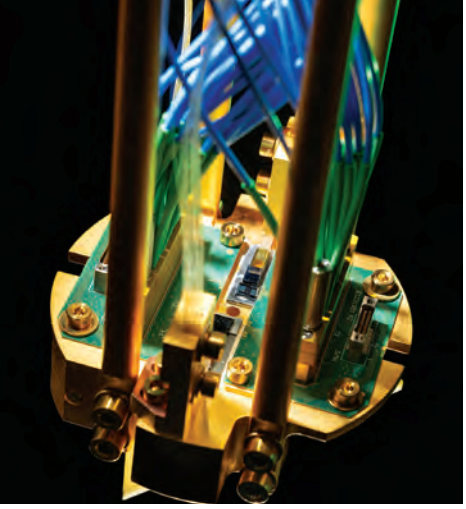
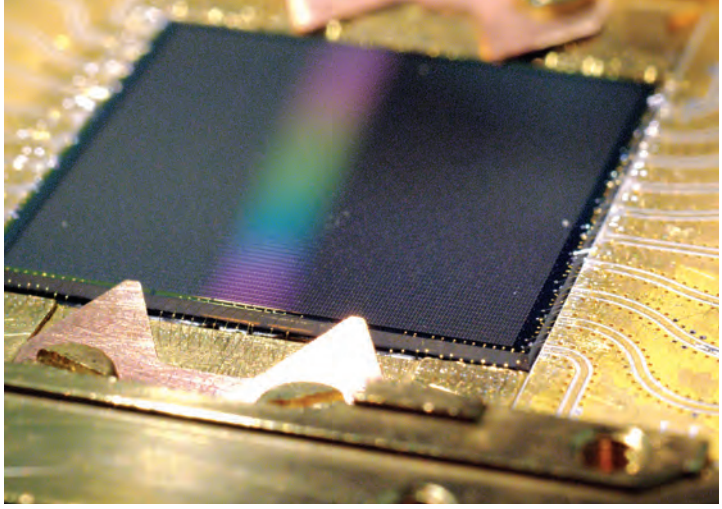
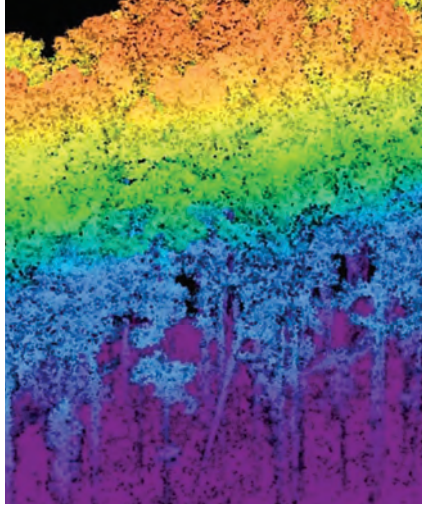


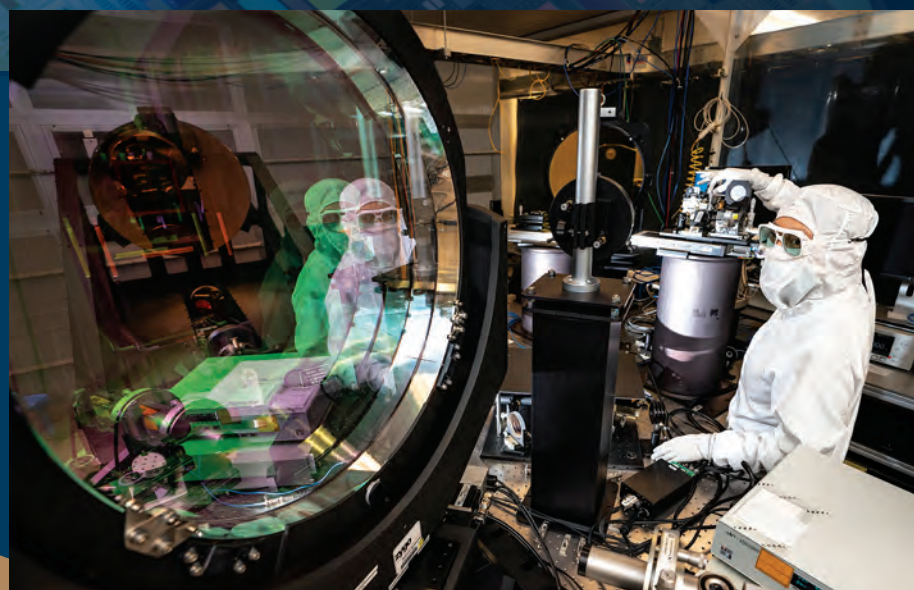




2023
ANNUAL REPORT

MIT LINCOLN LABORATORY

Technology in Support of National Security



Massachusetts Institute of Technology

MIT Lincoln Laboratory

Lincoln Space Surveillance Complex, Westford, Massachusetts

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2023

MISSION

Technology in Support of National Security

MIT Lincoln Laboratory employs some of the nation's best technical talent to support system and technology development for national security needs. Principal core competencies are sensors, information extraction (signal processing and embedded computing), communications, integrated sensing, and decision support. Nearly all of the Lincoln Laboratory efforts are housed at its campus on Hanscom Air Force Base in Massachusetts.

MIT Lincoln Laboratory is designated a Department of Defense (DoD) Federally Funded Research and Development Center (FFRDC) and a DoD R&D Laboratory. The Laboratory conducts research and development pertinent to national security on behalf of the military Services, the Office of the Secretary of Defense, the Intelligence Community, and other government agencies. Lincoln Laboratory focuses on the development and prototyping of new technologies and capabilities to meet government needs that cannot be met as effectively by the government's existing in-house or contractor resources. An emphasis is on R&D to address emerging DoD technology areas. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies. A strong emphasis is placed on the transition of systems and technology to the private sector. Lincoln Laboratory has been in existence for 72 years. On its 25th and 50th anniversaries, the Laboratory received the Secretary of Defense Medal for Outstanding Public Service in recognition of its distinguished technical innovation and scientific discoveries.

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Letter from the Director

Lincoln Laboratory has had another productive year with many program successes and much growth in our research and development collaboration across the nation. We have made significant progress in exploring several new technology areas, and we continue to hire very talented staff. The Laboratory is in a strong position to make further important contributions to address current and future national security needs.

In December 2023, I announced my decision to step down as director on July 1, 2024. On that date, I will have had the honor of serving in this role for 18 years. Through the outstanding work of the Laboratory's leaders; technical, administrative, and support staff; and subcontractors, we have advanced the state of the art for new technology and systems supporting many of the nation's most difficult challenges. Our Laboratory community should be very proud of all that they have accomplished, and it has been a privilege for me to be a part of an organization with an important mission and so much talent.

This year, many new systems and technologies transitioned to acquisition programs or operational applications. Projects within the Department of the Air Force–MIT AI Accelerator demonstrated advancements in global synthetic weather radar, squadron scheduling, and magnetic navigation. Artificial intelligence enhanced biotechnology programs in several areas, including by enabling neuron tracing in brain imagery and rapid analysis of medical countermeasures. We also saw the launch of several systems to space. The TROPICS small satellite constellation was completed, providing rapid-refresh data on tropical storms. The ILLUMA-T laser communication terminal was integrated on the International Space Station to demonstrate NASA's first two-way laser relay capability.

The Laboratory also made breakthroughs in several emerging fields, including quantum systems and technology. In collaboration with MIT and Harvard University, the Laboratory became the first in the world to send quantum information to a quantum memory across a telecommunications fiber, a key step toward realizing quantum networking. To drive technology development on a broader scale, the Laboratory also stood up a program to build quantum circuits for U.S. organizations lacking the requisite fabrication tools.

Other program highlights include the following:

- A prototype software system that tracks food-aid shipments was delivered to the U.S. Agency for International Development to improve the efficiency of humanitarian assistance.
- Upgrades to the Reagan Test Site's four radar systems are underway to meet the emergent needs of the hypersonic, space control, and missile development communities.
- Technologies that use machine learning to mitigate aviation cyber threats are supporting the transition of air traffic control systems to a zero-trust cybersecurity architecture.
- A method to reduce the read noise of charge-coupled devices is enabling new applications requiring single-photon counting or precise energy discrimination of high-energy particles.
- Analyses conducted by the Laboratory led to international approval of the Airborne Collision Avoidance System X for large uncrewed aircraft.
- Wearable sensors and algorithms were developed to provide early warning of disease for service member and civilian populations.

We also continued our efforts to foster an inclusive and supportive culture at the Laboratory. We started several new cultural enhancements initiated by our employee resource groups, and celebrated recognition as one of the best places to work for disability inclusion. Our community provided enriching educational opportunities to students, with K–12 STEM activities reaching underrepresented communities from Boston to Kwajalein.

In my final letter as director, I would like to thank every member of our organization for their unique and important contributions to fulfilling our mission. In my new roles at MIT campus and Lincoln Laboratory, I look forward to supporting the Laboratory's continued commitment to technical excellence, integrity, and service to the nation for many years to come.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

To be the nation's premier laboratory that develops advanced technology and system prototypes for national security problems

- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

STRATEGIC DIRECTIONS

- Continue evolving mission areas and programs
- Strengthen core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition, user, and commercial communities
- Find greater efficiencies and reduce overhead process
- Improve leverage through external relationships
- Improve Laboratory diversity and inclusion
- Enhance Laboratory facilities
- Enhance Laboratory community outreach and education

VALUES

How we approach our work

Integrity, Excellence, and Innovation

- We strive for the highest standards of integrity and excellence as we deliver technology in support of national security.
- Honoring Lincoln Laboratory's history, we believe interdisciplinary teams and a culture of collaboration drive research and development as we solve important problems in service to the nation.
- We take on bold endeavors with curiosity, ingenuity, humility, and dedication to our mission. We challenge our assumptions and accept the risk of failing as a critical part of innovation.
- As trusted stewards of government information and resources, we hold ourselves accountable to providing clear, accurate, and unbiased guidance to our sponsors and partners and using government resources efficiently and responsibly.
- We recognize the multidimensional impact of technology and our responsibility to conduct our research with the highest ethical standards.
- We challenge ourselves to face difficult facts, speak plainly about shortcomings in our systems, and overcome them.

How we interact with each other

Belonging, Respect, and Service

- We strive to make our community a welcoming place where everyone feels they belong and has the opportunity to thrive. We encourage work-life balance.
- We practice decency, kindness, empathy, and respectful dialogue. We promote psychological safety and strive to be transparent and worthy of each other's trust.
- We value accomplishments and potential over pedigree. We know that talent and good ideas can come from everywhere, and recognize that inclusive teams with diverse experiences foster innovation.
- We do not tolerate bad behavior or disrespect, especially on the basis of great accomplishment, talent, or power.
- We encourage service to our global, national, and local communities and take pride in creating opportunities for education and transfer of technology.
- We depend on contributions from every individual in every role to accomplish our mission.

MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. Sally Kornbluth (center)
President

Dr. Cynthia Barnhart (right)
Provost

Dr. Maria T. Zuber (left)
Vice President for Research

MIT Lincoln Laboratory

(Left to right)

Justin J. Brooke
Assistant Director

Chevalier P. Cleaves
Chief Diversity and Inclusion Officer

Heidi C. Perry
Chief Technology Officer

Eric D. Evans
Director

Melissa G. Choi
Assistant Director

Israel Soibelman
Chief Strategy Officer

Asha Rajagopal
Chief Technology Ventures Officer

C. Scott Anderson
Assistant Director – Operations

Eric Evans to Step Down as Director of Lincoln Laboratory

In 2023, Dr. Eric Evans announced his decision to step down as director of Lincoln Laboratory on July 1, 2024.

Eric Evans will have led Lincoln Laboratory for 18 years when he steps down in 2024.

The transition will mark the end of a successful 18-year tenure in which Evans led the Laboratory to adapt and strengthen during a time of significant change for national security needs. Under his leadership, the Laboratory established new R&D mission areas, strengthened ties with the MIT research community, increased diversity and inclusion efforts, advanced STEM education initiatives, and developed new models for technology transfer.

"It has been an honor and privilege to lead Lincoln Laboratory," Evans said. "I really appreciate what our Laboratory community has done over many years to develop some of the nation's most important and difficult technical advancements."

Evans will transition into the role of Director's Office Fellow at the Laboratory. He will also hold an appointment on MIT campus as a senior fellow in the Security Studies Program. He will support the ongoing growth of collaborative R&D between the Laboratory and MIT campus, including in areas related to climate change. He will also continue to work with the defense community to support studies for defense system and technology needs.

Lt. Gen. Ellen M. Pawlikowski and Gen. William L. Shelton join Evans to cut the ribbon commemorating a significant upgrade to the Haystack Ultrawideband Satellite Imaging Radar in 2014.

A Career in Service

Evans' career at the Laboratory began in 1988. In the ensuing years, he held positions of increasing responsibility in the air and missile defense technology area, before being named director in 2006.

Soon after his tenure began, he worked with many staff to establish a large mission area focused on homeland protection. Under this area, the Laboratory developed new homeland air defense capabilities and chemical and biological sensor systems for the Department of Homeland Security. Evans also directed the establishment of a cybersecurity mission area to address the dynamic threats posed by cyberattacks.

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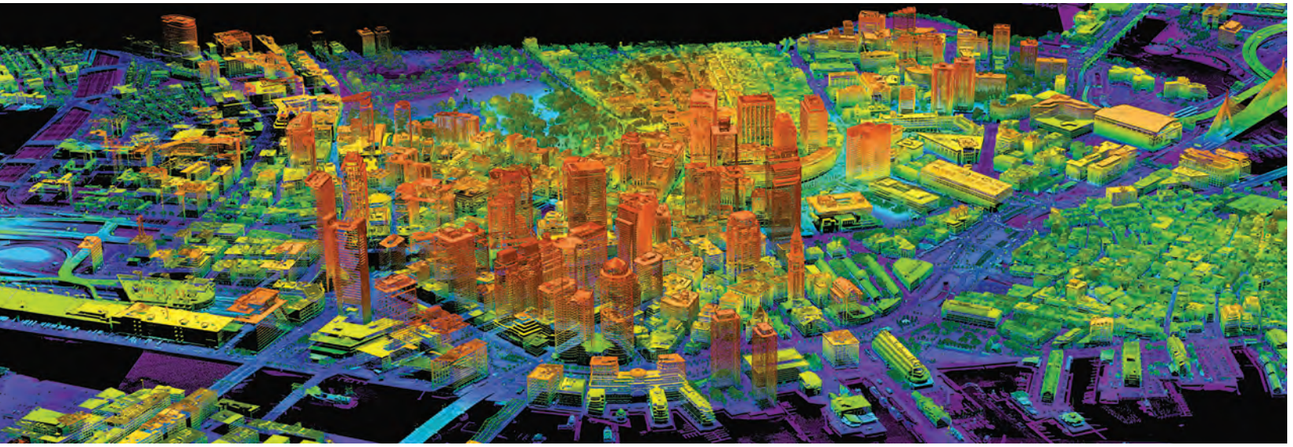
>> *Eric Evans to Step Down as Director of Lincoln Laboratory, cont.*



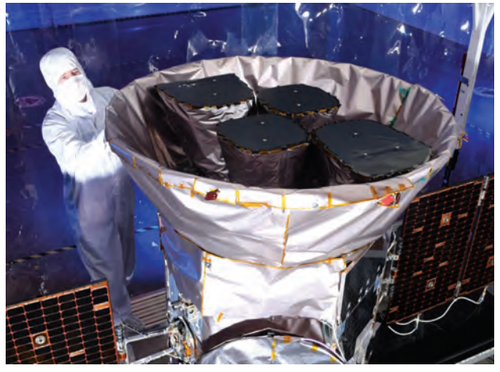
Airborne lidar technology developed at the Laboratory is being applied to disaster response needs, such as imaging damaged areas, monitoring infrastructure, and estimating debris volumes. Here, the technology was used to create a 3D point-cloud map of Boston.

