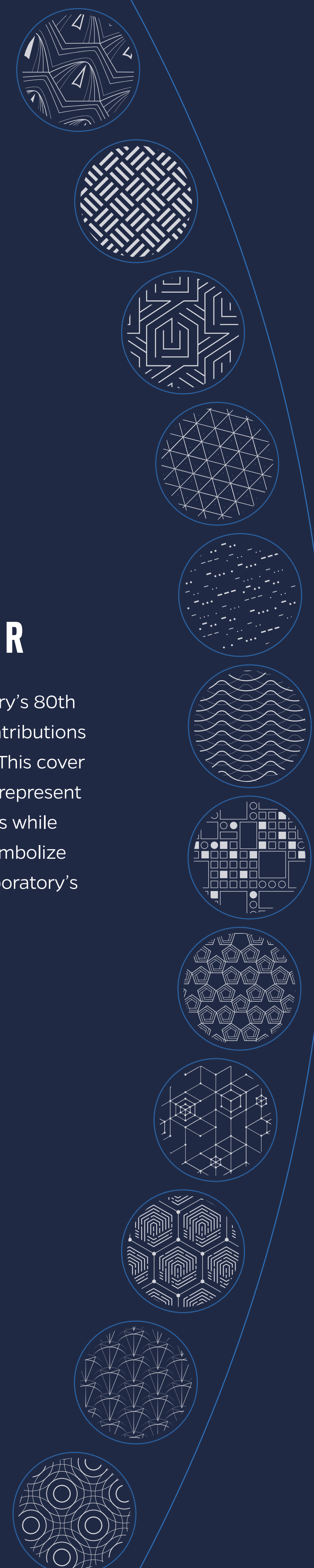
80 YEARS

2022 ANNUAL REPORT

THE JOHNS HOPKINS APPLIED PHYSICS LABORATORY



ABOUT THE COVER

As we commemorate the Laboratory's 80th year, we also pay tribute to the contributions of APL's sectors and departments. This cover features new patterns designed to represent each organization's unique qualities while also threading them together to symbolize the collaboration central to the Laboratory's game-changing impact.

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DIRECTOR'S MESSAGE

On March 10, 2022, the Johns Hopkins Applied Physics Laboratory celebrated its 80th year of trusted service to the nation. During these past eight decades, through times of crisis and calm, the dedicated staff members of APL have made thousands of critical contributions to critical challenges. Among those accomplishments, a select few have altered the course of history, beginning with our first defining innovation: the proximity fuze.

This remarkable technology helped turn the tide for the Allies during World War II, established the Lab's systems engineering focus and get-it-done culture, and served as the blueprint for how we create new capabilities across a variety of domains. Today, the breakthroughs created by our exceptional staff — in areas from undersea warfare to space exploration, from missile defense to cybersecurity, from strategic deterrence to biothreat response, and more — build on the lessons learned from the fuze and other early successes.

In this report, you will read about some of the Lab's more recent accomplishments. These include novel technologies for pioneering live-fire ballistic missile defense and strategic system tests in the Pacific, rapid genomic sequencing of environmental DNA in Arctic waters and capabilities to ensure the security of the Moon and the space between it and Earth. Also highlighted are methods to assess and improve how autonomous vessels avoid collisions in crowded sea lanes, artificial intelligence systems to accelerate materials development and the delivery of two crucial spacecraft modules for a mission to explore the ocean world Europa. And these are just a small sample of the highly impactful contributions made by the Lab's dozen mission areas.

I would be remiss if I did not highlight one accomplishment, in particular, that garnered worldwide attention. On Sept. 26, the Double Asteroid Redirection Test (DART) — conceived, built and operated by APL for NASA — proved for the first time that kinetic impact is a viable means to deflect an asteroid and demonstrated that it would be possible to defend Earth from a potentially catastrophic impact. Notably, DART drew on capabilities and expertise from across the Lab, underscoring once again the amazing things that are possible when we work together.

For 80 extraordinary years, our focus on delivering game-changing contributions has been a constant at APL. That commitment has rarely been more critical than it is today, as our nation faces increasingly daunting challenges across a wide range of areas.

As I reflect on this special anniversary, I am excited and energized by the incredible dedication and achievements of our staff. There is no greater inspiration than seeing our colleagues — enabled by our outstanding enterprise services — bring a seemingly impossible solution to life through research, design, experimentation, validation and implementation.

I look forward with great optimism and anticipation of the innovations that the next 80 years will bring.

Ralph Semmel

EXPANDING THE POSSIBLE

The complex challenges of today's world demand new technologies that can keep us safer and take us farther, and APL's engineers and scientists are meeting that demand head-on. Whether they are potentially thwarting natural threats from space, combating climate change or accelerating the creation of new materials, their endless ingenuity is enabling technology that pushes the very edge of what is possible to tackle some of the world's most pressing challenges.

DART team members in the mission operations center at Johns Hopkins APL celebrate after confirming DART's successful impact into the asteroid Dimorphos on Sept. 26. (Credit: NASA/Johns Hopkins APL/Ed Whitman)

AUTONOMOUS DETECTION, ASTEROID DEFLECTION

After years of planning and testing, on Sept. 26, 2022, at 7:14 p.m. EDT, APL made history as NASA's APL-led Double Asteroid Redirection Test (DART) mission struck its target asteroid after 10 months of travel through space. Cheers rang out, people embraced and fireworks lit up the sky at APL's Laurel, Maryland, campus. The world's first planetary defense test mission was a resounding success, marking the first time humankind had intentionally altered the orbit of a celestial object and demonstrating a viable mitigation technique to thwart an Earth-bound asteroid or comet should one ever be discovered.

"This first-of-its-kind mission required incredible preparation and precision, and the team exceeded expectations on all counts," APL Director Ralph Semmel said. "Beyond the truly exciting success of the technology demonstration, capabilities based on DART could one day be used to change the course of an asteroid to protect our planet and preserve life on Earth as we know it."

From its outset, the DART mission was a radical idea: target a double-asteroid system and strike the smaller of the two as a means to test deflecting an asteroid by hitting it, a technique called kinetic impact. Although neither body posed a threat to our planet, the impact would provide a relatively easy way to try the method and observe the results from Earth- and space-based telescopes.

Given the speed and distance of the target — some 7 million miles from Earth — APL engineers knew DART would need a type of autonomy never seen in a spacecraft before. The team reached out to air and missile defense experts at the Laboratory, drawing on their expertise with intercepting

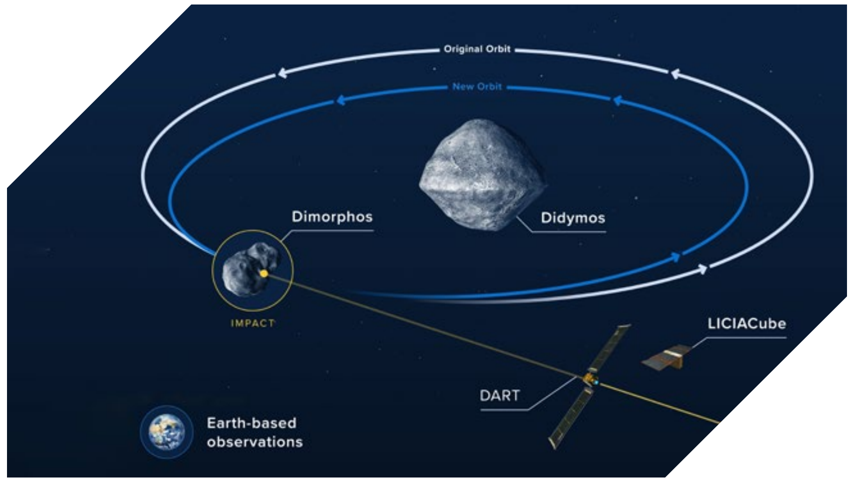


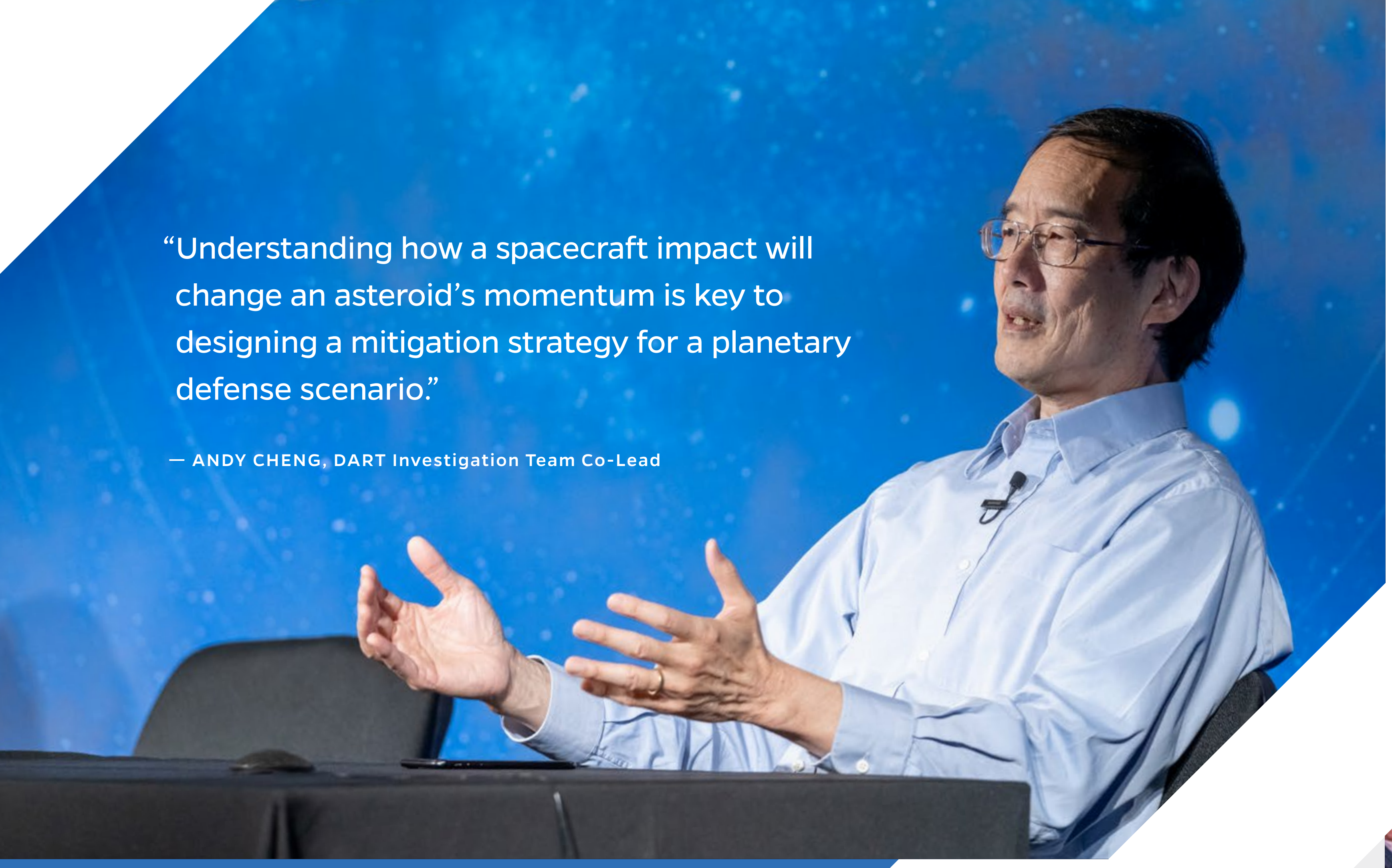
Illustration of how DART altered the orbit of the moonlet Dimorphos around Didymos. Scientists used data from telescopes on Earth and in space to measure the effectiveness of the impact.

About three weeks before impact at Dimorphos, the DART team gathers in the APL Mission Operations Center for a near-final mission simulation and practice run. The ties are a tribute to Ray Harvey, the DART mission operations manager who passed away a month earlier.

Artist's impression of the DART spacecraft speeding toward Didymos (foreground) and its moonlet Dimorphos. The images of Didymos and Dimorphos — the target for this first planetary defense test mission — are real, taken by DART itself.

ON SEPT. 26, 2022, AT 7:14 P.M. EDT

APL MADE HISTORY

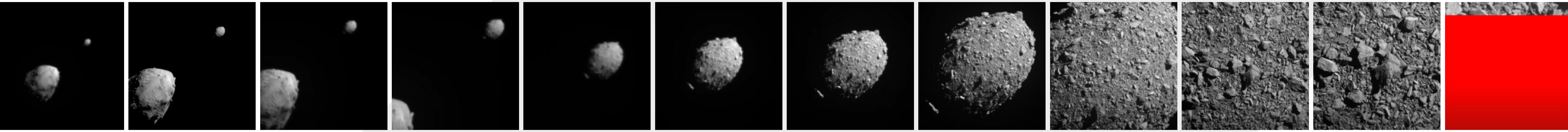


“Understanding how a spacecraft impact will change an asteroid’s momentum is key to designing a mitigation strategy for a planetary defense scenario.”

— ANDY CHENG, DART Investigation Team Co-Lead

fast, small targets, and developed the Small-body Maneuvering Autonomous Real Time Navigation (SMART Nav) algorithms, which would give DART the ability to guide itself during its last four hours of existence. Working together, the spacecraft’s sole instrument — the Didymos Reconnaissance and Asteroid Camera for Optical navigation (DRACO), inspired by the camera APL developed for NASA’s New Horizons mission to Pluto — and its sophisticated guidance, navigation and control system could distinguish the two asteroids, spot the correct smaller target and guide the 1,280-pound spacecraft to its quarry.

APL engineers put SMART Nav through thousands of simulations and a countless number of potential situations. On Sept. 26, racing in at 14,000 miles per hour, DART struck the 500-foot-diameter asteroid moonlet Dimorphos with such force that it cut the asteroid’s orbit around its larger companion, Didymos, by a substantial 33 minutes, dwarfing the mission’s requirement to change Dimorphos’ orbit by just 73 seconds. The resulting plume of debris — an estimated 2 million pounds or more of material — stretched over the subsequent months into a comet-like tail tens of thousands of miles long.



DART’s approach to Dimorphos, through the eyes of the spacecraft’s DRACO imager. The sequence begins at left with Didymos (bottom left) and its moonlet, Dimorphos, about 2.5 minutes and 570 miles before impact; it ends at right with the spacecraft about 4 miles from Dimorphos and only 1 second before impact. DART’s impact occurred during transmission of the image to Earth, resulting in a partial picture. (Credit: NASA/Johns Hopkins APL)

After examining post-impact data, the team estimated DART’s impact transferred roughly 3.6 times the momentum it would have had it not produced a plume at all — indicating the ejected material contributed to moving the asteroid more than the spacecraft did.

“Momentum transfer is one of the most important things we can measure because it is information we would need to know to develop an impactor mission to divert a threatening asteroid,” said Andy Cheng, DART investigation team co-lead from APL and the originator of the idea of DART. “Understanding how a spacecraft impact will change an asteroid’s momentum is key to designing a mitigation strategy for a planetary defense scenario.”

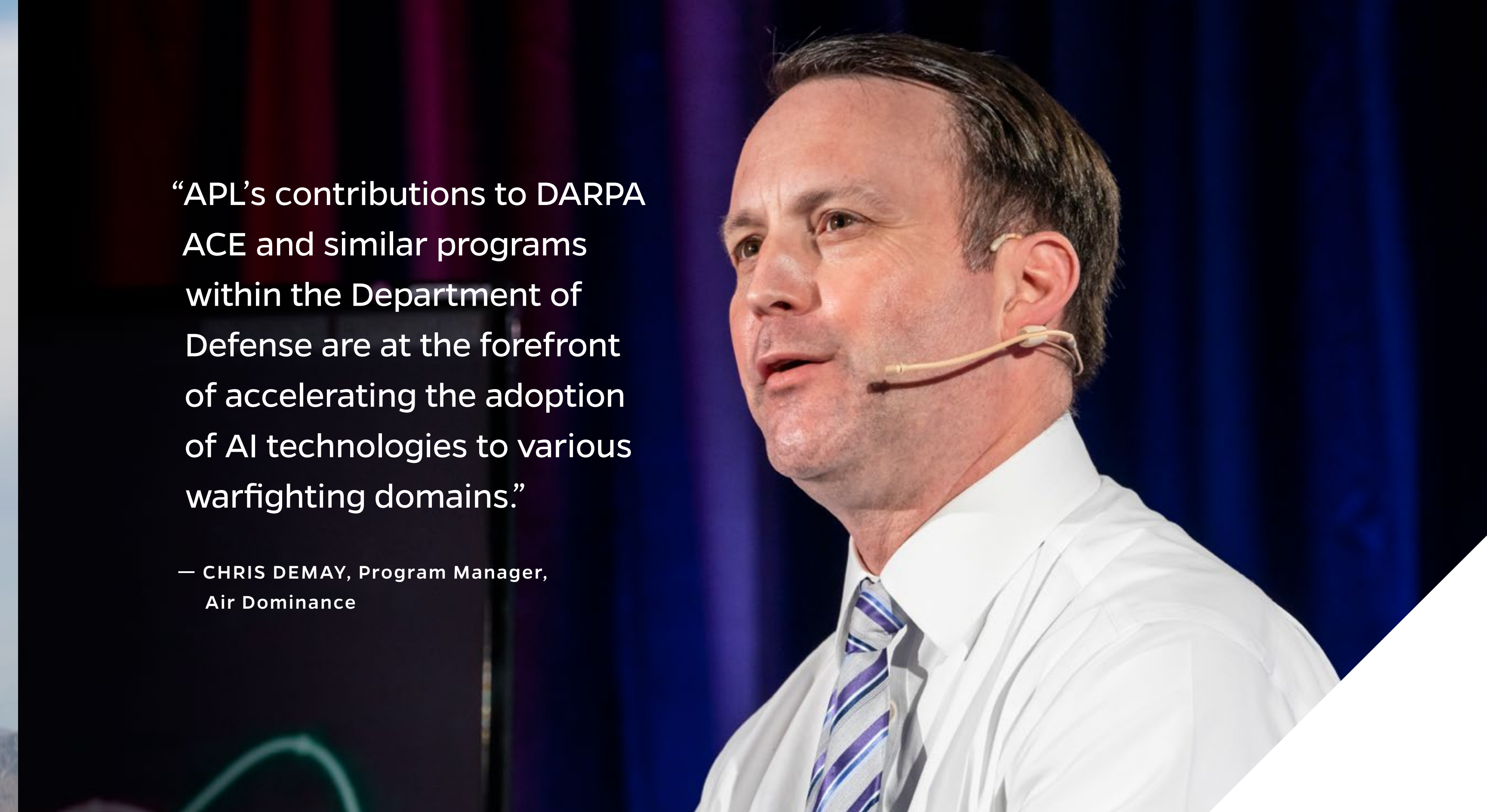
DART and its technologies delivered major advances in planetary defense and space science and engineering, improving asteroid impact models and enabling space and planetary scientists to continue exploring the capabilities of impactor spacecraft.

Planetary defense is just one of the bold, innovative and world-changing ideas APL researchers and engineers have been developing, pushing the boundaries of not just their fields, but also innovation itself.

DART mission team members celebrate the moment of impact with family, friends and other invited guests at APL on Sept. 26.

From left, NASA Planetary Science Division Director Lori Glaze, DART Coordination Lead Nancy Chabot and DART Program Scientist Tom Statler preview the Dimorphos impact during a press conference on Sept. 22. (Credit: AP/Alex Brandon)

Loading their AI software into a specially modified F-16 test aircraft, like the one shown above, APL developers demonstrated that AI agents can control a full-scale fighter jet — and in the process gathered invaluable live flight data. (Credit: U.S. Air Force)



"APL's contributions to DARPA ACE and similar programs within the Department of Defense are at the forefront of accelerating the adoption of AI technologies to various warfighting domains."

— **CHRIS DEMAY, Program Manager, Air Dominance**

ACCELERATING THE FUTURE OF AIR COMBAT

In less than three years, artificial intelligence (AI) algorithms developed under the Defense Advanced Research Projects Agency (DARPA) Air Combat Evolution (ACE) program have progressed from controlling simulated F-16s flying aerial dogfights on computer screens to controlling an actual F-16 in flight.

APL has hosted all three AlphaDogfight Trials events — one of the ACE program's most public successes — including the August 2020 finale viewed by more than 476,000 on YouTube.

In early December 2022, ACE algorithm developers uploaded their AI software into a specially modified F-16 test aircraft known as the X-62A or VISTA (Variable In-flight Simulator Test Aircraft) at the Air Force Test Pilot School at Edwards Air Force Base, California, and flew multiple flights over several days. The flights demonstrated that AI agents can control a full-scale fighter jet and provided invaluable live-flight data.

The live flight tests represented a critical milestone and significant accomplishment in the journey to revolutionize future air combat via uncrewed collaborative combat aircraft and were, in part, the culmination of more than three years of APL work.

As part of the DARPA ACE program, APL has developed infrastructure and autonomous solutions, including constructive simulation environments, virtual aircraft simulators, live subscale aircraft, and the interfaces required to integrate performer and APL autonomy solutions into full-scale tactical fighter aircraft.

Begun in 2019, ACE aims to develop trusted, scalable, human-level, AI-driven autonomy for air combat by using human-machine collaborative dogfighting as its challenge problem. One of the program's most public success, the AlphaDogfight Trials (ADT), pitted AI agents against each other flying simulated F-16s in a virtual dogfighting competition that culminated with the winning AI defeating an experienced F-16 fighter pilot in a 5-0 shutout. APL hosted all three ADT events, including the live August 2020 finale viewed by more than 476,000 on YouTube.

DARPA employed APL's expertise to develop the simulation environment and adversary agents for the trials. The Lab leveraged its capabilities in AI and software development, modeling and simulation, and aircraft dynamics and controls to create the "arena" for all three ADT competitions.

"We've made rapid progress in the ACE program. VISTA allowed us to skip the planned subscale phase and proceed directly to a full-scale implementation, saving a year or more and providing performance feedback under real flight conditions."

— **LT. COL. RYAN HEFRON, DARPA Program Manager, ACE**

FAST-TRACKING MATERIALS DEVELOPMENT

Traditional material development methods have involved creating large batches of samples and then testing each one for specific properties. Engineers then tweak one variable of the formula and test it again, repeating the process until they land on a material with the desired characteristics and

refining the material again to make it viable. To increase the speed of this process, Laboratory engineers pooled their expertise in artificial intelligence (AI), machine learning, modeling and simulation, additive manufacturing and materials science to accelerate the characterization and analysis pipeline of new materials, improving the field of novel material development.

These capabilities build on APL's rich heritage in materials science, which includes creating fast-acting underwater adhesives, coatings to endure the extreme operational conditions of hypersonic vehicles and even the heat shield that protects NASA's Parker Solar Probe from the punishing environment around the Sun.

Developing such materials is a complex undertaking. With the ability of machine learning models to process huge swaths of data, and the ability of additive manufacturing to rapidly produce material prototypes, APL researchers saw a potentially paradigm-shifting course for the field's future.

"When you have hundreds of samples to analyze in the quest to find a new material, well-trained models would help experts save a lot of time and resources," said Nam Le, a senior computational materials researcher at APL. "We're testing ways to train those models on cheap, synthetic data in combination with higher-quality but expensive data from physical experiments."

