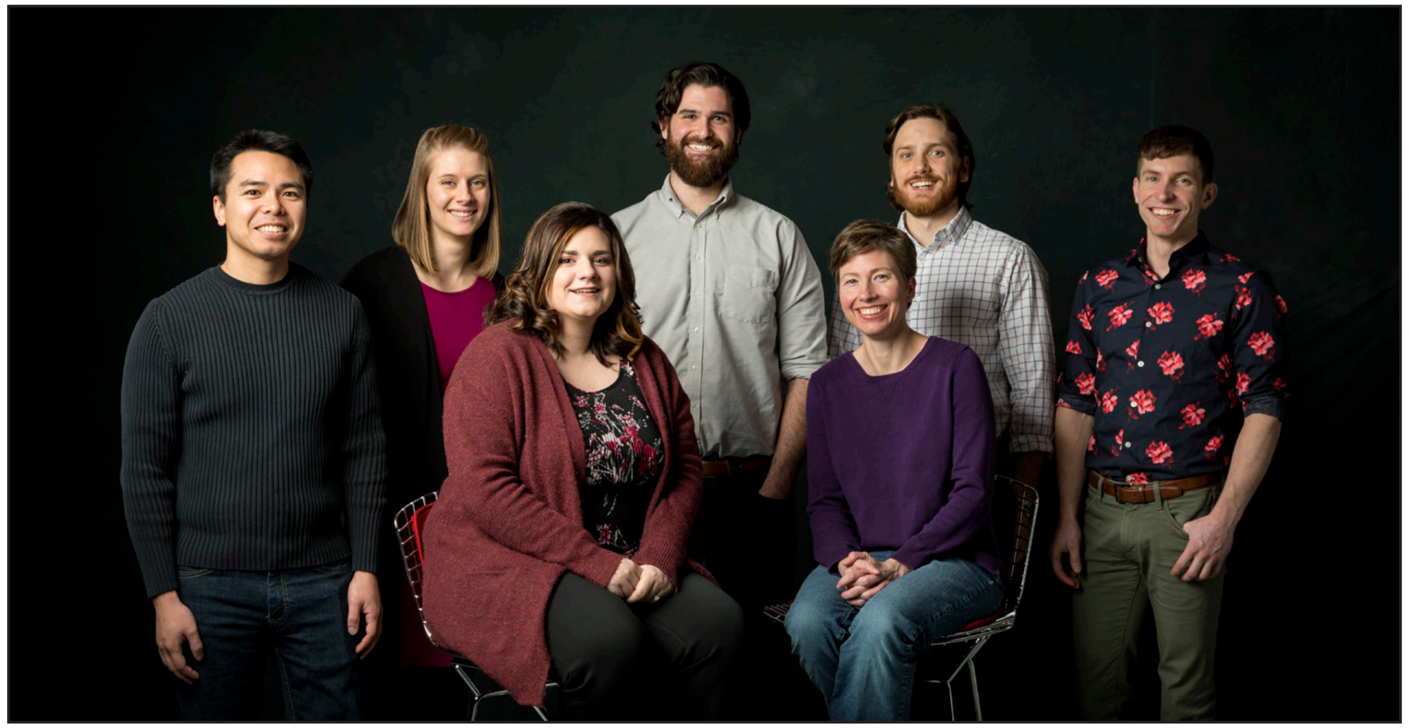
Even after three weeks of rigorous training—including eight qualifying jumps in the final week—paratroopers are still at serious risk of injury. It's not just the jump; the soldiers often carry close to 50 pounds of equipment as they parachute, fast rope, or rappel into drop zones. Their missions are often performed in the dark or during bad weather, and requirements for lower-altitude, higher-speed drops mean paratroopers sometimes have less control over how—and how hard—they land.

A significant part of their training includes learning the parachute landing fall technique, designed to reduce injuries by distributing the impact over a large area of the body and by increasing the time during which the impact is absorbed.

APL engineers Eyal Bar-Kochba, Leah Strohsnitter, John Clark, Connor Pyles, Mary Luongo, Quang Luong, and Catherine "Katy" Carneal are building on these techniques, developing technologies that promise to make military parachuting safer. The group is collaborating with the U.S. Army Natick Soldier Research, Development, and Engineering Center to analyze the internal loads and adaptive control strategies of paratrooper landings. Paratrooper subjects were outfitted with sensors before simulating parachute landings, letting the researchers evaluate impact forces, joint forces and movements, kinematics data, and muscle activity. Engineers then integrated high-fidelity human motion experimental



A montage of a static-line-qualified paratrooper from the 507th Parachute Infantry Regiment performing a parachute landing fall in the laboratory. The images are overlaid with a musculoskeletal model used to study the internal loads and control strategies of the parachute landing fall.



The Paratrooper Safety Research Team (from left): Quang Luong, Leah Strohsnitter, Mary Luongo, Eyal Bar-Kochba, Catherine Carneal, Connor Pyles, and John Clark.

data with advanced modeling and simulation dynamics software, enabling new insights into optimized techniques and equipment for advanced parachuting.

This critical work is happening in APL's Human Dynamics Laboratory, which is instrumented with high-resolution motion-tracking cameras, simultaneous bio-instrumentation, and integrated floor force sensors that allow researchers to simulate operational maneuvers and learn ways to prevent injuries from occurring under similar circumstances.

EXPANDING CARE FOR SERVICE MEMBERS

To say Navy Medicine has a large responsibility is an understatement. The health care network of 63,000 personnel handles health care for members of the Navy and Marine Corps, their families, and veterans in high-operational-tempo environments at expeditionary medical facilities, medical treatment facilities, hospitals, clinics, ships, and research units around the world.

Stateside, APL engineers are working with the Navy Bureau of Medicine and Surgery (BUMED) to expand the role of hospital corpsmen and improve access to medical care for military members through a pilot program called Connected Corpsmen in the Community (CCC).

The Laboratory is providing systems integration, capability assessments, and data analysis to improve health care delivery models for active-duty service members in Pensacola, Florida. As part of the newly developed treatment model (CCC), corpsmen are now treating service members for minor injuries, including sprains, strains, joint pain, upper respiratory infections, insect bites, suture removal, and more. They are supported by a virtual connection to credentialed providers using telemedicine technologies—allowing licensed Navy physicians to monitor exams and instantly review patient imagery to assist with diagnoses.

Working with staff members from BUMED, Navy Medicine East, Navy Medicine West, the Navy Medicine Education, Training and Logistics Command, and Naval Hospital Pensacola, the APL team tested CCC at Pensacola's Naval Air Technical Training Center to benefit the center's large population of students.

APL is uniquely positioned as a trusted, objective resource to play a key role in this critical initiative for Navy Medicine. The Laboratory's team is not only helping enlisted medical staff members maintain medical competencies in preparation for deployments but also improving access to and the convenience of care for active-duty service members.

CCC has since expanded to two additional sites. The Navy also used APL analyses to understand the prevalence of certain high-volume, low-acuity conditions across its forces and, consequently, the need for expanded routine care. CCC provides the active-duty force with more choices for routine care while giving enlisted medical personnel—those who save lives on the battlefield—additional experience while assigned to facilities at home.

Hospital Corpsman Third Class Spencer Martin, a hospital corpsman with Naval Branch Health Clinic Naval Air Technical Training Center, examines a patient's ankle as part of the Connected Corpsmen in the Community (CCC) concept implemented by Naval Hospital Pensacola. (U.S. Navy)

U.S. Navy

SOLVING PROBLEMS THROUGH CLOSE COLLABORATION

Our sponsors' needs vary—from automated data-analysis methods to durable materials for national security and space operations—so APL pulls specialized talent from across the Lab into collaborative teams that find affordable and effective solutions to some of the nation's toughest challenges.

From left, Ashley Llorens, Jennifer Sample, Chad Hawes, Pedro Rodriguez, Dmitriy Bekker, and Chris Gifford are among the many scientists across the Laboratory leveraging the power of deep learning to help sponsors sort through vast amounts of data for a fast analysis of what's going on in the air and on the ground.