The Laboratory also started significant new work in biotechnology and human systems, including systems for monitoring health status and assisting in injury recovery for the U.S. Army and other sponsors. Efforts in humanitarian assistance and disaster relief systems grew significantly, with rapid responses to the earthquake in Haiti, Hurricane Maria in Puerto Rico, and Hurricane Harvey in Texas. Evans also focused on expanding programs that address civilian needs, such as collision- and weather-avoidance technology for the Federal Aviation Administration.

During the COVID-19 pandemic, Evans directed staff to apply the Laboratory's biotechnology resources to the problems of medical resource allocation, health monitoring, automatic contact tracing, and virus dispersion analysis. Many of these technologies assisted in the pandemic response and have since transitioned to new applications.

As director, Evans also served as a key advisor on technology strategy to senior government leaders, including as chair of the Defense Science Board.

During the COVID-19 pandemic, Evans directed the Laboratory to apply its technology to address national-level challenges and keep the workplace safe.



At right, Evans greets Gen. Mark A. Milley, former Chairman of the Joint Chiefs of Staff, during his visit to the Laboratory in 2023. Far right, a collaboration between Lincoln Laboratory and the MIT Kavli Institute produced the Transiting Exoplanet Survey Satellite. This satellite was launched in 2018 and has enabled the discovery of many new planets orbiting distant stars.

Each year, the Laboratory welcomes a cohort of National GEM Consortium Fellows. Evans served as chair of the board for GEM, which matches highly qualified students pursuing graduate degrees with leading STEM organizations.

Community Connections

Throughout his tenure, Evans helped strengthen the Laboratory's relationship with MIT campus. In the past 15 years, the number of collaborative research programs with MIT has grown by nearly a factor of four. As some examples, the Laboratory partnered with the MIT School of Engineering to establish the Beaver Works Center; worked with the MIT Research Laboratory of Electronics to stand up the Center for Quantum Engineering; collaborated on NASA's Transiting Exoplanet Survey Satellite with the MIT Kavli Institute for Astrophysics and Space Research; and helped form the Department of the Air Force–MIT Artificial Intelligence Accelerator program.

Evans also took steps to enhance the Laboratory's culture to be more inclusive and supportive, significantly increasing the percentage of women and people of color in technical and leadership roles. He established an Office of Diversity and Inclusion and strengthened the Human Resources Department to improve staff recruiting, development, and retention.

During Evans' tenure as director, the Laboratory community established nine employee resource groups.

>> *Continues on page 8*

>> *Eric Evans to Step Down as Director of Lincoln Laboratory, cont.*

To support the national need for more diverse talent, Evans served for six years as the chair of the board for the National GEM Consortium, an organization that provides fellowships to underrepresented minorities pursuing graduate degrees in STEM fields. The number of GEM fellowships increased significantly during Evans' tenure leading the board.

Evans also strongly supported the creation of programs to promote K-12 student interest in STEM fields. Over the past 18 years, the Laboratory's STEM outreach programs have reached more than 100,000 students.

The Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) is one of many K-12 STEM outreach programs that Evans helped establish as director. Here, Evans discusses with LLRISE participants Jamal Grant and Yaovi Ayeh the small radar systems that students assemble.

Construction began in 2023 of the Compound Semiconductor Laboratory – Microsystem Integration Facility, which will facilitate the creation of advanced technologies for several applications. A new Engineering Prototyping Facility is slated for later this decade.

Positioned for Future Success

Moving forward, Evans has positioned the Laboratory to continue evolving its mission. The Laboratory is currently pursuing research in emerging technology areas, such as artificial intelligence, synthetic biology, and quantum systems, and is making major investments in new facilities and specialized laboratories.

"Eric's leadership has proven what an ambitious R&D laboratory and a major institute can achieve together: transformative improvements to the systems that keep the world safe, and a lasting impact on the practice of innovation itself," said Maria Zuber, MIT's vice president for research. "The culture of excellence, collaboration, and creativity that Eric has sustained at Lincoln Laboratory ensures its success well into the future. I'm thankful for his service and grateful that he will remain at MIT in his new roles."

ORGANIZATIONAL CHANGES

L. Reginald Brothers

Principal Staff, Director's Office

Dr. L. Reginald Brothers joined Lincoln Laboratory in July 2023 as principal staff in the Director's Office. Brothers will facilitate growth in non-Department of Defense (DoD) and nontraditional sponsor domains. He held leadership roles at Envoy Networks, Draper Laboratory, DARPA, and BAE Systems before serving as Deputy Assistant Secretary of Defense for Research at the DoD. In 2014, Brothers was confirmed by the Senate as the Under Secretary for Science and Technology at the U.S. Department of Homeland Security.

Sandeep S. Pisharody

Associate Technology Officer, Technology Office

Dr. Sandeep S. Pisharody joined the Technology Office in October 2023. While in the Cyber Operations and Analysis Technology Group, Pisharody contributed to a variety of cybersecurity research efforts and led multiple programs for the U.S. Army, U.S. Air Force, and U.S. Cyber Command and has served on the Laboratory's Advanced Concepts Committee. In the Technology Office, he will support the development of Lincoln Laboratory's internal R&D investment strategy and the implementation of initiatives to foster technology innovation.

Shireen M. Warnock

Associate Technology Officer, Technology Office

Dr. Shireen M. Warnock joined the Technology Office in October 2023. Warnock has worked in a variety of roles within the RF Technology Group including principal investigator and division representative to the Laboratory's Technology Office Advisory Group. Her responsibilities in the Technology Office will include supporting the strategic development of the Laboratory's internal R&D investments, developing and executing innovation initiatives, and aiding the coordination of the Laboratory's technology development strategy.

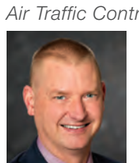
Jennifer A. Watson

Head, Homeland Protection and Air Traffic Control Division

Dr. Jennifer A. Watson was appointed to lead the Homeland Protection and Air Traffic Control Division in September 2023. Watson earned recognition as a national expert in passive sonar processing. Under her leadership, the Airborne Radar Systems and Techniques Group developed the first instantiations of the Laboratory's Airborne Radar Testbed for advanced airborne radar testing for ground surveillance. As assistant head of the ISR and Tactical Systems Division, she developed a portfolio of programs focused on analysis and technologies in support of Joint All-Domain Command and Control.

Jonathan D. Pitts

Assistant Head, Homeland Protection and Air Traffic Control Division



Dr. Jonathan D. Pitts was named assistant head of the Homeland Protection and Air Traffic Control Division in September 2023. As the former leader of the Chemical and Biological Defense Systems Group, Pitts expanded the Laboratory's portfolio to encompass broader counter–weapons of mass destruction applications beyond chem-bio defense. While in the Biotechnology and Human Systems Division, he initiated an innovation hub to deploy novel sensors that address emerging health incidents. Pitts played a significant role in the Laboratory's COVID-19 response as part of the COVID-19 Task Force.

Thomas G. Macdonald

Head, Communication Systems Division

In March 2023, Dr. Thomas G. Macdonald was appointed to lead the Communication Systems Division. Macdonald previously served as assistant head of the Communication Systems Division, where he helped socialize a national architecture for future space-based communication and identify key prototyping opportunities for critical portions of the architecture. He has supported numerous national studies, has chaired the Lincoln Laboratory Communications Workshop, and has served as the chair of the strategic steering committee for the IEEE Military Communications Conference.

>> *Continues on page 10*

Michele A. Schuman

Assistant Head, Communication Systems Division

Dr. Michele A. Schuman was named assistant head of the Communication Systems Division in April 2023. Schuman has focused on technologies and architectures for space-to-space communications to enable new space operations. She routinely briefs senior DoD leaders and was a key member of the U.S. government team that conducted high-level analyses that defined the next generation of military satellite communications. Schuman received a Lincoln Laboratory Technical Excellence Award in recognition of her contributions across the Laboratory and to the nation.

David A. Waldron

Deputy Director, Financial Operations, Financial Services Department

Mr. David A. Waldron was named deputy director of financial operations of the Financial Services Department in December 2023. Previously, as the senior manager of financial operations, he coordinated and oversaw the Laboratory's funding activities, including $1.3 billion in annual Air Force funding. In his new role, Waldron will expand his responsibilities to include management of the funding for the Property and the Travel Departments.

MIT LINCOLN LABORATORY FELLOW

The Fellow position recognizes the Laboratory's strongest technical talent for their outstanding contributions over many years.

Joseph P. Campbell

Dr. Joseph P. Campbell joined Lincoln Laboratory in 2001 after an esteemed career with the National Security Agency. In several Laboratory leadership positions, Campbell has made significant contributions to the field of Human Language Technology, including leading the Laboratory's efforts for the White House's Big Data Initiative in 2012 and developing big data analytics tools that had a tremendous impact on combating human trafficking. More recently, he and his colleagues developed cyber analytics technology for countering influence operations. Campbell has authored or co-authored more than 120 technical book chapters, proceedings papers, and journal articles with more than 8,000 citations. For his sustained outstanding achievements and impact in the areas of speech processing, biometrics, and artificial intelligence and their applications, Campbell was awarded a Lincoln Laboratory Technical Excellence Award in 2023.

Establishment of the Civil Space Systems and Technology Office

A 2022 NASA Engagement Strategy Study considered increasing the scale and impact of the Laboratory's work with NASA, NOAA, United States Geological Survey, and Department of Commerce with a goal of reaching a division-scale level in the next ten years. This study found many near-term examples of Laboratory technology that align with NASA's strategic priorities and several long-term objectives that pair well with national security and scientific space priorities.

In response, the Laboratory established a new Civil Space Systems and Technology Office. Its leaders remain in their current roles as they contribute to this Laboratory-wide initiative to advance the civil space portfolio and oversee the execution of the Laboratory's civil space strategy. This core team draws on team members from across the Laboratory to achieve its goals. The new office is organized into sub-teams aligned with the Laboratory's civil space strategy:

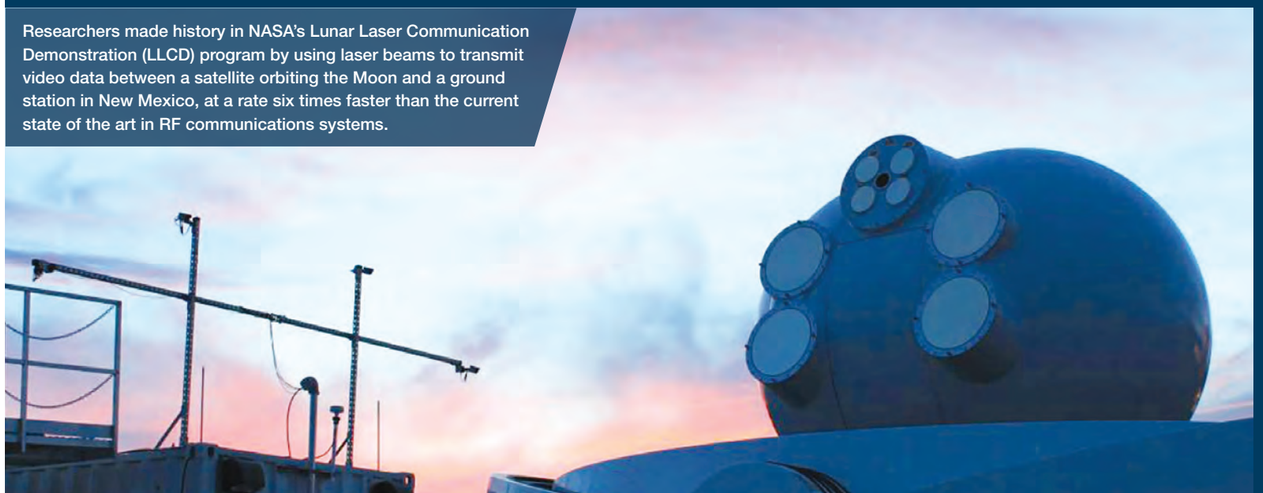
The **Science** team is identifying opportunities for Laboratory space programs related to scientific discovery. This team is led by Deborah Campbell and Deborah Woods.

The Transiting Exoplanet Survey Satellite (TESS) NASA Explorer Mission was launched in 2018. Lincoln Laboratory, in partnership with the MIT Kavli Institute for Astrophysics and Space Research, provided the detector arrays, optical subsystem, system engineering, integration and test, and program management for the science payload. After five years in space, TESS's cameras have mapped more than 93% of the entire sky, found 329 new worlds and thousands of candidates, and provided insights into a wide array of cosmic phenomena.

The **Missions and Operations** team is focusing on non-science payloads, mission support capabilities, and non-space programs within civil space sponsor organizations. This team is led by James Kuchar, Scott Hamilton, and David Bigelow.

The **Core Technology** team is identifying Laboratory technologies with applicability to current and future civil space missions, and will work with other teams to prioritize internal funding recommendations. The team is led by Jalal Khan and Christopher Leitz.

Researchers made history in NASA's Lunar Laser Communication Demonstration (LLCD) program by using laser beams to transmit video data between a satellite orbiting the Moon and a ground station in New Mexico, at a rate six times faster than the current state of the art in RF communications systems.



The **Outreach and Collaboration** team is fostering increased collaborations within the Laboratory, and with MIT campus and other universities, NASA Centers, and other FFRDCs and University-Affiliated Research Centers. This team is led by Jeffrey Mendenhall and Laura Kennedy.

The **Operations and Infrastructure** team will facilitate program proposal generation and execution, identify civil space program infrastructure needs, and develop the Laboratory's civil space external presence. This team is led by Jacob Williams and John Adams.

The **New Concept Development** team is facilitating and nurturing new cross-mission civil space programs, facilitating concept refinement, developing program plans and technology roadmaps, and pursuing program development opportunities with existing and new civil space partners. This team is led by William Blackwell, Jonathan Pitts, Andrew March, and Bryan Robinson.

The **Civil Space Systems and Technology Office** is co-led by Gregory Berthiaume, Thomas Macdonald, and Daniel Ripin, and is overseen by Melissa Choi. Laura Kennedy serves as deputy lead. Marc Bernstein serves as advisor.