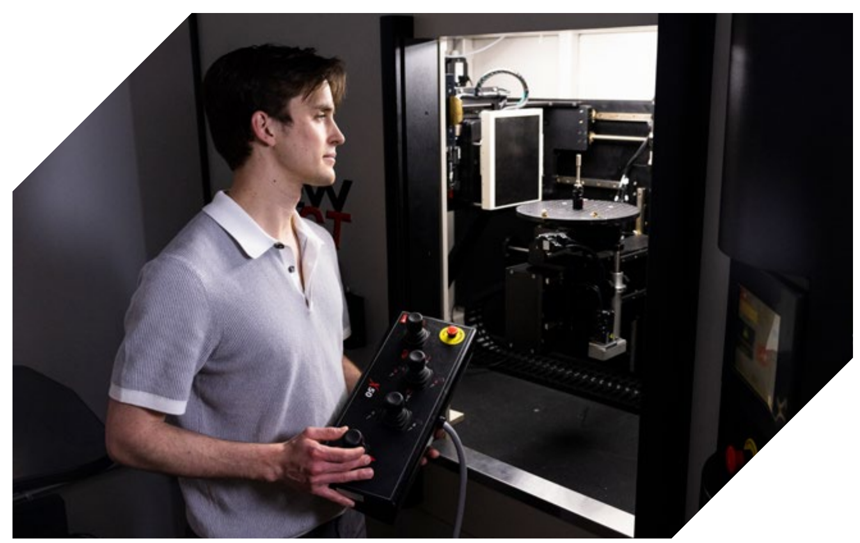
During 2022, Le led a team that developed an AI model that can determine whether a synthesized material is a candidate superconductor simply from the pattern of its crystal structure, which informs its overall behavior. The team trained the AI model using 30,000 simulated X-ray diffraction patterns, which contain information about the material's crystal lattice structure. Le explained that using the approach frees up experts' time by allowing them to examine only the best candidates, something that he hopes will accelerate the discovery of new materials with desired properties.

"When you have hundreds of samples to analyze, well-trained models would help experts save a lot of time and resources. We're testing ways to train those models on cheap, synthetic data in combination with higher-quality but expensive data from physical experiments."

— **NAM LE, Senior Computational Materials Researcher**

Senior materials and test engineer Sal Nimer led development of a prototype system (pictured here and at left) that uses a robotic arm to perform tensile strength tests on an array of samples in rapid succession combined with a load sensor to automatically and continuously record the results.

On another front, Sal Nimer, a senior materials and test engineer at APL, led a team focused on developing a rapid high-throughput prototype process for testing mechanical properties, such as tensile strength and elasticity. Combining a robotic arm (to perform tensile strength tests on dozens of samples in rapid succession) with a standard load sensor (that automatically and continuously records the results), the team's prototype system achieved a throughput rate 200 times faster than the standard approach, which, at best, could test just 20 samples per day.

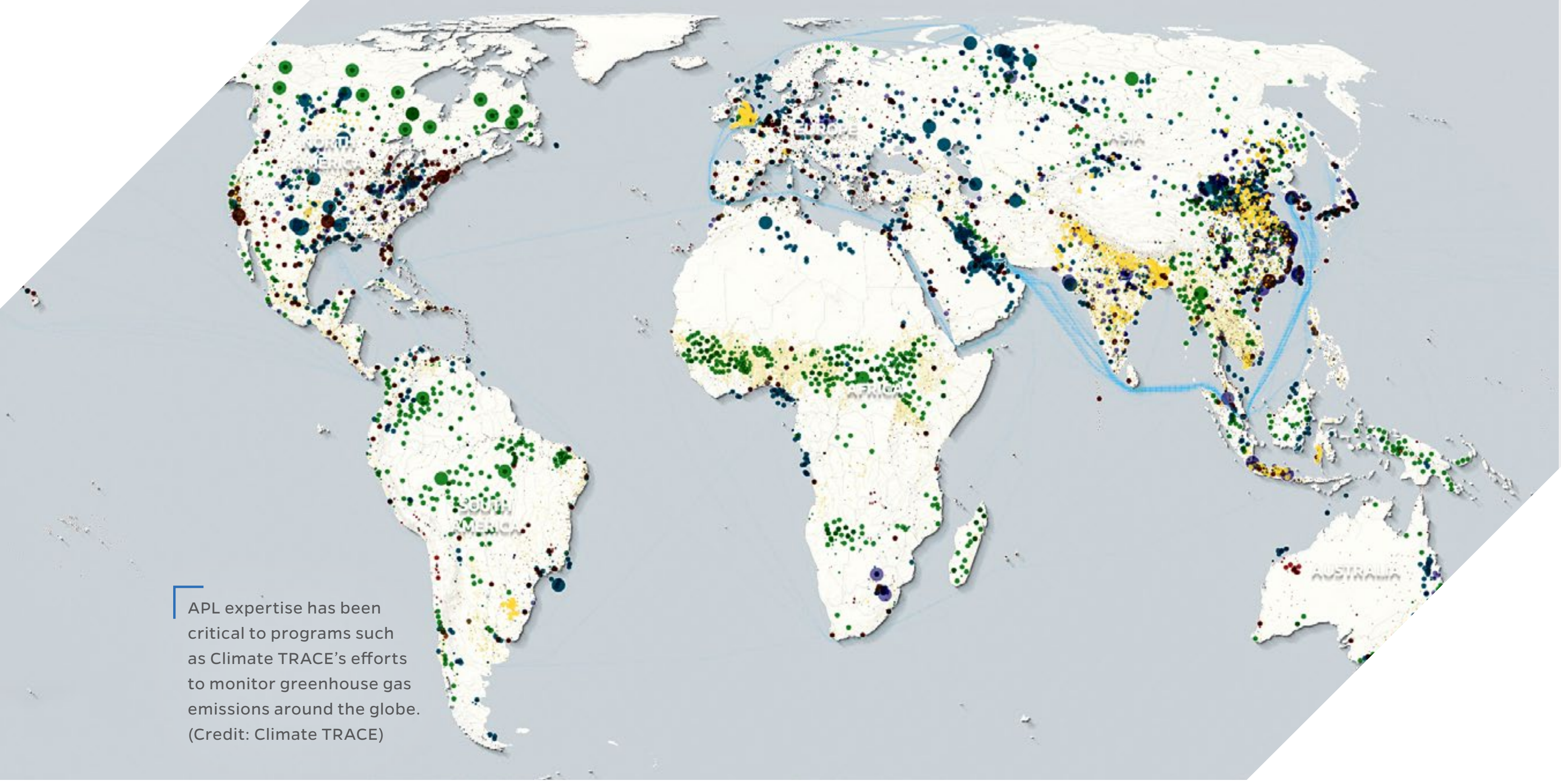


Brendan Croom led the creation of a machine learning model that can predict the stress response of porous, defect-containing additively manufactured metals.

"We envision this robotic-enabled approach being used to quickly and autonomously measure any design-critical property," Nimer said, "and we have other parallel efforts in the works — for example, with cyclic loading to test fatigue strength."

APL materials scientist Brendan Croom led the creation of a novel machine learning model that can predict a material's elastic stress response in just seconds after measuring only the material's porosity.

"We know, generally speaking, that a lot of porosity may not be mechanically robust, but previously we would have to perform a mechanical test to validate and quantify that relationship," Croom explained. "With this model, however, we can quickly assess how porosity will affect the elastic stress response of the material. And because the model is trained by using data from high-fidelity computer simulations, we know we can trust the results."

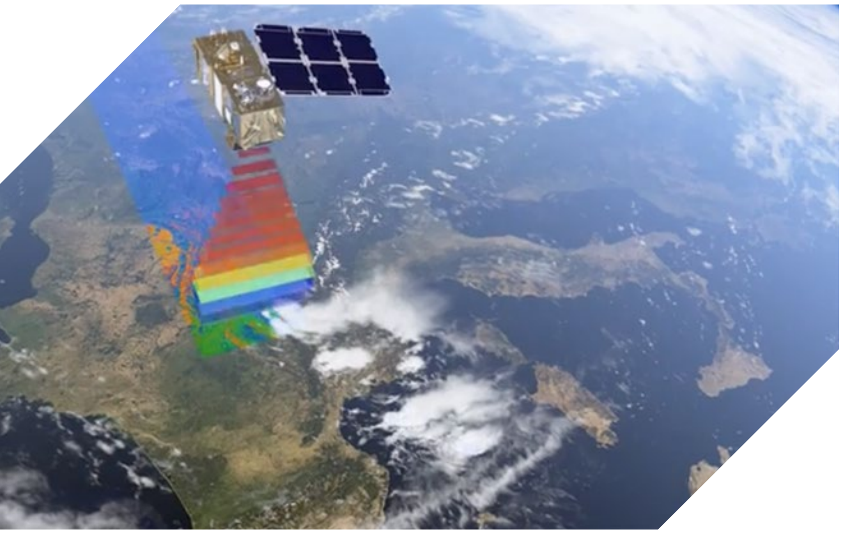


APL expertise has been critical to programs such as Climate TRACE's efforts to monitor greenhouse gas emissions around the globe. (Credit: Climate TRACE)

MAPPING THE WORLD'S GREENHOUSE GASES

APL research teams are also helping combat a global threat very different from an asteroid impact: climate change.

These researchers became the first to combine machine learning and satellite data to accurately predict the quantity of greenhouse gases that city transportation networks around the world emit each year. Previously, the data proved challenging to determine because of the vast number of very small contributions (individual vehicles, for example) happening over time.



APL is the first organization to use machine learning and satellite data to attempt a global estimate of greenhouse gas emissions from road transportation. (Credit: European Space Agency)

"It's a great example of how our unique skills and capabilities across machine learning, satellite imaging and systems modeling can be applied to understand and one day solve complex problems," said Bobby Armiger, who co-leads the Labwide focus on climate change research with Marisa Hughes.

The world's estimated 1.4 billion internal-combustion motor vehicles emit a staggering amount of greenhouse gases. In the United States alone, the transportation sector accounts for roughly 27% of greenhouse gas emissions, according to estimates from the Environmental Protection Agency, and road transportation makes up a large chunk of that value. The difficulty for researchers has been isolating exactly where the emissions come from.

Building a neural network and training it on globally available inputs, including satellite imagery and road network data, the APL team created a model that could predict emissions from cities with astounding accuracy. During test runs against real-world data collected from cities across the United States, the model's predictions came within just 39.5 kilograms of CO_2 per 100 square meters of estimates generated by ground sensors. The team subsequently built a computer pipeline so the model could run at a global scale. As of November, the researchers had released their results on 500 cities around the world.

"The ability to calculate emissions per road segment provides an unprecedented level of detail and global coverage," said Hughes, the assistant program manager for Biological and Chemical Sciences at the Lab. "The combination of machine learning-predicted road activity along with region-specific emissions data creates automated, accurate, global, timely and actionable estimates of road transportation greenhouse gas emissions."

The team's efforts feed into APL's broader contributions to an international coalition called Climate TRACE — Tracking Real-time Atmospheric Carbon Emissions. The alliance was created to fast-track climate action by providing rapidly acquired but detailed greenhouse gas emission data. Coalition members have rallied around a goal they call radical transparency, which would mean knowing where all of the world's emissions come from while remaining open about how those estimates were derived. In the coming year, the coalition aims to understand how to fuse overlapping datasets from various sources to create a new best estimate for greenhouse emissions.

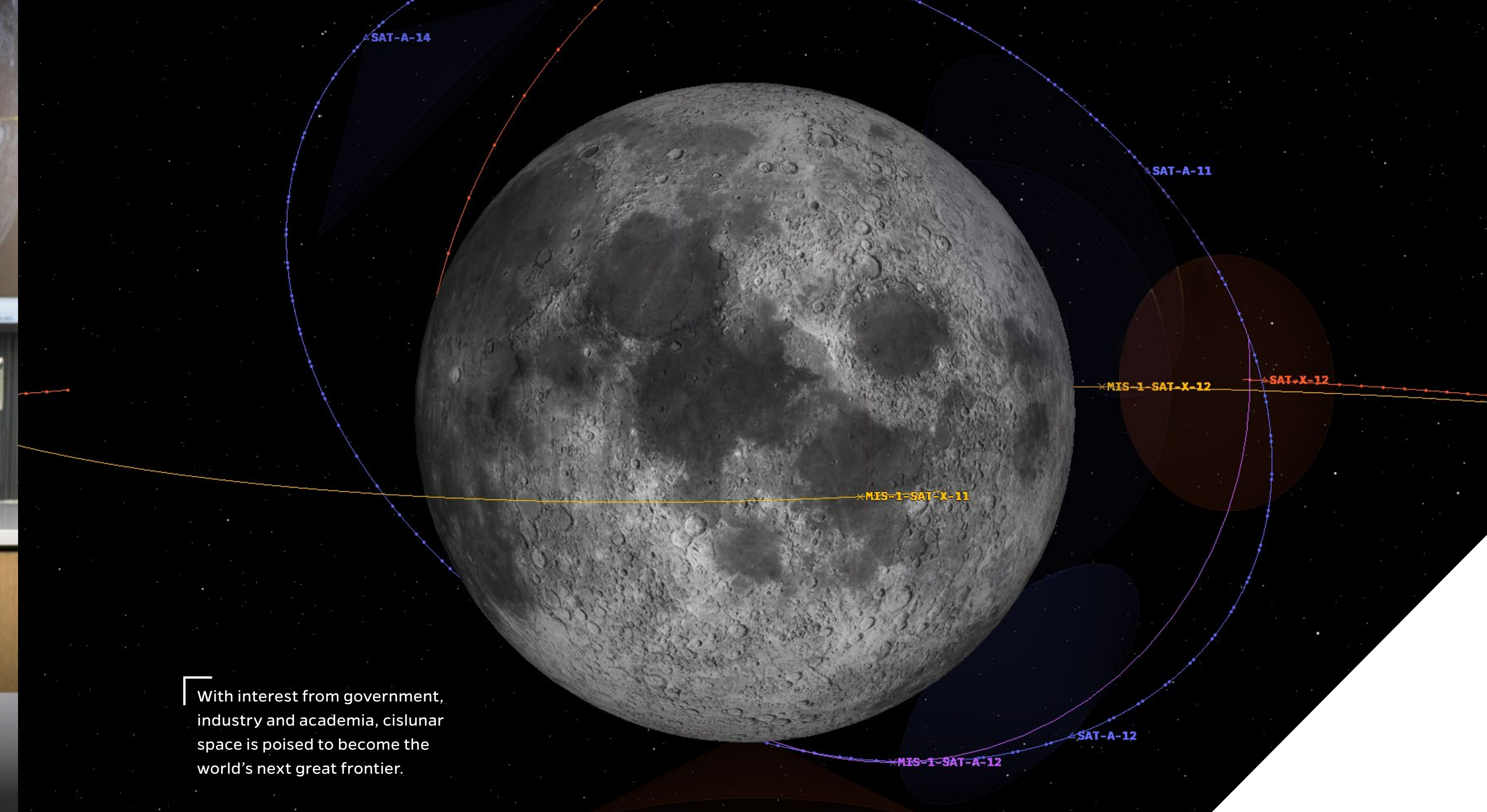
"The ultimate vision of radical transparency and knowing where all of the emissions are coming from in real time, updated with every new satellite image, is still a ways ahead of us," Hughes said. "But now it feels within reach."

"It's a great example of how our unique skills and capabilities across machine learning, satellite imaging and systems modeling can be applied to understand and one day solve complex problems."

— **BOBBY ARMIGER, Head of Exploratory Science**

Marisa Hughes leads an APL team using new technologies to predict and monitor global sources of greenhouse gas emissions.

From left, Chuck Quintero, Jeff Welling, Cameron Brand and Mary Daffron are among the APL experts assessing policies and technologies to enable safety and stability in cislunar space.



With interest from government, industry and academia, cislunar space is poised to become the world's next great frontier.

CREATING BOLD VISIONS FOR CISLUNAR SECURITY

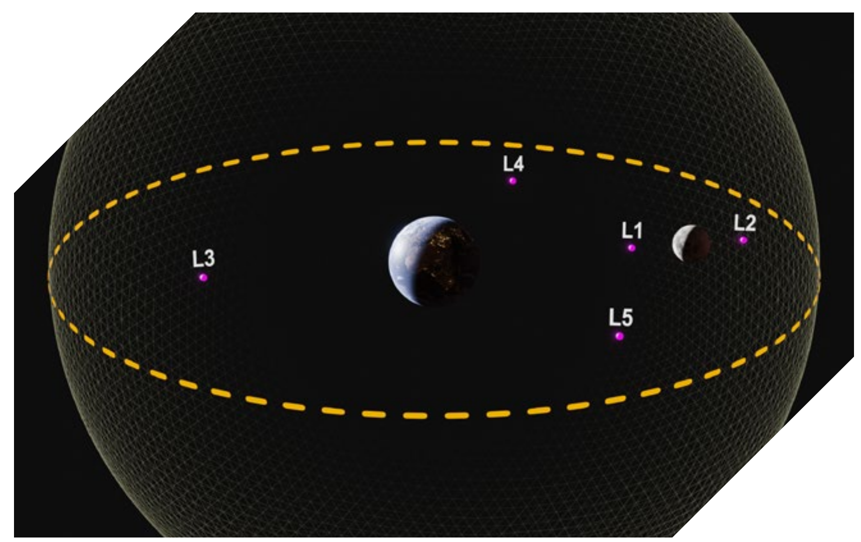
As space becomes easier to access through the proliferation of commercial launch vehicles, the lunar surface and a large swath of space between Earth and the Moon are poised to become the world's next great frontier. Industry, civilian space agencies and militaries all see this region — known as cislunar space — and the lunar surface as strategic locations for activities ranging from addressing the need for space domain awareness to resource mining, scientific exploration and more.

Cislunar space is the region of the Earth–Moon system that is beyond Earth's geosynchronous orbit, which is approximately 22,000 miles from our planet's surface. The increase in activity in this region and, ultimately, on the Moon increases the potential for security conflict. To consider this problem more deeply, APL launched the Bad Moon Rising challenge as part of the Laboratory's Propulsion Grants program, which engages diverse teams from across APL to develop high-risk ideas with the potential for disruptive impact.

Two multidisciplinary teams were competitively selected to analyze the strategies, policies and technologies needed to promote peaceful, collaborative use of the cislunar regime, and to defend American interests if necessary. One team, led by national security analyst Sarah Brothers, focused on deterring conflict in the region. The team interviewed more than 40 members of the U.S. space community — from industry, NASA and national security organizations — and synthesized the data and searched for key takeaways and common concerns. They found that the primary need was not technical, but policy oriented. Many stakeholders discussed concerns about accidental interference sparking conflict. Stakeholders reported a need for the U.S. government to work collaboratively with industry to define responsible operating behaviors — and, ultimately, to uphold an environment of noninterference. "There's so much unknown about the environment and safe operating practices," Brothers said. "Industry actors really look to the U.S. government to develop guidance on how they should act in proximity to other entities."

"You can't have helicopters or airplanes [on the Moon], or anything that hovers in the air, really. Similarly, there's no water to float on. If you want to get around, you have to drive over the rocks, or you have to launch and land somewhere."

— **CAMERON BRAND, Structural Engineer**



Cislunar space is the region of the Earth-Moon system that is beyond Earth's geosynchronous orbit, which is approximately 22,000 miles from our planet's surface.

A second team set out to characterize the worst-case scenario — a conflict in cislunar space or on the lunar surface. Led by Cameron Brand, a structural engineer, the team identified a number of challenges to moving Earth-based defense capabilities to the Moon: the lack of a lunar atmosphere, huge daily temperature swings and low surface gravity. "You can't have helicopters or airplanes [on the Moon], or anything that hovers in the air, really," said Brand. "Similarly, there's no water to float on. If you want to get around, you have to drive over the rocks, or you have to launch and land somewhere because rockets are your best option to resist the Moon's gravity and they're not very fuel efficient for the low-thrust and long-duration propulsion needed to hover."

The distance from Earth also makes transporting material impractical, so the team looked at ways to use materials already present on the Moon to build infrastructure, including some small-scale physical testing. They also created a software simulation tool to help characterize the region's operational environment, which helped the team evaluate a wide array of technologies and potential conflict scenarios.

DEFENDING THE NATION

Since its founding in 1942, APL has proudly served as a world-class research and development institution and has created some of the nation's most critical defense technologies. In that time, threats to our national security have continued to emerge and evolve, increasing in complexity and involving new operational environments and regimes. To meet these challenges and maintain the nation's defensive edge, APL calls upon its deep expertise in a number of technical domains, both cutting-edge and foundational, provided by the more than 8,000 staff members who collaborate in teams across the Lab.

APL played a key role as part of Japan Flight Test Mission-07, which marked a significant milestone in the cooperation between Japan and the United States in missile defense. Here, a Standard Missile-3 Block IB is fired from the JS Haguro during the test. (Credit: U.S. Missile Defense Agency)

A multinational group of ships sails in formation during an exercise that enhances forces' ability to track and report on air and missile defense targets. APL was involved in similar exercises in 2022. (Credit: U.S. Navy)

MILESTONES IN MISSILE FLIGHT TESTING

APL — in cooperation with the Japan Maritime Self-Defense Force (JMSDF) and the U.S. Missile Defense Agency (MDA) — played a key role in live-fire intercept demonstrations of the Standard Missile-2 (SM-2) and SM-3 guided missiles during the campaign designated Japan Flight Test Mission-07 (JFTM-07). The event was held in cooperation with the U.S. Navy.

A Standard Missile-3 Block IIA launches from the JS Maya as part of the first live-fire demonstration of Japan Flight Test Mission-07. (Credit: U.S. Missile Defense Agency)

JFTM-07 Event 2 demonstrated a successful live-fire engagement of an SM-3 Block IIA fired from the JS Maya (DDG-179) against a medium-range ballistic missile target. The JS Maya tracked and fired on the target, successfully destroying it over the Pacific Ocean. This is the first time a Japanese Maya-class destroyer has fired an SM-3 interceptor.

JFTM-07 Event 4 demonstrated a successful integrated air and missile defense scenario with the JS Haguro (DDG-180) concurrently engaging a short-range ballistic missile (SRBM) target with a live SM-3 Block IB Threat Upgrade and an anti-air warfare engagement against a BQM-177 with a live SM-2 Block IIIB.

JFTM-07 is a significant milestone in the cooperation between Japan and the United States in the area of missile defense. JFTM-07's goal was to support the JMSDF ballistic missile defense modernization and certification of the Japanese Aegis Weapon System Baseline J7 and Maya-class destroyer deployment. It also demonstrates the capability of the SM-3 Block IIA, which was cooperatively developed by Japan and the United States, to defeat medium- and intermediate-range ballistic missiles. The SM-3 Block IIA interceptor operates as part of the Aegis Ballistic Missile Defense system and can be launched from Aegis-equipped ships and Aegis Ashore sites.

"The success of this joint test marks a critical milestone in demonstrating, for the first time, a live fire of an SM-3 Blk IIA from a Japanese ship. The cooperative development of the SM-3 Blk IIA…, and the integration with the Aegis Weapon System on Japan's Ballistic Missile Defense-capable ships, is a remarkable achievement and vitally important in defending against an ever-increasing threat."

— **VICE ADM. JON HILL, MDA Director**

The APL team was instrumental in the JFTM-07 event scenario definitions, modeling of the test targets, preflight weapon system performance assessment, flight test execution and postflight assessment of objectives. As the technical direction agent for the Aegis Ballistic Missile Defense system, APL is integral in the full systems engineering life cycle, including testing of ballistic missile defense capability and transitioning it to U.S. and allied fleet forces.

A Standard Missile-3 Block IIA missile is fired from the JS Maya as part of Japan Flight Test Mission-07, which marked a significant milestone in the cooperation between Japan and the United States in missile defense. (Credit: Japan Maritime Self-Defense Force)

STREAMLINING COMMUNICATIONS AND NETWORKING FOR MULTIDOMAIN WARFARE

Uncrewed systems (UxS) have risen rapidly to prominence in the defense industry, but the very speed at which UxS programs have produced and procured these systems has resulted in the implementation of a wide variety of communications standards and methods that are often incompatible.