DEEP LEARNING

Sorting through vast amounts of data is a growing challenge for defense, intelligence, and security agencies that need fast analysis of what's going on in the air and on the ground to secure environments and dispatch assistance. APL is leveraging the power of deep learning to help sponsors tackle this challenge, and our work is unlocking the power and possibilities of artificial intelligence (AI).

For decades, the Lab has harnessed the power of machine learning, particularly for automatic target recognition. As we sought to more broadly apply the technique to sponsors, researchers found that though data was abundant, there were few samples accessible to obtain the target of interest and train the computer.

Pedro Rodriguez, a biomedical and electrical engineer, recognized that a transfer learning process he had been using on a previous project could be applied to deep learning. The method allowed researchers to take a deep neural network trained on many images from one domain—people, dogs, and horses, for example—and use it to extract discriminatory features from images obtained from sponsor-relevant domains, such as images of tanks obtained from satellites. Then he could train a classifier on features extracted from far fewer samples.

This entry to the field of deep learning at APL has spawned collaborations across the Laboratory. Computer Scientist Chris Gifford oversees one of our largest system-level deep learning efforts, which is focused on porting deep learning-based object detection, automatic target recognition (ATR), and segmentation algorithms to low size, weight, and power hardware so that ATR algorithms can be put on unmanned aerial vehicles—or even spacecraft—for onboard processing to support time-critical missions, reduce bandwidth requirements, and relieve analyst burden.

Computer engineer Dmitriy Bekker worked with Rodriguez to expand deep learning methods to the space domain, particularly to respond to time-critical targets observed from space. They looked into building processing systems that would fit less-expensive small satellites and perform ATR directly at the sensor.

For the last 13 years, electrical engineer and mathematician Chad Hawes has been applying his signal processing, statistics, and machine learning expertise to exploit remote sensing data of various sensor modalities. Over the last three years, he has led or participated in internal research projects, applying deep learning techniques to the limitations of realistic passive sonar, active sonar, and electronic warfare (EW) datasets. With his teams, he has been able to show significant promise using deep learning for these problems and is working with sponsors on applying deep learning to improve classification for passive sonar, active sonar, and EW.

The Avenger-class mine countermeasures ship USS Chief (MCM-14) pulls into Jeju Island in the Republic of Korea as part of a routine port visit on September 26, 2017. (U.S. Navy)

As a program manager leading advanced science and technology efforts at the Lab, Jennifer Sample recognized the impact of AI on the national security landscape, as well as the need to address significant longer-term technology gaps. Her team is working to protect AI algorithms against adversarial use, creating algorithms that learn continuously during execution without forgetting previous learning, and teaching machines common sense reasoning.

Ashley Llorens, who heads APL's Intelligent Systems Center, is helping to foster a community of practice around machine learning, making emerging techniques like deep learning more accessible to researchers and programs across APL.

Soon enough, Rodriguez predicts, researchers everywhere will have to be familiar with deep learning and machine learning—methods that are laying the groundwork for true AI.

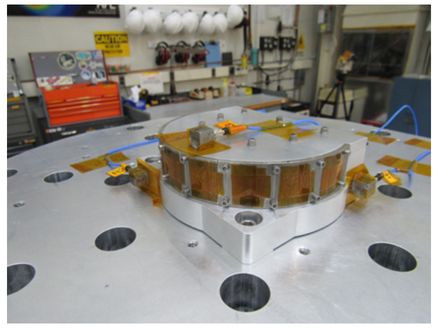
ADDITIVE MANUFACTURING

Building on our substantial advanced mechanical fabrication capabilities, APL established a center of excellence two years ago to guide major advances in additive manufacturing—more commonly known as 3D printing. Since then, APL's Additive Manufacturing Center has guided our efforts to creatively apply this disruptive technology, which is rapidly revolutionizing how a wide variety of parts and systems are designed and built.

Experts in APL's Additive Manufacturing Center guide efforts to revolutionize how a wide variety of parts and systems are designed and built.

One collaboration with APL's Intelligent Systems Center (ISC) is developing a low-cost, 3D-printed humanoid robotic system for research in AI and human–machine interaction. The robotic system, named ISaaC (for Intelligent System as a Concierge), leverages an open-source robotic framework, commercially provided arms and hands, and APL-developed control and AI software. ISaaC is a low-cost research platform for the Centaur program, which is teaming humans and machines to unlock new capabilities in AI and improve human performance.

ISC interns developed "concierge" capabilities that let ISaaC answer questions, give directions, perform demonstrations, provide conference information, and email ISC employees to let them know when visitors arrive. But beyond research and giving tours, the versatile ISaaC has potential applications for APL's government sponsors, including ordinance disposal, improvised explosive device disassembly, and other tasks that are hazardous to warfighters.

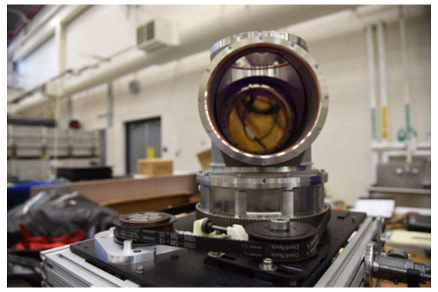


Space engineers needed a device that focuses radiation into a sensor while also protecting the sensor from Jupiter's harsh radiation. This collimator is pictured on a full-size instrument mock-up during successful trials in APL's Vibration Test Laboratory.

Space engineers came to the center for help on an instrument set to fly aboard the European Space Agency's JUpiter ICy moon Explorer—a package known as PEP-Hi that, in part, will study higher-energy particles around Jupiter and its moons Ganymede and Callisto. They needed to develop a new collimator, a device that focuses radiation into a sensor, while also protecting the sensor from Jupiter's harsh radiation.

A collimator's sensitivity is determined by the number of holes it includes to allow radiation through to the sensor, in the same way a larger telescope (more holes) is more sensitive than a smaller one (fewer holes). Designers came up with a material as well as a method to cut hundreds of tiny holes in that material—upping the sensor's sensitivity—all in a package that is thin and light enough to accommodate the holes yet tough enough to deflect extra radiation.

The initial work required an additive engineer, several machinists, an X-ray computed tomography expert, mechanical engineers, and designers to prove out the concept, not to mention the large number of planners and support staff members who helped juggle other jobs to push the first builds through. Yet proving feasibility was only the first step; next came flight qualifying, another multidisciplinary effort that spans not only APL but also NASA. The collimator has passed its critical design review and the team is on track to build the actual parts for what will be APL's first additive-manufactured space instrument.



Using additive manufacturing, APL is meeting a Navy need for a novel high-speed scanner able to pick up exposures of a target periscope.

The center applied this deep-space method to a similar deep-sea challenge. APL served as the sensor system lead for the Surface Ship Periscope Detection and Discrimination (SSPDD) program, an Office of Naval Research effort to apply optical techniques to periscope detection.