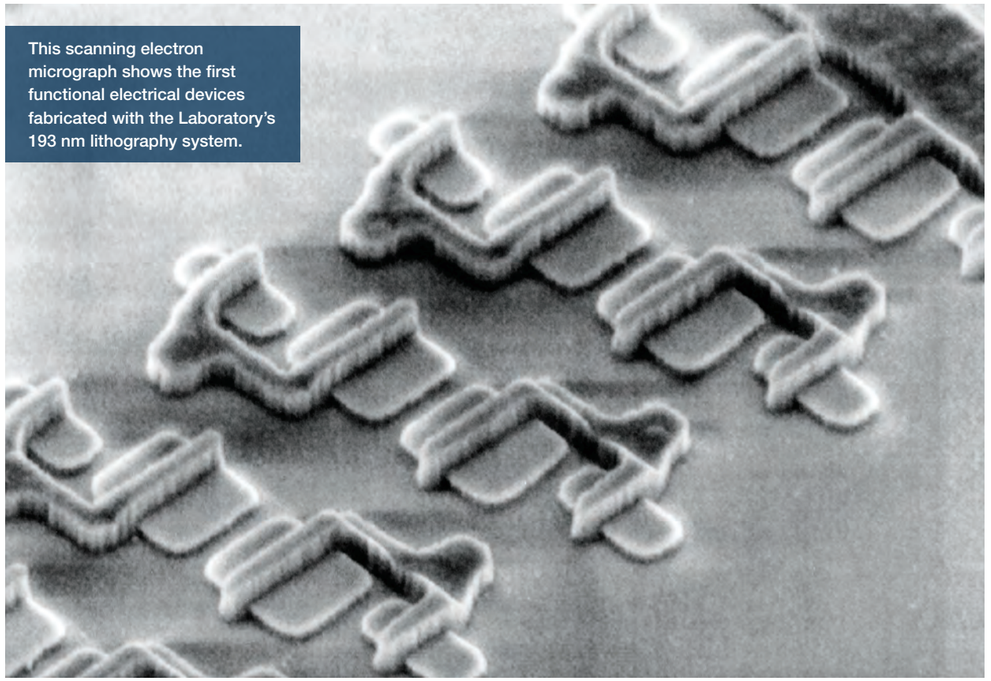
Achievements in Air Traffic Control, Microelectronics, and Lasers are Named IEEE Milestones

The Institute of Electrical and Electronics Engineers (IEEE) elected three historical Lincoln Laboratory inventions as IEEE Milestones: the Mode S air traffic control (ATC) radar beacon system, 193-nanometer (nm) photolithography, and the semiconductor laser.

As the world's largest technical professional organization, the IEEE aims to advance technology for the benefit of humanity. The Milestone program commemorates innovations developed at least 25 years ago that have done just that.

All three awarded technologies are integral to everyday life. Anyone who has flown on commercial aircraft has benefited from Mode S, the system that air traffic controllers use to track planes. The integrated circuits that power modern devices were manufactured using 193 nm photolithography. Perhaps most ubiquitous of all are semiconductor lasers—tiny light-emitting devices that have made possible high-speed Internet, among many other technologies underpinning today's information society.

Lincoln Laboratory holds three previous IEEE Milestones for pioneering the use of packet networks for speech communications, for developing the nation's first air defense system, and for developing the Whirlwind computer with MIT campus.



This scanning electron micrograph shows the first functional electrical devices fabricated with the Laboratory's 193 nm lithography system.

Powering the Microelectronics Industry

The 193 nm projection photolithography technique, originated at Lincoln Laboratory, has enabled the fabrication of every chip in every laptop, smartphone, military system, and data center for the last 20 years.

Photolithography uses light to print tiny patterns onto a silicon chip. The patterns are projected over a silicon wafer, which is coated with a chemical that changes its solubility when exposed to light. The soluble parts are etched out, leaving behind tiny structures that become the transistors and other devices on the chip.

Shorter wavelengths of light allow for printing smaller features, enabling more densely packed chips. By the 1980s, the accepted wisdom in the industry was that 248 nm was the shortest wavelength possible for photolithography.

Despite widespread skepticism and technical obstacles, the Laboratory pioneered photolithography at the 193 nm wavelength, fabricating the world's first microelectronic devices using the technique. The first-ever 193 nm projection system was installed in the Microelectronics Laboratory in 1993. The Laboratory soon opened its doors to industrial partners to guide 193 nm semiconductor manufacturing and pave the way toward its widespread adoption. Today, it is the industry's mainstream technique and has enabled increasingly powerful integrated circuits.

Tracking Aircraft Globally

The Mode S ATC radar beacon system was developed to address the challenges posed to the existing ATC beacon radar system used in the late 1960s. Commercial air traffic was growing quickly, causing interference between beacon replies from aircraft and interrogations from ATC ground radars. This interference threatened to disrupt aircraft surveillance in the highest-density airspace.

The Laboratory led the technology developments necessary to address this safety issue. The advanced communication architecture of Mode S allowed radars to select a specific aircraft to interrogate. To selectively communicate, the system design included improved aircraft transponders each assigned a unique address code. Upgrades to radar antennas and signal processing also allowed Mode S to accurately determine airplane position with far fewer air-to-ground messages.

Under Federal Aviation Administration (FAA) sponsorship, the Laboratory developed, tested, and verified the technical approach underlying Mode S—now an industry standard. Today, an estimated 100,000 aircraft are equipped with Mode S transponders, and more than 900 Mode S radars are deployed across the globe. The technology has enabled other breakthrough safety systems, such as collision avoidance, and is the foundation for the FAA's newest ATC surveillance system, which allows continuous flight tracking independent of ground radars.

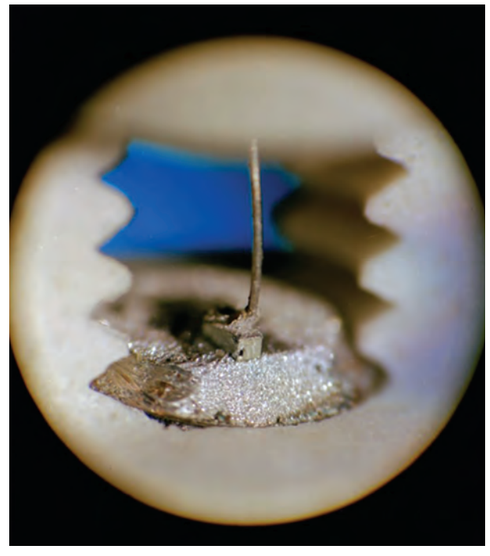
The Mode S production antenna (orange) is now a familiar sight at major airports throughout the world. Above, a Mode S antenna is pictured at Boston Logan International Airport.

Lighting Up A World of New Technologies

In the fall of 1962, General Electric, IBM, and Lincoln Laboratory each independently reported the first demonstrations of the semiconductor, or diode, laser. In the 60 years since, it has become the most widespread laser in the world and a foundational element in a vast range of technologies: DVDs, CDs, computer mice, laser pointers, barcode scanners, medical imagers, and printers, to name a few. However, its greatest impact is arguably in communications. Every second, a semiconductor laser encodes information onto light and sends it in fiber-optic cables across oceans, forming the backbone of the Internet.

While lasers were invented a few years earlier in 1960, the semiconductor type was exceptional because it realized all laser elements within a piece of semiconducting material no bigger than a grain of rice. When injected with electrical current, the material converts the electrical energy to light.

Semiconductor lasers are everywhere today, and they dot many other stories of success at Lincoln Laboratory. In 2023, a semiconductor laser was used to demonstrate the fastest space-to-Earth communications link yet. The sky is not the limit for these tiny but powerful sources of light.



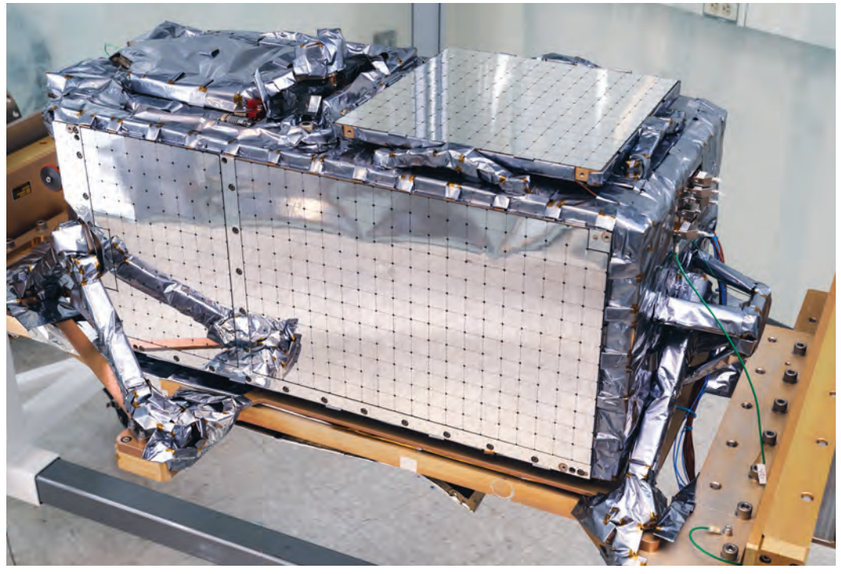
One of the Laboratory's first semiconductor lasers, pictured above, was made from a block of gallium arsenide and had a metallic base and a wire contact attached to the top for injection of an electrical current.

Sensors Increase Space Security in Collaboration With Japan

In 2023, Lincoln Laboratory shipped a pair of Situational Awareness Camera Hosted Instruments (SACHI) to Japan as part of a partnership program to increase space domain awareness (SDA) across Eurasia. The cameras will be integrated onto two satellites, set to launch in the next few years, that will join the Japanese-operated Quasi-Zenith Satellite System (QZSS) in geosynchronous orbit (GEO). The primary purpose of the QZSS is to augment the global navigation satellite system to enhance navigation and timing services for users in Japan and neighboring countries. A secondary purpose is the SDA effort with the United States.

For the past few decades, satellite launches across the globe have been steadily increasing as countries initiate and progress their own space-related activities. More launches create space debris and a higher risk of collisions, complicating space security. Both the United States and Japan share interests in fortifying SDA within the increasingly crowded GEO space, and thus the idea for the SACHI collaboration was born. Working together and sharing SDA serves as a cost-effective way for both countries to gain the awareness they need, and the program's success could inform the future of collaborative space-based efforts between the United States and allies.

The Laboratory's Space Systems and Technology Division built the SACHI sensors because of its extensive experience in SDA sensor development and, in particular, the success of the Operationally Responsive Space (ORS)-5 satellite, also known as SensorSat, launched in 2017. SACHI leverages technologies that were built for SensorSat, such as unique optical charge-coupled-device cameras fabricated in the Microelectronics Laboratory and a search-based optical system that enables passive sky surveying. This optical system uses a gimballed mirror that allows it to scan large regions while maintaining good performance.



The SACHI payload is 45 × 31 × 19 inches, with a mass of 154 pounds. The small size and design of the satellite make it more cost-effective and quicker to build and launch than satellites traditionally used for space domain awareness.

Daniel Howe, left, Jake Barone, middle, and Casey Bennett prepare the SACHI payload for its shipment to Japan. Howe and Barone accompanied the first payload on its journey, monitoring its custom nitrogen delivery system and dewpoint to ensure that condensation would not form within the shipping container.

Development on SACHI began in 2019. The program's rapid timeline was challenged by the complexities of collaborating with partners during the COVID-19 pandemic. In January 2023, the first of the two sensors was loaded onto a C-17 aircraft at Hanscom Air Force Base in Lexington, Massachusetts, and was flown to Japan. Staff accompanied the sensor on its journey to keep a close eye on the fragile components. The second camera was delivered in May.

Flight Tests Demonstrate Magnetic Navigation

A U.S. Air Force C-17A Globemaster III strategic airlift aircraft successfully demonstrated the use of magnetic navigation, or MagNav. The MagNav system combines artificial intelligence (AI) with the age-old method of using the Earth's magnetic field for navigation. During flight, a MagNav solution was computed on board in real time. The milestone shows potential for performing real-time navigation with such a system in the future.

Today, most aviators rely on GPS to navigate. However, a growing national security concern is the susceptibility of GPS to threats ranging from signal jamming to spoofing or even the physical destruction of GPS satellites. If GPS is disrupted, a pilot can use an aircraft's inertial navigation system to determine its position, but the accuracy of that position will diminish over time. The MagNav system could be implemented to bound the error growth and maintain accuracy.

With MagNav, a sensor on the aircraft takes measurements of the Earth's magnetic field. These measurements are compared against a preexisting map of a local area's magnetism. Rich variations in Earth's magnetic field created by iron ore near the crust cause anomalies that can be mapped, measured, and utilized for navigation.

A historical barrier to using this method in real time has been sources of electromagnetic noise from the many transmitters, computers, and metallic components on aircraft. Such noise makes getting a sufficiently accurate measurement of the Earth's magnetic field difficult.

With AI, removing the noise is now possible. The MagNav project was funded through the AI Accelerator, a collaboration between MIT, Lincoln Laboratory, and the Department of the Air Force to apply AI to national security challenges. Through global teamwork enabled by the AI Accelerator, the MagNav team built machine learning models capable of decoupling the Earth's and aircraft's magnetic signals to derive a clean signal.

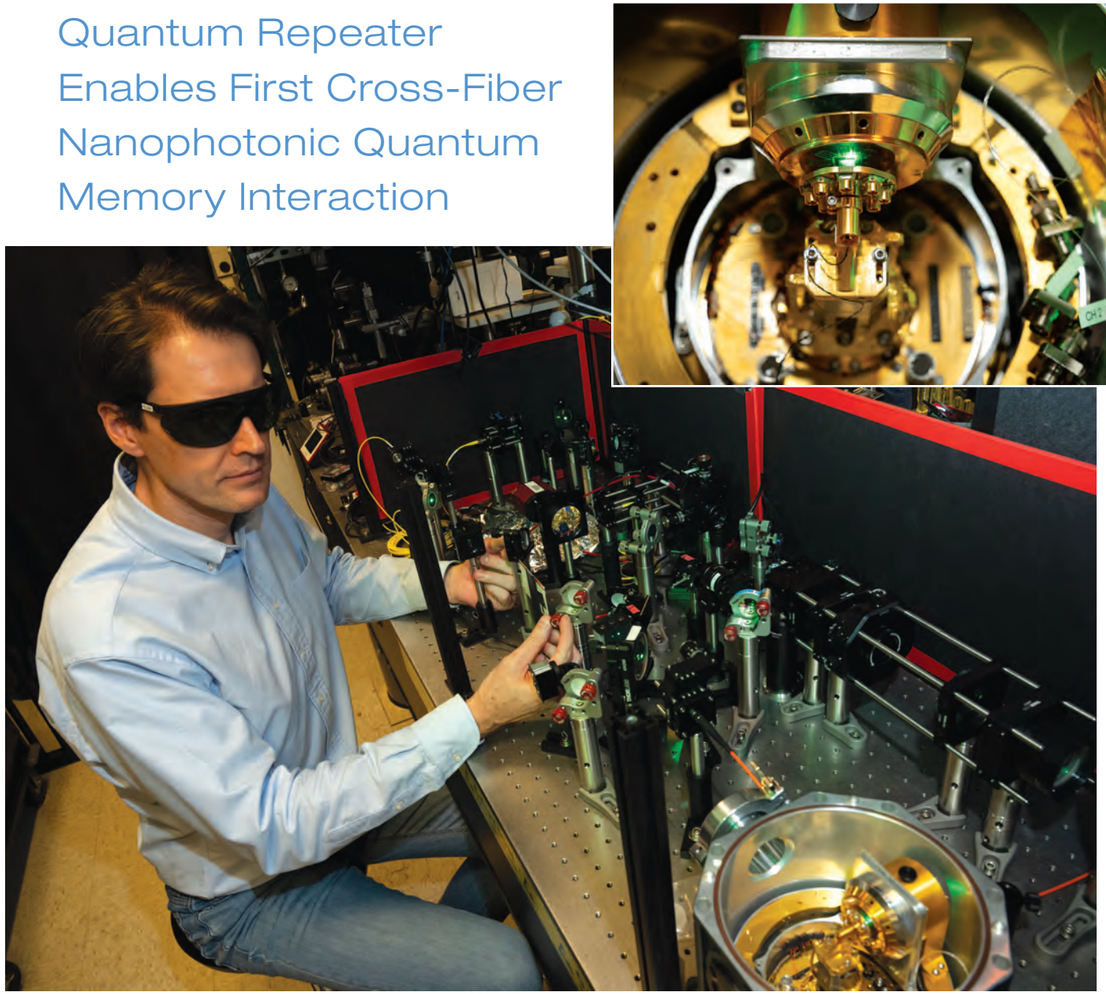
The team demonstrated the MagNav capability in flight during two separate U.S. Air Force exercises: Golden Phoenix in May and Mobility Guardian in July. During the flights, the system ingested magnetic measurements, compensated for noise, and then fed the clean data into navigational algorithms that positioned the aircraft within the magnetic map. The algorithms had been prototyped using data from previous C-17 flights, accelerating the processing to within minutes on a laptop.