APL innovation is leading to a new generation of frequency-flexible, modular communications on land mobile radios and other systems. (Credit: U.S. Air Force/Tech. Sgt. Lauren M. Snyder)

The Joint Communications Architecture for Unmanned Systems (JCAUS) addresses this problem, laying the foundation for a new generation of frequency-flexible, modular communications systems. APL led the development of this new architecture for the U.S. Office of the Secretary of Defense, collaborating with stakeholders across the Department of Defense (DoD), academia and industry.

UxS systems employing JCAUS radios can be configured to be interoperable by simply replacing one radio component. The plug-and-play capabilities that JCAUS delivers will vastly improve interoperability of both uncrewed and traditional systems. Its proven robustness led to the approval of JCAUS as an emerging standard by the Joint Enterprise Standards Committee in May 2022.

The research and development of JCAUS went hand in hand with APL's support on the Flexible Cyber Secure Radio (FlexCSR) project, sponsored by the Navy's Expeditionary Missions (PMS 408) program office. FlexCSR is a frequency-agile radio that supports operations in a wide variety of regions and mission profiles and provides secure wireless communications to UxS. The testing of FlexCSR was so successful that it is now in production for use in the field.

"Initially, JCAUS started out purely as a research endeavor. But as our team progressed, there became a need to provide material prototypes — something that could prove the viability and success of JCAUS to the DoD," said Reed Young, Robotics and Autonomy program manager. "The FlexCSR prototype was that solution. It's one thing to say, 'Hey, we have this really great idea on paper.' It's another to go out and prove it with a real system."

APL was also recognized with the 2022 Maverick Award by U.S. Special Operations Command for its technical leadership in the development of the Mod Payload standard. A modular standard similar to JCAUS, Mod Payload revolutionized the way radio frequency and related communications and electronic warfare technologies are integrated into UxS, and it has seen widespread adoption by DoD vendors since its official debut in 2020. Mod Payload-compliant systems can switch mission packages in a fraction of the time and cost in comparison with standard platform architectures.

"It's one thing to say, 'Hey, we have this really great idea on paper.' It's another to go out and prove it with a real system."

— **REED YOUNG, Robotics and Autonomy Program Manager**

APL is developing systems to optimize search plans for the Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2), a transportable phased-array radar designed specifically for missile defense. (Credit: U.S. Missile Defense Agency)

A PROTOTYPE PLANNER FOR QUICK RADAR SEARCH PLANS

The questions a ballistic missile defense system sensor manager is faced with are both manifold and complex: If two radars have 10 different search plans, what's the optimal combination to support a certain mission? How about to help defend a particular location? And what about to detect short-, intermediate- and long-range missiles?

Previously, getting the answers through a Request for Analysis (RFA) submission was a long process that produced a limited result: an unwieldy written document that could not account for shifting variables and emerging questions on the ground. To improve this, the U.S. Missile Defense Agency (MDA) asked APL to conceptualize how to transform that static document into a dynamic computer program, known as a planner.

The ambition was for a planner to run on laptops and workstations closer to the warfighters and battle managers who control the ground-based Army Navy/Transportable Radar Surveillance and Control Model 2 (AN/TPY-2) radars that serve as the front line of ballistic missile defense. APL drew on over a decade of expertise in operational mission planning for AN/TPY-2 radar deployments, going back to the first in 2007, to create a computational mathematical process to quickly and automatically optimize search plans. Along the way, APL worked closely with warfighters at the helm of AN/TPY-2 radars around the world to understand their needs.

Mark McMillen, APL's MDA Sensor Directorate operational mission planning lead, led the team that developed the prototype, which included applied mathematicians Eric Farmer and Lauren Williams. The prototype can now generate new search plans and build data visualizations, 3D visualizations and reports almost entirely automatically. It also includes a series of training videos that help warfighters quickly get up to speed on how to use the tool.

Its analytical capabilities have also helped APL more quickly optimize AN/TPY-2 search plans, several of which are currently fielded and serve as the default plans for primary missions. The same capabilities enable the Lab to rapidly address questions from warfighters and senior defense decision-makers in response to unfolding events, providing answers to one recent request in under 24 hours.

"With innovative computer science and mathematical approaches, we evolved the limits of 'feasible design,' pushed the community to take on more challenging missions and produced designs to effectively cover those," reflected McMillen. "It's still a one-of-a-kind capability, orders of magnitude faster than the alternatives."

APL researchers have developed a first-of-its-kind, metrics-based approach for assessing the navigation capabilities of unmanned surface vehicles (USVs), such as the Sea Hawk medium displacement USV. (Credit: U.S. Navy)

GRADING AUTONOMOUS PERFORMANCE AGAINST HUMAN OPERATIONS

APL researchers are developing a first-of-its-kind, metrics-based approach for assessing the navigation capabilities of unmanned surface vehicles (USVs) at sea — a critical capability as our nation and adversaries evolve naval strategies and operationally blend human and unmanned platforms. The Performance Analysis Toolset (PAT) effort has developed a novel approach of quantifying and scoring actions taken during at-sea encounters with other vessels and how those actions comply with COLREGS standards.

COLREGS, the International Regulations for Preventing Collisions at Sea, comprise a set of maneuvering protocols that all vessels must follow to minimize confusion in a potential collision encounter. The protocols are meant for humans to follow, and as such, they are left intentionally vague, leaving room for common sense and intuition — qualities that navigation autonomies decidedly lack. This makes quantifying COLREGS compliance difficult.

To develop the PAT, APL researchers studied COLREGS, interviewed ship-handling instructors about what qualities they look for in navigation tests and translated their findings into a scoring algorithm.

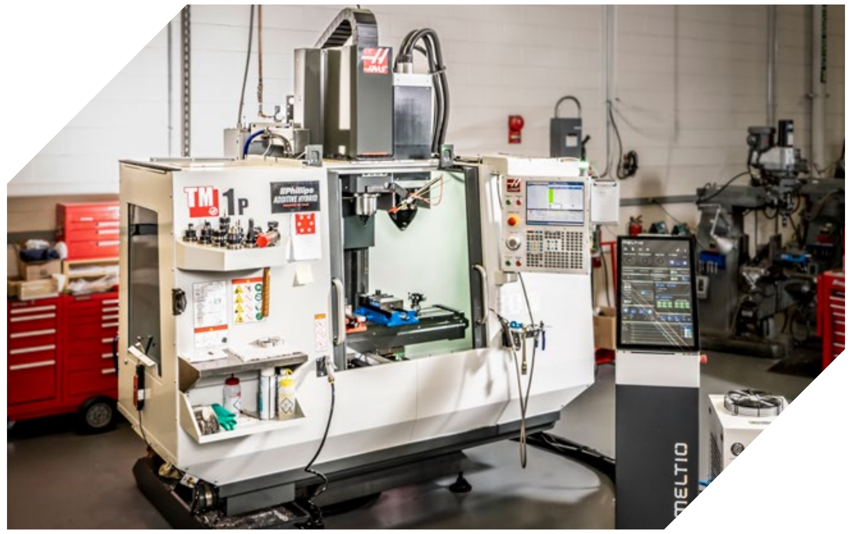
Translating the qualities of a good human captain into quantitative metrics took years of research, guidance from dozens of experts and countless rounds of revision, but the resulting algorithms have been introduced to study autonomous navigation in several Navy programs, including the Sea Hunter and Sea Hawk USVs.

To test the PAT's applicability to support assessment of USV platforms, APL is completing a study — called the Performance Analysis Toolset – Human Operator Comparison (PAT-HOC) — with the support of the Surface Warfare School Command (SWSC) in Newport, Rhode Island, and sponsorship from the Naval Sea Systems Command Unmanned Maritime Systems Program Office. PAT-HOC will compare the PAT results with performance grades from the Officer of the Deck Phase II training course, which is intended for Surface Warfare Officers (SWOs) in between their first and second division officer tours, and includes a milestone assessment that determines whether a sailor will continue within the SWO community.

Early results from the PAT-HOC study are showing some correlation between the PAT scores and the SWSC instructor scores. As testing continues, parts of the algorithm are being refactored to refine and improve its performance. The goal is for the algorithm to provide a quantifiable metric-based assessment that could support the government to define a minimum threshold for USV performance during encounters with other vessels.

APL BRINGS ADDITIVE MANUFACTURING AFLOAT

Even with decades of experience in systems installation and engineering aboard military submarines and surface vessels, APL stepped into unchartered territory in 2022 and installed the first metal additive manufacturing machine aboard a Naval ship, the USS Bataan. The installation enables efficient and timely production of metal components while the vessel is underway.



Below, from left, Hunter Turco, Jason Reese, Ben Miller, Alan Huang, Deepu David and Sarah Bostwick stand in front of an additive manufacturing machine (also above) identical to the one installed aboard the USS Bataan.

The system includes a computer numerical control (CNC) mill for precise machining of custom components and a state-of-the-art laser metal wire print head that prints 316L stainless steel, a prevalent material in U.S. Navy ship construction. The metal printer weighs nearly 2 tons and is similar in size to an SUV at 6.5 feet tall, 68 inches back to front and 8 feet wide.

To support the system and the sailors using it, APL also developed a digital manufacturing environment (DME), which is a communication system that enables the transmission of NAVSEA-developed technical data packages (TDPs) from shore to ship. TDPs provide instructions and print files to build parts on the printers. The DME could be utilized in future manufacturing installations across the fleet.

As the Navy seeks to expand additive manufacturing capabilities, APL researchers will continue to test and evaluate systems that will best support sailors and Marines at sea and around the world.

APL *at* 80

CELEBRATING 80 YEARS OF GAME-CHANGING IMPACT

Founded on March 10, 1942 — just three months after the United States entered World War II — APL was created as part of a federal government effort to mobilize scientific resources to address wartime challenges. Since then, APL has served as an indispensable resource, contributing to the nation's defense and security, and has developed significant technologies and capabilities that have secured the United States against threats at home and abroad.

As the Lab looks ahead toward its centennial and beyond, it is fortified by the work happening across its mission areas, sectors and departments, a deep-rooted culture of innovation and an emphasis on the mission that has enabled the Lab's work for the last 80 years: solving complex research, engineering and analytical problems that present critical challenges to our nation.

80TH ANNIVERSARY ALL HANDS

In March, staff members were invited to celebrate technical successes of the last five years and the people and teams who made them possible through a special virtual 80th anniversary edition of the Director's State of the Laboratory address.

Director Ralph Semmel noted that this milestone was dedicated to celebrating recent events. That meant acknowledging new staff members, new buildings, new capabilities — and new challenges. Expert panelists from the teams behind APL's unbreakable battery, Parker Solar Probe mission, hypersonics advances, the AlphaDogfight Trials, the COVID-19 response and wargames teams shared insights on their successes.

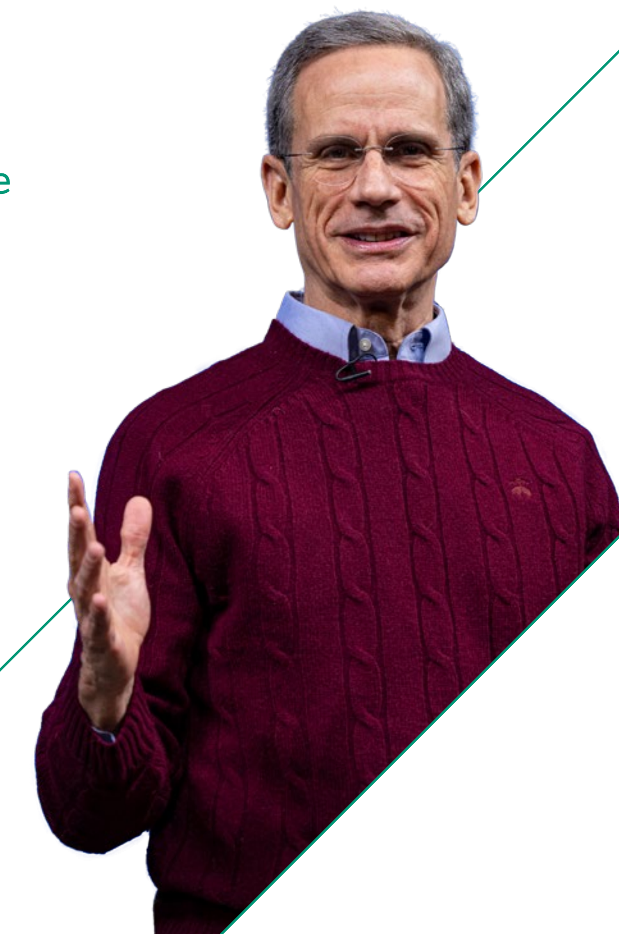
"Throughout APL's 80 years, it is the world-class expertise, the collective knowledge and wisdom embedded in our teams, that has enabled us to make the many thousands of contributions so critical to our nation," Semmel said. "And it is that world-class expertise that is on full display today."

The director's annual fall strategy update (left) was a celebration of APL's 80th year and a look at critical areas the Laboratory would focus on in the next fiscal year.

The 80th anniversary edition of the Director's All Hands took staff members through a series of panels (right).

"We are stronger when we work together as one APL. . . . We explicitly promote this in our strategy and in our innovation initiatives. . . . Incredible achievements like DART are an example of what APLers do every day and what the Laboratory has been doing for more than 80 years now — making critical contributions to critical challenges."

— **RALPH SEMMEL, Director**



EXPLORING THE EXTREMES

At APL, we create technologies and innovations that enable humanity to discover new insights in places humans cannot inhabit. From the unforgiving, harsh environment of outer space to the evolving new domain of mixed reality, APL is pioneering solutions in both the real and digital worlds to tackle critical national challenges.

Artist's impression of NASA's Europa Clipper spacecraft, enabled by APL innovation on its mission to explore Jupiter's icy moon in unprecedented detail. (Credit: NASA)

EXPLORING DEEP SPACE

The challenges of exploring our outer solar system and beyond — whether directly or through observation — require a wide range of expertise, skill and collaboration to solve. In 2022, much of that focus was on Jupiter's moon Europa and planets discovered beyond our own solar system.

APL engineers work on Europa Clipper's radio frequency (RF) panel, which is part of the larger RF module that houses the spacecraft's telecommunications subsystem.

The ocean world of Europa — with an intriguing water-ice crust and a thin oxygen atmosphere — is considered by many to be the most promising place in our solar system to find life beyond Earth. NASA's groundbreaking Europa Clipper mission, set to launch in October 2024, will perform nearly 50 flybys of the moon to reveal its secrets, and APL is a major contributor to this spacecraft, developed with the Jet Propulsion Laboratory.

The APL team designed and built two of the spacecraft's three main modules: the propulsion module — the spacecraft's "workhorse" — and its radio frequency (RF) module, two components critical to the spacecraft achieving its mission and sending its discoveries back to Earth.

Europa Clipper's propulsion module comprises about two-thirds of the spacecraft's main body. The enormity of the structure — comprising two aluminum cylinders, each about 5 feet in height and diameter — mirrors its monumental purpose: getting Europa Clipper into orbit around Jupiter. After nearly six years of space travel, Europa Clipper will come hurtling in toward Jupiter so fast that it will swing right around the gas giant and continue out to deep space if it does not slow down on approach. The propulsion module is responsible for achieving the necessary change in velocity through a series of engine burns.

Mounted near the top of the propulsion module is the spacecraft's RF panel, a component of the much larger RF module that houses the spacecraft's telecommunications subsystem as well as mechanical, thermal and harness components to support it. The RF panel will connect to the spacecraft's high-gain antenna — the device that will enable science data downloads and allow ground controllers to communicate with the spacecraft while it orbits Jupiter, hundreds of millions of miles away.

Both components were delivered in 2022 to NASA's Jet Propulsion Laboratory, where they will be integrated with the rest of the spacecraft and tested before launch.

Far beyond our solar system, the much-anticipated 2021 launch of NASA's newest astrophysics observatory, the James Webb Space Telescope (JWST), has allowed APL scientists to make use of the new observatory to provide unprecedented insights into planets outside our solar system, called exoplanets.

"We expected JWST to be a powerful tool to study exoplanet atmospheres, and these observations are among the first real evidence that that is true. The precision of these measurements is unmatched by previous telescopes, and we're really just scratching the surface of what we'll be able to learn about exoplanets going forward."

— ERIN MAY, Astrophysicist

Using James Webb Space Telescope data, APL researchers marked the first definitive detection of carbon dioxide in an exoplanet's atmosphere. (Credit: NASA/European Space Agency/Canadian Space Agency/Leah Hustak and Joseph Olmsted, Space Telescope Science Institute)

Only six months after Webb's launch, scientists, including team members from APL, reported that, for the first time, Webb definitively detected carbon dioxide in the atmosphere of exoplanet WASP-39b. The presence of this molecule suggests that in the future, Webb will be able to detect atmospheres on smaller, terrestrial-sized planets and help researchers understand if life could exist on those Earth-like exoplanets.

As part of the same program, Webb detected the first comprehensive list of molecular ingredients in the atmosphere of WASP-39b, which is roughly 700 light-years away. From that, an international team of researchers, including APL scientists, revealed not only the first detection of active chemistry happening in the atmosphere of an exoplanet — but also how that exoplanet potentially formed.

"We expected JWST to be a powerful tool to study exoplanet atmospheres, and these observations are among the first real evidence that that is true," said APL astrophysicist Erin May, who was a coauthor on the new studies. "The precision of these measurements is unmatched by previous telescopes, and we're really just scratching the surface of what we'll be able to learn about exoplanets going forward."

The team is currently searching for carbon dioxide on small, rocky planets orbiting the nearest red dwarf stars to determine whether they have atmospheres — a crucial step toward assessing red-dwarf planet habitability.

In the first set of observations, the APL-led team confirmed the discovery of an exoplanet by JWST. Formally logged as LHS 475b, the planet orbits a red dwarf star roughly 41 light-years away, and it's almost exactly the size of Earth, clocking in at 99% of our planet's diameter.

"Missions like Webb are among the boldest NASA projects ever undertaken, uniquely positioned to answer foundational questions about our home and its place in the cosmos," said Jason Kalirai, the Civil Space mission area executive at APL and former Webb project scientist at the Space Telescope Science Institute. "The discovery of an Earth-sized planet in Webb's first year paves the way for a powerful new exploration of rocky exoplanets and the opportunity to place Earth in a broader context."

With almost 2,100 feet of wiring, the electrical harness on Europa Clipper's propulsion module is one of the largest APL has ever built.

> "There has been a lot of investment into understanding how microbes, especially bacteria or viruses, are causing harm to people and animals on land. Now we're taking those same tools and applying them to the ocean."
>
> — SARAH HERMAN, Biological and Chemical Sciences Program Manager

ILLUMINATING THE OCEAN'S SECRETS

Building on rapid genomics capabilities developed by APL to respond to outbreaks and pandemics like COVID-19, new research at the Laboratory is now enabling advanced analysis approaches for underwater environmental monitoring. As organisms move through their environments, they leave behind cells containing DNA. The study of this marine environmental DNA (eDNA) can help researchers track changes to the ocean's ecosystem for environmental and national security purposes.

On board a ship headed for Monterey Bay, genomics research scientist Hayley DeHart loads water samples into a sequencer.

"There has been a lot of investment into understanding how microbes, especially bacteria or viruses, are causing harm to people and animals on land. Now we're taking those same tools and applying them to the ocean," said Sarah Herman, APL Biological and Chemical Sciences program manager.

It is the immediacy of the techniques used in this effort that makes them so unique. Previously, these insights required specialized laboratories that could rarely be rapidly deployed at sea. In April, a team of APL scientists led by Peter Thielen tested new underwater genomics capabilities in Monterey Bay. As the team's vessel passed through the water, members of the research team from APL and Monterey Bay Aquarium Research Institute identified biological eDNA in near real time, processing the data in hours, rather than weeks to months.

The work supports several Office of Naval Research-specific initiatives, including one in support of the Marine Mammals and Biology program, which studies the psychological, behavioral, ecological and population-level effects of sound on marine mammals, working to ensure marine mammals are not harmed during field tests. Another is providing data for the Marine Mammal Health program, which studies the ongoing health and overall longevity of the Navy's operational marine mammals.

Scientists on expeditions to the Arctic and Southern oceans and other regions of the world can use the open-source laboratory and software capabilities for their own research. The APL team hopes that this new capability will ultimately provide a constant data stream from ships that is open to all scientists and easily accessible, expanding knowledge about Earth's oceans.

As development continues, the researchers see full-scale eDNA sequencing automation as key to the future of eDNA analysis.

An APL team (above and below) traveled twice to the Arctic aboard the National Geographic Endurance to set up a permanent eDNA analysis platform. (Credit: Johns Hopkins APL/Peter Thielen)

Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) Principal Investigator Scott Murchie has overseen critical contributions to the discovery of ancient water on the Red Planet.

INVESTIGATING EARTH'S NEIGHBORS

In addition to investigating our outer solar system and beyond, APL furthered its extreme exploration with significant contributions to our knowledge of the celestial body closest to home — our Moon — as scientists and engineers advance the future of human space exploration.

Lunar hydrogen is a critical resource for future space travel — lunar water could be consumed by astronauts or inhabitants, or used to create rocket fuel or even breathable air. This year, APL scientists made use of decades-old data from the Apollo and Lunar Prospector missions to create a groundbreaking map of lunar hydrogen.

"We were able to combine data from lunar soil samples from the Apollo missions with what we've measured from space and finally put together a full picture of lunar hydrogen for the first time," said David Lawrence, an APL planetary scientist.

The first-of-its-kind map identified two types of lunar materials containing enhanced hydrogen and corroborates previous ideas about lunar hydrogen and water. This supports the idea that water likely played a role in the Moon's original magma-ocean formation and solidification.

Team members from APL and NASA's Ames Research Center used orbital neutron data from the Lunar Prospector mission to build their map. The probe, which was deployed by NASA in 1998, orbited the Moon for a year and a half and sent back the first direct evidence of enhanced hydrogen at the lunar poles.

"We were able to combine data from lunar soil samples from the Apollo missions with what we've measured from space and finally put together a full picture of lunar hydrogen for the first time."

— DAVID LAWRENCE, Planetary Scientist

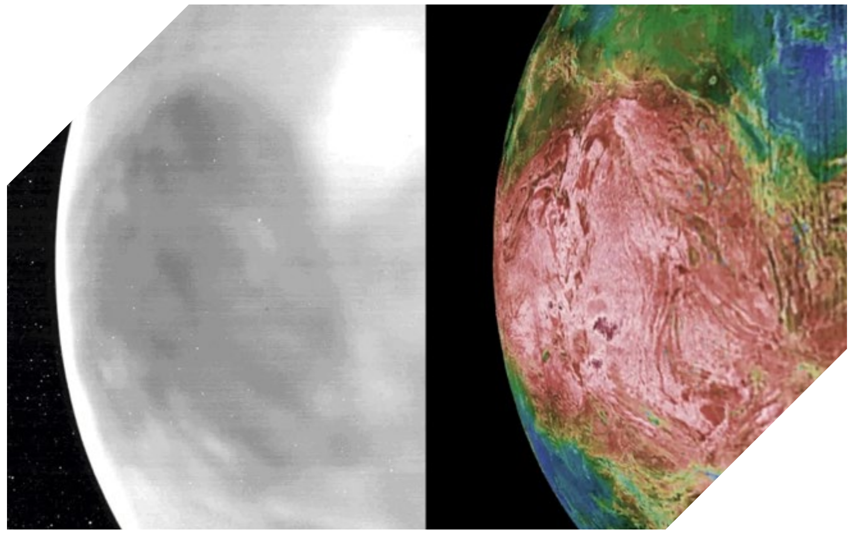
This new map completes the inventory of hydrogen on the Moon, and it could also lead to quantification of how much hydrogen and water were present in the Moon when it was born. In 2013, APL researchers also confirmed the presence of water ice at the poles on the planet Mercury using data from the neutron spectrometer on the APL-built MESSENGER spacecraft. These discoveries are important for planning future human exploration.