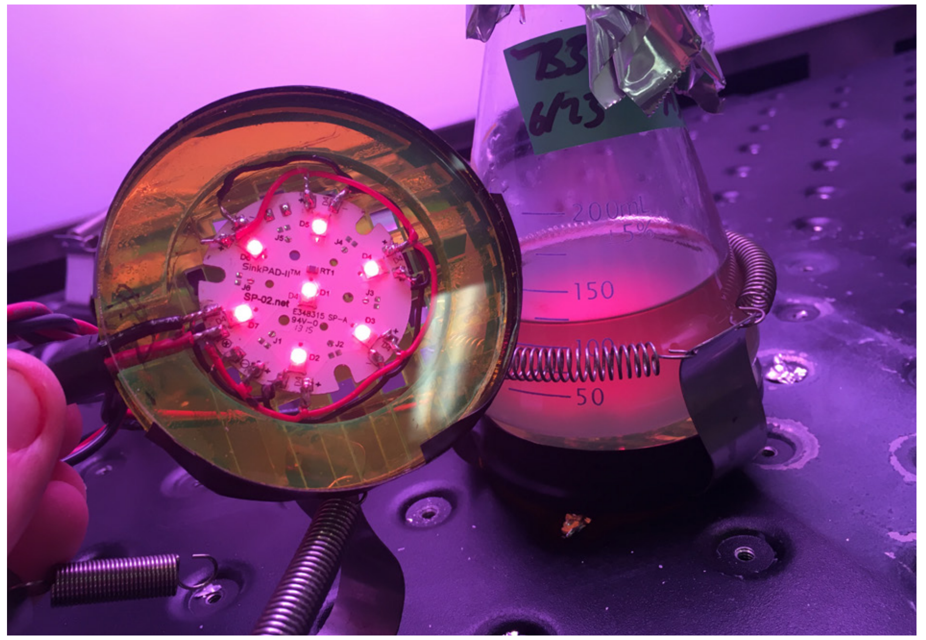
The program called for a novel high-speed scanner able to pick up even fleeting exposures of a target periscope. Designed to house a custom scan mirror, protect the internal optics from the harsh maritime environment, and provide the mechanical structure to hold demanding tolerances of the optical design under operational conditions, the part posed several challenges for traditional manufacturing.

For APL and SSPDD, this was an opportunity to evaluate the potential of additive manufacturing to create complex metallic parts suitable for operational deployment on surface ships, while saving costs. The program pulled expertise from across the Lab: light detection and ranging (LIDAR) system development and integration from the Asymmetric Operations Sector; mechanical engineering and marine environment experience from the Force Projection Sector; optical analysis of the scanner window and mirror from the Space Exploration Sector; and additive manufacturing design, production, and finishing from the Research and Exploratory Development Department.

When SSPDD ended, weight reduction in the high-speed scanner was a topic of significant interest, and leveraging the potential of additive manufacturing to infuse exotic materials and implementing novel design methods were seen as logical next steps to achieving this objective. The team has also been considering opportunities to use additive manufacturing to expand the scanner's capabilities.

Regardless of the technology—whether used at sea, in space, or anywhere in between—future designs will almost certainly leverage the rapid prototyping advantages of additive manufacturing.

EMBRACING NEW CHALLENGES



Producing modified chlorophylls using cyanobacteria grown in far-red light.

In a field normally focused on health, Ally Bissing-Gibson is using biology to strengthen national security. Bissing-Gibson leads APL's new Biological and Chemical Sciences program, launched to connect biotech to missions across the Lab and use biology for novel capabilities, including information collection and sensing platforms, and in critical areas such as food security and environmental stability.

Based in APL's Research and Exploratory Development Mission Area, the program is focusing specifically on novel sensing, forensics indications and warnings, biomaterials and biomimetics (human-made processes, substances, devices, or systems that imitate nature), and environmental/infrastructure sustainability.

Novel sensing involves developing sensors that can be used in denied areas or be controlled with genetic switches, and developing mobile platforms with intelligent behavior. One example is a plant sensor under development to covertly sense and report information to existing remote-imaging platforms.

Forensics indications and warnings initiatives are aimed at developing novel detection paradigms, intelligence capabilities, and forensic tools. An example of work being done in this area is a protein-based methodology to augment DNA identification of humans.

Researchers focused on biomaterials and biomimetics are developing functionalized and adaptable materials for a variety of applications, such as detecting hazardous agents or characterizing exposure signatures. This work may lead to novel operational capabilities, like materials that can absorb oxygen from water to enable underwater breathing without scuba gear, or bioprinting to prototype unique 3D products.

Researchers are also exploring environmental and infrastructure sustainability to develop sensors of environmental and agricultural health. A platform that will use advanced, next-generation genomics techniques for autonomous, in-situ biological population characterization using DNA sequencing is one example of this effort.

STRATEGIC CONTRIBUTIONS TO CRITICAL NATIONAL ISSUES

APL's rigorous, technically informed analysis shapes technology and national security investments, and it enables senior government leaders to respond to emerging threats.

(Front, from left) Fazle Siddique and Tom Falk, along with (back, from left) Assistant Director for Policy and Analysis Christine Fox and National Security Analysis Mission Area Executive Preston Dunlap, were critical to the development of a senior leader "space game" to address challenges related to national security policy and decision-making at the highest levels of government.

SPACE STRATEGY

Tom Falk and Fazle Siddique are unlikely policy shapers. Siddique came to APL in 2011 to design space science missions; Falk joined the Lab a year earlier to design cutting-edge satellites for the Missile Defense Agency. Although challenges related to national security policy and decision-making at the highest levels of government were outside their areas of expertise, the two aerospace engineers were crucial leaders of the team that developed a senior leader "space game" to address those very issues.

In fact, the APL team that designed this critical exercise didn't set out to change policy—it aimed to provide a technically rigorous scenario that would illuminate the opportunities and consequences of policy and technology acquisition choices. Our nation faces especially challenging decisions when it comes to space operations, research, and development. Technologies within the space domain are changing rapidly, and the acquisition and policy decisions made today will shape national security, as well as international norms and policy, for years to come.

Along with Assistant Director for Policy and Analysis Christine Fox and National Security Analysis Mission Area Executive Preston Dunlap, APL experts in space operations, technology development, military operations, international policy, and acquisition designed an operationally challenging scenario that forced the game's participants—some of the nation's most senior national security decision-makers—to grapple with realistic and technically informed timelines, authority questions and rules of engagement, and the operational implications of pursuing different space architectures.

Falk, Siddique, and colleagues needed to integrate the technical underpinnings and national security challenges in space while examining the novel cross-cutting opportunities at the nexus of global commercial and national security communities. The game leveraged the best of APL's technical and analytical talent to support a difficult but nonetheless crucial exercise in which technical choices influenced policy options, and vice versa. It had important impacts for the senior decision-makers and subsequent investment choices in the president's budget, and the post-game analyses continue to help inform the nation's leadership. A second game is being planned for FY 2019.

More than 20 of America's most senior national security leaders gathered at APL to take part in a "game" that explored potential responses to scenarios that threatened U.S. space-based assets.

STRATEGIC CONTRIBUTIONS TO CRITICAL NATIONAL ISSUES

DECISION-MAKER'S PERSPECTIVE

Having coordinated the Department of Defense's response to Superstorm Sandy in 2012, Paul Stockton wondered: what if the nation's critical infrastructure had been hit not by a physical storm but by a cyber storm instead?

The former assistant secretary of defense knew APL had the resources and expertise to help him answer that question, and the resulting report—Stockton's first as an APL Senior Fellow—explored how the response to a cyberattack on the nation's electrical grid might stress and strain current industry practices and policies.

Stockton and the 10 other national leaders designated by the Lab as Senior Fellows bring a decision-maker's perspective to APL technology development and, at the same time, provide insight into the capabilities and limitations of emerging technologies. Stockton's question was well-suited to APL, with its wealth of technical understanding and ongoing research by experts eager to share what they know with those responsible for securing the nation's critical infrastructure.

His report not only had an impact on decision-makers grappling with these important issues but also inspired additional analyses by Sue Lee, an expert in critical infrastructure and computer scientist, and Mike Moskowitz, a leader in operations analysis for the departments of Defense and Homeland Security. Their probabilistic risk assessment of a widely read, hypothesized cyberattack on the U.S. electric grid allowed for some quantification of the value of certain cyber-defensive measures. A key insight was that small changes in the level of cyber defense for a given system could have an outsized impact on security.

In an effort to connect technical elements with policy, APL analysts have published a number of papers examining scenarios that feature technical elements in the cyber domain; these works include a look at cross-domain deterrence, an analysis of the 2014 cyberattack on Sony, an assessment of the risk of a catastrophic cyberattack, and an examination of how power companies can partner with the Department of Energy to defeat attacks on the U.S. electric system.

APL's National Security Analysis Department released a series of reports to provide impactful analysis from around the Laboratory for national security leaders and the public.