While the tests were successful, the technology still faces obstacles in adoption, such as the resources required for first creating the magnetic maps. But the experiments show promise for a system that could help diversify navigational technology, improving safety for aviators everywhere.

MagNav equipment (contained in the black boxes) and a laptop are loaded on the back of a C-17A Globemaster III. The system successfully positioned an aircraft within a magnetic map.

A formation of C-17s lines the runway for Exercise Golden Phoenix, during which the MagNav system was tested in May.
Photo: Senior Airman Alexander Merchak

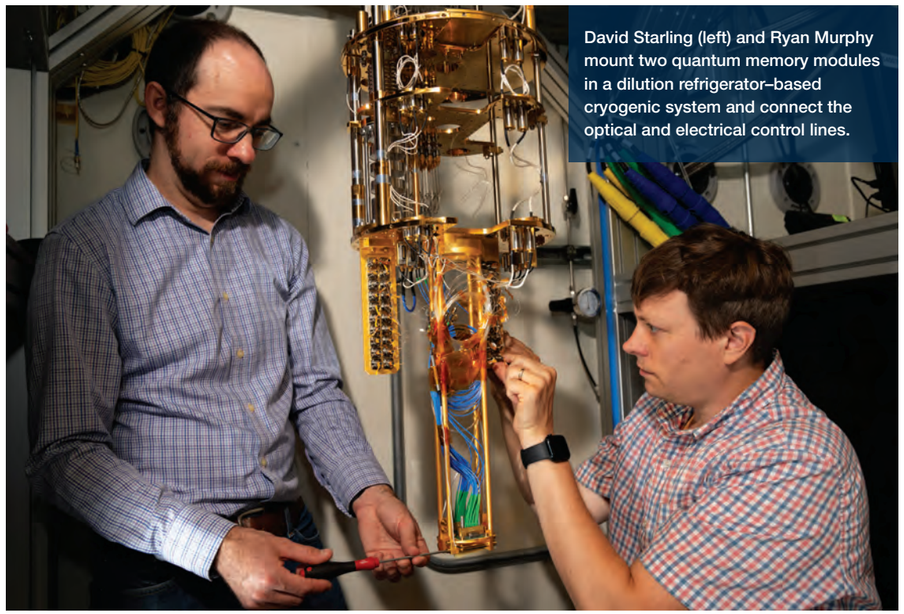
Quantum Repeater Enables First Cross-Fiber Nanophotonic Quantum Memory Interaction



Benjamin Dixon characterizes a Lincoln Laboratory–grown diamond (glowing green, zoomed-in photo at top) in a cryogenic microscope system that can identify and measure the optical properties of individual silicon-vacancy defects within the diamond.

In July, Lincoln Laboratory, in collaboration with MIT and Harvard University, became the first in the world to send quantum information to a nanophotonic quantum memory across a deployed telecommunications fiber. Connecting the Laboratory to MIT and MIT to Harvard, this 50-kilometer-long optical network fiber is part of a test bed that local industrial partners can also tap into through the Boston-Area Quantum Network.

Moving quantum states between multiple quantum systems is one of the big challenges in quantum networking, which promises to unlock unprecedented computing power and enable high-precision sensing. The challenge stems from the inherently fragile nature of qubits, the basic unit of quantum information. Whether existing as particles of light (photons), electrons, atoms, or other forms, qubits can easily lose the information they store through interactions with their environment. Because of this sensitivity, transmission and interconnection losses are common, especially over long distances. In classical networks, amplifiers overcome these losses. Placed periodically along optical fibers to copy bits as they propagate down the line from sender to receiver, amplifiers essentially divide the transmission distance into smaller, more manageable segments. However, qubits cannot be measured or copied without destroying their state. For quantum networks to successfully send information over lossy links, they need the quantum equivalents of classical amplifiers: quantum repeaters. Such devices work by leveraging quantum phenomena known as entanglement (when particles are correlated across infinite distance) and teleportation (when information between distant systems is sent without moving actual particles).



David Starling (left) and Ryan Murphy mount two quantum memory modules in a dilution refrigerator–based cryogenic system and connect the optical and electrical control lines.

The Laboratory team has been developing quantum repeaters built with a quantum memory platform devised by collaborators at Harvard and MIT. This qubit-storing platform is based on diamond crystals only billionths of a meter in size (nanometer) engineered to have atomic defects by removing two carbon atoms and replacing these vacancies with a silicon atom. Manipulated with visible light, silicon's outermost electron can transfer and store a photonic qubit in its magnetic orientation, or spin. Like a bar magnet with north and south poles, an electron spin can point up or down. These spin-up and spin-down states can represent the 1s and 0s (on and off) that computers use to process and store information.

The quantum engineering effort at the Laboratory involves on-site custom diamond growth; the development of a chip that merges nanophotonic and electronic functionalities to control the silicon-vacancy qubit; and integration and packaging of the components into a system that can be cooled to the cryogenic temperatures currently needed to minimize environmental disturbances and ultimately preserve memory. The current system has two memory modules, each capable of holding eight optical qubits.

For the test bed demonstration, the researchers sent photons encoded with quantum states from the Laboratory, across the fiber, and interfaced them with a silicon-vacancy quantum memory, located at Harvard, that captured and stored the transmitted quantum states. They measured the electron on the silicon atom to determine how well the quantum states were transferred to the silicon atom's spin-up or spin-down position. Compared to other leading quantum repeater efforts around the world, the Laboratory team achieved best or near best for the relevant performance parameters of state transfer fidelity and efficiency, technology scalability, and link distance.

The next step is combining multiple quantum memories at each of the three network nodes and incorporating additional nodes into the test bed to explore quantum networking protocols at a system level. Simultaneously, the MIT and Harvard collaborators will investigate materials science for alternative atoms that, when added to diamond, can be implemented at temperatures warm enough for practical system operation.

During a flight over Falmouth Harbor, the ARTB collected SAR photos, left, and the EO/IR imaging system collected visible-light photos, middle and right.

Modified Aircraft Offers Versatile Technology Demonstration Platform

At the Flight Test Facility, the newest member of Lincoln Laboratory's airborne testbed fleet—a Saab 340B twin-engine turboprop—is ready for takeoff. But this is no ordinary aircraft; it was recently modified to host the Airborne Radar Testbed (ARTB), a high-performance radar system based on a computer-controlled array of antennas that can be electronically steered (instead of physically moved) in different directions. With its open-architecture design and compliance with open standards, the ARTB can be rapidly reconfigured to accommodate specific data collections for various radar modes and to test new sensing and communications technology. Research teams from across the Laboratory have been using the ARTB as a demonstration platform for various technologies.

For instance, one team mounted an electro-optical/infrared (EO/IR) imaging system under the front of the aircraft. This system is designed for long-range maritime patrol and persistent surveillance from high altitudes. Its operation across visible and infrared wavelengths allows for imaging in a wide range of conditions, from bright sunlight, to overcast and smoke, to complete darkness.

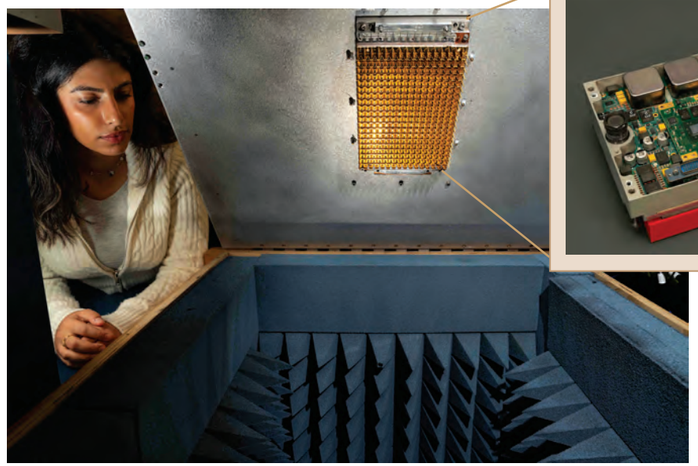
In 2023, the integrated imager and ARTB flew over Falmouth Harbor and other local areas in Massachusetts, producing valuable datasets for prototyping real-time sensor data–fusion capabilities. This airborne multisensor platform will be demonstrated during a major Department of Defense exercise in spring 2024, fusing high-resolution synthetic aperture radar (SAR) and EO/IR imagery to identify ground targets via artificial intelligence and machine learning techniques and onboard processing.

Above, William O'Connell, left, and Nicholas Winicki install and test a small platform radio in a Cessna 206 for air-to-air communications. Below, the Saab aircraft outfitted with the ARTB takes off.

Another team is leveraging the ARTB to mature a radar-based communications waveform for communications between large and small platforms (like fighter jets and uncrewed aerial vehicles). The waveform uses existing ground-imaging radar arrays, which are widely deployed, offer wide antenna apertures and high bandwidth, and are evolving to support flexible backend architectures with standardized interfaces. In designing the waveform, the team overcame challenges related to using a radar platform for communications, including a limited window of time during which the radar is actually transmitting, meant to reduce power consumption and prevent system overheating. Implemented on the ARTB, the waveform proved its ability to provide communications at the data rates and ranges predicted through analysis and modeling. Several other capabilities have been demonstrated: real-time pointing and tracking to synchronize data sharing between platforms, multiplatform scheduling for prioritized data transfer, and integration of miniaturized electronics on a small platform. This year, the team demonstrated communications between moving air and ground vehicles, incorporating seven simultaneous users into the communications link.

A third team is building phased array antenna panels, 10 of which will be arranged side by side in a rear structure on the ARTB. These panels will provide 1.5 meters of aperture for large-area imaging at high resolution—relevant for applications including disaster response, environmental monitoring, and military reconnaissance. Operating at both X- and Ku-band frequencies and simultaneously supporting horizontally and vertically polarized radio waves, the panels enable long-range target detection in all weather conditions, in contested environments, and over ocean or land. Their compact design—each panel is only 6 × 11 × 2.5 inches and weighs eight pounds—necessitated a solution to manage the high heat generated by the densely packed electronic assembly. For this thermal management, the team 3D printed liquid-cooled cold plates with printed circuit boards laminated on each side. Testing of prototype panels is now underway and informing design refinements for improved performance and producibility.

Jeffrey Wildman, front; William O'Connell, far back; and Tom Murphy integrate and ground test the waveform at the Flight Test Facility.



Unlike traditional slat array architectures, which integrate antenna elements and electronics on parallel "cards" lined up like library books, this panel (prototype pictured at left with red handling cover) condenses all components into a single card, turned on its side.

In the Laboratory's RF Systems Test Facility, Parisa Zandi inspects the first prototype panel (gold rectangle) as it undergoes acceptance testing. Individual RF elements are turned on and off to assess basic functionality, with RF-absorbing material (blue spikes) suppressing noise and external interference.

MISSION AREAS 21

Technicians in the Microelectronics Laboratory (ML) operate equipment to fabricate advanced devices on 200-millimeter semiconductor wafers. The ML is considered to be the U.S. government's most capable foundry.

Space Security

Ensuring the resilience of the nation's space enterprise by designing, prototyping, operating, and assessing systems to provide space domain awareness, resilient space capability delivery, active defense, and associated cross-domain battle management

Leadership

Dr. Grant H. Stokes
Division Head

Mr. D. Marshall Brenizer
Assoc. Division Head

Dr. Gregory D. Berthiaume
Asst. Division Head

Dr. Timothy D. Hall
Asst. Division Head

Mr. Lawrence M. Candell
Principal Staff

Four of the TROPICS satellites shown above were launched in 2023 and are providing tropical cyclone data at high revisit rates to NOAA, NASA, the international science community, and the U.S. Navy. The Laboratory led the program's development. Image: Blue Canyon Technologies

Principal 2023 Accomplishments

- Lincoln Laboratory launched four identical satellites as part of the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) NASA-funded Earth Venture project. These high-performance satellites provide passive microwave sounding and imagery data of tropical cyclones comparable to that of operational systems, but at about 1,000× reduced size, weight, and power for each unit and at about 10% of the system cost. This enhanced capability is enabling improvements in understanding tropical storm formation and evolution and in forecasting landfall.
- The Laboratory delivered two identical space domain awareness (SDA) sensors to Japan for the Situational Awareness Camera Hosted Instrument program, which aims to increase SDA capabilities across Eurasia. The Laboratory-developed sensors are now preparing for spacecraft integration and environmental testing.
- The Laboratory led the modernization of networking, data architecture, and processing capabilities of new and legacy space surveillance sensors to improve the timeliness of tactical missions. Laboratory-built prototypes of net-centric data libraries enabled a system by which U.S. Space Force operators can leverage a vast array of DoD and commercial SDA data. The Laboratory applied machine learning and artificial intelligence to SDA data to enable effective decision support for the space domain.
- Laboratory researchers continued advising and engaging with the national space community to help identify the most pressing problems. With funding from the U.S. Department of the Air Force, the Laboratory invested in prototyping and testing passive radio-frequency capabilities and in developing ground-based infrared threat surrogates. The Laboratory's cross-domain assessments on ensuring survivable architectures and work to identify gaps in U.S. sensor capabilities supported the Space Warfighting Analysis Center, Space Security Defense Program, Space Systems Command, and other organizations.

Future Outlook

With the DoD's growing reliance on space systems to deliver tactical effects, the resilience of the nation's space enterprise is a significant national security issue. Improved SDA and responses on tactical timelines will be the foundation for increasing the survivability of space systems. Space systems will need to be made fundamentally more resilient to potential adversary actions. The creation of the U.S. Space Force and the reestablishment of the U.S. Space Command highlight the growing importance of the space domain.

Major Laboratory focuses are information extraction and integration, and decision support. Developing a net-centric, multidomain architecture with the agility to discover and incorporate new data sources and services on short timelines is critical for a capability that can respond in the time frames required to support space survivability efforts.

Radar Upgrade

The Millstone Hill Radar in Westford, Massachusetts, at the Lincoln Space Surveillance Complex has been operating since the 1950s. This satellite-tracking radar, shown right, uses an 84-foot steerable antenna operating in L-band. Recently, the Laboratory completed a five-year, $25 million effort to replace the original transmitter hardware and increase the radar's sensitivity and reliability. The new transmitter shelter contains two lead-lined enclosures, each housing a 3-megawatt klystron to generate sufficient power to form and transmit L-band waveforms. Operating since May 2023, this latest L-band transmitter doubles the radar's average power, enabling the tracking of smaller satellites out to geostationary orbits near 40,000 kilometers.