NASA's Parker Solar Probe, launched in 2018 and built, managed and operated by APL, has revolutionized our understanding of the Sun, but it is also providing an unexpected benefit: images and in situ observations of Earth's sister planet, Venus.

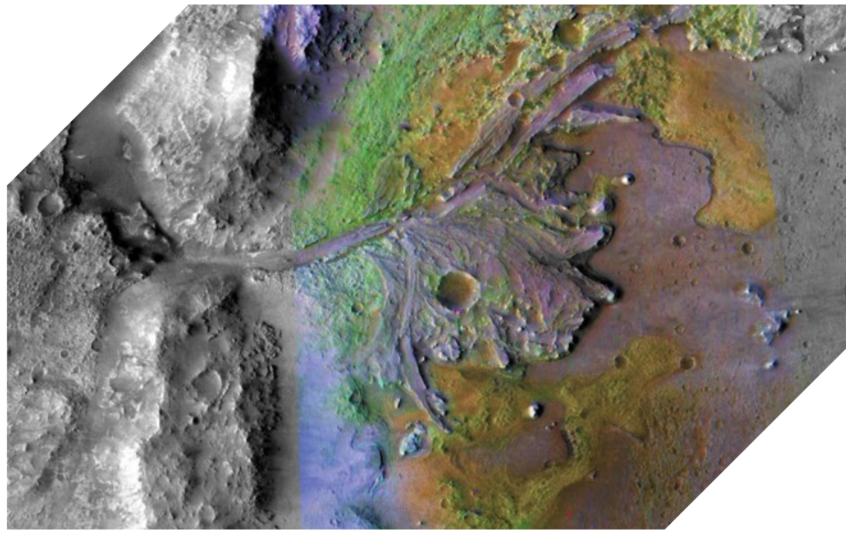
The planet has been notoriously difficult to observe due to its thick shroud of clouds. In two flybys in 2020 and 2021, Parker used its Wide-Field Imager, or WISPR, to capture images of the entire night side of the planet. In 2022, scientists published a full analysis of the images and a video in the journal Geophysical Research Letters, adding to scientists' understanding of Venus.

"Both imaging and in situ data we collected during the Venus gravity assists are opening our eyes to new features on the planet's surface and atmosphere unknown to us so far," said Nour Raouafi, the Parker Solar Probe project scientist at APL.

The video, comprising a compilation of the images, reveals a faint glow from the surface that shows distinctive features like continental regions, plains and plateaus. A luminescent halo of oxygen in the atmosphere can also be seen surrounding the planet.



The Magellan mission offered the first global view of what was below Venus' thick clouds. Surface features seen in Parker Solar Probe images (left) match ones seen in those from Magellan (right). (Credit: left, NASA/Johns Hopkins APL/Naval Research Laboratory; right, Magellan Team/Jet Propulsion Laboratory/United States Geological Survey)



CRISM has been searching for mineralogical evidence of water that once existed on Mars by capturing images (like the above) in up to 544 different colors of reflected visible and infrared light. (Credit: NASA/Jet Propulsion Laboratory/Johns Hopkins APL)

The new WISPR images will help scientists better understand the geology and mineral makeup of Venus. Given the similarities between Earth and Venus, this information can help scientists on the quest to understand why Venus became inhospitable and Earth became an oasis.

Beyond Earth's orbit, the team behind the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument on NASA's Mars Reconnaissance Orbiter (MRO) spacecraft enabled the world to see Mars like never before.

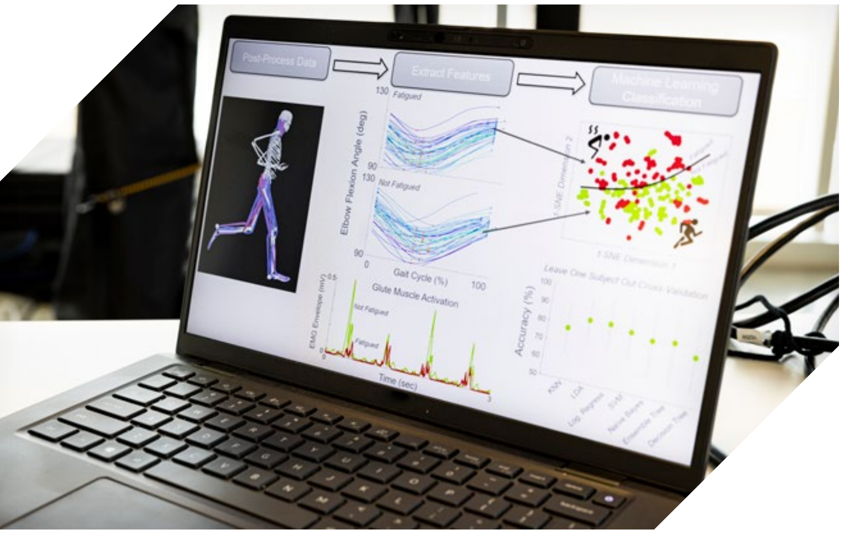
In June, the APL team began releasing the first pieces of a new near-global map of the Martian surface — a massive 5.6-gigapixel image in 72 colors — conveying its mineral composition. Over the course of 2022, the team released 639 of 1,764 tiled product sets — mosaicked strips of mapping data that include a collection of data visualizations, each revealing something different about the chemical composition of Mars — to NASA's Planetary Data System.

"It's effectively a whole new data set that will fuel a second wave of discoveries about Mars' surface composition," said Scott Murchie, an APL planetary scientist and CRISM's principal investigator.

Scientists have already used the map to identify hundreds of new target areas of interest for the NASA's High Resolution Imaging Experiment (HiRISE) camera on MRO.

PREVENTING INJURIES FROM FATIGUE

Musculoskeletal injuries account for roughly 82% of injuries in the U.S. Army, according to some estimates, and many of them occur in soldiers fatigued from hours of strenuous activity while carrying heavy packs.



APL-developed machine-learning algorithms make it possible to estimate physical fatigue from sensor measurements of an individual's physiology and biomechanics.

APL biomechanical engineer Mike Vignos and his team have been developing a near real-time machine learning algorithm to help spot fatigued military personnel and predict musculoskeletal injury long before it happens. Drawing on past and parallel APL studies, the project produces computational models of the human body and compiles data that links an injury to the environment in which it occurred.

"Once we're armed with an objective score for physical fatigue, there are a variety of ways we could apply it to improve the health of our warfighters," said Kathleen Perrino, manager of APL's research portfolio dedicated to predictive health. Such improvements could include changing the armor soldiers wear or altering how gear is distributed across their bodies.

In 2021, the team developed the system using a set of sensors fitted to 10 individuals tasked with running on a treadmill and characterized their fatigue in simple binary terms: fatigued or not fatigued. The results indicated that muscle activation metrics are the strongest indicator of physical fatigue, with movement, impact and heart rate data providing additional indications.

In the project's second year, Vignos and his team worked to improve the system by creating a numerical score that can more precisely quantify fatigue and having people do a wider range of exercises beyond running, including push-ups, high jumps, squats and lunges. What's more, they're trying to identify the smallest set of sensors they can use to obtain the data without saddling already over-burdened soldiers with more gear.

"We're still working out what the sweet spot is — that minimally viable sensor setup of ideally one or maybe two wearable sensors that will allow us to assess fatigue without contributing to the problem we're trying to solve," Vignos said.

"[I]f you want to assess a person's potential performance, you need to understand the interplay of physical and cognitive fatigue as well as the effects of other factors like sleep deprivation and caffeine intake. That's where this work gets really interesting, and where it's headed in the long term."

— **MIKE VIGNOS, Biomechanical Engineer**

The project dovetails with APL's broader portfolio of work on predictive health and human performance modeling. While Vignos and his team's project examines fatigue from physical activity, other investigations are examining and modeling cognitive fatigue and sleep deprivation. The ultimate goal is to develop a comprehensive suite of tools for real-time human-state estimation and predictive health.

"In the real world, there is no hard distinction between physical fatigue and mental or cognitive fatigue," Vignos said. "Think of a common military task like reconnaissance, where if you want to assess a person's potential performance, you need to understand the interplay of physical and cognitive fatigue as well as the effects of other factors like sleep deprivation and caffeine intake. That's where this work gets really interesting, and where it's headed in the long term."

APL's system to monitor physical fatigue in near real time could prevent countless musculoskeletal injuries.

ADVANCING ENHANCED REALITIES

The deep reaches of outer space and the waters of our oceans are not the only frontiers APL aims to explore. Today, technologists can create whole worlds that exist only inside a pair of goggles, or overlaid over reality on a camera screen. And the possible applications of this new technology are growing.

Extended reality, or XR, is now a proven tool for visualization, engineering and exploration. Virtual (an artificial environment that replaces one or more senses), augmented (an overlay of digital content on real-world elements to enhance the environment) and mixed (the blending and manipulation of both digital- and real-world environments) realities all present opportunities for tasking, such as training health care workers and helping to design complex missions remotely.

One such application where extended reality has an immediate impact is CPR training. There are many roadblocks to successfully resuscitating children with CPR. For one, it is difficult to retain CPR training without frequent refreshers and practice, and pediatric CPR guidelines change with age. Plus, because the number of children who go into cardiac arrest is relatively small on the scale of the entire U.S. population, the resources to effectively respond to this emergency are often lacking.

To improve the quality of pediatric CPR, immersive technology specialists at APL and pediatric emergency physicians from Johns Hopkins Children's Center in Baltimore began developing an augmented-reality-based CPR coaching system to be used in community care settings.

The coaching system comprises a sensor that sits under the performer's palm and measures changes in compression depth and rate, a lightweight headset that provides the performer with a heads-up display (HUD) and a laptop to process the sensor's raw data and send it to the HUD.

Johns Hopkins Children's Center pediatrician Dr. Keith Kleinman demonstrates an APL-developed augmented-reality-based CPR coaching system.

"REACTOR provides a mechanism to bridge the gap between in-person meetings and virtual meetings through the use of extended-reality technology."

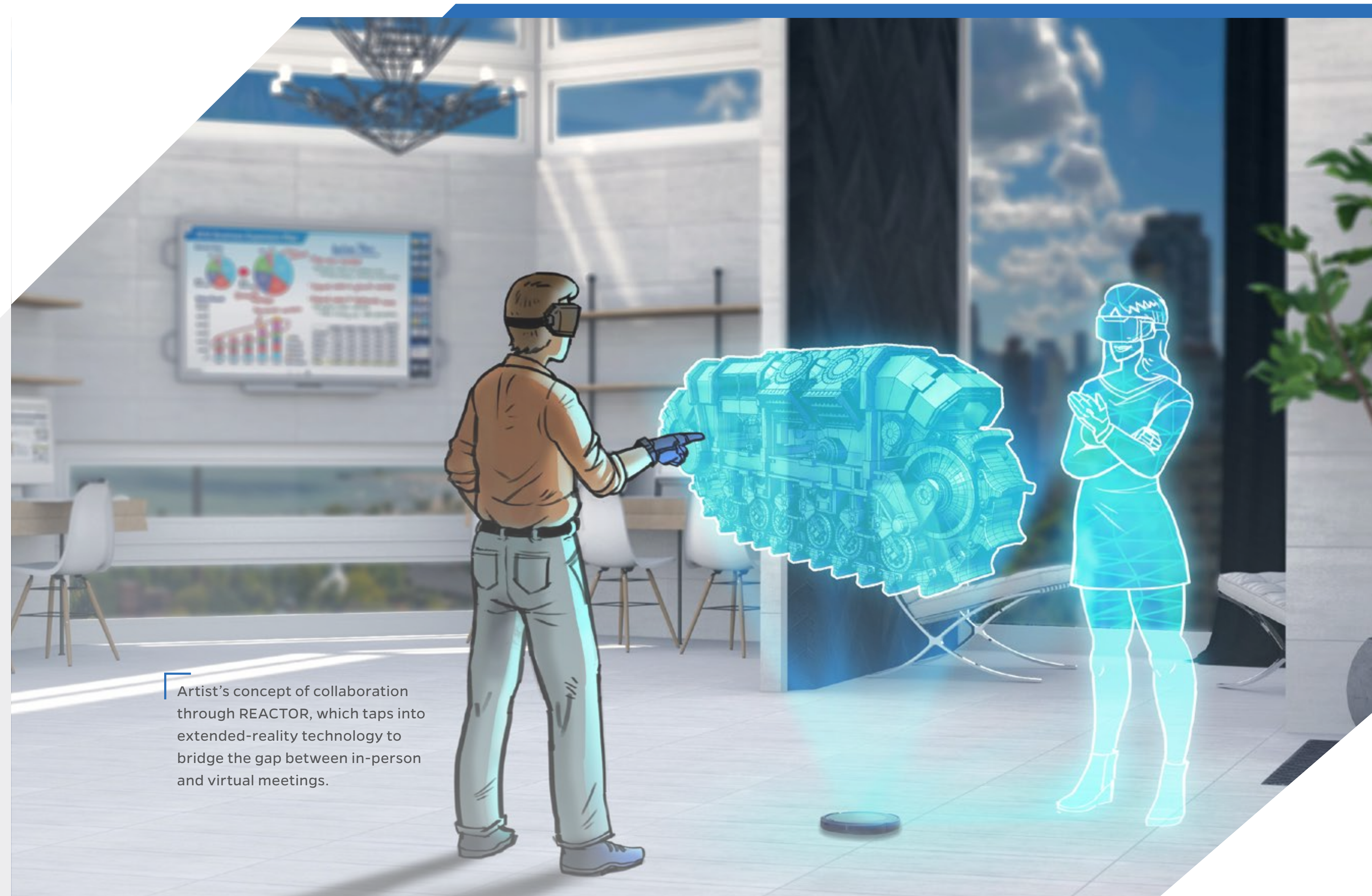
— JUSTIN RENGA, Software Engineer

The team conducted a feasibility test with community hospital providers that do not specialize in pediatrics. Using the augmented-reality CPR coaching system, their adherence to chest compression guidelines improved from 16% to between 77% and 90%. In addition to supporting the hypothesis that the coaching system is effective as a clinical and educational tool, the data shows that users retain learned skills after using it.

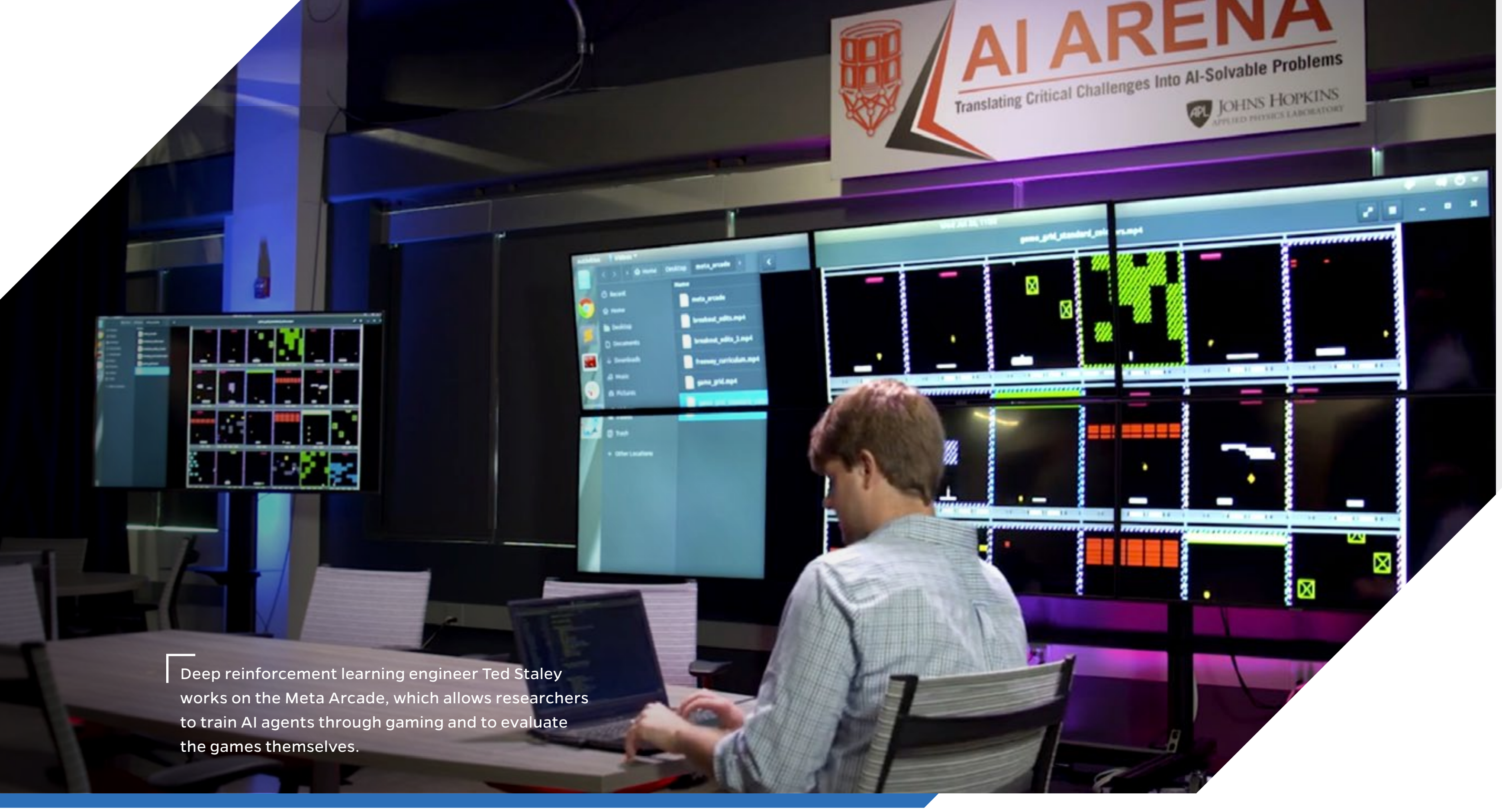
Alongside feasibility testing and progressive iteration of the prototype to a more mature coaching system, the team is looking to transition the concept to industry with commercial and military partners, where it has the potential to impact the lives of children worldwide.

APL researchers also applied mixed-reality technologies to aid collaboration. Whether in person or virtual, collaborating across wide physical distances can create challenges that seriously hamper the creative process and limit overall productivity. Engineers at APL addressed this challenge with the Mixed-Reality Collaboration Environment framework (REACTOR). This unique system allows subject-matter experts and analysts to interact globally and customize the approach to the user's needs, all without externally hosted servers.

This XR technology supports bringing virtual, augmented and mixed reality into a collaboration framework that promotes remote, synchronous and cross-domain analysis and discussion.



Artist's concept of collaboration through REACTOR, which taps into extended-reality technology to bridge the gap between in-person and virtual meetings.



Deep reinforcement learning engineer Ted Staley works on the Meta Arcade, which allows researchers to train AI agents through gaming and to evaluate the games themselves.

REACTOR uses include mission planning, trajectory analysis and data visualization. REACTOR, which is a base from which richer applications can be built, has grown into a stand-alone framework that can support multiple users' platforms. It also enables all users to see, in near real time, other users' manipulations of the XR scene they are viewing.

Even if not using XR tools, APL researchers are finding ways to apply well-known virtual spaces, like video games, to important areas of study. One such area is deploying AI agents in operational environments.

Researchers at APL created Meta Arcade, a suite of arcade games configured and used as training tasks for AI systems to fill a critical gap in AI research on exercising and evaluating continual or lifelong learning agents. Initially developed under the Defense Advanced Research Projects Agency's Lifelong Learning Machines program, Meta Arcade trains AI agents to quickly adapt to new and changing scenarios without forgetting previous learning.

The games in Meta Arcade are modeled on classics like Pong and Breakout, common benchmarks in the deep reinforcement learning (DRL) community. An AI agent is given the freedom to play a game repeatedly, making and learning from its own decisions. Each time the agent makes a decision, it is given a signal that describes how successful it was. Those signals allow the agent to learn through trial and error: Strategies that seem to produce positive signals are reinforced, and behaviors that lead to bad outcomes are used less and less.

Unlike a typical game, where settings and features are fixed, a researcher can use Meta Arcade to control the sizes, speeds and colors of game entities, or even create new games. This not only allows researchers to train AI agents through gaming, but also prompts researchers to evaluate the games themselves. By creating new gaming environments, researchers can create problems and therefore benchmarks to evaluate algorithm performance.

The team presented on their work at the NeurIPS conference, the premier AI research forum, in 2021, and APL researchers are already using Meta Arcade to study strategies for producing AI agents for a number of different purposes and applications.

"The value in creating new environments and setting new benchmarks is that they help us push the state of the art," said Chace Ashcraft, an APL AI engineer.

The tool is available to the public through the development platform GitHub, and the team hopes it sparks conversation about other potential tools the DRL community is currently lacking.

IMPROVED FLYING THROUGH URBAN ENVIRONMENTS

Urban environments might not seem like an extreme frontier. Humans have been living in them for millennia. But for airborne vehicles — especially those piloted remotely — it is a different story.

There are numerous challenges to flying a fixed-wing uncrewed aerial vehicle (UAV) through the extremely constrained spaces of a major metropolitan city. To even get off the ground, they must be able to lift off without a runway. Once airborne, they must dodge skyscrapers, billboards and even other airborne vehicles careening around corners — a time-consuming and exhausting task for a remote human UAV pilot. Though the obstacles are significant, fixed-wing UAVs are capable of a crucial capability — staying aloft longer than other UAVs.

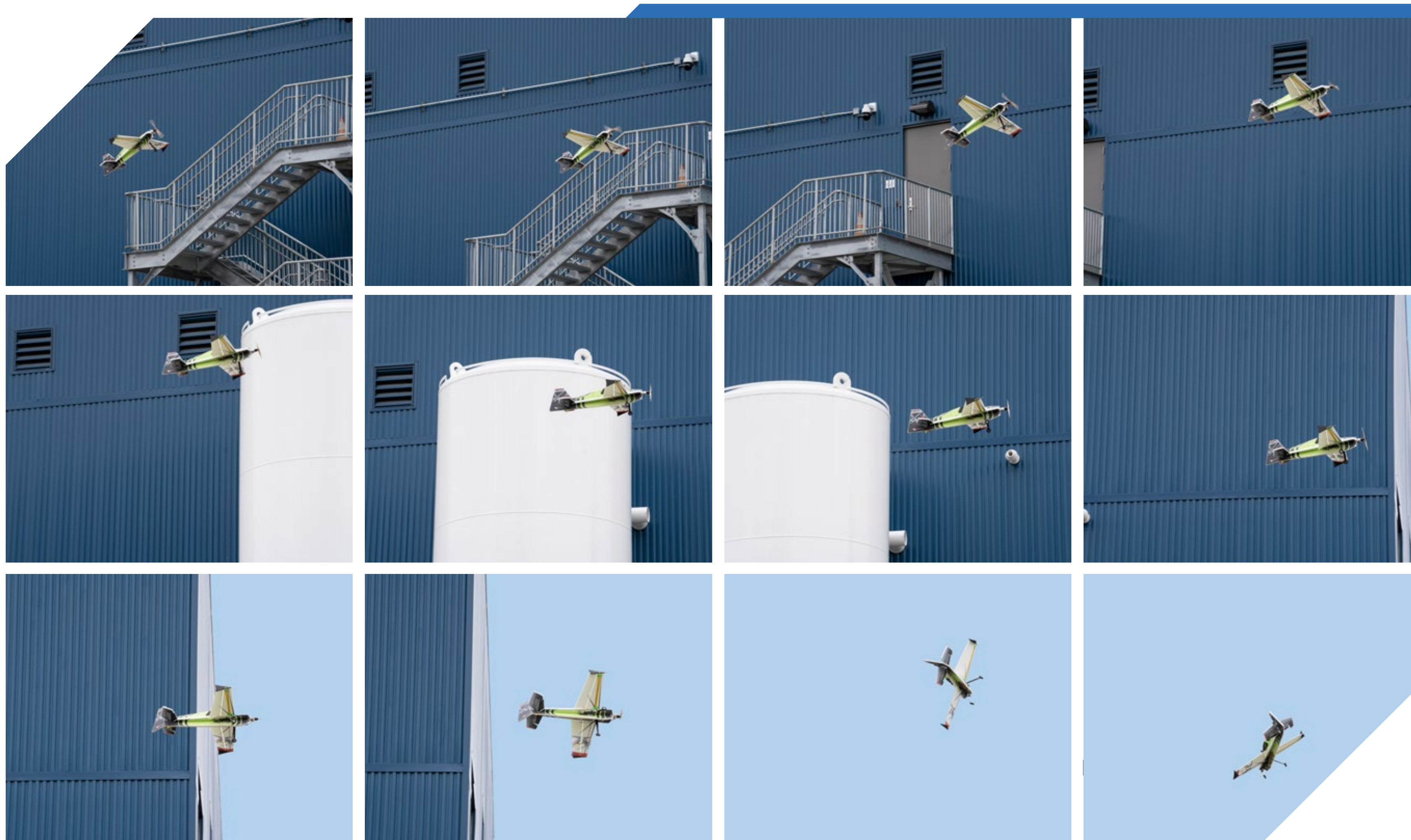
Using an onboard depth camera and a mapping capability called NanoMap, a team at APL created a model predictive-control algorithm that allows UAVs to autonomously navigate complex environments, removing a number of stressors on the operator. Flying a UAV equipped with this system, an operator can safely guide the vehicle through extremely constrained spaces — even at high speeds of up to 20 miles per hour.