SENIOR FELLOWS

JOHN ALLEN

President of the Brookings Institution; retired U.S. Marine Corps four-star general and former commander of the NATO International Security Assistance Force and U.S. Forces in Afghanistan

RICHARD DANZIG

Member of the Defense Policy Board and the President's Intelligence Advisory Board; trustee of the RAND Corporation and of Reed College; director of the Center for a New American Security; and former secretary of the Navy during the Clinton administration

PHIL DEPOY

Former president and CEO of the Center for Naval Analyses; former president of the National Opinion Research Center at the University of Chicago; and founding director of the Wayne E. Meyer Institute of Systems Engineering at the Naval Postgraduate School

LISA DISBROW

Former under secretary of the Air Force who also served as the assistant secretary of the Air Force for financial management and comptroller; held a variety of positions on the Joint Staff as a senior civilian, including the Joint Staff vice director for Force Structure, Resources and Assessment

JAMES GOSLER

One of the nation's foremost experts on cybersecurity and information operations; served more than three decades in various cyber- and nuclear weapon-related positions at Sandia National Laboratories; previously served as director of the Clandestine Information Technology Office at the Central Intelligence Agency

AVRIL HAINES

Former deputy national security adviser with wide-ranging expertise in policy, strategy, and law; served as the deputy director of the Central Intelligence Agency, legal adviser to the National Security Council, and deputy counsel to the president for national security affairs at the White House

SAMUEL LOCKLEAR

Served 40 years in the U.S. Navy as a surface warfare officer, rising to become commander of U.S. Pacific Command; command positions at sea include commander of the U.S. 3rd Fleet and commander of U.S. Naval Forces Europe, U.S. Naval Forces Africa, and Allied Joint Force Command Naples

JAMES MILLER

President of Adaptive Strategies, LLC; former under secretary of defense for policy; known expert and government leader in the fields of nuclear deterrence, missile defense, space policy, and cyber warfare

JAMES STAVRIDIS

Dean of The Fletcher School of Law and Diplomacy at Tufts University; led the NATO Alliance in global operations from 2009 to 2013 as supreme allied commander and also served as commander of U.S. Southern Command; the longest-serving combatant commander in recent U.S. history

PAUL STOCKTON

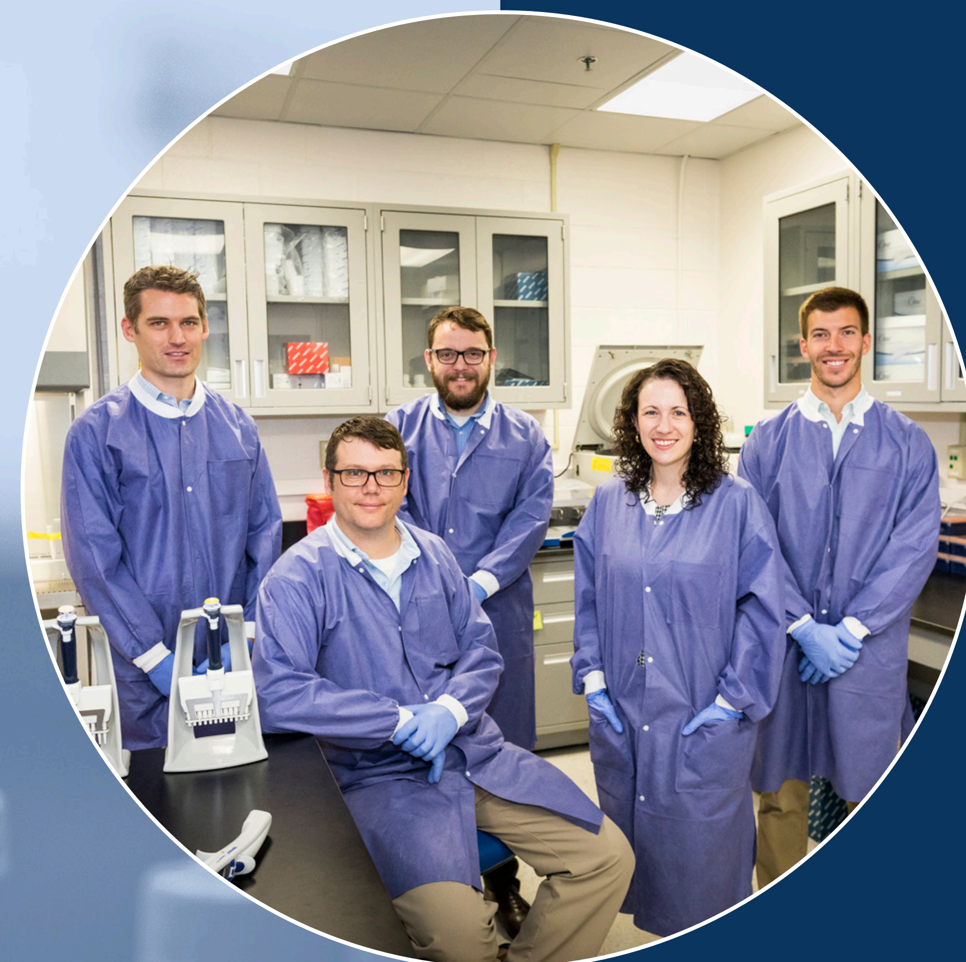
Former assistant secretary of defense for homeland defense and Americas' security affairs; managing director of Sonecon, LLC; internationally recognized leader in infrastructure resilience, continuity planning, installation and personnel security, and, more generally, U.S. national security and foreign policy

ROBERT WORK

Former deputy secretary of defense; distinguished senior fellow for defense and national security at the Center for a New American Security; owner of TeamWork, LLC, which specializes in national security affairs and the future of warfare

A MODEL ORGANIZATION FOR INNOVATION AND INCLUSION

APL is transforming its approach to building teams to enhance inclusion and maximize the generation of creative ideas.



Members of the Provenance research team—(from left) Peter Thielen, Joshua Wolfe, Thomas Mehoke, Briana Vecchio-Pagan, and Craig Howser—received a Propulsion Grant to push the boundaries of metagenomic analysis to establish an experimental and conceptual framework for the detection, analysis, and attribution of engineered viral pathogens in clinical samples.

EMBRACING RISK AND ENCOURAGING NEW THINKING

Making critical contributions to our sponsors' critical challenges typically involves risks in developing advanced capabilities. At the same time, we are always looking to go even further—to anticipate challenges and explore innovations that will define the future of defense, space exploration, and health care. We do this through competitive internal funding opportunities that enable staff members to propose bold ideas that could change the game for our sponsors and the world.

These funding mechanisms are all via internal research and development (IRAD). Most of our IRAD work is guided by our mission areas' strategies and allows our scientists and engineers to advance innovative concepts for present and projected sponsor challenges, resulting in hundreds of proposals and many exciting results each year. These projects often lead to significant advances in the state of knowledge in a given field.

For example, an IRAD project led to the creation of a groundbreaking, scalable algorithm that provides clustering and classification as well as anomaly detection and link inference capabilities. It will enable sponsors to quickly analyze large data sets. IRAD funding also led to the development of converting human-driven surface vessels into autonomous swarming unmanned surface vessels capable of patrolling borders, detecting intruders, and even chasing intruders away from areas they are protecting.

We have reserved a portion of our annual IRAD funds for a program known as Project Catalyst for even bolder ideas and technologies that, if they work, might one day become defining innovations. Project Catalyst empowers staff members to address the greatest projected challenges of our time and consists of three types of grants: Ignition, Combustion, and Propulsion.

The Lab's autonomous swarming unmanned surface vessels—equipped with hardware and autonomy software developed under an IRAD program—performed numerous self-guided tasks at the Advanced Naval Technology Exercise 2017 at Marine Corps Base Camp Pendleton, California.