Leadership

Dr. Katherine A. Rink
Division Head

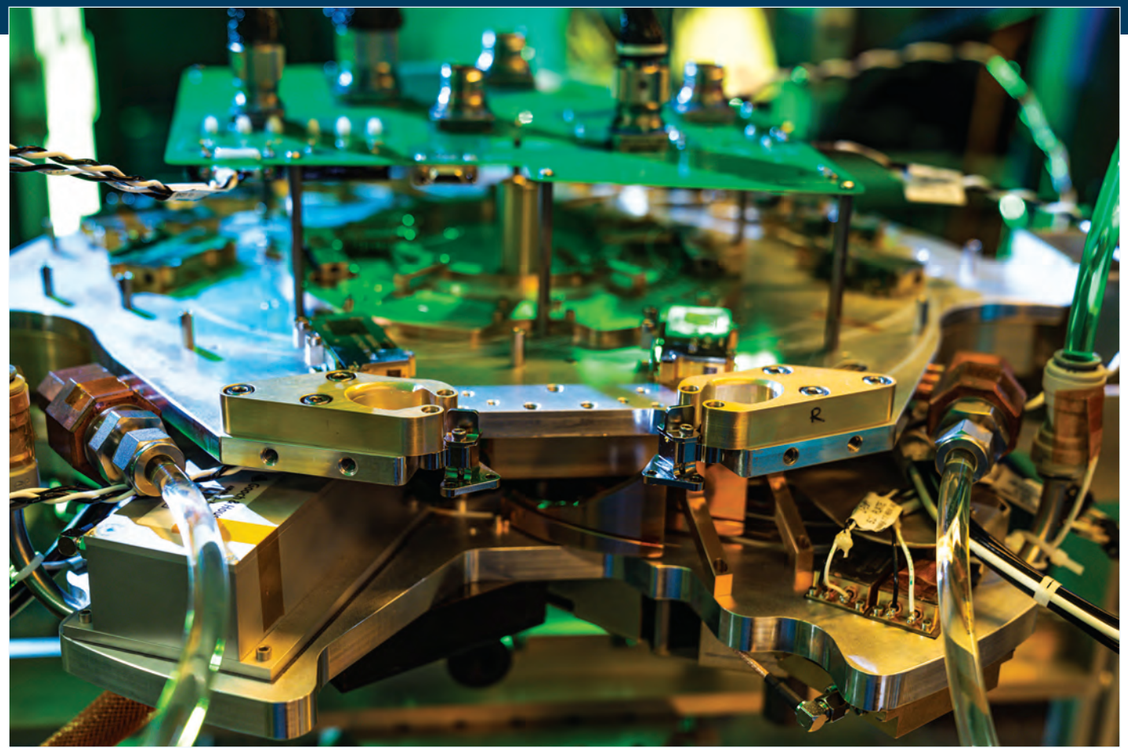
Dr. William J. Donnelly III
Asst. Division Head

Dr. Aryeh Feder
Asst. Division Head

Dr. Sung-Hyun Son
Asst. Division Head

Air, Missile, and Maritime Defense Technology

Advancing defense of the homeland, deployed forces, and allies against air and missile threats by enabling robust deterrence, assessing system architectures, prototyping pathfinder technologies, and demonstrating integrated systems for airborne, surface, and undersea defenses



The Advanced Sensor Technology Ruggedized Integrated Experiment program demonstrated a novel, highly capable ruggedized fiber-laser prototype, pictured above, suitable for future air- or space-based sensing applications.

Principal 2023 Accomplishments

- The Transportable Over-the-Horizon Radar, developed in collaboration with the Defense Advanced Research Projects Agency (DARPA), was rapidly deployed to a remote location, where it now provides a critical real-time surveillance capability.
- To enable dynamic real-time optimization of complex engagements in future fire-control systems, the Laboratory spearheaded the development and delivery of a constrained-engagement planning approach for mixed interceptor fleets.
- The Laboratory continues to drive the advancement of the Missile Defense System capabilities against advanced adversary tactics through the development of complex countermeasures. The Laboratory recently completed the development and delivery of multiple flight units for an upcoming Aegis live-fire test.
- Leveraging artificial intelligence and machine learning (AI/ML), the Laboratory developed deep learning architectures applied to maritime and undersea acoustic signature classification, anomaly detection, and oceanographic forecasting.
- The sparse-aperture acoustic ocean-mapping team developed and deployed a GPS lidar-visual-inertial odometry maritime test bed to demonstrate subcentimeter-precision relative navigation technology with multiple uncrewed surface vehicles.
- The Laboratory demonstrated new algorithms for hypersonic vehicle design and provided analysis to the DoD community. These algorithm methodologies were matured, tested, and transitioned to industry and DoD organizations.
- Laboratory staff led the development of reference algorithms, the definition and implementation of digital and RF interfaces, and the architecture and design of control software to enable large-scale, many-on-many, real-time virtual battlespaces for DARPA's Digital RF Battlespace Emulator program.

Future Outlook

Great-power competition has increased national focus on strategic deterrence and power projection, while advancing missile threats necessitate fundamental shifts to defense architectures. The Laboratory is developing sensing technologies to enable long-range engagements and driving the integration of air and missile defense.

Dynamic multidomain operations offer a competitive national advantage. The Laboratory is prototyping concepts and forging collaborations that cross traditional mission areas.

The Laboratory is developing AI and autonomy technology to address growing decision complexity.

The Laboratory is executing a portfolio to understand the pacing hypersonics threat to our nation and allies, define future architectures, and mitigate technical risks.

Radar Modernization on Kwajalein Atoll

Lincoln Laboratory recently celebrated 60 years of service as the scientific advisor to the Reagan Test Site on Kwajalein Atoll. About a dozen employees, accompanied by their families, complete multiyear assignments here in support of systems analysis, technology development and integration, and mission operations. The Laboratory is currently embarking on a major technology upgrade of the site's four world-class instrumentation radar systems, pictured right. Funded jointly by the DoD Test Resource Management Center and the U.S. Army Space and Missile Defense Command, the six-year modernization effort will help ensure the range has the technology to meet the emergent needs of the hypersonic, space control, and missile development communities.

Communication Systems

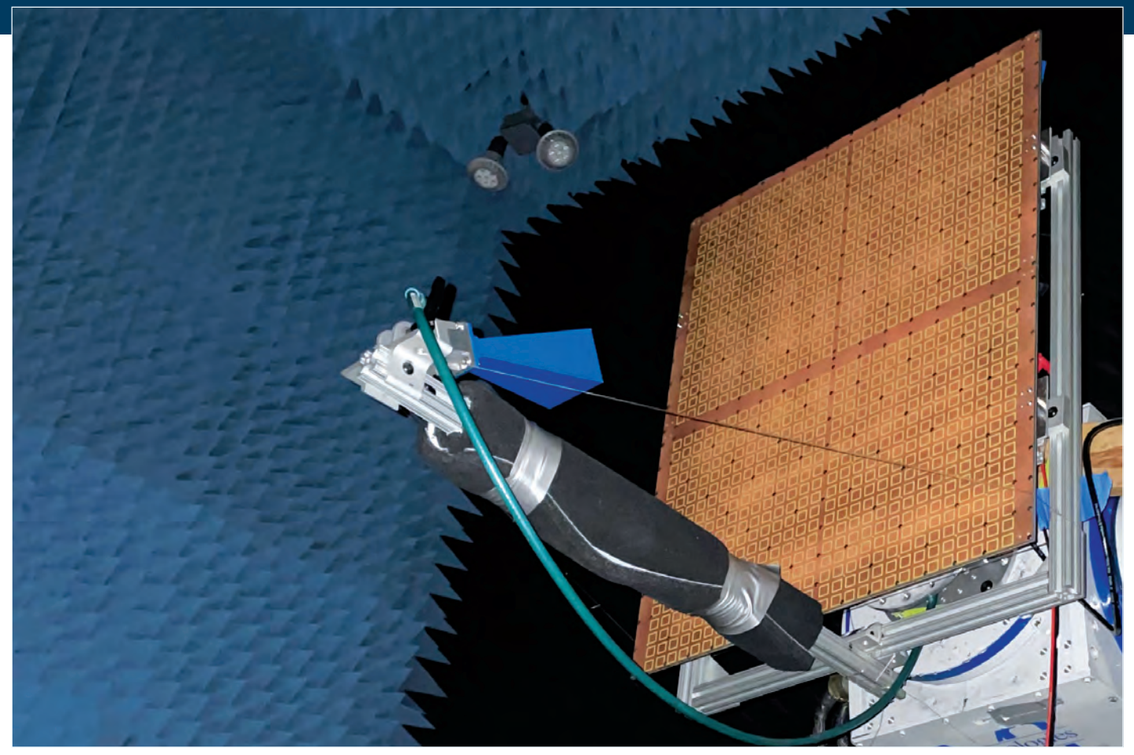
Advancing communication capabilities for national security and space exploration through technology development in satellite communications, robust networking, laser communications, quantum systems, and agile spectrum operations

Leadership

Dr. Thomas G. Macdonald
Division Head

Dr. James Ward
Assoc. Division Head

Dr. Michele A. Schuman
Asst. Division Head



The adaptively beamformed reflectarray prototype (copper square with blue feed antenna)—developed in collaboration with the Advanced Technology mission area—provides a low-cost solution for X-band radio communication links to operate in congested spectrum and interference.

Principal 2023 Accomplishments

- A Laboratory-developed laser communications (lasercom) space terminal was launched by NASA to the International Space Station to demonstrate high-rate communications with the Laser Communications Relay Demonstration satellite.
- Through multiple 2023 flight campaigns, the Laboratory demonstrated network protocols that enable reliable and timely information across highly asymmetric and high-latency airborne data links.
- The Laboratory prototyped and transferred to industry a government-owned, local-area space-to-space communications waveform that provides robust, meshed communications capability for satellites.
- Through DoD FutureG Office–funded research, the Laboratory demonstrated a method for restoring the performance of radar systems in the presence of commercial 5G co-channel spectrum occupancy.
- During the Northern Edge 2023 field training exercise, the Laboratory's prototype Protected Tactical Waveform joint hub was deployed to demonstrate airborne use of the waveform in an operational environment.
- In a single five-minute pass, 4.8 terabytes of data were downloaded from the Laboratory-designed and -built TeraByte InfraRed Delivery lasercom payload launched last year onboard a satellite into low Earth orbit (LEO).
- A novel air-to-air communication system between an airborne radar and a Laboratory-developed small-form-factor software-defined radio was field tested.
- The Laboratory developed and tested a next-generation telescope using free-form optics.
- The Laboratory demonstrated the viability of airborne host platforms to support a rapidly deployable vertical electric monopole antenna system used for national communication initiatives.

Future Outlook

Precision synchronization of quantum uplinks to satellites will enable picosecond-level time-of-arrival control of qubits from different ground stations.

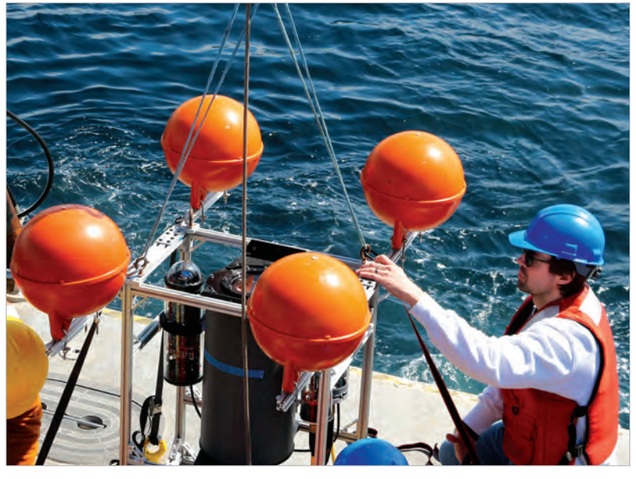
New space networking capabilities will be defined to enable robust and dynamic DoD space-to-theater data dissemination via a hybrid DoD and commercial architecture.

A path-to-flight proliferated LEO prototype will demonstrate a new narrowband waveform and low-complexity beamforming for robust communications.

Machine learning techniques will be used to characterize the electromagnetic spectrum and adaptively change antenna beam patterns and signals to optimize reception of DoD communications.

Air-Sea Optical Communication

Lincoln Laboratory developed a system for bidirectional optical communication through the air-sea interface. This system demonstrated 20 Mb/s data rates from a helicopter down to an undersea platform and 5 Mb/s up. At right, W. John Nowak prepares to deploy the system to conduct tests off the coast of San Diego. These tests showcased capabilities including automatic acquisition and tracking of narrow beams from a moving platform and robust communication despite midday background sunlight. Fully automatic processing of all tracking and communication functions was implemented in low–size, weight, and power electronics.



Cyber Security and Information Sciences

Conducting research, development, and evaluation of cyber components and systems, and developing solutions for processing large, high-dimensional datasets acquired from diverse sources, including speech, imagery, text, and network traffic

Leadership

Mr. Stephen B. Rejto
Division Head

Dr. Marc A. Zissman
Assoc. Division Head

Mr. Jeffrey C. Gottschalk
Asst. Division Head

Dr. Joseph P. Campbell
Laboratory Fellow

Dr. Jeremy Kepner
Laboratory Fellow

Melinda Burns, front, and Richard Gentile inspect an RF sensor to be loaned to a U.S. government sponsor for use in theater. This prototype unit builds on the hardware and processing architecture developed in recent years by the Lincoln Experimentation and Novel Technology Innovation Lab team.

Principal 2023 Accomplishments

- Field demonstrations were conducted of newly developed cyber-RF capabilities intended to provide advantages for joint forces in highly contested environments.
- To improve U.S. Space Command's capacity to execute its mission in a cyber-contested environment, the Laboratory created mission-dependency models of satellite command-and-control infrastructure and participated in the OUSD(A&S)-led Mission Resiliency II wargame alongside the U.S. Indo-Pacific Command, U.S. Cyber Command (USCYBERCOM), and Department of the U.S. Air Force (DAF).
- With USCYBERCOM and the DoD Chief Information Officer, the Laboratory created the congressionally mandated five-year roadmap on the development, acquisition, deployment, and sustainment of AI for mission advantage under the National Defense Authorization Act, Section 1554.
- The Laboratory is performing assessments and producing capabilities to evaluate the vulnerabilities of AI systems. To date, Laboratory researchers have successfully performed red team evaluations and proposed defenses of discovered AI vulnerabilities in cyber, vision, and language systems.
- Through the DAF-MIT AI Accelerator, the Lincoln Laboratory Supercomputing Center enabled advanced technology demonstrations in global synthetic weather radar, squadron scheduling, and magnetic navigation.
- The Air Force cyber red team performed assessments that critically informed the development and acquisition of key systems.
- The Laboratory continued to develop its cyber-resilient operating system layer, Magnetite. Efforts included architecting and developing high-assurance software cryptography and cyber-hardened software for small satellites. Prototypes were delivered to the Intelligence Community and Air Force Research Laboratory Space Vehicles Directorate.
- USCYBERCOM selected a Laboratory staff member to assume a chief technical leadership role for their Joint Cyber Warfighting Architecture effort. The Laboratory delivered prototypes that are enhancing the capability, resiliency, and survivability of joint cyber operations.

Future Outlook

The Lincoln Laboratory Supercomputing Center will continue to grow the Laboratory's and MIT's world leadership in interactive supercomputing, AI, big data, and machine learning.

The Laboratory will develop, test, and transition leap-ahead capabilities for the United States, leveraging strengths in microelectronics, quantum sensing, communications, and electronic warfare.

The Laboratory is working closely with sponsors and academia to create an AI center to address critical challenges facing the U.S. government, including threats from and opportunities posed by generative AI.

Novel methodologies and technical prototypes will be developed for instrumenting, reverse engineering, and analyzing embedded systems to understand their potential cyber vulnerabilities.