Success relies on generating both a real-time flight trajectory and a history of depth images. A stereo camera enables triangulated data gathering of the UAV's surroundings, giving the vehicle a sense of depth perception. The control algorithm uses those depth measurements to plan aerobatic maneuvers and avoid potential collisions in real time.

In addition to vision-based collision avoidance, APL researchers have designed a gimballed propulsion system that enables near-vertical takeoffs for fixed-wing UAVs, similar to the takeoffs of their quad-rotor counterparts. When takeoff is initiated by an operator, the fixed-wing UAV can first elevate into a hover before smoothly transitioning to forward flight. With this capability, the UAV no longer requires considerable space for a cleared runway or a manual launch (being thrown into the air by hand).

Taken together, these advancements allow fixed-wing UAVs to operate in tight spaces, including those crowded with other coordinating UAVs, ultimately enabling the fixed-wing UAVs to more effectively participate in multiplan operations and missions.

A fixed-wing UAV hugs a building perimeter during testing of collision avoidance technology for the Defense Advanced Research Projects Agency OFFensive Swarm-Enabled Tactics (OFFSET) program, which envisions small-unit infantry forces using swarms of uncrewed vehicles/systems in urban environments.



COUNTERING EVOLVING THREATS

Eighty years after its founding, the Laboratory continues to provide technological advances in anticipation and response to ever-evolving security challenges to the United States.

Drawing on decades of experience in systems engineering, research and development, and analytics, researchers at the Laboratory continue to deliver critical insights and technologies that support national security needs in emergent and changing fields, such as climate change, health care and critical infrastructure.

Molecular biologist Peter Thielen leads an APL genomic surveillance team that has sequenced influenza and SARS-CoV-2—the virus that causes COVID-19.

PATHOGEN GENOMIC SURVEILLANCE AT HOME AND ABROAD

APL's public health surveillance expertise dates back to the 1990s and includes the development of the Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE) in 1997, the Suite for Automated Global Electronic bioSurveillance (SAGES) in 2017 and, most recently, crucial data science and analytics for the Johns Hopkins Coronavirus Resource Center and its dashboard in response to the COVID-19 pandemic.

Genomic research scientist Abhi Srikanth performs sequencing work in APL's genomics laboratory.

To better prepare for, and possibly prevent, future pandemics, APL researchers are leveraging more than 30 years of public health and data analysis experience to build tools and outline strategies that will best enable effective decision-making during an outbreak response.

The COVID-19 pandemic showed officials and organizations that pathogen genomic surveillance technology was critical to effectively responding to new virus variants — data collected by the World Health Organization shows that in March 2021, 54% of countries had this capacity. By January 2022, that number increased to 68%. Though the increase is significant, there is room to expand and improve use of the technology around the world.

The trouble is that sequencing is technically and technologically intensive, as well as expensive. APL is tackling this problem using a multifaceted approach. The Laboratory continues to expand global access to Basestack, a modular, open-source software suite for complex informatics work. Sequencing applications that were previously difficult to set up, unwieldy to use and required powerful hardware and high-speed internet can now be run locally, on off-the-shelf laptops, by way of a clean and intuitive interface, making advanced genomics tools accessible and user-friendly for scientists and public health workers around the world.

"We're trying to enable data production as early in the process as possible," said Peter Thielen, a molecular biologist at APL.

While teams of Laboratory researchers are making advancements in digital data acquisition, others are turning those pieces of digital information into powerful insights — but they face additional barriers as well.

Varied health data infrastructures, patient confidentiality and other factors limit the ability to pair research data with clinical data. But this capability could help scientists and researchers characterize the symptoms and severity of certain disease variants, leading to better-informed public health responses.

"The capabilities we're developing will enable public health practitioners to link data streams in a way that will provide truly critical insights."

— **NATALIE LEE, Virologist**

"The best time to implement new systems is not during an outbreak. The better we can plan and prepare, the better equipped we are to improve, expand and deliver these capabilities around the globe."

— **SHERI LEWIS, Deputy Mission Area Executive, National Health**

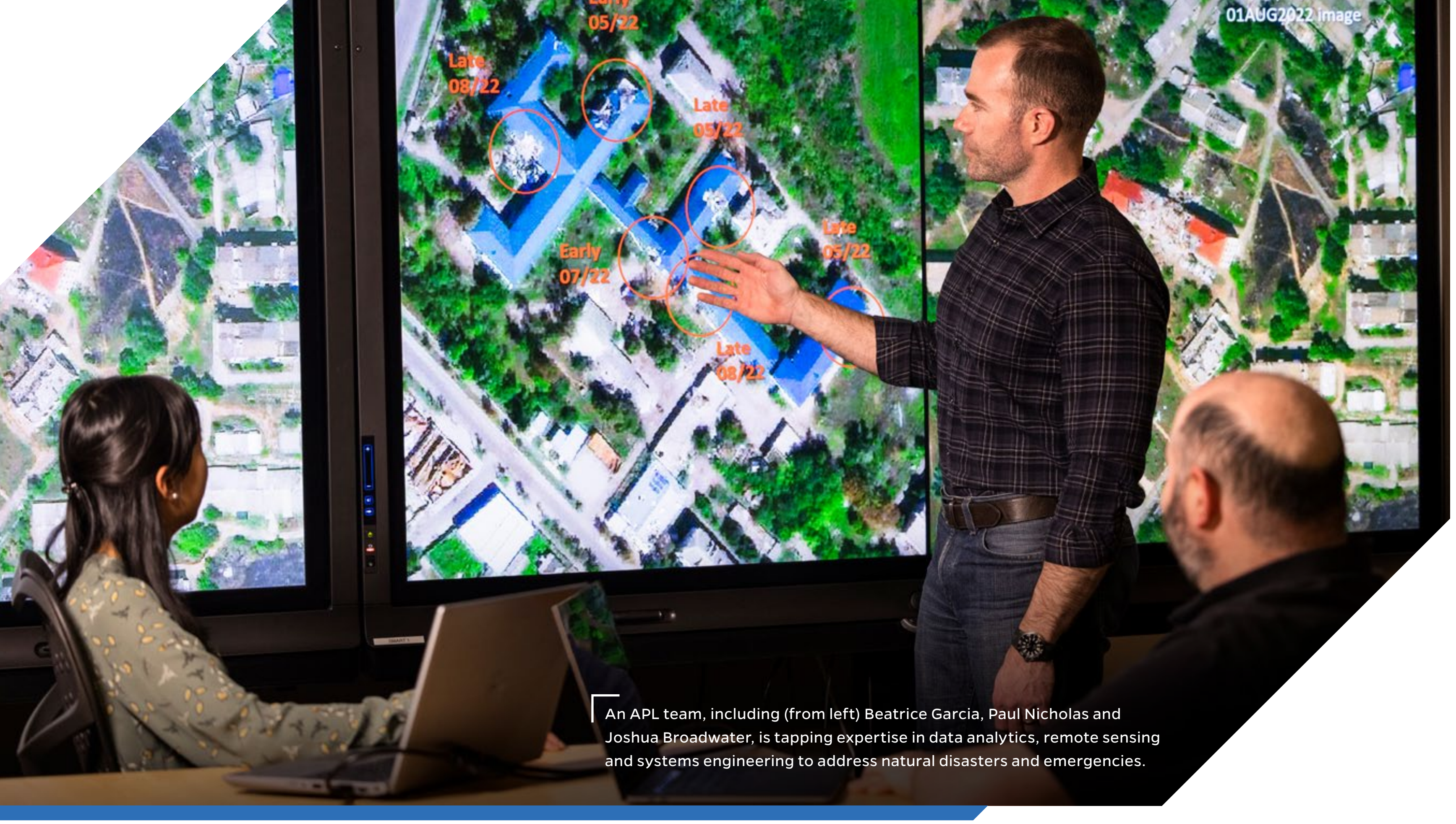
"There are two disconnected groups of data; for example, the genomic surveillance data can show that there's a new variant emerging, and the clinical data can show that there has not been an increase in intensive care unit admissions," said Thielen. "How can we connect those data streams and determine the extent of concern for each variant?"

APL is innovating ways to make advanced genomics tools accessible and user-friendly for scientists and public health workers around the world.

With funding from the Department of Defense Center for Global Health Engagement and in coordination with U.S. Southern Command, an APL team is aiming to answer that question. Natalie Lee, an APL virologist, and her teammates are developing a public health surveillance capability that will enable analyses of viral genomic data and then integrate that data with clinical and epidemiological information to provide critical insight into the evolution, transmission and clinical outcomes of disease during outbreaks.

In 2022, this team began working with the National Health Laboratory in Guatemala to implement the tool, which will allow information to be analyzed more rapidly and enable the Guatemalan government to make more informed decisions.

In addition to providing informatics and analytics tools and software, APL published an implementation strategy for developing sustainable surveillance activities in low- and middle-income countries through adoption of a target operating model that will increase their overall impact and sustainability.



An APL team, including (from left) Beatrice Garcia, Paul Nicholas and Joshua Broadwater, is tapping expertise in data analytics, remote sensing and systems engineering to address natural disasters and emergencies.

EMPOWERING EFFECTIVE DISASTER RESPONSE

APL is also using its world-class expertise in data analytics, remote sensing, systems engineering and other relevant disciplines to assess and address natural disasters and emergency situations. In 2022, the Laboratory developed several tools and technologies that deliver critical information to first responders and decision-makers when disasters strike.

Residents evacuate Irpin, Ukraine, amid a Russian attack in March 2022. Shortly after Russia invaded Ukraine, the U.S. government engaged APL's Disaster Response Corps to assess the condition of Ukraine's medical infrastructure. (Credit: Bigstock/Mikhail Palinchak)

The Disaster Response Corps (DRC), an initiative that rapidly mobilizes APL expertise and technology in support of mitigating dangerous events, was activated in March, shortly after Russia invaded Ukraine. The U.S. government engaged APL's DRC to assess the condition of Ukraine's medical infrastructure.

In a matter of weeks, the APL team had adapted existing pipelines for collecting and verifying a wide variety of relevant data, including open-source and publicly available information, as well as overhead and synthetic-aperture radar imagery, and was producing weekly reports on the status of medical infrastructure in Ukraine. That information enhanced situational awareness capabilities to help officials make informed decisions about logistics and personnel deployment when the time comes to rebuild.

"Within a week of getting to work, we'd set up the pipeline for one city," said Joshua Broadwater, a remote-sensing scientist. "And then we did the same for five or six cities, adding a city roughly every week and producing reports on every city each week."

"Our ultimate goal is to create a completely integrated and automated capability that is data-agnostic — one that can take in satellite imagery, overhead imagery, synthetic-aperture radar, images from social media and news media and even video."

— **BEATRICE GARCIA**, Data Scientist

Broadwater co-led APL's DRC Ukraine work along with data scientist Beatrice Garcia. The work then transitioned into a sponsor-led effort by the Centers for Disease Control and Prevention late in 2022, led on the APL side by Marc Kolodner.

The increased frequency, severity and unpredictability of disasters necessitates advancements and innovations in rapidly providing aid to those affected. Compounding that unpredictability is the fact that legacy systems for acquiring and analyzing information during disasters are largely antiquated. The DRC was designed to bridge the gap between the research and operations communities, enabling the rapid adaptation and deployment of innovative technologies and approaches for a variety of disaster situations.

Also delivering crucial information to disaster responders is Oz, a capability that identifies impacted critical infrastructure and tracks dependencies and cascading effects during and after a disaster event. It leverages two tools previously developed at APL: Humanitarian Assistance and Disaster Relief (HADR) and Dagger.

HADR uses artificial intelligence and machine learning to scan overhead imagery and detect building damage and areas of flooding. Dagger tracks dependencies across a network of assets — people, facilities, systems and processes — and provides the user with a high-level awareness of the status of those assets and the missions and capabilities they support.

Both HADR and Dagger are operational capabilities, and government organizations are currently using Dagger to aid decision-makers during disasters.

Oz provides a user interface that allows the user to upload HADR output files and a critical infrastructure asset list, to compute risk assessments for each asset, and, finally, to output alerts and indicators to Dagger. If HADR is a set of eyes, and Dagger a brain, Oz serves as a kind of nervous system connecting the two. The result is a capability that can help responders adapt nimbly in an unfolding crisis.

"Within a week of getting to work, we'd set up the pipeline for one city. And then we did the same for five or six cities, adding a city roughly every week and producing reports on every city each week."

— **JOSHUA BROADWATER**, Remote-Sensing Scientist

CAPTURING AND DESTROYING FOREVER CHEMICALS

Perfluoroalkyl and polyfluoroalkyl substances, or PFAS, are fluorine-containing chemicals found in many household products, such as nonstick cookware, food packaging, cleaning products and stain-resistant carpets. They are also a major component in aqueous film-forming foams used to fight fuel fires.

APL is working on methods to destroy harmful perfluoroalkyl and polyfluoroalkyl substances (or PFAS), known as "forever chemicals."

Multiple studies have linked PFAS exposure to harmful health effects in humans and animals, and without a natural way to break them down, the chemicals persist in soil and contaminate the environment — including water. The Environmental Protection Agency recently declared PFAS an urgent public health and environmental issue facing communities across the United States.

Scientists at APL have developed two new technologies to deal with PFAS: an enhanced filtration technique to capture them and an ecofriendly way to destroy them. Adding to a previously published electrochemical destruction technique and ongoing work related to stable byproduct sequestration, APL is building a portfolio of technologies aiming to enable full PFAS remediation.

In a 2022 study, APL scientists outlined a cost-effective filtration technique that uses novel amphiphilic functionalized membranes — films that are slightly charged on one side and neutral on the other — to selectively trap molecules, so when the researchers pumped PFAS-contaminated water through a roughly quarter-sized sieve that contained the membranes, the PFAS remained trapped while the water passed through. This filtration technology demonstrated greater than 90% removal of 15 out of 18 types of PFAS defined in an EPA declaration of hazardous substances.

In a second 2022 study, the APL team demonstrated a strategy that uses UV-Fenton chemistry — an advanced oxidation process that leverages hydrogen peroxide and ultraviolet light — to create highly reactive oxygen species capable of breaking PFAS molecules' strong carbon-fluorine bonds. APL's UV-Fenton destruction method proved extremely efficient, destroying greater than 90% of 14 out of 18 common PFAS.

The PFAS-capture materials can be applied to any standard filter, and the PFAS-destruction technologies are designed to be implemented in a range of water-treatment systems, from home systems to filtration plants, and may eventually protect communities across the country from these hazardous chemicals.

"APL's destruction methods are designed to operate at or near room temperature, without the use of harsh chemicals or environments."

— **LESLIE HAMILTON, Materials Science Engineer**

HELPING THE U.S. SPACE FORCE BRIEF AND TRAIN FUTURE LEADERS

Solidifying the continued partnership between the Space Force and Johns Hopkins, the JHU School of Advanced International Studies is leading an effort to promote the professional development of top Space Force leadership candidates. APL is providing candidates state-of-the-art facilities for collaboration on world-class research and development projects, and access to specialized and highly classified facilities for work related to their national security missions.

APL's subject-matter experts will also draw on deep domain expertise in space and defense to give Space Force personnel insights and hands-on development time with existing and emerging technologies and capabilities to meet their mission requirements.

"It has always been an honor to partner with the Space Force to help them meet their needs through the research and development of capabilities at APL," said Patrick Binning, National Security Space mission area executive at APL. "Now, with this program, we are looking forward to deepening this partnership and further collaborating alongside Guardians who are newly responsible for the challenges of national security in the space domain."

Johns Hopkins and the U.S. Space Force are teaming up to provide professional development for Space Force leadership candidates, including access to APL research facilities and experts. (Credit: U.S. Space Force)

COASTAL DEFENDERS: PROTECTING THE NATION'S COASTS WITH NATURAL SOLUTIONS

Our nation's 95,471 miles of shoreline is home to 40% of the nation's population, $9 trillion in contributions to the U.S. economy every year and 1,700 Department of Defense-managed military installations. Within the next 30 years, the sea level along the U.S. coastline is projected to rise an average of 10-12 inches, according to the National Oceanic and Atmospheric Administration, and cause a profound shift in coastal flooding. At risk is much of the infrastructure — as well as many of the communities, resources and ecosystems — on which our nation relies.

Recognizing the need to safeguard our coastlines and the important role natural structures play in their protection, researchers at APL are finding ways to use materials science to support coral reef growth and restoration.

Jenny Boothby, a biomaterials engineer, began partnering with the Lab's marine science researchers, including Maddison Harman, a marine biologist, on internally funded projects to explore a structure called a coral scaffold.

The group utilized tools and technologies within APL's NAMI facility, a 3,000-square-foot, first-of-its-kind laboratory dedicated to unique maritime biology research. The laboratory houses aquariums sized from 10 to 1,000 gallons and has the capability to make its own seawater.

"I have a background in biomedical engineering and remembered reading a paper about using coral skeletons as bone tissue implants," Boothby recalled. "I just sat with that idea for a minute and thought, 'What if we reverse that process?' It's common practice to build ceramic scaffolds for bone tissue — maybe we could do that for corals too."

The team's research has since continued into a collaboration with researchers from the University of Miami on Reefense, a Defense Advanced Research Projects Agency (DARPA) program. The aim is to develop novel hybrid biological and engineered reef structures to mitigate wave and storm damage and reduce the ecological impact of current coastal protection measures.

"Coral and oyster reefs, mangroves and seagrasses are all essential to attenuate large waves and storm surge. These structures slow waves down and hold on to the ground to reduce erosion. As we adjust to live in a world impacted by climate change, we need to think about innovative ways to handle this additional threat," explains Marisa Hughes, the assistant program manager for Biological and Chemical Sciences at the Lab.

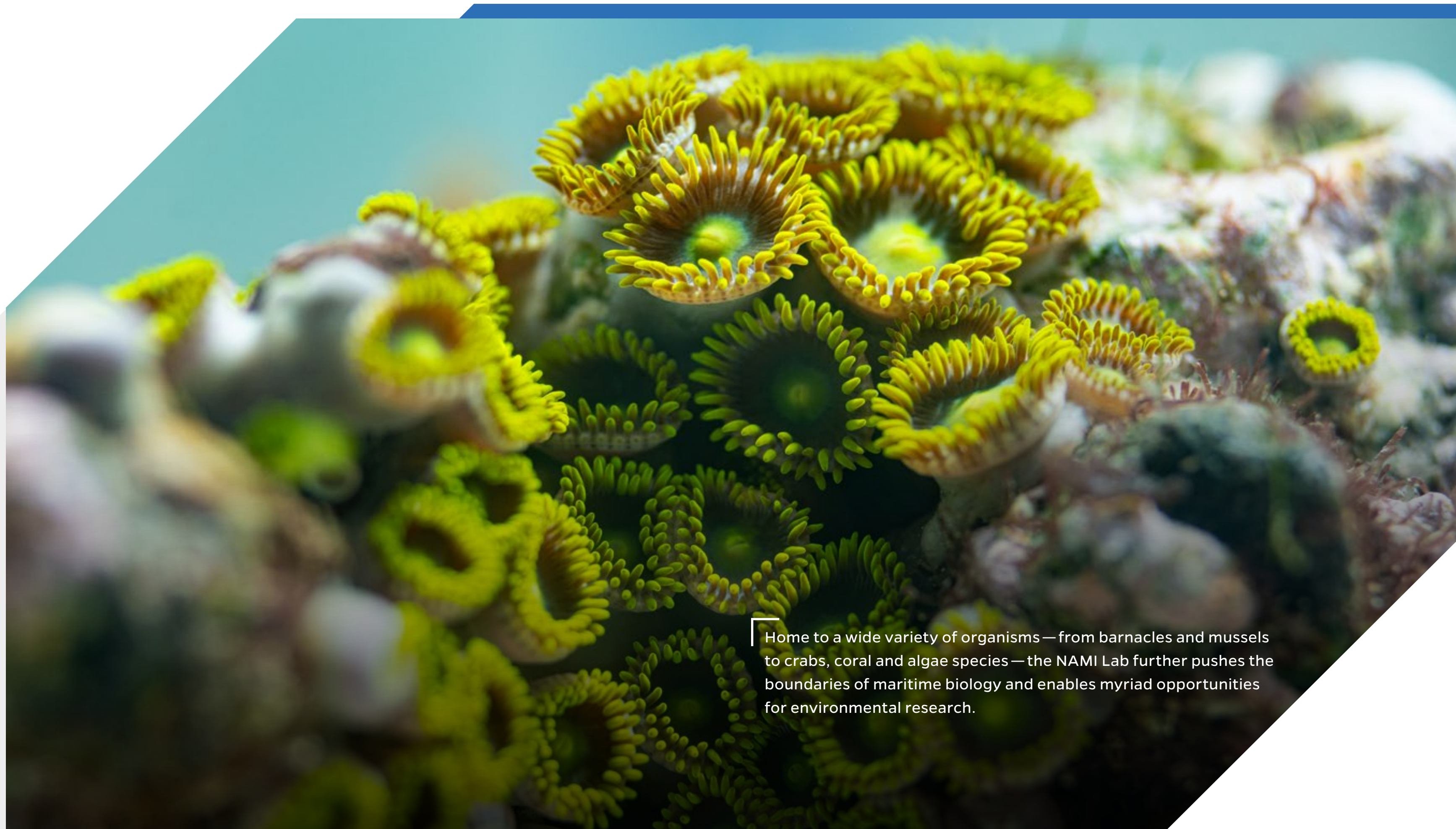
The team has developed hydrogels that can adhere to underwater structures, enabling scientists to take spawned coral larvae, encapsulate them in the hydrogel and apply them directly to the artificial coral scaffolds. This method allows researchers to spatially control the larvae, provide them with sufficient nutrients and encourage them to grow down into the coral's protective substrate.