IG

IGNITION GRANTS

Ignition Grants provide $20,000 of seed money for staff members to check out their innovative ideas. These ideas are solicited around a given theme, and winners are selected by the votes of the staff members across APL. One such grant explored the fabrication of bone structures by using additive manufacturing. There are current gaps in predicting head injury because of the large differences between human skulls. But 3D printing skulls directly from human computed-tomography scans allowed researchers to evaluate properties through biometric surrogates. This enabled the creation of mechanically accurate and biologically viable bone surrogates for use in injury treatment, biomechanical testing, and regenerative medical applications.

CG

COMBUSTION GRANTS

Combustion Grants of $50,000 are awarded by a panel of peer reviewers and provide slightly more funding for higher-risk, high-impact technical ideas, such as a concept to provide a new wavelength line-of-sight communication capability in a radio-frequency-jammed environment: a potential game-changer for the warfighter. A Combustion Grant also enabled the development and demonstration of a novel and precise electromagnetic pulse weapon that has the potential to be useful in a variety of situations and in attacks on shielded targets.

PG

PROPULSION GRANTS

The Laboratory competitively awards **Propulsion Grants** of up to $1.1 million over three years for disruptive ideas that seek to solve challenges specific to one of our core mission areas in a completely new way. This mechanism has supported the Provenance research team, which created technologies for the detection, analysis, and attribution of novel biological attacks as well as machine learning algorithms that significantly improved the search for undersea mines.

BUILDING BETTER TEAMS: APL MOSAIC

APL values world-class teams—not just world-class experts. Our past defining innovations were the products of teams, and we know the same will be true of our future defining innovations.

The pace at which the world is changing requires us to be even more innovative, including in the way we build inclusive teams.

With APL Mosaic, we're intentionally connecting staff members from very different backgrounds and experiences to promote creative engagements. Research shows that teams of diverse people, who work together and leverage the collective experience and wisdom of the group, will produce better results. Cognitive diversity takes advantage of team members' unique perspectives and different approaches to problem-solving, and when teams operate inclusively, where all voices are heard, possibilities begin to emerge in exciting ways.

APL Mosaic introduced a customized framework for building better teams as well as two new tools to support APL's goals. APL Lynx is a team-building platform that helps leaders widen their search for talent and look beyond resumes to understand and enhance the cognitive diversity of their teams. APL Sparks is an online platform for creating, sharing, and exploring techniques that help teams interact and innovate more effectively.

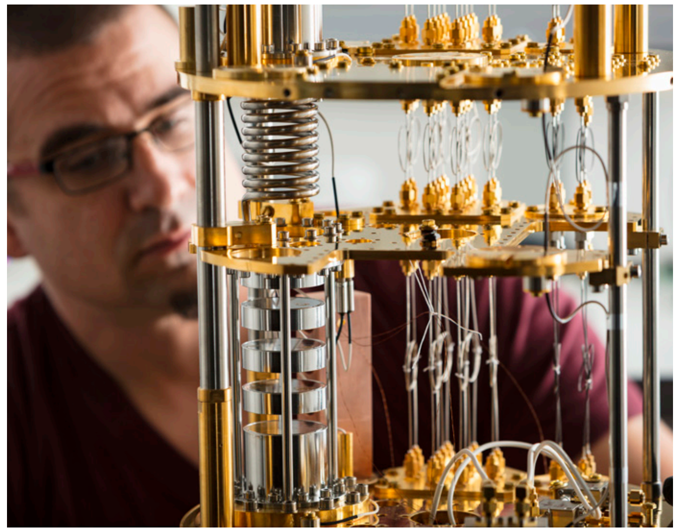
With APL Mosaic, we are leveraging cognitive diversity and effective teaming to promote creative engagements among staff members. Only by working together can we create bold, previously unimaginable solutions to our nation's most complex challenges.

A MODEL ORGANIZATION FOR INNOVATION AND INCLUSION

(From left) Amina Ryan, John Burke, Sarah Rigsbee, Claudia Yee, Anthony Tripoli, Camille Daniel, Michaela Kerem, and Crystal Farmer are all part of a team critical to shaping APL Mosaic.

LABS OF THE LAB

Making critical contributions requires taking some risks, and risks (and experiments) are best taken in labs. Here are some of APL's notable research and collaboration spaces.

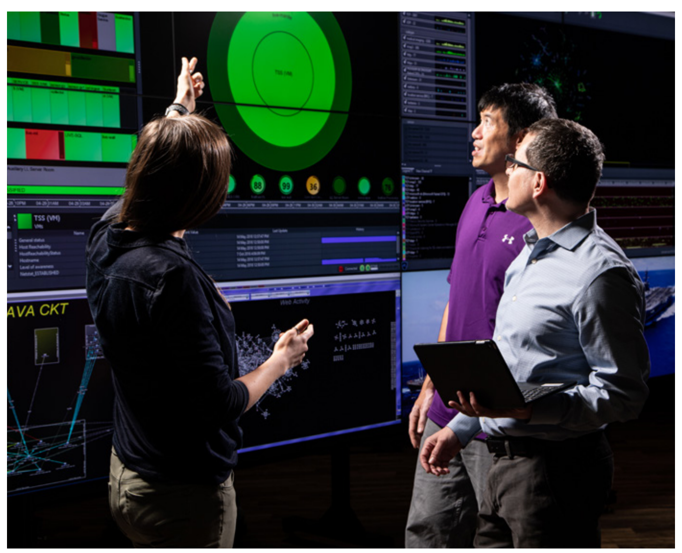


QUANTUM DEVICES LABORATORY

The Quantum Devices Laboratory was established as a key resource for addressing critical challenges in quantum information science. The state-of-the-art microwave, cryogenic, and quantum control enable testing of new theories and devices critical to harnessing the power of quantum for computing and sensors.

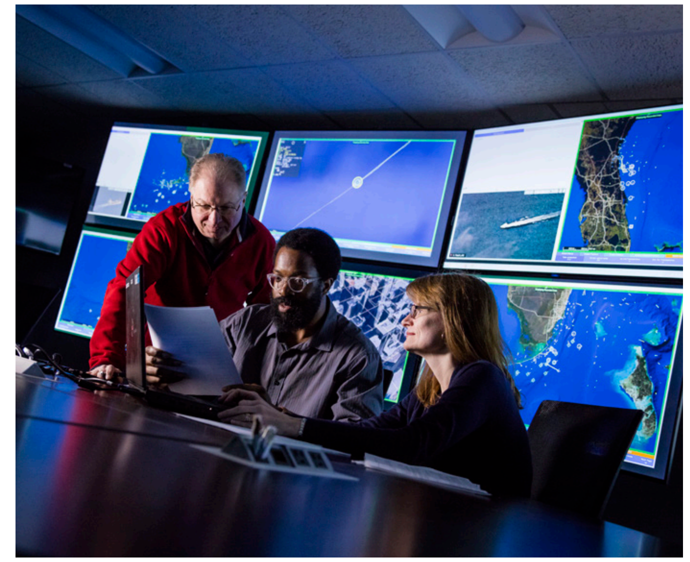
HEALTH ENGINEERING AND ANALYTICS LAB (HEAL)

The Health Engineering Analytics Lab (HEAL) offers a central location for staff members to work and share information—including systems to support Health Insurance Portability and Accountability Act (HIPAA) data use and storage; state-of-the-art technology for visualization, computation, and collaboration; and a robust virtual presence to facilitate and strengthen partnerships with all Hopkins entities. It includes a mock intensive care unit, as well as dedicated areas for sponsor engagement, collaborative analysis, meetings, and breaks.



LIVE LAB

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



COMBAT SYSTEMS EVALUATION AND MINOTAUR LABORATORIES

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

METEORITE LABORATORY

The Meteorite Laboratory hosts a number of geochemistry facilities that are used to investigate planetary materials and understand the chemical processes that operate in our solar system. The Meteorite Lab has supported a wide range of NASA-related projects, such as studies of extraterrestrial samples, including meteorites and samples from the moon; projects for spacecraft instrument development; and experimental investigations of the formation and evolution of planetary bodies.