Securing Uncrewed Systems

The Security/Cyber Module End Cryptographic Unit (SCM ECU), shown right, is the latest National Security Agency–certified encryptor to be transitioned from the Laboratory, protecting classified data links among uncrewed systems. The SCM ECU was built to be compatible with open DoD standards and features advanced key management capabilities found only in this technology. Full-rate production of the unit began in 2023 to serve U.S. Navy explosive ordnance disposal missions. Lincoln Laboratory continues to advance the open-architecture radio concept, addressing future quantum-computing threats and incorporating advanced transmission-security capabilities.

ISR Systems and Technology

Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

Dr. Marc N. Viera
Division Head

Dr. Daniel J. Ripin
Asst. Division Head

PHOENIX High CASTLE—a next-generation photon-counting 3D imaging lidar sensor funded by the U.S. Army Engineer Research and Development Center's Geospatial Research Laboratory—is hoisted into the Army C5ISR (Command, Control, Communications, Computers, Cyber, ISR) aircraft.

Principal 2023 Accomplishments

- The Laboratory continued to devise and analyze ISR and air dominance concepts. Detailed modeling and systems analyses assessed the potential impact of advanced technologies and innovative system-of-system architectures, with a focus on joint-service and multidomain capabilities for contested environments.

- The Laboratory began an effort with the new Department of the Air Force (DAF) Program Executive Office for Command, Control, Communications and Battle Management. Mission-based assessments and prototyping of communications, command and control battle management architectures, and additional supporting technologies are informing potential investments in key future DAF Battle Network components and establishing requirements to guide system acquisition.

- At the Emerald Flag 23-2 exercise at Eglin Air Force Base, the Laboratory employed the Airborne Radar Testbed (ARTB) and other flight assets to demonstrate several new airborne capabilities. Demonstrations included the remote tasking of the ARTB's multi-intelligence sensing, processing, and communication payloads to collect and disseminate data products in a machine-to-machine fashion in tactically representative scenarios.

- The Laboratory continued to develop multistatic radar concepts and algorithms for combining information from high-resolution imaging and other ISR modalities collectable in contested airspace. The algorithms were prototyped and demonstrated using ARTB flight data from multiple noncooperative emitters.

- Using a new generation of Geiger-mode lidar, the PHOENIX High CASTLE (PHOton Exploration and Novel Imaging eXperiments High-altitude Collaborative Airborne System for Tactical Lidar Experimentation) standoff imaging system demonstrated beyond-state-of-the-art 3D resolution from an airborne platform.

- Researchers completed the latest generation of the Noncontact Laser Ultrasound. This medical imaging device seeks to overcome limitations of traditional contact probes and shows promise for DoD and civilian applications.

Future Outlook

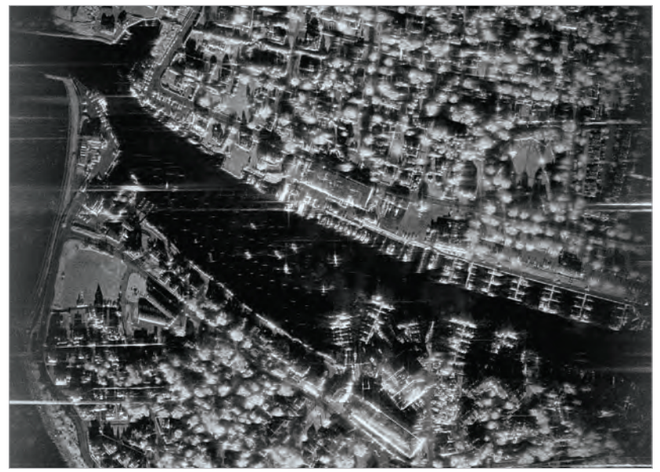
The Laboratory will continue to develop and analyze novel concepts and advanced technologies with the potential to create revolutionary ISR capabilities.

The Laboratory will increase its impact on architectures and technologies for Joint All-Domain Command and Control by developing techniques for distributed battle management, combining expertise in edge computing, data architectures, cybersecurity, and networking.

The Laboratory will continue to lead the DoD community in applying optical and radar sensing to new applications, concentrating on novel sensing bands, multiplatform operations in relevant scenarios, and new optical techniques for long-range and high-frame-rate sensing.

SAR Imaging

Synthetic aperture radar (SAR) can generate high-resolution imagery from long ranges, during day or night, and through cloud decks. Shown at right is a Ku-band SAR image of Falmouth Harbor in Cape Cod, Massachusetts, that was collected by the Laboratory's ARTB. The ships and their mooring buoys stand out in bright contrast against the less-reflective saltwater background. The location of the shadows of the buildings in the top-left portion of the image, for example, indicate that the ARTB was below the scene when this image was collected.



Tactical Systems

Improving the development of tactical air and counterterrorism systems through systems analysis to assess the impact of technologies on real-world scenarios; rapidly developing prototype systems; and conducting precise instrumented testing of systems

Leadership

Dr. Marc N. Viera
Division Head

Dr. Daniel J. Ripin
Asst. Division Head

Dr. Janet T. Hallett
Group Leader

Dr. Emily E. Lesser
Group Leader

Using Boston Dynamics' Spot robot, Eric Cristofalo, left, and Dan Griffith test a real-time, hierarchical, indoor, sparse-mapping algorithm called Hydra. The advanced algorithm supports complex navigation with very low–size, weight, and power requirements.

Principal 2023 Accomplishments

- Lincoln Laboratory hosted the 10th annual U.S. Air Force Family of Systems Technical Review for Government in collaboration with the Department of the Air Force Rapid Capabilities Office. The meeting involved more than 350 attendees representing the Services, Intelligence Community, Combatant Commands, and FFRDC/UARCs, including 12 general officers and 35 senior executive service members. The keynote was given by Vice Admiral Sara Joyner.

- The Laboratory developed and transitioned the foundations of an open battle management architecture in support of the U.S. Navy. The architecture was implemented to demonstrate command, control, and data sharing through integrated surveillance, weapon, and platform support. A roadmap will be maintained to show how the architecture will evolve over time to integrate with the U.S. Air Force and other DoD systems.

- Researchers completed systems analyses and engineering assessments of candidate technologies to address challenging mission problems for U.S. Air Forces Europe (USAFE). This work is briefed regularly to USAFE leadership and is supporting their development of strategies for evolving operational capabilities.

- Working closely with the U.S. European Command and Component Commands, with support from OUSD R&E Innovation and Modernization, and other DoD stakeholders, the Laboratory is providing capabilities to support both urgent needs in the theater and longer-term U.S. and NATO security requirements. Analysis and prototyping efforts included novel, low-cost capabilities for countering adversary uncrewed air vehicles and robust intelligence, reconnaissance, and surveillance technologies and platforms.

- The Laboratory continued assessing the threat of long-range engagements and technology options for ensuring U.S. air dominance, focusing on identifying system requirements to counter evolving adversaries in a diverse mission set and across multiple domains. These studies combine understanding of adversary capabilities and U.S. technologies to inform future Air Force acquisition decisions.

Future Outlook

Lincoln Laboratory researchers will continue to conduct systems analyses, laboratory testing, and flight-system data collections that inform assessments of the performance and limitations of U.S. Air Force aircraft against current and future threats. These assessments include investigations of missile system performance, electronic attack and protection, and radio-frequency (RF) and advanced infrared kill chains.

To support these efforts, the Laboratory will continue partnering with the government to make substantial investments in hardware development and integration to recapitalize the current Tactical Systems test infrastructure. These efforts will align capabilities with the evolving multidomain threat and will include airborne sensor test beds and prototyping of new airborne and ground-based RF and IR sensors to facilitate future testing.

Integrated Ka-band Radar Instrumentation System

Recently, Lincoln Laboratory modified the U.S. Department of the Air Force Red Team's newest airborne test bed, a Gulfstream IV-SP, with a centerline pylon that enables the aircraft to carry large sensors to support flight testing for a range of DoD programs. These flight tests evaluate both the effectiveness and functionality of the programs' systems, drive solutions to identify capability gaps, and feed data into detailed systems analyses. A key Red Team sensor, the Integrated Ka-band Radar Instrumentation System, was installed onto the test bed in preparation for an upcoming flight test campaign.

Advanced Technology

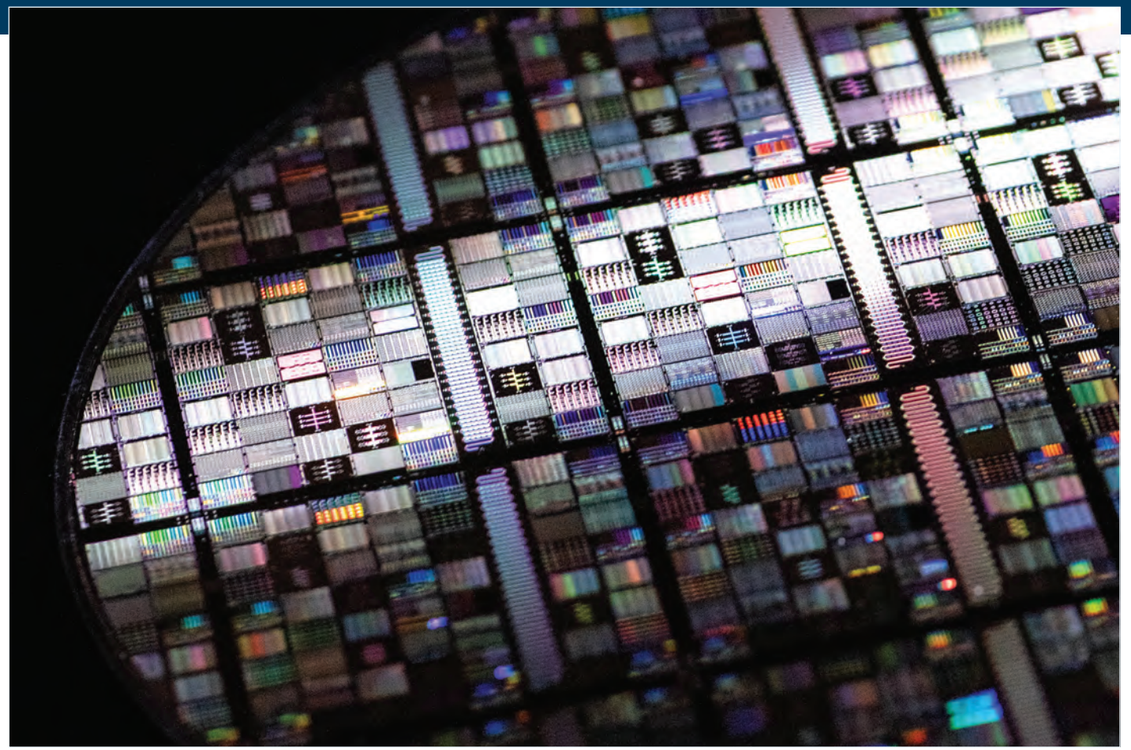
Leveraging solid-state electronic and electro-optical technologies, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

Leadership

Dr. Robert G. Atkins
Division Head

Dr. Craig L. Keast
Assoc. Division Head

Dr. Mark A. Gouker
Asst. Division Head



This superconducting qubit wafer was fabricated as part of the Superconducting Qubits at Lincoln Laboratory (SQUILL) Foundry program. Through the SQUILL foundry, the Laboratory is expanding access to quantum research by fabricating quantum circuits for U.S. research organizations.

Principal 2023 Accomplishments

- The Laboratory developed and demonstrated advanced camouflage designs as a counter to evolving adversary capabilities in intelligence, surveillance, and reconnaissance. The project involved several phases, including material development, swatch-sized sample evaluation, and a field demonstration of a design on a scaled model. Results indicate that the performance of the camouflage would improve survivability for a variety of tactical and strategic systems.

- A demonstration was conducted of a breadboard laser the Laboratory is developing for use as a transmitter in a space-based lidar system intended to make global measurements, at a high spatial resolution, of water-vapor concentration in the atmosphere. Compared to other approaches for a space-based water-vapor lidar transmitter, this laser technology showed higher power, higher efficiency, and simpler laser architecture—all parameters key for deployment.

- A wideband direction-finding receiver was deployed to Hawaii for sea testing during an exercise. The system's wideband, tunable RF front end digitizes the received spectrum and channelizes the data for storage onto a high-speed data recorder. Developed for a U.S. Navy sponsor, the system is extending the performance of wideband RF geolocation systems.

- The Laboratory demonstrated CCD imagers with repetitive nondestructive readout. Each pixel of the CCD is sampled multiple times, reducing the read noise to deep, subelectron levels. This technology will enable new applications that require single-photon counting or precise energy discrimination of high-energy photons and particles.

- Silicon-nitride spiral resonators fabricated in the Microelectronics Laboratory demonstrated an ultrahigh quality factor of 300 million, enabling access to optical nonlinear processes such as stimulated Brillouin scattering on chip. Using these spiral resonators, Laboratory researchers demonstrated ultrastable chip-based lasers for use in atomic clocks. These lasers can be interfaced with an atom to perform timekeeping at a precision better than one part in 10^{14}.

Future Outlook

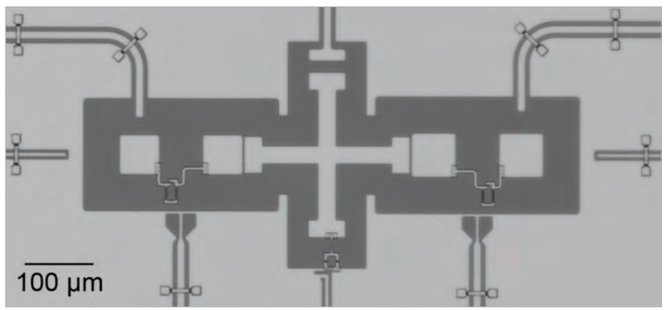
Hands-free event monitoring is important in many civilian and DoD applications. A new program will integrate audio, video, and geolocation sensor systems into fibers and fabrics that feature the same washability and comfort of regular textiles. The Laboratory has delivered baseline systems for all three sensor types to benchmark the current state of the art.

The Laboratory has designed low-temperature silicate-glass materials that will be critical to creating wafer-scale packaging solutions for advanced 3D-heterogeneous-integration microsystems.

A modified chemical-vapor-deposition system and silica draw tower will enable the Laboratory to produce state-of-the-art fiber amplifiers, incorporating advanced large-mode-area designs, highly doped fibers for pulsed-based systems, and matching passive-delivery fibers.

Fluxonium Qubits

Quantum computation offers the promise of solving certain classes of problems exponentially faster than classical computers. A major bottleneck for the realization of a large-scale quantum processor is the error rate of single- and two-qubit operations. The Laboratory and MIT campus demonstrated fluxonium circuits in an on-chip architecture with record-breaking qubit lifetimes of 1.3 ms, leading to > 99.99% and > 99.9% fidelities for single- and two-qubit gates, respectively. The image at right shows two long-lifetime fluxonium qubits capacitively coupled to a tunable-transmon coupler (shown in the center of the image). This device was fabricated at the Laboratory and is currently being evaluated by the joint research team.



Homeland Protection

Innovating technology and architectures to help prevent attacks on the U.S. homeland, to reduce the vulnerability of the nation to terrorism, and to improve the security and resiliency of critical infrastructure, including energy systems, against natural and human-made threats

Leadership

Dr. Jennifer A. Watson
Division Head

Dr. James K. Kuchar
Asst. Division Head

Dr. Jonathan D. Pitts
Asst. Division Head

Dr. Chris A.D. Roeser
Asst. Division Head

Francesca D'Arcangelo, left, and Alexandra Chin develop and evaluate surveillance and tracking systems for air defense of U.S. bases. An operational test bed with instantiations at the Laboratory and in Europe supports rapid integration of industry sensors and algorithms.