Using materials science to help coral reefs grow is just one tool APL is developing as part of its larger coastal resilience tool kit. From artificial intelligence-driven Arctic sea-ice modeling to deriving valuable resources from atmospheric carbon, Laboratory researchers are tapping into varied strengths with interdisciplinary teams to address national security and global challenges resulting from climate change.

Marine biologist Maddison Harman shows a coral sample in APL's NAMI facility, a 3,000-square-foot laboratory dedicated to unique maritime biology research.

"I remembered reading a paper about using coral skeletons as bone tissue implants and thought, 'What if we reverse that process?'"

— JENNY BOOTHBY, Biomaterials Engineer



Home to a wide variety of organisms — from barnacles and mussels to crabs, coral and algae species — the NAMI Lab further pushes the boundaries of maritime biology and enables myriad opportunities for environmental research.

LABS OF THE LAB

Making critical contributions requires taking risks and running experiments — work that is best done in labs. Here are some of APL's notable research and collaboration spaces.

THE WOODS (WORKSPACE FOR INNOVATIVE OPERATIONAL DECISION SYSTEMS)

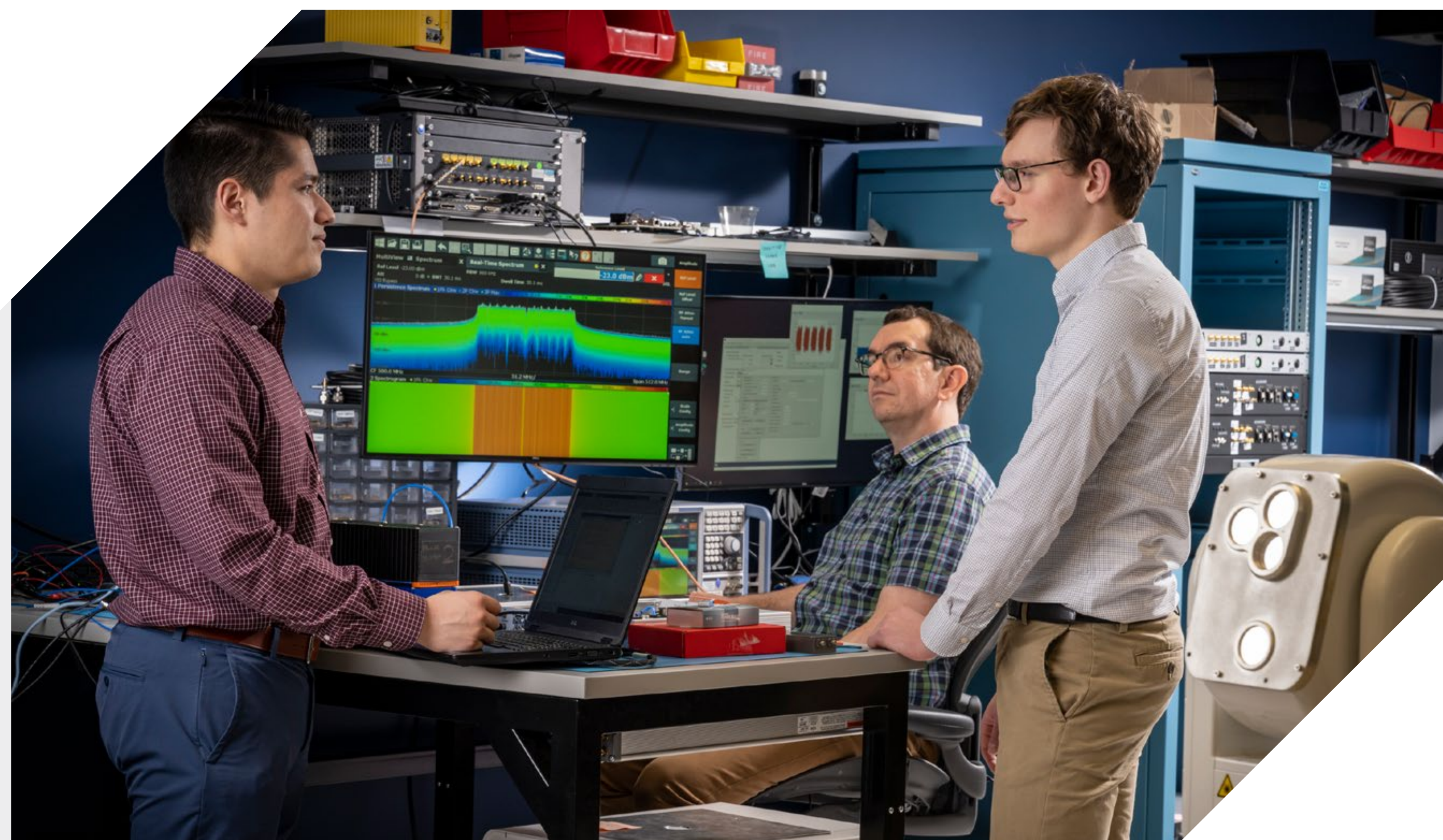
The WOODS is a collaborative space designed to support experimentation and development related to operation centers and decision systems, e.g., for emergency or incident response operations. WOODS resources include high-fidelity displays, collaboration tools and meeting areas. Its reconfigurable design supports 24/7 operations, and it has redundant power and infrastructure to provide resilience. Since May 2020, this space has been the home of the Current Operations team supporting the national COVID-19 response, providing direct analytic support to the White House, the Centers for Disease Control and Prevention, and the Department of Health and Human Services.

FORCE PROJECTION SECTOR SYSTEMS DEVELOPMENT BRANCH HIGH BAY

This 4,000-square-foot, climate-controlled space is used for active project support, such as fabrication, assembly/disassembly, equipment testing, maintenance and field test preparation. Large systems — like buoys, boats and autonomous vehicles — are tested in this space. It is equipped with a 20-ton overhead crane that runs along the 81-foot length of the space and provides a lift up to the 780-square-foot mezzanine with roll-up doors on the second floor. The space also houses a 20-foot saltwater test tank, providing engineers the ability to conduct testing for sea-based sensors, modeling and more.

INTELLIGENT RESILIENT INTERNETWORKED SYSTEM (IRIS) LABORATORY

The IRIS Lab brings together experts from across APL to address challenges in providing cognitive secure, resilient communications in heterogeneous networks of networks. IRIS combines communications and networking infrastructure and knowledge ranging from the physical layer to the application layer, algorithm development using new artificial intelligence/machine learning techniques and systems integration expertise that is necessary for this new technology to be fielded to the warfighter. This integrated hardware and software development lab houses a number of test and measurement tools in both radio frequency and optical spectra, software-defined radios, communications link hardware and more. The 18-screen monitor setup has been used to support networked demos across campus with the IRIS Lab serving as the command and control center.



TRANSPORTATION SYSTEMS CENTRAL

Transportation Systems Central is a facility outfitted to enable cyber evaluation of a wide range of vehicles. The lab is a unique combination of mechanic shop and cyber evaluation lab, allowing engineers to test the cybersecurity of the software, hardware and communications on modern commercial and military vehicles. It is equipped with a variety of capabilities, including exhaust and vehicle lifts, a dynamometer and links to the Laboratory's tools and resources.

DRAGONFLY FLIGHT LABORATORY

In the Dragonfly Flight Laboratory, engineers are developing the flight control system and navigation algorithms for NASA's revolutionary Dragonfly rotorcraft-lander mission to Saturn's moon Titan. The indoor facility has a 900-square-foot flight area for testing, integration and maintenance of two half-scale Dragonfly flight vehicles and a thrust test stand used to evaluate motor and propeller performance. Dragonfly marks the first time NASA will fly a rotorcraft for primary science on another world.

MICROWAVE DIGITAL ARRAY LAB AND ANECHOIC CHAMBER

These laboratories allow for the development and testing of new technologies associated with advanced shipboard electronic warfare, radar and phased array-based communications. The anechoic chamber houses a near-field range with a 6-foot by 6-foot planar scanner and is used for continued development of APL's digital array technology for radar, electronic warfare and communications. The near-field range facility is a critical phased array antenna testing and characterization resource across multiple APL programs and sectors.

FACILITY FOR EMP AND RF DIRECTED ENERGY (FEARDE)

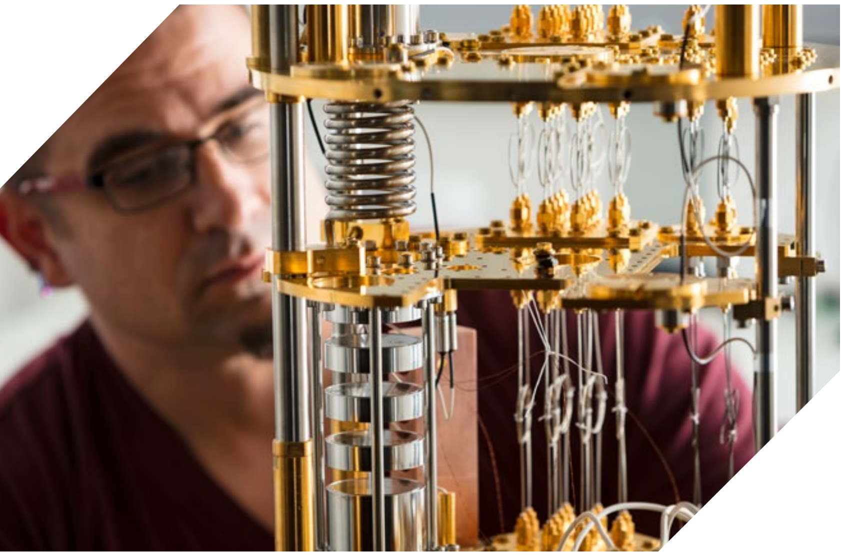
High-power microwave (HPM) weapon systems use very high-power pulses of electromagnetic energy to disrupt or damage electrical systems, and our adversaries are fielding HPM weapons that are quickly becoming a threat to U.S. military assets. FEARDE is dedicated to evaluating the susceptibility of electrical components and systems to HPM signals and offers three large test chambers to support HPM projects. The facility is also equipped with a full suite of specialized RF test equipment, including high-power amplifiers, electric field and magnetic field probes, complex signal generators, signal analyzers and wideband receivers to allow for the configuration and execution of custom test designs.

MATERIALS FOR EXTREME ENVIRONMENTS LABORATORY

APL develops mission-critical systems for the extreme environments of hypersonic flight, space exploration and deep-sea operation — where heat, pressure, oxidization, corrosion and other factors challenge the survivability of even the toughest systems. In the Materials for Extreme Environments Laboratory, innovative formulations and processing techniques, as well as unique testing, are used to enhance material performance and survivability — and create mission-engineered materials to enable critical capabilities.

LIVE DATA, INTEGRATION, VALIDATION AND EXPERIMENTATION (LIVE) LAB

The LIVE Lab allows 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.

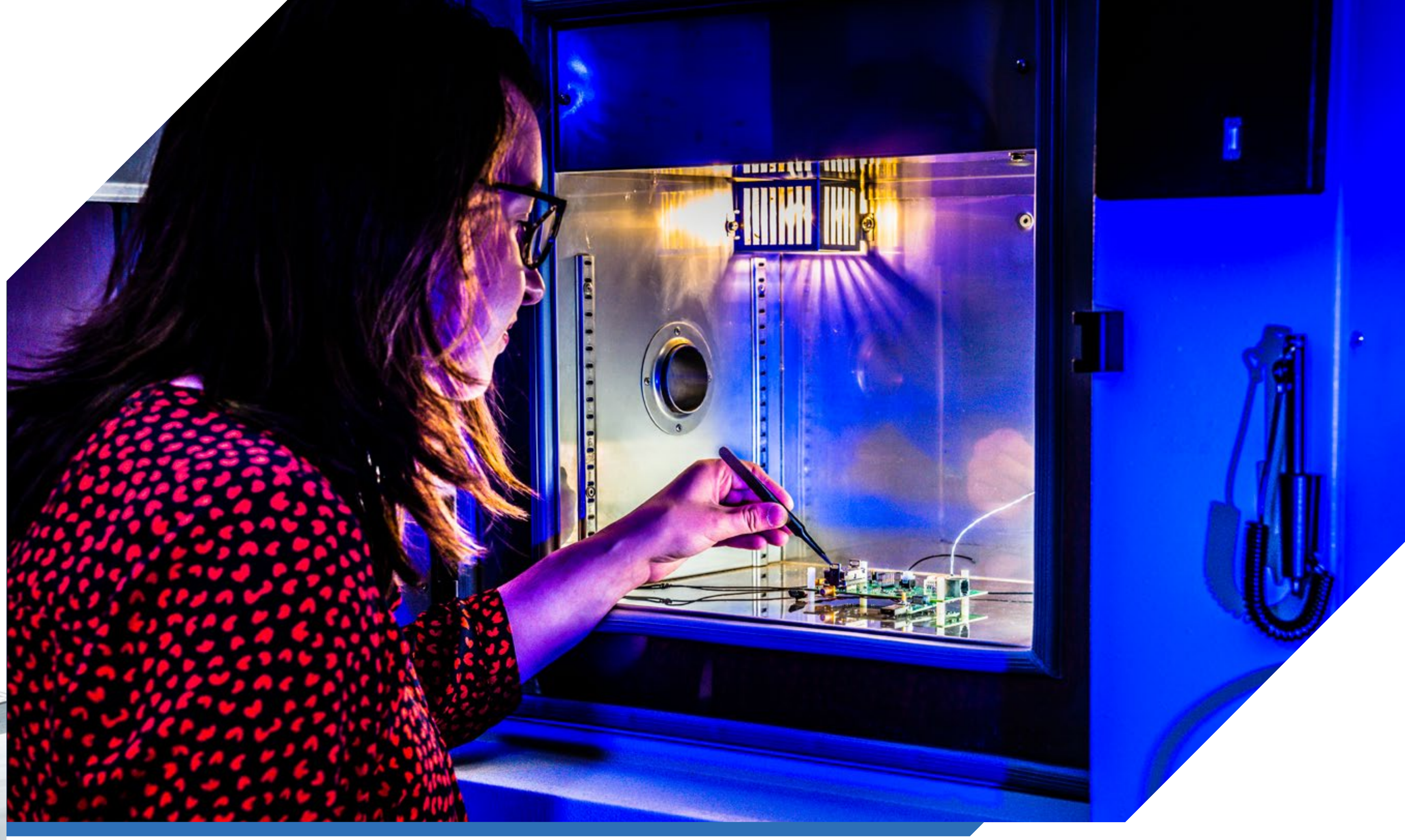


QUANTUM DEVICES LABORATORY

The Quantum Devices Laboratory is a key resource for addressing critical challenges in quantum information science. State-of-the-art microwave, cryogenic and quantum control technologies enable researchers to test new theories and devices critical to harnessing the power of quantum for computing and sensors.

PLANT AND ENVIRONMENTAL TESTING (PET) LAB

The PET Lab allows researchers to create multiple unique, isolated environments by programming lighting, temperature and humidity to mimic real-world conditions and to grow a diverse array of plants, including model organisms, crops, invasive species, aquatic plants and algae. The facility enables novel research on plant technologies, as well as climate change mitigation and food security — all areas of growing concern for APL sponsors. It has been approved by the Defense Counterintelligence and Security Agency as a closed space, meaning it has been built and accredited to store classified information when the material cannot be stored inside a safe approved by the General Services Administration.



THE EXPERIMENTAL COMMUNICATIONS LABORATORY

This laboratory is dedicated to the development and testing of radio frequency (RF) transceiver systems and devices for signal-collection applications. Equipped with signal distribution capabilities, signal analyzers, RF signal isolation capabilities, electrostatic discharge laboratory benches, multiple soldering stations and stand-alone local area networks, the facility also features several temperature chambers and spaces for hardware prototype assembly and for testing large pod-based transceiver systems.

COMBAT SYSTEMS CYBER WARFARE ANALYSIS LABORATORY (CSCWAL)

This laboratory provides a stand-alone classified environment for the development, integration and testing of cyber capabilities to support air and missile defense systems. The lab serves as the primary space for testing cyber effects, evaluating and validating cyber vulnerabilities, and developing cyber defense systems against nation-state adversaries. Because of the unique nature of CSCWAL and the array of capabilities available, APL has been able to provide several significant contributions to our sponsors.

SPACE SIMULATION AND VIBRATION TEST LABORATORIES

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

TECH TRANSFER

Tech Transfer ensures the broadest possible impact of APL innovation — enhancing the reach of some of our ideas and technologies while promoting and protecting the intellectual property (IP) our staff members have developed to address the nation's most critical challenges.

Rama Venkatasubramanian (foreground), shown in APL's Metal Organic Chemical Vapor Deposition Lab, leads a team of researchers exploring innovative thermoelectric devices.

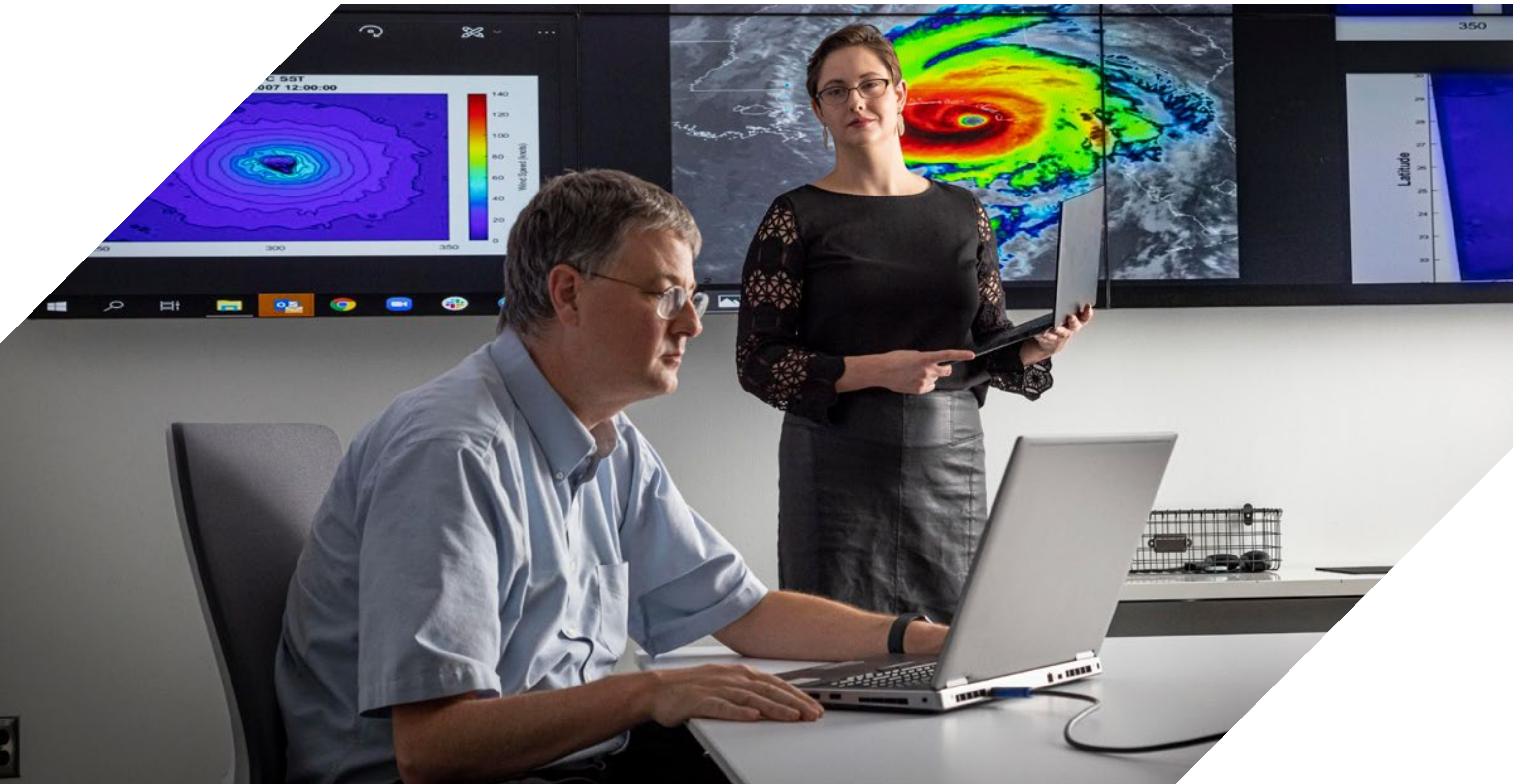
ADDRESSING CLIMATE CHANGE

Climate change is reshaping nearly every aspect of life on Earth, with significant implications for national security. APL is bringing all of its core competencies to bear on this critical challenge area, assembling top experts from a variety of scientific fields and partners from across the Johns Hopkins enterprise, industry and government to explore strategic opportunities to make the greatest impact on climate change.

In 2022, the Lab's Tech Transfer office hosted a "Shark Tank"-styled internal Climate Change challenge to identify impactful solutions to mitigate the adverse consequences of climate change and further develop these technologies so that they are better able to attract external partners willing and capable to bring them to market. From 22 submissions from across the Laboratory, two projects were awarded:

- **Extracting Rare Earth Elements from Electronic Waste**, which explored the use of a carbothermal shock (CTS) method to remove rare earth elements (REEs) from electronic waste. By applying the CTS method to e-waste, the team demonstrated that the material could be thermally degraded rapidly and the REEs recovered from resulting oxide material.
- **Hurricane Severity Prevention**, which further developed a prototype assessment framework to assess the impact of technologies for reducing the severity of hurricanes. This end-to-end assessment capability may inform investment in future environmental modifications of extreme weather. A manuscript on the team's research is pending publication.

Research meteorologist Pete Winstead and mechanical engineer Victoria Campbell won funding in APL's Climate Change Challenge for devising a capability to assess investments in environmental modifications against extreme weather.



IP DISCLOSURES, AGREEMENTS AND START-UPS

In 2022, APL submitted 424 IP disclosures and entered into 68 new licenses and other agreements. A few of the more notable Tech Transfer agreements include the following:

- **Rocket Lab USA**. APL executed a license agreement with Rocket Lab USA for the Laboratory's Frontier Radio communications technology. The license enables Rocket Lab to commercialize the Frontier Radio for spacecraft radio telemetry, tracking and control, and it represents an expansion of APL's work with the burgeoning new commercial space sector.
- **Pall Corporation**. APL executed an option agreement with Pall Corporation, which gives the company a six-month option period to evaluate APL's patent-pending microcapsule adhesive technology. Pall, a global supplier of filtration, separations and purification products, is exploring whether APL's technology could increase the capacity of Pall's production plants by reducing cure times for commercial adhesives from hours to minutes without installing costly new capital equipment.
- **Zitara Technologies, Inc**. APL executed an option agreement with Zitara Technologies, Inc., to evaluate the Laboratory's patented lithium-ion battery thermal sensor platform. Zitara, a three-year-old start-up in Oakland, California, recently raised $16 million to commercialize its battery management software for monitoring the performance of companies that manage large battery deployments (e.g., electric scooters).
- **Reconnaissance Blind Chess App**. The Reconnaissance Blind Chess (RBC) mobile apps for Apple and Android devices are now available on the Apple App Store, the Google Play Store and the Amazon App Store for public download. RBC, invented at APL in 2015, is a powerful twist on chess that incorporates uncertainty and sensing. Players cannot see the positions of their opponent's pieces, except through private sensing action. One of APL's ASPIRE (APL's Student Program to Inspire, Relate and Enrich) interns developed this app to enable RBC to be played on mobile devices.
- **Meta**. APL executed a historic license agreement with Meta for innovative thermoelectric technologies, which impart sensations of hot or cold. The technologies can also collect and convert waste heat to electrical energy. This technology transfer resulted from APL's inaugural Power on the Move event in February 2021.