RESEARCH ADVANCING PHYSICAL THREAT REDUCTION (RAPTR)

The RAPTR lab facilitates technological innovation aimed at combating all manner of physical threats to soft targets through activities ranging from applied research to prototype integration to system testing and evaluation.

IMMERSION CENTRAL

Immersion Central combines virtual/augmented/mixed/merged reality technologies with multimedia capabilities. This new lab is a focal point for discovery, experimentation, training, education, and development resources for anyone interested in immersive technologies. The Lab has two "room-scale" virtual reality environments, three "standing" virtual reality environments, plus access to open-space augmented reality devices such as the Microsoft HoloLens.

INTELLIGENT SYSTEMS CENTER

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

AUGMENTED REALITY ENVIRONMENT AT APL (ARENA)

ARENA is a visual-simulation test and demonstration facility, made to showcase the interactive virtual environments that APL develops for military training. For example, the Virtual Instructor Project, which can train sailors to launch weapons from submarines, can be displayed across the multitude of screens in the room to provide an immersive demonstration of the application.

HYDRODYNAMICS RESEARCH LABORATORY

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

SPACE SIMULATION AND VIBRATION TEST LABS

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

TECHNOLOGY TRANSFER

The Office of Technology Transfer (OTT) ensures the broadest possible impact of APL innovation—enhancing the reach of our best ideas and technologies while promoting and protecting the intellectual property our staff members develop every day to address the nation's most critical challenges.

COMMERCIALIZATION INITIATIVES

On the recommendations of our recently formed Commercialization Working Group, and after a careful analysis of the Lab's commercialization policies, practices, and accomplishments, we revised our commercialization and technology transfer strategy. The plan will contribute to a vibrant innovation ecosystem by:

- Transferring knowledge and technology responsibly and with speed, agility, and transparency;
- Promoting strategic research and development partnerships; and
- Discovering technological advances throughout the world and transitioning them to APL, enhancing our own abilities to solve the nation's most complex national security and space exploration challenges.

These commercialization initiatives will strengthen APL's collaboration with Johns Hopkins Technology Ventures, better protect intellectual property, foster an enriching environment for APL-affiliated start-ups, and help us to identify technological innovations in industry and elsewhere.

The Johns Hopkins Center for Bioengineering Innovation and Design (CBID) at Johns Hopkins University is a highly exclusive, first-of-its-kind graduate program carefully designed to prepare the next generation of leaders in global health innovation and design. CBID graduates are highly valued and engage in disruptive innovation to improve patient care and health care delivery around the globe.

JOHNS HOPKINS COLLABORATIONS

Through coordinated efforts with other Johns Hopkins organizations, APL disclosed 18 technologies developed in collaboration with university partners this year.

Researchers in APL's National Health Mission Area joined with the Center for Bioengineering Innovation and Design (CBID) on two projects that address different methods for rotating a guidewire within a bile duct. CBID is a joint effort of the Whiting School of Engineering and the School of Medicine. As a result of this collaboration, CBID graduate students tested the prototype rotational devices in India and have since generated interest in the method from health care organizations.

Working with another Whiting School student team, APL researchers developed a prototype finger-like gripping device. Made of advanced materials, the device has attracted the interest of a local robotics company—established by a former APL researcher—and could be the centerpiece of a research and development partnership to advance robotic dexterity.

NEW LEADERSHIP

In 2018, Paul Oostburg Sanz, already serving as APL's director for commercialization, added the duties of general counsel and head of OTT. Before joining APL in 2017, Oostburg Sanz was general counsel for the Department of the Navy. As the longest serving presidential appointee in that position, he was the department's chief legal officer and advised the secretary of the Navy, the service chiefs, and other senior Navy and Marine Corps officials.

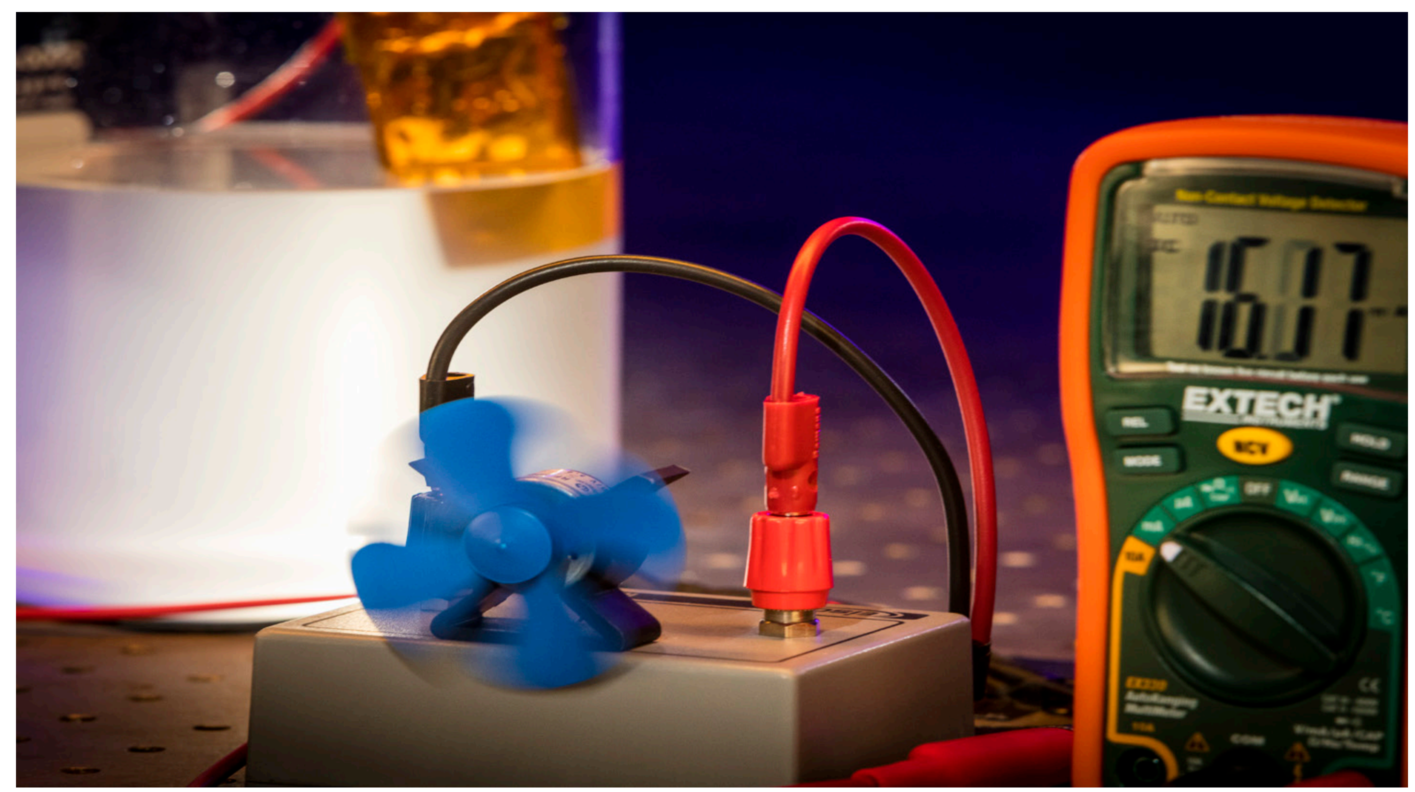
STATISTICALLY SPEAKING

APL Technology Transfer Program Data (FY 2018)

- 419 inventions disclosed
- 30 U.S. patents issued
- 94 U.S. provisional patent applications filed
- 16 U.S. nonprovisional patent applications filed
- 63 license agreements executed
- 1 company created

TOP INVENTION PLAUDITS

Speaking to the strength and relevance of APL's research and development (R&D) breakthroughs, the Laboratory's Invention of the Year, a flexible, cuttable, submersible, and bulletproof lithium-ion battery (pictured), was selected as a 2018 R&D 100 Awards finalist by *R&D 100 Magazine*.