Principal 2023 Accomplishments

- Methods to detect narratives and reveal causal-influence pathways in complex networks were developed and applied to DoD operations in the information environment.
- The Laboratory supported the U.S. Coast Guard through systems analysis of critical operational challenges leveraging novel on-ship data collection campaigns.
- The Laboratory developed a scalable risk-assessment operational prototype for critical infrastructure that integrates cost-benefit analyses for optimal resource allocation.
- The Laboratory enhanced its AI-enabled decision support technologies for border security, deploying new edge capabilities for detection and tracking of objects of interest within surveilled maritime environments.
- An operational prototype of an air-base air-defense system at Ramstein Air Base was employed by the U.S. Air Forces Europe in multiple exercises. The fusion of disparate sensing modalities and advanced tracking and decision support tools enhances operators' situational awareness of the airspace.
- A prototype passive radar system was developed to mitigate impacts of wind turbines on securing the national airspace.
- A new architecture for processing concealed-threat screening data for security checkpoints was demonstrated. The architecture combines data from multiple standoff sensors to clear individuals as they pass by.
- The Laboratory worked with industry leaders to quantify the effects of different crowd control configurations at music festivals to improve safety and security at mass gatherings.
- Energy-resilience readiness exercises were conducted at DoD installations to identify potential operational vulnerabilities resulting from disruption of the electrical grid.
- The Laboratory served as the technical lead on a joint government and industry effort that developed a new military microgrid standard. This standard will enhance the scalability, modularity, and resiliency of DoD operational energy architectures.

Future Outlook

Securing the nation and responding to the spectrum of emerging threats necessitates new architectures for sensing hostile activities and characterizing environmental conditions. The Laboratory will develop highly capable sensors adopting advances in low–size, weight, power, and cost electronics.

Open architectures for leveraging data, applying AI, and providing secure environments in the cloud will enable advanced command-and-control systems for homeland and base air defense, protecting critical infrastructure, securing borders, and countering influence operations.

Critical infrastructure protection and domestic resilience will compel advancements in cybersecurity, advanced energy, and defense against hostile foreign influence operations.

Resilient Infrastructure Monitoring System

The Laboratory has executed more than 20 energy-resilience readiness exercises in which power to a DoD installation is turned off to assess real-world mission readiness during natural disasters or adversary attacks. To enable real-time data collection and increased situational awareness during exercises, the Laboratory developed a deployable sensing and communication system consisting of multimodal sensors that can operate during long periods of power outages. In the photo, the yellow boxes contain acoustic, vibration, and RF sensors, and the gray boxes contain nodes for communication relay and cyber-secure data exfiltration. Data collected from this system are used to identify potential infrastructure vulnerabilities and support development of mitigation approaches.

Biotechnology and Human Systems

Advancing technologies and systems for improved chemical and biological defense, human health and performance, responses to the impacts of climate change, and resilience to both natural and human-made disasters

Leadership

Mr. Edward C. Wack
Division Head

Dr. Jeffrey S. Palmer
Asst. Division Head

Dr. Christina M. Rudzinski
Asst. Division Head

Arianna Comendul, left, and Victor Cabrera assess cell cultures as part of their work developing a methodology to empirically measure vast numbers of antibody binding reactions. This capability is critical to effectively and rapidly predict and produce the next generation of medical treatments.

Principal 2023 Accomplishments

- Lincoln Laboratory developed and delivered to the U.S. Agency for International Development a prototype software system that tracks food-aid shipments to improve the efficiency of international humanitarian assistance.
- Researchers continued prototyping the Climate Resilience Early Warning System Network (CREWSnet), a climate forecasting and adaptation decision support tool, to aid communities across the globe. CREWSnet is one of MIT's five flagship Climate Grand Challenges projects.
- The Laboratory computationally analyzed the effectiveness of combining various medical countermeasures, such as vaccines and therapeutics, to assess treatment plans based on specific operational environments for the U.S. military.
- Staff leveraged data from particle-dispersion exercises, led by the Laboratory in New York City last year, to recommend advances to U.S. biodetection and response architectures.
- During the Able Resolve 2023 biothreat exercise hosted by the U.S. Indo-Pacific Command, the Laboratory ascertained key capability needs for developing a future interagency biosurveillance capability.
- Laboratory staff are developing a hardware prototype of a small sensor that uses rapid polymerase chain reaction methods to detect biological threats in under 10 minutes.
- At the joint U.S. and Australian Talisman Sabre exercise, the Laboratory demonstrated wearable sensors and algorithms that can be used to provide early warning of disease for both military and civilian populations.
- Innovative bioengineering and chemical synthesis capabilities, along with process optimization tools, are being developed to improve the security and resilience of supply chains for critical defense materials.
- The Laboratory partnered with the U.S. Navy to improve sailor performance by developing an offline system that leverages wearable sensor data and algorithms to measure sleep and detect fatigue.

Future Outlook

Improving humanitarian assistance, global health, and disaster response activities, and reducing the security impacts of global climate change, will motivate work on advanced architectures, sensors, and analytics.

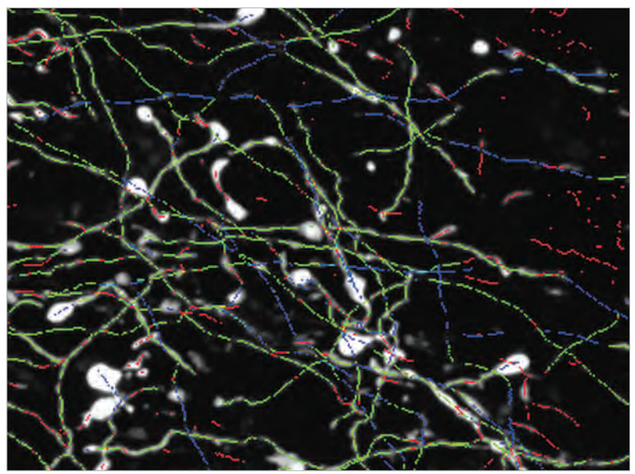
The Laboratory will develop advanced technologies and system architectures for chemical and biological threats, including pandemics, to protect deployed forces and civilians.

Improving soldier health and performance will require advances in brain-related technologies, physiological sensors, and engineered and synthetic biology.

Artificial intelligence will be leveraged to interpret vast amounts of biological and health data, assist in decision-making, and provide insights for new discoveries.

AI-Guided Brain Mapping

The Neuron Tracing and Active Learning Environment (NeuroTrALE), developed in collaboration with MIT Prof. Kwanghun Chung, is an artificial intelligence tool that automates and boosts the efficiency of long-range axon tracing in volumetric microscopy images. Such tracing improves the accuracy of brain-connectivity atlases, which will help researchers understand the structural and functional basis of neurological diseases. In the 3D brain microscopy image at right, green indicates correctly traced axons, while red and blue indicate segments that require inspection by human reviewers. NeuroTrALE is now available to the neuroscience community as the Laboratory continues to increase the tool's accuracy and ability to trace human brains at the subcellular level.



Air Traffic Control

Developing advanced technologies and decision support architectures for surveillance, integrated weather sensing and processing, collaborative traffic management, information security, and optimization to support the nation's air transportation and logistics systems

Leadership

Dr. Jennifer A. Watson
Division Head

Dr. James K. Kuchar
Asst. Division Head

Dr. Jonathan D. Pitts
Asst. Division Head

Dr. Chris A.D. Roeser
Asst. Division Head

Mr. James M. Flavin
Principal Staff

The Laboratory is developing airspace management algorithms in support of a collaborative NASA program. Here, a University of Texas at Austin researcher and a Laboratory intern configure a vehicle from the Laboratory's small uncrewed aircraft systems test bed prior to a flight demonstration.

Principal 2023 Accomplishments

- The Laboratory conducted analyses leading to international approval of the Airborne Collision Avoidance System X (ACAS X) for large uncrewed aircraft. Development of an ACAS X variant for rotorcraft and advanced air mobility continues.
- The Laboratory supported technology development and analysis to enhance Federal Aviation Administration (FAA) air traffic management capabilities, weather sensing and processing systems, and environmental impact mitigation, and to enable the integration of space and urban air mobility operations into the airspace.
- The Advanced Technology Demonstrator, a dual-polarization phased-array radar developed in part by Lincoln Laboratory, was used to collect data for weather research in collaboration with the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory in Norman, Oklahoma. The Laboratory began fabrication of a two-panel proof-of-concept engineering radar that will demonstrate its next-generation, all-digital phased-array technology.
- The Laboratory deployed to Toronto Pearson International Airport prototype systems that predict weather impacts on airport and airspace capacity. These deployments are part of a suite of integrated technologies being developed in collaboration with NAV CANADA.
- The Laboratory is supporting zero-trust cybersecurity architecture use in air traffic control systems. The Laboratory is also developing technologies that use artificial intelligence and machine learning to assess, detect, and mitigate aviation cybersecurity threats across the commercial aviation ecosystem.
- The Laboratory continues to support the Department of Defense's weather tracking and forecasting needs through the development of synthetic weather radar, contrail forecasting capabilities, and numerical weather model blending algorithms.
- The Laboratory continues to support the U.S. Transportation Command and its component commands. Decision support tools were developed to address agile basing, mass casualty operations, optimized mission planning, predictive maintenance, and assessment of logistics options.

Future Outlook

The Laboratory will continue to develop advanced aviation system concepts, including trajectory-based operations, collision avoidance, new airspace entrants (e.g., commercial space, high-altitude operations, and urban air mobility) and environmental impact reduction. Cybersecurity efforts will address potential vulnerabilities in aviation systems. Innovation in weather capabilities will focus on sensing technologies and algorithms for managing airspace capacity. Meteorological surveillance of severe storms will continue to improve as next-generation phased-array radar systems are developed. Advanced techniques will be leveraged to forecast weather and system demand and to allocate resources more efficiently and effectively for civilian and Department of Defense transportation applications. The Laboratory will also continue to develop technical performance standards, safety evaluation methods, and threat-avoidance algorithms for aviation.

Detect-and-Avoid Technology Evaluation

The Laboratory is conducting research and development to enable the use of uncrewed aircraft for government and commercial flight operations. These projects include developing systems to detect and avoid other air traffic, performing risk assessments of operational areas and procedures, and evaluating new surveillance sources such as lower-cost primary radars and electro-optical sensors. Here, a government helicopter serves as a test target in a Laboratory evaluation of primary radar to support small uncrewed aircraft operations. Following their approval by the FAA, surveillance technologies such as this radar can be integrated into a suite of sensors to enable the detect-and-avoid capabilities of ACAS sXu, a collision avoidance system for small uncrewed aircraft.

Engineering

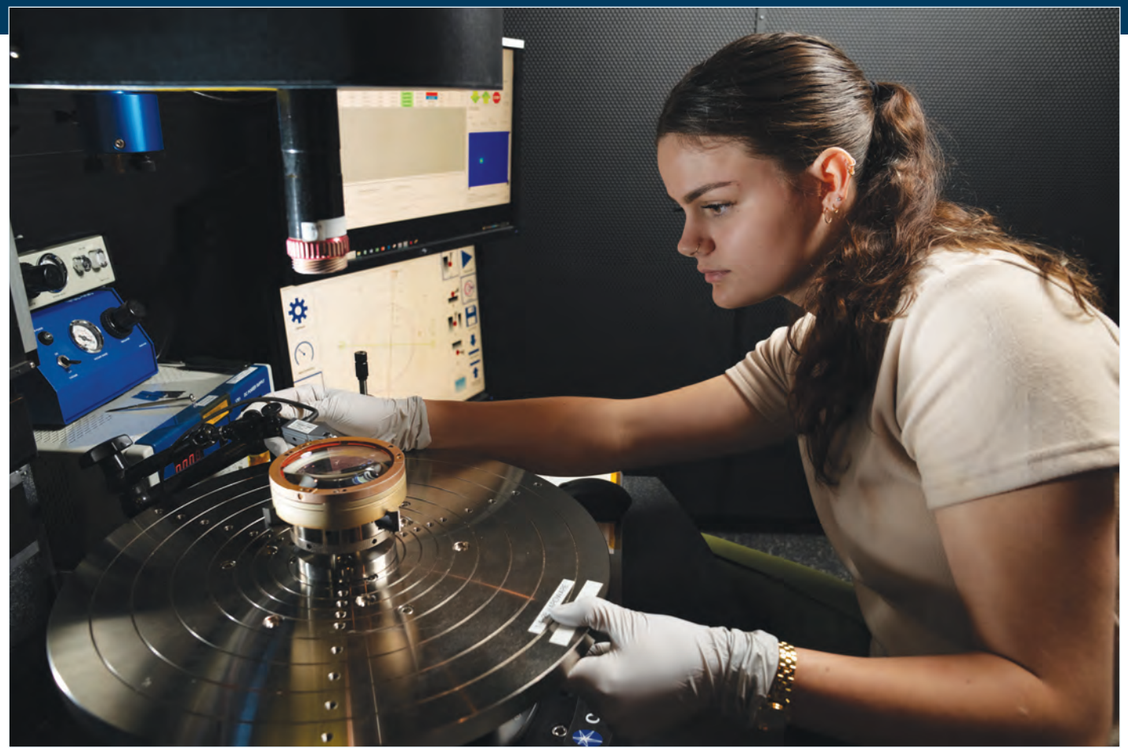
Employing expertise in a broad range of interdisciplinary engineering fields to design, build, integrate, test, and field advanced prototype systems and enabling technologies

Leadership

Dr. Ted David
Division Head

Dr. Keith B. Doyle
Asst. Division Head

Kristin N. Lorenze
Asst. Division Head



The Laboratory has developed a compact hyperspectral spectrometer that achieves state-of-the-art optical and signal-to-noise performance while being significantly smaller than existing spectrometers. Here, Bayleigh Nugent aligns an optical element for the hyperspectral imaging spectrometer.

Principal 2023 Accomplishments

- The Laboratory collaborated with the U.S. Space Force and Japanese collaborators to deliver two space payloads that will be hosted on Japanese satellites. The payloads will augment space domain awareness capabilities.
- An advanced laser detection and ranging system was installed on a C5ISR Twin Otter aircraft to characterize complex and urban environments for the U.S. Army, funded by ERDC GRL. The system captured 15 terabytes of high-quality imagery over Maryland, Virginia, and parts of downtown Washington, D.C.
- The Laboratory is continuing to develop and mature technologies in support of critical national needs for hypersonic applications. A risk reduction prototype of a key enabling capability was successfully flight tested at hypersonic conditions. This effort leveraged the Laboratory's rapid prototyping capabilities in advanced design, vehicle payload testing, and high-fidelity modeling and simulation.
- A prototype antenna payload to measure radio emissions from space auroras for NASA was developed. The antenna will be used to better understand the upper layers of the Earth's atmosphere and how solar emissions interact with the Earth.
- The Laboratory has continued to deepen its utilization of digital engineering tools by implementing model-based design workflows for software, firmware, and hardware co-design and testing that increase the speed of system development.
- Numerous new capabilities have elevated the precision, accuracy, range, capability, and throughput of the Laboratory's fabrication shops, enabling higher-performing prototype systems needed for modern national security applications.
- The Laboratory developed novel modeling and simulation tools, including machine learning algorithms that drastically reduce aerodynamic analysis computation time, multidisciplinary modeling techniques that compute pointing errors when viewing through hypersonic flow fields, and the ability to predict the behavior of very-low-Earth-orbit satellites.