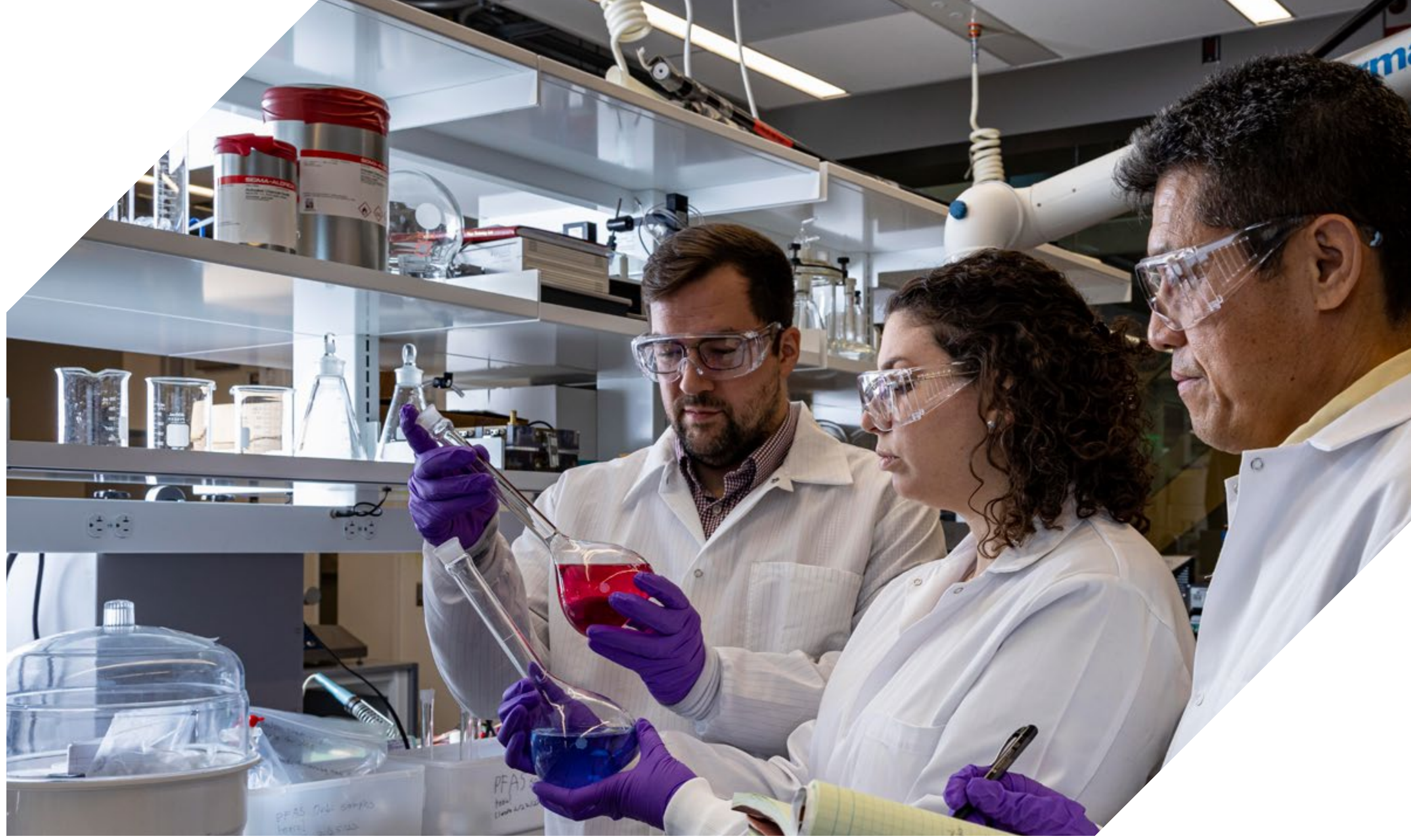
The start-up Enigma Science and Technology, LLC (EST) was founded by APL's second Archimedes Award recipient, Malik Little. A license was executed with the company to commercialize patent-pending IP aimed at reducing arrest-related fatalities within law enforcement and helping maintain the safety of officers and first responders. As part of APL's Entrepreneurial Staff and Alumni Program's collaboration with Johns Hopkins Technology Ventures (JHTV), EST is benefiting from JHTV's FastForward, a suite of start-up support services, and moved into the FastForward innovation space for start-up companies.

NOTABLE COLLABORATIONS: LEVERAGING SMART CITY INNOVATION

For nearly a decade, APL has been working with the Howard County Economic Development Authority (HCEDA) on a technology transfer partnership to market APL-developed technologies and establish new companies. In fiscal year 2022, the two launched another effort to plan and implement a smart and connected community concept within the Columbia Gateway Innovation District. The memorandum of understanding includes provisions for autonomous systems, clean and sustainable energy, population health and cyber-security concepts that support the advancement of the county's objectives and APL's research goals.

APL and HCEDA plan to use the Columbia Gateway Innovation District as a proving ground for their smart city concepts. Howard County has positioned the more than 900-acre business park as a future mixed-use activity center that will incorporate sustainable development and smart-community practices. The collaboration will draw heavily on APL's expertise in artificial intelligence and autonomous systems — as well as capabilities and research generated by the Johns Hopkins University Institute for Assured Autonomy (IAA) — to address a variety of possibilities, such as:

- Applying novel technologies to make energy consumption in the Columbia Gateway Innovation District buildings more efficient and to make energy resources more available, secure and capable of meeting the needs of the community
- Determining how emerging autonomous transportation systems can safely improve mobility and ensure access for all
- Devising standards and controls that support all members of the community as intelligent systems become more prevalent
- Learning from the pandemic to improve health awareness and access



A team including (from left) James Johnson, Danielle Nachman and Zhiyong Xia earned APL's Invention of the Year Award for its polyfluorinated alkyl substances (or PFAS) removal process.

From left, APL Director Ralph Semmel, Howard County Executive Calvin Ball and Howard County Economic Development Authority CEO Larry Twele met to discuss plans to implement a smart and connected community concept within Howard County's Gateway District.

INVENTION RECOGNITION

Awarded in 2022, the Laboratory's 2021 Invention of the Year went to James Johnson, Jesse Ko, Nam Le, Danielle Nachman and Zhiyong Xia for the invention Per- and Polyfluorinated Alkyl Substances (or PFAS) Removal by Magnetite Nanoparticle Catalyzed Fenton Reaction. The team invented a cost-effective solution that better captures PFAS substances, the fluorine-containing chemicals found in many household products — such as nonstick cookware, food packaging, cleaning products and stain-resistant carpets — and in fire-fighting foams. Their filtration method uses novel amphiphilic functionalized membranes — films that are slightly charged on one side and neutral on the other. This selectively traps molecules so when the researchers pump water contaminated with PFAS through a roughly quarter-sized sieve that contained the amphiphilic functionalized membranes, the PFAS remain trapped while the water passes through.

STATISTICALLY SPEAKING — FY 2022 DATA FOR TECH TRANSFER

424 IP assets disclosed

129 U.S. provisional patent applications filed

1 New company created

30 U.S. patents Issued

68 Licensing and other agreements

UNIVERSITY COLLABORATIONS

As the nation's largest university affiliated research center and a division of Johns Hopkins University (JHU), APL regularly partners with other Johns Hopkins divisions to solve some of the nation's—and the world's—toughest problems. These interdisciplinary collaborations enhance education and research, strengthen the university's intellectual outreach and facilitate ties with the larger scientific and technology community.

With our colleagues across Johns Hopkins, APL collaborates to tackle a variety of challenges and missions in health, engineering, science and security analysis. These interdisciplinary partnerships include the Johns Hopkins Hospital, the School of Medicine, the Whiting School of Engineering, 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

APL collaborates with the Johns Hopkins Whiting School of Engineering (WSE) to sponsor graduate programs through the Johns Hopkins Engineering for Professionals (EP) program. EP offers part-time and online graduate courses leading to master's degrees, graduate certificates and post-master's certificates in 23 program areas. APL staff members chair 12 of these programs. Courses are designed to meet the needs of both students and employers, with new programs created in collaboration with local industry leaders to keep pace with technology and the marketplace.

APL continues to play a critical role in the development of programs at EP, which had its origins as an in-house program for the advanced training of APL employees. Over the years, it has grown and been opened to the public, with up to 90% of students coming from outside of APL. The faculty comprises scientists and engineers from APL and WSE; from regional aerospace, engineering and information technology companies; and from government agencies. EP faculty are actively practicing what they teach, and a number of them have written textbooks that are widely used in their respective fields.

APL and WSE also provide a path for more Whiting School doctor of engineering candidates to conduct their research at APL while offering flexibility for APL staff members seeking doctorates through the Whiting School. The partnership also supports joint academic appointments with many JHU schools and academic divisions—with WSE receiving the largest number. These collaborative efforts enable APL staff members, who hold appointments ranging from assistant professor to full professor, to spend up to 20% of their time collaborating and teaching with JHU faculty and graduate students.

The mission of the multimillion-dollar SURPASS initiative—a partnership between APL and the Johns Hopkins Whiting School of Engineering—is to "go beyond possible" to tackle society's seemingly impossible challenges.

SURPASS

Imagine being able to detect unhealthy brain activity just by putting on a hat that could detect future incidences of dementia and Alzheimer's years before onset, or making transportation in the upper stratosphere to and from space as common as air travel. These are just two of the revolutionary innovations that teams from WSE and APL addressed in this year's initial round of SURPASS proposals.

In 2022, WSE and APL embarked on a journey together to propose groundbreaking solutions to ostensibly insurmountable challenges. The multimillion dollar initiative is called SURPASS, and the mission is to "go beyond possible" to tackle society's seemingly impossible challenges.

In its inaugural year, the program received 47 initial white papers, which were narrowed down to seven. The researchers responsible for those seven papers were invited to proceed to the full proposal stage. Each proposal is led by two principal investigators (PIs), one from APL and the other from WSE. SURPASS leverages WSE and APL's unique technical strengths and research and development communities, supporting cross-divisional teams dedicated to using innovative, multidisciplinary approaches to solving some of the world's most pressing problems. The program also pulls in experts from across JHU, including the university's School of Medicine and the Bloomberg School of Public Health.

SURPASS teams submitted research proposals addressing issues ranging from climate change, to curing blindness and cancer, to early disease detection, among many others.

The team behind one of the winning SURPASS proposals, BEAST (Between Earth and Space, the Next Strategic Flight Regime), includes (clockwise from left) Dave Van Wie, Michael Brupbacher, Tamer Zaki, Joseph Katz, Morgan Trexler, Kevin Hemker and Melissa Terjale.

Ultimately, four teams were funded to move forward with their proposed research.

The four winning proposals include Photoacoustic Retinal Prosthesis; BEAST: Between Earth and Space, the Next Strategic Flight Regime; CEREBRO: Enabling the Next Step of Human Evolution; and Organoid Intelligence: Synthetic Biological AI.

SURPASS program organizers say these proposals have the potential to lead to larger translational efforts with external funding upward of $100 million. WSE is providing funding of approximately $3.75 million to be shared across the four selected projects over an 18-month period.

CIRCUIT

The Cohort-based Integrated Research Community for Undergraduate Innovation and Trailblazing, or CIRCUIT, provides undergraduate students an opportunity to participate in cutting-edge research while building skills to make significant contributions to science. In 2022, 100 CIRCUIT-affiliated participants worked on more than 20 projects around the Lab. Students in the program got hands-on experience and delivered solutions to real-world problems on everything from artificial intelligence to precision medicine, connectomics, planetary exploration and cybersecurity. Projects incorporate two to five students working together to solve an important research or sponsor challenge, ranging from undersea to outer space domains, and including major activities in artificial intelligence and robotics. The most recent cohort presented findings from projects on topics such as climate change, COVID-19 tracing, cybersecurity and solar system exploration. Mentors work with students

CIRCUIT interns gather outside the new home of APL's Research and Exploratory Development Department. The 2022 CIRCUIT program included some 100 participants working on more than 20 projects around the Lab.

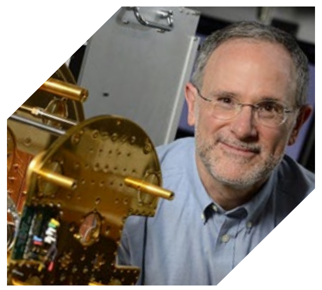
throughout the summer and meet during the fall and spring semesters, in parallel with the training and mentoring activities provided by the program.

BLOOMBERG DISTINGUISHED PROFESSORS

Bloomberg Distinguished Professors serve as a bridge between JHU's academic divisions and facilitate innovative research across disciplines. Four Bloomberg professors hold joint appointments with APL. Sabine Stanley, a professor in the Krieger School of Arts and Sciences' Department of Earth and Planetary Sciences with a joint appointment in APL's Space Exploration Sector, is an eminent planetary physicist focusing on magnetic fields as a means of studying the interiors of planets, including those in little-understood realms light years away from our solar system. Michael Tsapatsis, a tenured professor in WSE's Department of Chemical and Biomolecular Engineering with a joint appointment in APL's Research and Exploratory Development Department, is a renowned materials scientist whose groundbreaking work has had tremendous impact across the research community, industry and society. Charles Bennett, a professor of physics and astronomy at the Krieger School of Arts and Sciences and senior scientist in the Laboratory's Space Exploration Sector, is a renowned researcher in experimental astrophysics and cosmology who focuses on extending our understanding of the universe by observing the cosmic microwave background. James Bellingham, a professor in WSE's Department of Mechanical Engineering and a senior adviser in APL's Asymmetric Operations Sector and executive director of the Johns Hopkins Institute for Assured Autonomy, is a pioneer in the worldwide autonomous marine robotics field who has led research expeditions from the Arctic to the Antarctic for military, industry and scientific communities.

Sabine Stanley (Credit: JHU)

Michael Tsapatsis (Credit: JHU)



Charles Bennett (Credit: JHU)

James Bellingham (Credit: JHU)

The Johns Hopkins Whiting School of Engineering. (Credit: JHU)

RISE@APL

The RISE@APL program is for JHU students majoring in engineering, computer science, applied mathematics or physics who want to better prepare for a technical career. Launched in 2014, the program — known as Research Internships in Science and Engineering — allows students to conduct research in areas like ballistic missile systems, prosthetics, computer vision and secure mobile communications. As a part of RISE@APL, students work alongside APL experts in their field of study, focus on professional development and make critical contributions to APL's mission. In 2022, 38 JHU students participated in the program.

INSTITUTE FOR ASSURED AUTONOMY

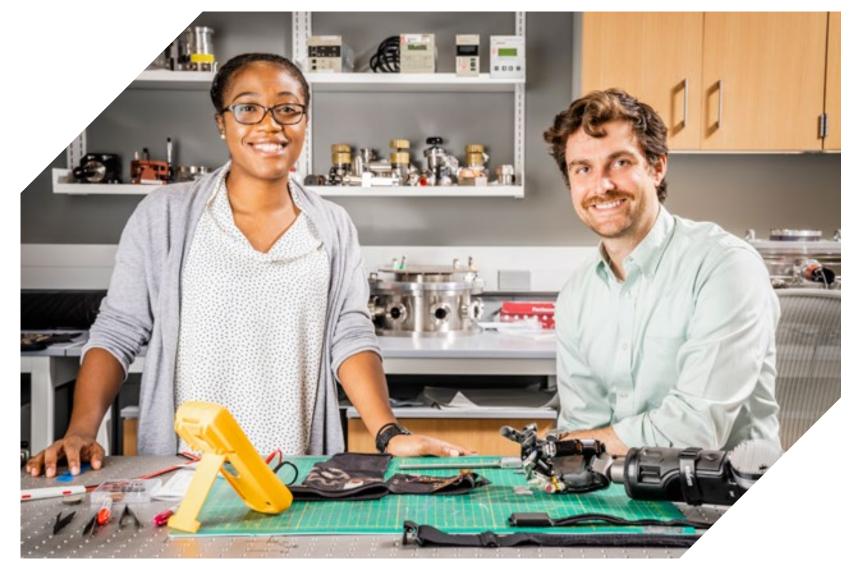
Autonomous systems have become increasingly integrated into many aspects of people's daily lives. In response, the Johns Hopkins Institute for Assured Autonomy (IAA) focuses on ensuring that those systems are safe, secure and reliable, and that they do what they are designed to do. Co-led by APL and WSE, IAA serves as a national center of excellence focused on ensuring that autonomous systems can be trusted to operate as expected, respond safely to unexpected inputs, withstand corruption by adversaries and integrate seamlessly into society. Leveraging the expertise across JHU and APL, IAA creates strategic collaborations with external partners to deliver a unique breadth and depth of technical knowledge. IAA is led by Executive Director Jim Bellingham, a pioneer in the worldwide autonomous marine robotics field and global leader in the development of small high-performance autonomous underwater vehicles, resulting in a class of systems that are now widely used within the military, industry and scientific communities. Bellingham concurrently serves as a Bloomberg Distinguished Professor in the Whiting School's Department of Mechanical Engineering and as a senior adviser in APL's Asymmetric Operations Sector, where he helps advance government and defense innovations for national security.

Johns Hopkins Institute for Assured Autonomy leadership includes, from left, Research Director David Silberberg, Executive Director James Bellingham, Director Anton Dahbura and Director Cara LaPointe.

DISCOVERY AWARDS

The Discovery Awards program was launched across JHU in 2015 to encourage cross-university collaborations that promise to result in high-quality and impactful work. Teams are composed of members from at least two schools or affiliates of the university. In 2022, the winning project teams, chosen by faculty members from 199 proposals, featured individuals representing 12 Johns Hopkins entities. Four teams featuring investigators from APL were awarded this year. One principal investigator and six project contributors were among the 105 individuals from 35 teams selected to receive awards of up to $100,000.

Projects spanned multiple domains across APL and JHU. One team comprising APL and WSE researchers aimed to embed multilayered tactile sensors to enhance robotic systems. By creating flexible touch sensors that can be placed directly onto surfaces, such as the fingertips of a robotic hand, they hoped to improve how a robot behaves. The School of Medicine teamed up with APL to continue to push the boundaries of medical innovation on two other winning projects. The first was development of a nanostructured, drug-eluting stent to enhance natural outflow pathways in glaucoma treatment. The second medically focused project was a wearable ultrasound transducer that would continuously monitor venous blood flow, which could help predict and detect deep vein thrombosis. The final effort homed in on food systems, the interconnected actors and relationships along the food chain that culminate in the consumption and disposal of food in communities around the world. APL and JHU researchers focused on how components of the system interact with each other and in response to external stimuli, especially a shock, like wheat or fertilizer shortages due to the war in Ukraine or climatological events such as flood, drought or other natural disasters.



APL's Korine Ohiri and Luke Osborn lead a JHU Discovery project team aiming to embed multilayered tactile sensors to enhance robotic systems.

A CULTURE OF INNOVATION

From incubating bold research proposals and the next generation of leaders to building collaborative workspaces, APL fuels creativity and new ideas at every level.

At APL, we base our approach to innovation on the simple premise that the next game-changing concept could come from anyplace — or anyone — at the Laboratory. To help our staff come together and push the boundaries of what's possible, APL supports the exploration of great ideas through its robust grant system and collaboration initiatives.

IRAD

The Independent Research and Development (IRAD) program is an innovation cornerstone at APL. Every year, each of the Lab's 12 mission areas embarks on a search for research and development projects to meet future sponsor needs. IRAD calls for proposals identify critical national problems that have yet to be solved and whose solutions have the power to produce breakthroughs.

IRAD projects are selected for funding annually by mission area leadership on the basis of the research's relevance to their particular domains. Leaning into APL's technical competencies, staff members investigate national defense capabilities through basic and applied research, system and concept formulation studies, and development. IRADs often mature into technologies or contributions that successfully address ongoing sponsor challenges.

Staff members gathered on APL's Central Green in May to learn about all of APL's internal funding opportunities, ranging from Innovation programs to Independent Research and Development calls, to partnerships with other Johns Hopkins institutions.

From left, Michael Berkson, Sharon Maguire, Sarah Hasnain, Katie Zaback and Evan Sun won the Building Leaders, Accelerating Science and Technology (BLAST) Cislunar Space Safety Challenge with their concept for Pulsar Autonomous Navigation Testbeds. Below, the team meets to discuss its project.

BLAST

When the Laboratory recognized a need several years ago to more heavily involve new, early-career staff members in established collaboration and innovation ecosystems, the BLAST program — short for Building Leaders, Accelerating Science and Technology — was born. BLAST offers early-career staff members, from any sector or department, the opportunity to tackle a challenging technical problem relevant to APL's sponsors.

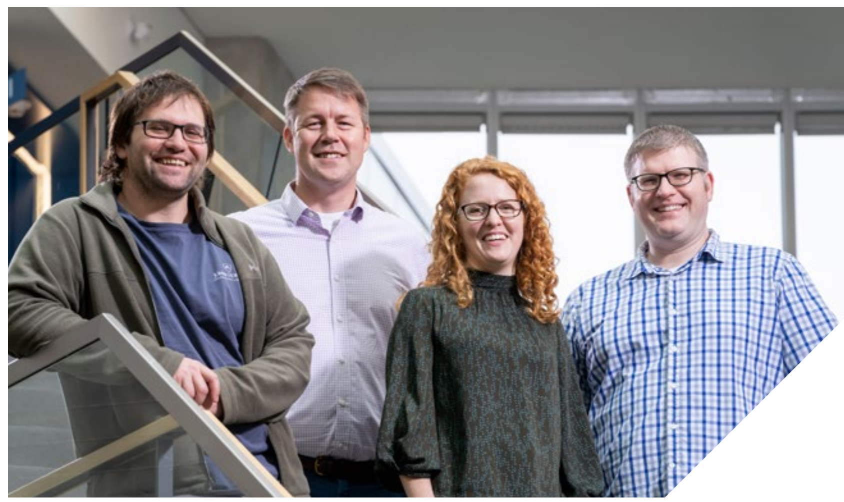
Each summer, BLAST participants work in several teams on a technical problem and develop a demo-ready solution by the end of August. Teams present their solutions to a panel of judges, and a winner and runners-up are selected. Participants are grouped with teammates with whom they have not previously worked and who bring different skill sets and backgrounds to the table. Early-career staff members learn how to manage a project from start to finish, as well as its budget. Participants also expand their peer networks and develop relationships with senior staff members, who serve in advisory roles and as judges at the end of the BLAST cycle. In response to rapid space developments — from infrastructure to increasingly complex and affordable missions — in 2022, BLAST challenged 50 staff members to identify, develop and demonstrate a novel solution to ensure cislunar space safety.

PROJECT CATALYST

Project Catalyst is a Labwide grant program comprising three internal funding opportunities for APL staff members. These grants advance high-risk, transformative ideas that can run from initial hypothesis explorations to significant research and development — and, perhaps, the next APL Defining Innovation.

- **Ignition Grants** are awarded to solutions for a themed challenge and encourage initial hypothesis testing. Teams post their proposals online, and their peers provide feedback and suggestions for improvement. A Labwide, crowdsourced voting process then determines the winners.
- **Combustion Grants** fund visionary ideas that advance the current state of the art and show promise for solving a sponsor's challenge. A panel of APL peer reviewers selects the winning proposals.
- **Propulsion Grants** support the search for game-changing solutions to critical challenges that have yet to be solved through conventional methods. The high-risk, high-reward proposals can span multiple years, with recipients competing to earn subsequent funding.

Marisel Villafane-Delgado earned a Combustion Grant for Geometric Deep Learning for Climate Change, which identifies a potential solution for modeling climate data by drawing from work in neuroscience.



From left, Tom Lawton, Ian MacLeod, Claire Marie Filone and Chris Hoffman earned a Propulsion Grant for their idea to stabilize and apply enzymes to break down waste in a wide variety of environments.