UNIVERSITY COLLABORATION

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

ENGINEERING FOR PROFESSIONALS

More than 200 APL staff members teach engineering, applied science, engineering management, technical management, and information technology courses within the Johns Hopkins Engineering for Professionals (EP) program. APL staff members also serve as chairs and vice chairs for 11 of EP's 20 master's degree programs. EP students can attend classes at APL, the Homewood campus, or four other regional locations—and about 90 percent of total course enrollments and 18 of the master's degree programs are also offered online.

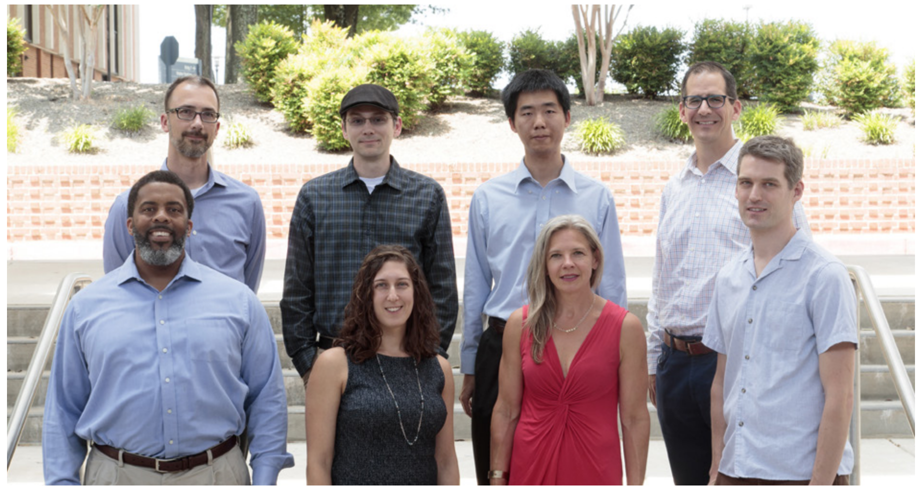
The 11 APL-based programs—applied and computational mathematics, applied physics, computer science, cybersecurity, data science, electrical and computer engineering, engineering management, information systems engineering, space systems engineering, systems engineering, and technical management—account for about 90 percent of the more than 650 annual master's degrees awarded to students.

During the 2017–18 academic year, more than 3,600 students participated in the 11 APL-based EP programs, accounting for approximately 9,000 course enrollments. EP conferred more than 670 master's degrees during the year.

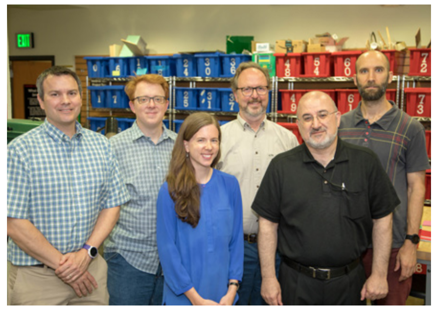
Since 1968, more than 1,650 APL staff members (and more than 18,000 other students) have received master's degrees from these programs. Starting in spring 2019, a new Healthcare Systems Engineering master's degree program will prepare students for tackling modern health care's most pressing and complex challenges.

DOCTORATE IN APPLIED ENGINEERING

APL teamed up with the Whiting School of Engineering to launch a doctor of engineering (D.Eng.), designed with the needs of working, mid-career engineering professionals in mind. Like traditional Ph.D. programs, its foundation is a candidate's advanced research guided by a faculty advisor. But where traditional Ph.D. programs tend to emphasize foundational work to further the body of scientific or technical knowledge, the D.Eng. program is application-based, focusing on engineering advances such as prototypes, inventions, and new software. Students shape their program to meet professional goals and immediately contribute to their current job responsibilities.



Eight APL staff members are the first cohort of students accepted into a new doctor of engineering program conferred by the Johns Hopkins Whiting School of Engineering in partnership with APL. (Back row, from left) Myron Brown, Seth Myers, Peter Gu, and Bart Paulhamus; (front row, from left) Jeffrey Chavis, Kara Shipley, Jennifer McKneely, and Peter Thielen.



(From left) APL's Christopher Bradburne, Jacob Alldredge, Clara Scholl, Bob Schaefer, Ra'id Awadallah, and Andrew Strikwerda are among the individuals across JHU to receive 2018 Discovery Award grants.

DISCOVERY AWARDS

APL scientists were among the Johns Hopkins researchers chosen for the second round of JHU Discovery Awards. In 2018 the program, part of a $15 million commitment to cross-University, faculty-led research, attracted 190 proposals, from which 30 teams, each composed of members from at least two Johns Hopkins divisions, received awards. Six APL researchers were on four winning teams investigating diagnosing concussions, gene sequences, brain tumors, and the cosmic dark sector in space.

As part of RISE@APL, Bijan Varjavand, a senior double-majoring in materials science and engineering and applied mathematics and statistics at the Whiting School of Engineering, worked on a project developing deep learning for object detection, used in autonomous vehicles or smart video surveillance. (Homewood Photography)

RISE@APL

In 2014, APL and the Whiting School of Engineering launched the Strategic Partnership for University Research, a prestigious and competitive summer internship program. The program, now known as Research Internships in Science and Engineering (RISE@APL), is open to highly qualified undergraduate and graduate students from the Whiting School of Engineering and the Krieger School of Arts and Sciences, providing the opportunity to conduct research at APL on a variety of topics, including ballistic missile systems, prosthetics, computer vision, and secure mobile communications.

Michael Tsapatsis is the third APL researcher to be named a Bloomberg Distinguished Professor. (Homewood Photography)

BLOOMBERG DISTINGUISHED PROFESSOR

Michael Tsapatsis, a tenured professor in the Whiting School of Engineering's Department of Chemical and Biomolecular Engineering with a joint appointment in APL's Research and Exploratory Development Department, was named a Bloomberg Distinguished Professor, joining a cohort of world-class scholars working across fields to address major world problems and teach the next generation of researchers.

The Bloomberg Professors bridge the University's academic divisions, conduct and stimulate innovative research that crosses traditional disciplinary boundaries, and train a new generation of native "interdisciplinarians." Tsapatsis is a renowned materials scientist whose groundbreaking work has had tremendous impact across the research community, industry, and society. As APL strengthens our capabilities and leadership in the development and application of advanced materials, his contributions will help us solve some of the nation's most critical technical challenges.

SPACE@HOPKINS

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

COMMUNITY INVOLVEMENT

APL has always invested in the next generation of scientists and engineers, and nowhere is that more evident than its extensive science, technology, engineering, and mathematics (STEM) education and outreach programs, which reached more than 5,000 students this year, a record-breaking number. More than 500 volunteers worked together to educate kids on careers in STEM through many outreach efforts.

Jason Massey (center) supervised the work of three college interns in APL's Force Projection Sector in the summer of 2018. Two of them, Jordan Woo and Mya Tsang (pictured in back) are ASPIRE program graduates who worked closely with fellow intern Daniel Mansfield (right).

DEVELOPING TALENT

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

STEM Academy. APL STEM Academy was established in 2017 to identify and develop STEM talent, increase the diversity of students pursuing STEM majors and careers, and create a path toward a future career in STEM. The program, available to students in grades 8–12, offers a variety of courses in three cycles per year, including Python, MATLAB, Coding, and Youth Leadership and Communication. In FY 2018, the program served 161 students from Howard, Montgomery, Frederick, Prince George's, Baltimore, and Anne Arundel counties.

APL's Student Program to Inspire, Relate, and Enrich (ASPIRE). For the 2017–18 school year and summer, ASPIRE placed 269 high school juniors and seniors recommended by their schools into internships with 176 APL volunteers. Interns worked on sponsored and internal research and development projects and gained valuable skills and career experience.