JANNEY GRANTS

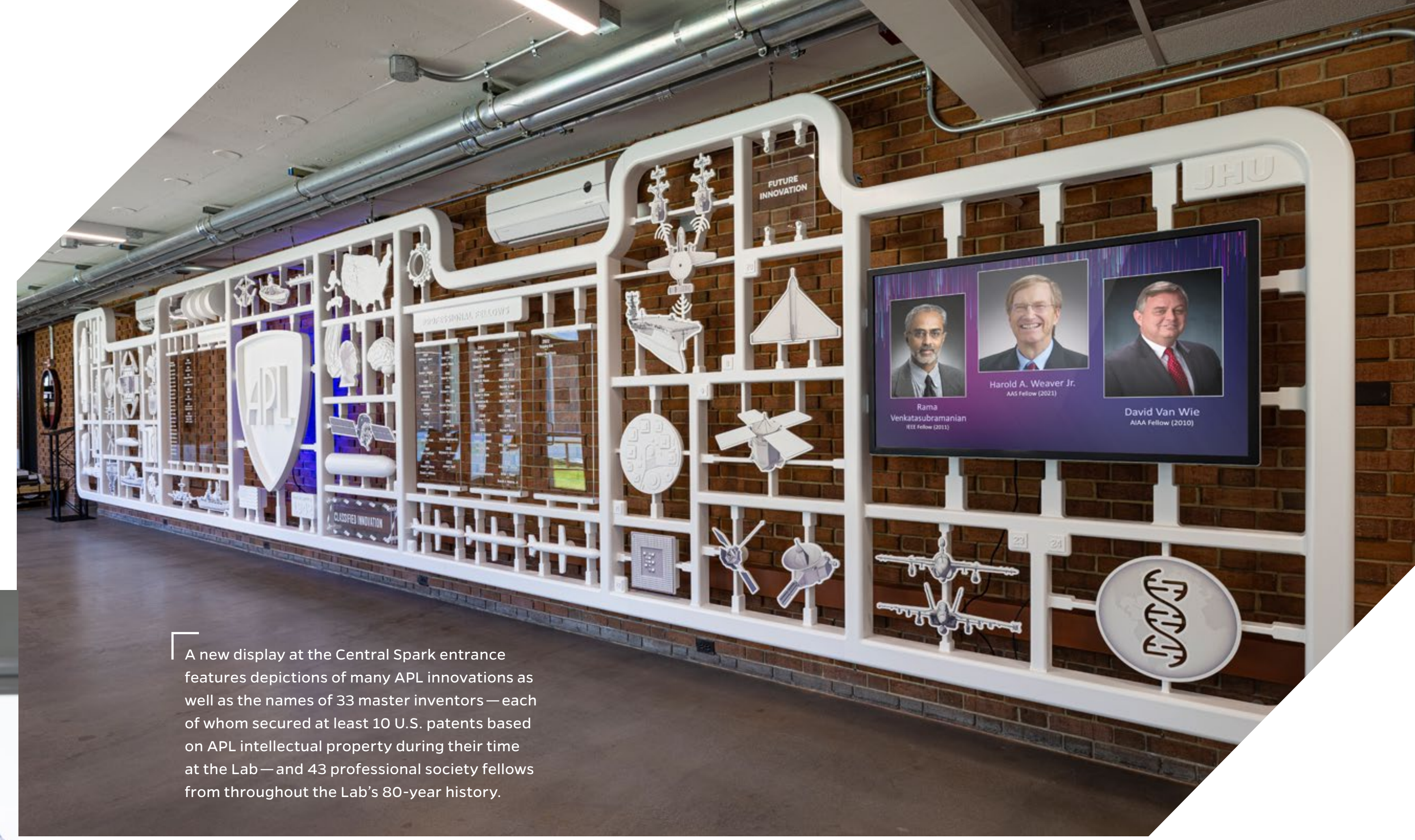
In 2022, APL renewed its commitment to remaining at the center of a larger, evolving innovation ecosystem.

Janney Grants, a reimagination of the original Janney Program, provides a new approach to supporting staff members' external engagements with a streamlined funding application process, tailored mentorships to help staff members optimize their Janney awards and increased collaboration opportunities with trusted partners in the nation and around the world.

As APL approaches its centennial in 2042, Janney Grants has prepared a special effort aligned with the Lab's Centennial Vision. Janney's Centennial Vision Conference Grants support the vision established by the Lab's Centennial Task Force, which has forecasted key technologies for 2042 and makes recommendations regarding APL actions for the next 19 years.

Staff members can also use support from Janney Grants to explore the Lab's research tools, collaborate within the Johns Hopkins University ecosystem and take advantage of APL's professional growth opportunities, including the Future Fellows Program and the Sabbatical Fellow and Professorship Program.

APL's Janney awards date back to 1984 and are named after Stuart Janney Jr., longtime chair and member of the Johns Hopkins University board of trustees and APL board of managers. The program, in all its iterations, has remained steadfast in encouraging staff members to pursue new ideas in emerging technology. The program complements APL sector and department education and training funds.



A new display at the Central Spark entrance features depictions of many APL innovations as well as the names of 33 master inventors — each of whom secured at least 10 U.S. patents based on APL intellectual property during their time at the Lab — and 43 professional society fellows from throughout the Lab's 80-year history.

CENTRAL SPARK

Central Spark is the Laboratory's open, collaborative space for makers, tinkerers and ideation. In Central Spark, staff members are free to pursue any innovation effort, whether for sponsor programs or (on their own time) personal projects. The facility almost tripled its footprint in 2020 with a move to a fully renovated 9,000-square-foot space, and Central Spark remains open around the clock and readily accessible to all staff members who wish to collaborate, create, design, prototype and take advantage of the innovation center's sophisticated virtual reality, augmented reality, 3D printing and other capabilities. Central Spark continues to capture the attention of users within APL and has served as the launchpad for a number of inventions and concepts developed for our sponsors.

Conceived in 2014 by merging two visionary Ignition Grant proposals, Central Spark garnered the support of APL Director Ralph Semmel, who encouraged the creation of a space dedicated to enabling and supporting staff members' innovation efforts. In May 2022, the Lab unveiled a display at the entryway to Central Spark featuring a physical depiction of many of the Lab's innovations as well as the names of 33 master inventors — each of whom secured at least 10 U.S. patents based on APL intellectual property during their time at the Lab — and 43 professional fellows (from seven premier technical societies) from throughout the Lab's 80-year history. The new display is intended to celebrate APL's impactful, established leadership, recognize many of the Lab's innovations and inspire staff members to strive for continued engagement with and service to larger technical communities.

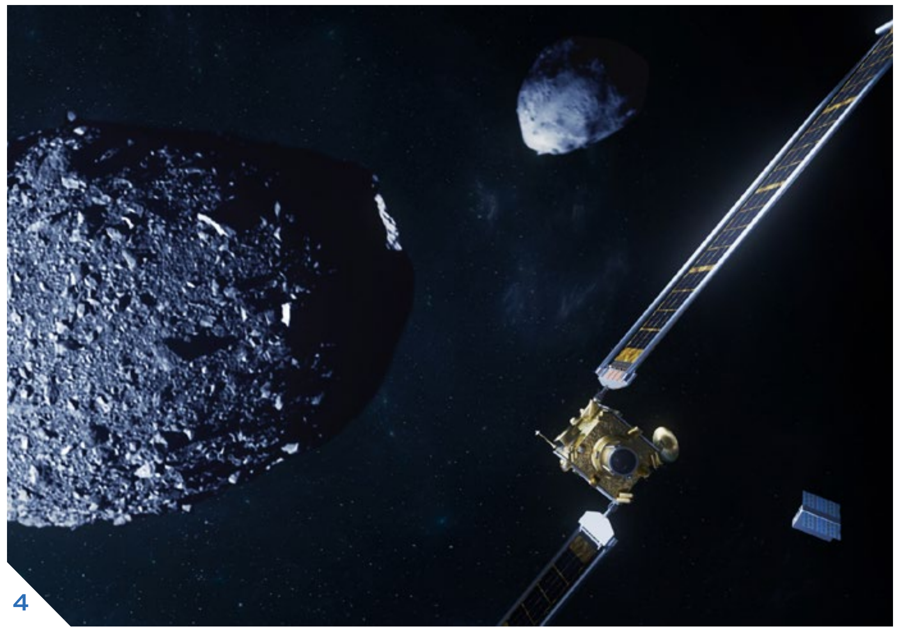
With equipment ranging from 3D printers to virtual reality, Central Spark is the Laboratory's open, collaborative space for makers, tinkerers and ideation.

AWARDS & HONORS

FAST COMPANY BEST WORKPLACES FOR INNOVATORS 2022 1

glassdoor BEST PLACES TO WORK 2022 2

COMPUTERWORLD BEST PLACES to Work in IT 2022 WORLDWIDE 3



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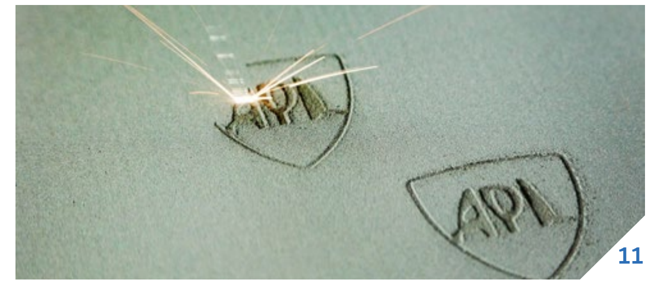

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2022 R&D 100 WINNER 13

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1. For the fourth consecutive year, Fast Company has featured APL on its Best Workplaces for Innovators list. This award honors the top 100 organizations and businesses that demonstrate steadfast commitment to encouraging innovation at all levels. Three APL initiatives were honored with Fast Company's 2022 World-Changing Ideas awards. APL's Basestack software, PFAS elimination methodology and subset seekers partnership with Johns Hopkins Medicine earned honorable mentions in the pandemic response, water and health categories, respectively. APL landed at No. 3 on Fast Company's 2022 World's Most Innovative Space Companies list for building and managing NASA's DART mission.

2. APL was honored with a Glassdoor Employees' Choice Award, ranking No. 15 out of 100 U.S. large companies on the Best Places to Work in 2022 list.

3. For the fifth year in a row, APL earned a leading place among Computerworld's Best Places to Work in IT, coming in at No. 17 overall among large organizations, with additional rankings at No. 1 for career development and No. 9 for both diversity and IT growth.

4. Popular Science magazine named NASA's DART — designed, built and managed by APL — a winner of their Best of What's New awards for the greatest innovations of 2022.

5. The APL Achievement Awards ceremony celebrated a record 824 staff members nominated in 150 entries for 25 different award categories. Ultimately, 178 staff members were recognized among 29 winning entries.

6. APL was awarded the Neuromod Prize, a $9.8 million initiative from the NIH Common Fund Stimulating Peripheral Activity to Relieve Conditions program to expand spinal cord injury research.

7. Director Ralph Semmel was named to The Daily Record's second annual Power 30 Higher Education List.

8. Force Projection Sector Head Lisa Blodgett (right) and Anti-Submarine Warfare Program Area Manager Jon Berry were honored at the National Defense Industrial Association (NDIA) 2022 Undersea Warfare Fall Conference. Berry was awarded the Undersea Warfare Bronze medal, and Blodgett received the Vice Adm. Charles E. Weakley Award.

9. Assistant Director, Policy and Analysis James Miller and Air and Missile Defense Sector Head David Van Wie were appointed to the Defense Science Board, which provides independent advice and recommendations on national security matters to the Department of Defense.

10. Former APL Space Exploration Sector Head Mike Ryschkewitsch was recognized with the National Space Club and Foundation's Norman J. Baker Astronautics Engineer Award for outstanding personal contributions to the nation's space program.

11. APL researchers earned three modeling challenge awards from the Additive Manufacturing Benchmark 2022 Test Series, known as AM-Bench. APL's submissions earned two first-place awards in the modeling prediction of the Track Liquid Cooling Rate and Track Time Above Melt challenges, and one second-place award in the modeling prediction of the Track Solid Cooling Rate challenge.

12. Four research teams featuring APL investigators — Luke Osborn, Korine Ohiri, Jason Lee, Hans Mair, Steven Storck, Joseph Sopcisak (not pictured) and George Coles — have been awarded 2022 Johns Hopkins Discovery Awards. The awards program provides funding to cross-university collaborations that promise to result in high-quality and impactful work.

13. APL researchers, and their collaborators at other institutions, have captured 2022 R&D 100 Awards for their contributions on a comprehensive and automated cyber defense capability, known as More Situational Awareness for Industrial Control Systems (MOSAICS), and the Airborne Collision Avoidance System for Small Uncrewed Aircraft Systems (ACAS sXu). The MOSAICS team is led by Harley Parkes and includes Alex Beall, David Flanigan, Triton Pitassi, Daniel Thomas and Carol Vermilye. APL's ACAS X project, active for more than 10 years, is currently led by Josh Silbermann alongside a team of more than 20 researchers.

14. The International Academy of Astronautics (IAA) presented its 2021 Laurels for Team Achievement award to NASA's Parker Solar Probe mission during the COSPAR 2022 event.

15. US Black Engineer magazine recognized APL as a top supporter of engineering schools at Historically Black Colleges and Universities. APL was among the top 20 Government/Non-Profit Supporter honorees for efforts to help strengthen education-to-employment pipelines for students in STEM fields. (APL's ATLAS internship program team is pictured.)

16. Trena Lilly, Shaleta Handy and Angie Lilly received Black Engineer of the Year Awards. Trena Lilly received the John D. Harris Legacy Award, Handy was selected as a Science Spectrum Trailblazer and Angie Lilly was honored as a Modern-Day Technology Leader.

17. Jaime Arribas Starkey-El was recognized by the Intelligence and National Security Alliance (INSA) with the Edwin H. Land Industry Award, which celebrates the accomplishments of early- and mid-career professionals who work in industry on intelligence, defense and homeland security issues.

18. Yanping Guo and was elected a fellow of the American Institute of Aeronautics and Astronautics (AIAA). Glen Fountain was named as an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA), Debra Buczkowski was named as a fellow of the Geological Society of America (GSA) and Brian Olson was selected as a fellow of the American Society of Mechanical Engineers (ASME).

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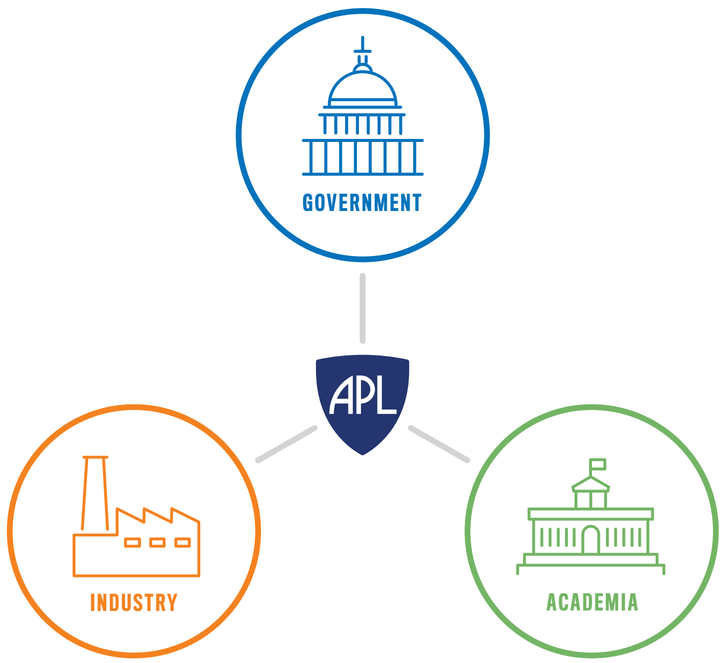
ABOUT UARCS

"[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
- Broad corporate knowledge
- Independence and objectivity
- Quick response capability
- Current operational experience
- Freedom from real or perceived conflicts of interest

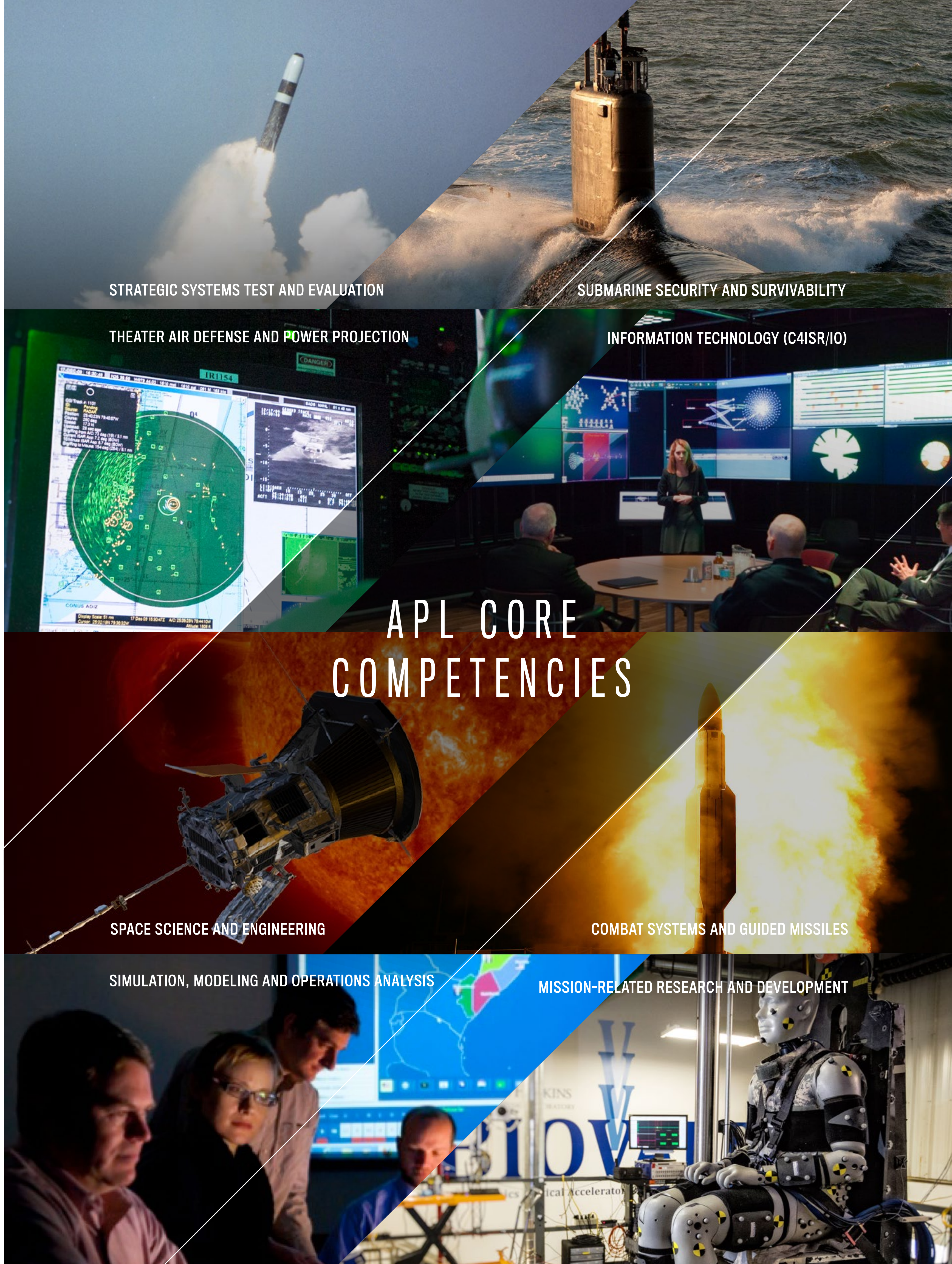
AS A UARC, APL IS A DIVISION OF JOHNS HOPKINS UNIVERSITY

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 experts, often developing advanced system prototypes that accelerate the infusion of new technology into operational use. 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.

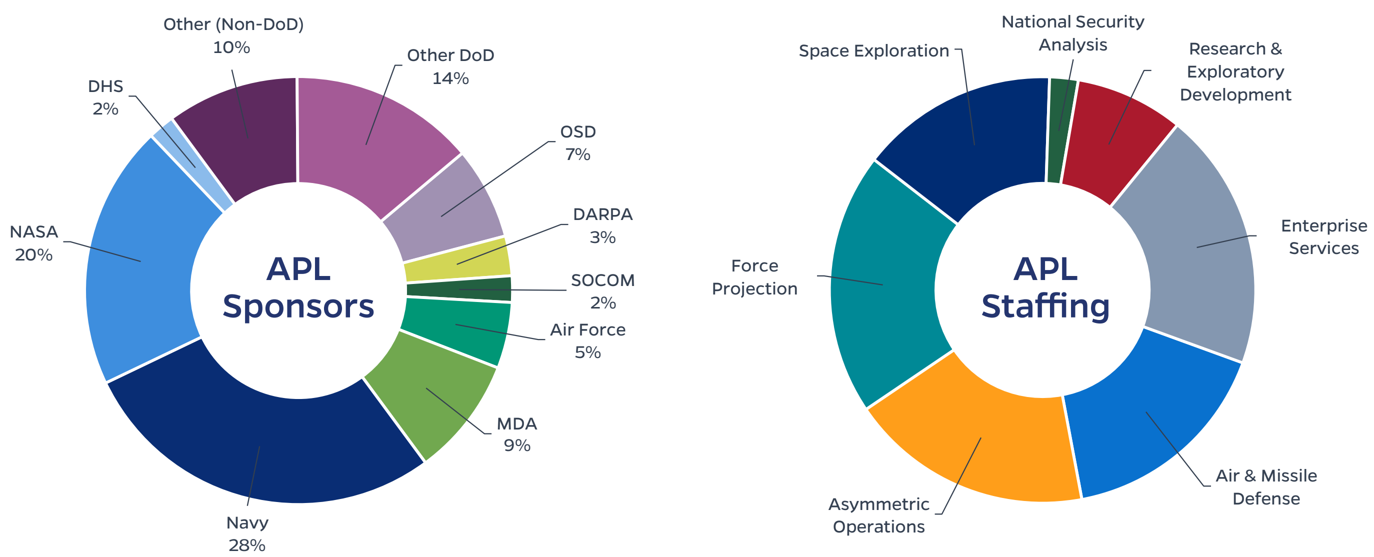
The majority of our work comes from the Department of Defense as sole-source (noncompetitive) funding under the Competition in Contracts Act, primarily through the exception for essential research and engineering.



FINANCE AND STAFFING

During the fiscal year that ended September 30, 2022, the Johns Hopkins Applied Physics Laboratory recorded revenue from contracts and grants totaling $2.09 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.

FY22 Revenue: $2.09 Billion



APL'S CORE PURPOSE IS TO MAKE CRITICAL CONTRIBUTIONS TO CRITICAL CHALLENGES

Our success as a UARC depends on:

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

OUR ACCESS TO NUMEROUS INNOVATION ECOSYSTEMS HELPS US IN OUR WORK

In 2022, we had:

- 155 different government sponsors
- 105 subcontracts to 44 different universities

APL FIELD OFFICES

Colorado Springs
565 Space Center Drive
Suite 135
Colorado Springs, CO 80915

Fort Walton Beach/ Eglin Air Force Base
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Fort Walton Beach, FL 32548

Hill Air Force Base
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Suite 202
Hill AFB, UT 84056

Lexington Park
46579 Expedition Drive
Suite 300
Lexington Park, MD 20653

Los Angeles
400 Continental Boulevard
Suite 310
El Segundo, CA 90245

Raleigh
The Forum, Building I
8601 Six Forks Road
Raleigh, NC 27615

CRITICAL CONTRIBUTIONS TO CRITICAL CHALLENGES