OUTREACH PROGRAMS

Boys & Girls Clubs Math Tutoring. In 2018, we again partnered with the Boys & Girls Clubs of Metropolitan Baltimore to offer math tutoring. Lab volunteers met weekly with 15 students on the APL campus for 10 weeks, during sessions in the spring and fall, helping the students strengthen their core math skills.

Events. APL hosted the 12th annual "Girl Power" STEM expo in March, with more than 600 elementary through high school girls and their families visiting the daylong interactive event to learn about STEM education and careers. In April, more than 600 staff members' children came to campus for "Take Our Daughters and Sons to Work Day," touring the Lab and learning about STEM through a range of fun, interactive activities.

STRATEGIC PARTNERSHIPS

College Prep Program. Seventeen students participated in APL's award-winning summer mentoring program that encourages high school students to apply to top colleges, pursue advanced degrees, and explore STEM careers. Most participants have little or no exposure to the college application process when they start the program, but with the help of 25 APL volunteers and additional members of the community, they quickly acquire tools to help them apply to college, excel in their studies, and pursue their dreams. A recent survey found that 98 percent of participants are on track to earn a bachelor's degree, and many are pursuing advanced degrees. This year marked the 10th session for the program—186 students have completed the program to date.

FIRST LEGO League. For the ninth straight year, APL hosted one of Maryland's FIRST LEGO League and LEGO League Junior robotics qualifying competitions. More than 200 students between the ages of 6 and 14 converged on the Kossiakoff Center in teams of up to 10 students to design, build, program, and test autonomous LEGO robots that had to perform a series of tasks, or missions, within a 2.5-minute time limit.

Cyber Defenders. Each summer since 2014, APL has exposed 30–50 students in grades 9–12 to the fields of cybersecurity, online safety, and ethical hacking/penetration testing. Students are typically not exposed to the introductory curriculum until their junior or senior years of college—too late if we want to seriously address our national and global labor shortage.

COLLEGE INTERNSHIPS

APL offers numerous opportunities for students through the **College Internship Program**. Summer internships are open to qualifying students; the students work with APL scientists and engineers, conducting research, developing leadership skills, and growing professionally. More than 471 students from 144 colleges and universities completed an internship or co-op at APL in FY 2018.

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

The **APL Technology Leadership Scholars (ATLAS)** program, open to rising juniors, seniors, or graduate students majoring in engineering, math, physics, or computer science from Historically Black Colleges and Universities, Hispanic-Serving Institutions, and Minority Institutions, included a record cohort of 41 students—many of whom will be eligible for full-time employment at APL by May 2019.

Eighty-two of this year's college interns were previously high school ASPIRE interns.

AWARDS AND HONORS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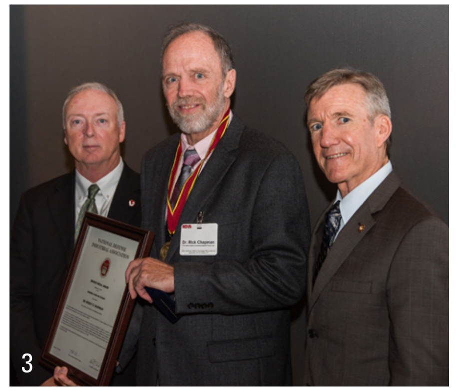
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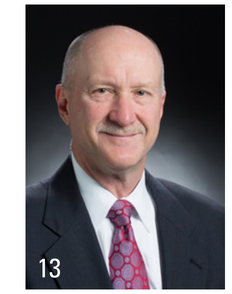
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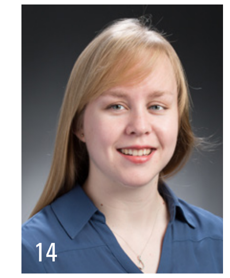
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(1) Isaac Bankman (left) received the U.S. Navy Meritorious Public Service Award, the third-highest civilian honor the Navy can bestow.

(2) The Maryland Academy of Sciences named Philip Graff (right) as its 2017 Outstanding Young Scientist and Adam Watkins (left) as its 2017 Outstanding Young Engineer.

(3) Rick Chapman (center) received a Bronze Medal from the National Defense Industrial Association's Undersea Warfare Division.

(4) Director Ralph Semmel (not pictured), National Security Analysis Department Head Mark Lewellyn (ret., third from left), John Ivancovich (right), and Matthew Schaffer (second from left) earned Patriot Awards from the Maryland Employer Support of the Guard and Reserve in recognition of outstanding patriotic support of and cooperation with their employees.

(5) Systems engineer and cybersecurity expert Melissa Wong earned a 2017 Women of Color Professional Award.

(6) Kaushik Iyer, a materials physicist, was elected a Fellow of the American Society of Mechanical Engineers.

(7) The Laboratory was presented with a 2017 TechConnect Defense Innovation Award at the Defense Innovation Summit in Tampa, Florida, in recognition for its development of a high-bandwidth, free-space optical communications system. APL is the first organization to successfully operate such a high-capacity optical communications capability—up to 10 gigabits per second—on the move, on ships at sea, and in challenging near-shore environments.

(8) Ann Darrin, managing executive in the Space Exploration Sector, was named an Influential Marylander by *The Daily Record.*

(9) Former Force Project Sector Head Dan Tyler (ret.) was recognized with the Naval Submarine League's Distinguished Civilian Award, presented yearly to an individual whose work has contributed significantly to the submarine force.

(10) Andrew Adams was presented with the Research Leadership Award at the 2018 Black Engineer of the Year Awards Science, Technology, Engineering, and Math conference. The Research Leadership Award is given to scientists who have proven to be consistent leaders in discovering, developing, and implementing new technologies, and whose work changes the way people live and work.

(11) APL's commemorative 75th anniversary book, *Defining Innovations: A History of the Johns Hopkins University Applied Physics Laboratory*, along with posters illustrating the Lab's defining innovations and the *Johns Hopkins APL Technical Digest*, were all recognized by the Washington-Baltimore chapter of the Society for Technical Communication. The book received publication "Best in Show" and honors as a "Distinguished Technical Communication." The *Technical Digest* also was recognized in the latter category. The defining innovations poster series won the "Excellence" award for its creative take on the Lab's pioneering work through the decades.

(12) David Taubenheim was named the LGBTQ+ Engineer of the Year by the National Organization of Gay and Lesbian Scientists and Technical Professionals.

(13) Gary Sullins was awarded the Missile Defense Agency's prestigious Aegis Ballistic Missile Defense Pathfinder award, given annually to individuals who have demonstrated outstanding leadership, extraordinary technical excellence, and innovation on naval ballistic missile defense programs of critical national importance.

(14) Guidance, navigation, and control engineer Sylvie DeLaHunt was among those honored at the Johns Hopkins Diversity Leadership Council's 16th annual Diversity Recognition Awards.

(15) Miquel Antoine, a chemist, earned a 2018 Women of Color Professional Award.

(16) Alice Bowman was elected an Associate Fellow of the American Institute of Aeronautics and Astronautics.

(17) APL was named one of IDG's Computerworld Best Places to Work in IT for 2018. APL was ranked number 16 among large organizations on the list.

(18) Nancy Chabot, a planetary scientist, was elected a Fellow of the Meteoritical Society.

(19) For creating the first-ever spacecraft designed to fly through the inferno of the sun's corona—Parker Solar Probe—APL earned a place as one of Fast Company's Top 10 Most Innovative Companies in Space for 2018.

Note: This list is not all-inclusive.

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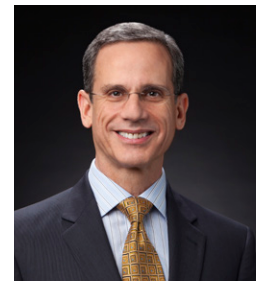

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During the fiscal year that ended September 30, 2018, the Johns Hopkins University Applied Physics Laboratory recorded revenue from contracts and grants totaling $1.52 billion. As a scientific and educational nonprofit organization, we reinvest proceeds from our contract research and development activities into programs, facilities, and capabilities that further our scientific and technology development mission.

THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY

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