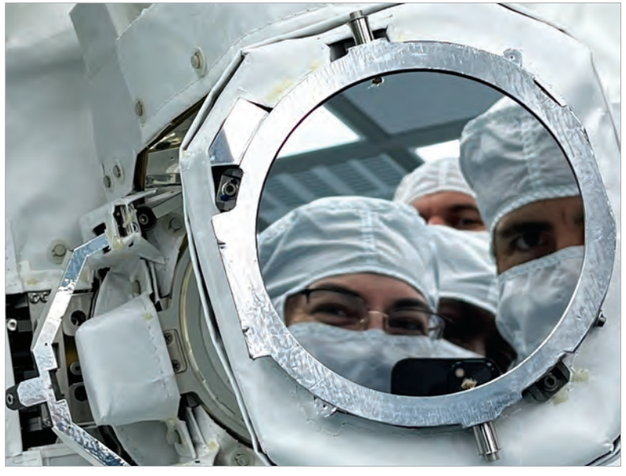
Future Outlook

The Engineering Division is working with architecture firms to finalize the design of the new Engineering Prototyping Facility that will enable the Laboratory to develop increasingly complex prototypes to address future national security needs. Construction is expected to start in 2025, and the building is scheduled to open in 2027.

The Laboratory's increasing utilization of digital engineering processes will accelerate the development of novel and innovative prototypes through the adoption and development of model-based practices, physics-based simulations, shared data, and artificial intelligence. The Laboratory will also extend connections to relevant Department of Defense strategic efforts to streamline the development of fully integrated platforms and to deliver capabilities more rapidly.

ILLUMA-T Final Inspection

Lincoln Laboratory's Steve Gillmer and Kyle McAnney, along with NASA's Lamont Franklin and Trisha Randazzo, are shown performing the final inspection of the ILLUMA-T (short for Integrated Laser Communications Relay Demonstration Low Earth Orbit User Modem and Amplifier Terminal) Optical Module solar rejection window at the Kennedy Space Center prior to the system's integration into the SpaceX Dragon capsule. ILLUMA-T was successfully launched to the International Space Station on November 9, 2023, for a six-month demonstration mission as part of the Laser-Enhanced Mission Communications Navigation and Operational Services program, also known as LEMNOS, a joint effort between Lincoln Laboratory and the NASA Goddard Space Flight Center.



TECHNOLOGY INVESTMENTS

A custom-designed active-mixing nozzle uses specially tailored nanocomposite inks to additively manufacture RF devices.

Technology Investments

THE TECHNOLOGY OFFICE

The Technology Office manages Lincoln Laboratory's strategic technology investments and helps to establish and grow technical relationships outside the Laboratory.

LEADERSHIP

(Left to right)

Dr. Q. Chelsea Curran
Associate Technology Officer

Dr. Sandeep S. Pisharody
Associate Technology Officer

Ms. Heidi C. Perry
Chief Technology Officer

Dr. Shireen M. Warnock
Associate Technology Officer

Investments cultivated and managed by the Technology Office support the development of new technology and seed collaborations and ideas that push the frontiers of innovation.

The Technology Office

- Oversees investments in both mission-critical technology and potentially impactful emerging technology
- Interacts regularly with the Office of the Under Secretary of Defense for Research and Engineering and other government agencies to maintain awareness of emerging national security problems and applicable technologies
- Fosters collaborations with MIT campus and other university researchers
- Aids in the transfer of next-generation technology to the Laboratory's mission areas
- Enhances inventiveness at the Laboratory through various investments and programs that promote a culture of innovative thinking and creative problem solving

TECHNOLOGY OFFICE INVESTMENT AREAS

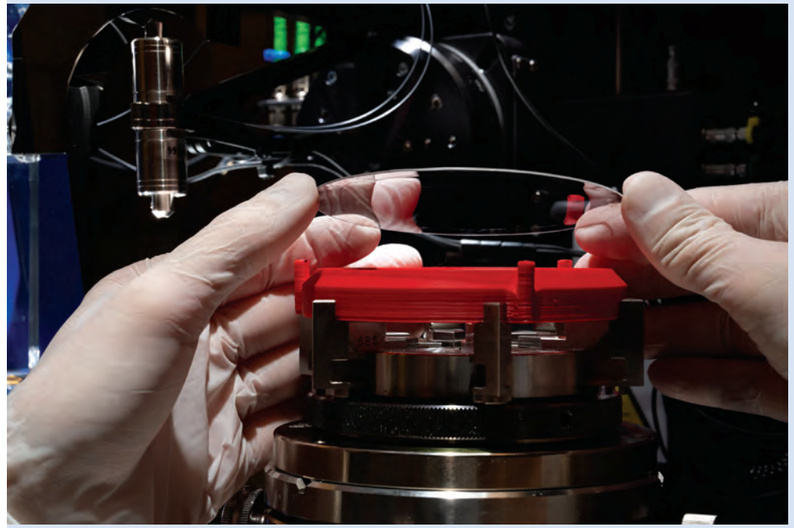
INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

Enabling development of technologies that address long-term challenges and emerging issues within the Laboratory's core mission areas

Optical Systems Technology

Research into optical systems technology enables future mission capabilities in ISR and communications. The goal of this research is to fill critical technology gaps in emerging DoD threat areas. Projects emphasize research in lidar, high-energy lasers, imaging systems, optical communications, and novel optical components. In 2023, the Laboratory made notable progress in several efforts:

- Designed and modeled a thin, switchable-emissivity device that will enable novel thin-film radiators for small satellites and other systems. This device utilizes electrowetting technology to create a surface that can rapidly switch between high and low emissivity. A detailed model was developed to predict device performance based on material selection. Optimized material pairs have been selected for the device, and spectral performance of the materials has been characterized.
- Designed and prototyped a thin, multiple-bounce optical telescope that significantly reduces the volume of a conventional Cassegrain-style telescope. This telescope utilizes a Laboratory-developed microbaffle array for stray-light rejection. The volume reduction of the telescope enables large-aperture optical systems that fit within volume constraints of small satellites deployable from secondary payload systems on orbital launch vehicles.
- Invested in a number of novel mission-enabling concepts. For example, staff conducted research on a coherent lidar concept for identifying ground-moving targets through dense foliage.
- Demonstrated a pressure-tolerant, underwater, wide-field-of-view camera. The image quality of the camera was tested in the engineering tank in the Jere A. Chase Ocean Engineering Laboratory at the University of New Hampshire.



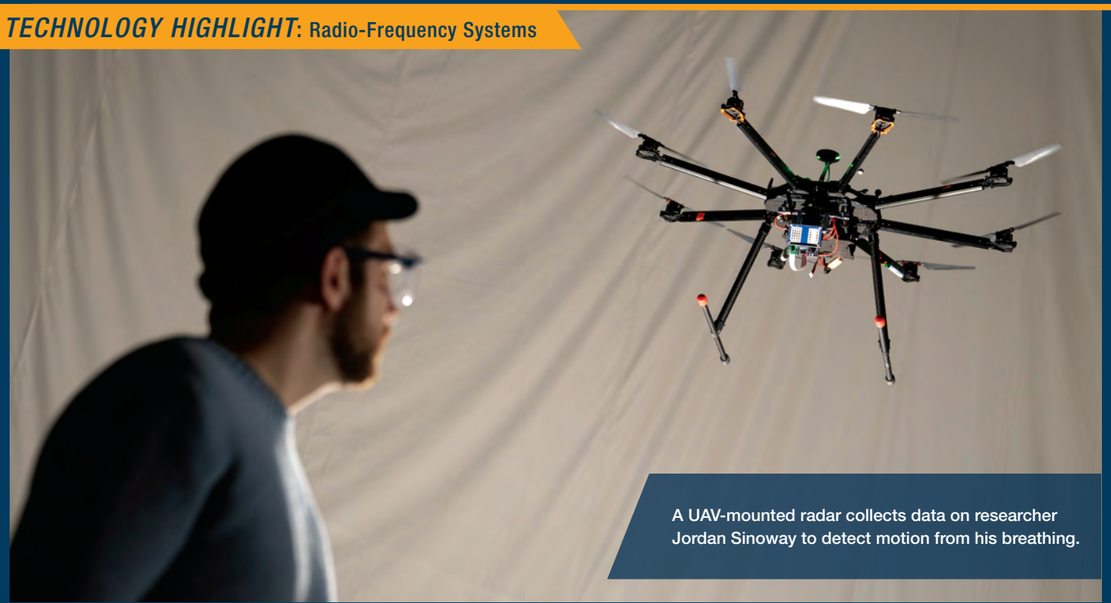
Optical Systems Technology

Ultrafast Laser Stress Figuring Processing

Lincoln Laboratory and the University of Arizona Wyant College of Optical Sciences are investigating the use of ultrafast laser stress figuring (ULSF) for permanently, accurately, and rapidly figuring already coated and mounted thin mirrors to correct optical-prescription errors without producing debris. Focused ultrafast laser pulses can generate strain within an optical material at the focus position, permanently bending the mirror. Laboratory researchers are performing optical and optomechanical characterization of thin curved mirrors, shown here, both before and after ULSF processing.

>> *Investments in Mission-Critical Technology, cont.*

TECHNOLOGY HIGHLIGHT: Radio-Frequency Systems



A UAV-mounted radar collects data on researcher Jordan Sinoway to detect motion from his breathing.

Wall-Penetrating Radar System for Remote Detection of Breathing Signals

The Laboratory's 2021 R&D 100 Award-winning Motion Under Rubble Measured Using Radar (MURMUR) technology was created with a dual purpose: to strengthen operator situational awareness when entering an unknown building and to help rescue teams save lives in complex disaster environments. The technology uses radar mounted on an uncrewed ground vehicle to sense through walls, rubble, and debris to detect the motion that results from a human breathing.

Mounting this technology on an uncrewed aerial vehicle (UAV) could enable the military or first responders to rapidly deploy it in remote locations with unnavigable ground terrain. However, UAV-borne radar is prone to platform motion errors due to wind turbulence, drift, and limits in the precision of platform position estimates from onboard navigation systems. These errors would reduce the radar's ability to detect the subtle motion of a human.

To correct for platform motion errors, the Stabilization of Radar on a UAV Mount (STRUM) project developed real-time motion-compensation algorithms for a UAV-mounted life-sensing radar. The algorithms estimate platform motion and then direct a gimbal to counteract the motion in real time.

Because the common platform motion error happens at a specific instant in time, scattering from various elements in the scene at different locations and distances from the radar will experience different delay errors. To address these delay errors, STRUM algorithms use innovative multi-element array processing for both range- and angle-dependent corrections. The quality of the motion estimate can then be evaluated based on the improvement in sharpness of the resulting image. Over the course of the project, Laboratory researchers iteratively improved STRUM techniques through simulation and by flight testing a prototype in the Autonomous Systems Development Facility.

Further research is needed to improve the accuracy of the algorithms and optimize their computational efficiency to enable real-time operation. This research is now continuing under a new program funded by the Department of Homeland Security Science and Technology Directorate.

Radio-Frequency Systems

In the RF systems area, R&D explores innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Emerging national security challenges include a rapidly expanding threat spectrum, the integration of sensors on platforms with constrained payloads, operations in strong clutter and interference environments, detection and tracking of difficult targets, and robustness against sophisticated electronic countermeasures. To address these mission requirements, current research projects focus on innovative antenna array topologies and construction, hybrid photonic-electronic systems, and advanced algorithms.

The 2023 projects included several noteworthy accomplishments:

- Demonstrated adaptive reflectarray beamforming for interference mitigation.
- Developed, tested, and validated decentralized algorithms for positional awareness in an indoor environment using only RF communications links.
- Applied photonic integrated circuits to enable new system concepts for antenna array remoting, spectrum sensing, and ultrastable oscillator development.

Information, Computation, and Data Exploitation

Research in the information, computation, and exploitation domain addresses challenges in the application of emerging AI and big data technology for national security needs. Themes of current research are data and AI algorithms, computing foundations, and engineering of AI systems. Researchers made the following progress:

- Investigated AI applications for complex data—such as multimodal data and time-series data—in the areas of ISR, space situational awareness, and medical imaging.
- Developed novel algorithms for knowledge-informed ML applied to processing of radar and sonar data, and for collaborative games to improve human-machine teaming.
- Applied data-centric AI at scale to improve the energy efficiency and computational efficiency of AI algorithms.
- Prototyped embedded-AI and edge-computing technologies to assess, design, and adapt AI algorithms for edge devices and novel hardware.
- Improved the robustness of AI technologies to address the brittleness and vulnerability of AI to natural and adversarial causes.

Information, Computation, and Data Exploitation

Flight Tests of AI Autonomy

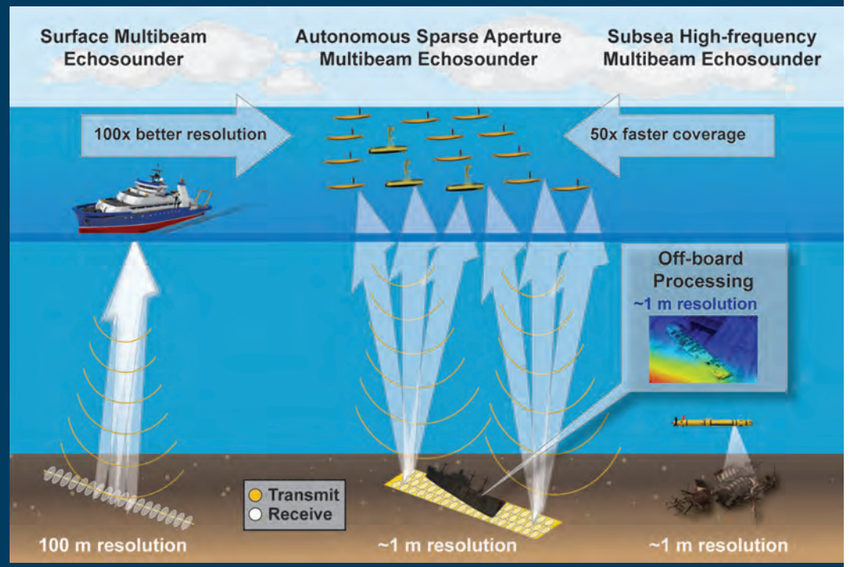
The Collaborative Autonomy in Competitive Environments (CACE) team stands in front of an X-62 VISTA aircraft at Edwards Air Force Base after successful flight tests of AI autonomy, as part of the DARPA Air Combat Evolution program. The CACE project aimed to rapidly develop fully autonomous flight controllers based on reinforcement learning and novel AI architectures known as liquid neural networks. In less than six months, the CACE team trained, integrated, and flight tested this autonomous capability.

>> *Investments in Mission-Critical Technology, cont.*

TECHNOLOGY HIGHLIGHT: Integrated Systems

Wide-Area Ocean Floor Mapping

A high-resolution map of the ocean floor is important for many purposes: researchers could better locate undersea resources, such as oil and mineral deposits; track the consequences of human-made activities, such as deep-sea mining; monitor sea life; and model the climate effects of deep-ocean currents. An ocean floor map is also useful for navigating underwater vehicles and searching for missing objects and wrecks. However, most of the Earth's oceans remain virtually unmapped and unexplored.



The autonomous sparse-aperture array can enable significant improvements in the resolution and coverage rate of ocean floor mapping.

No existing technology can produce meter-scale resolution of the seafloor from the ocean surface. Because of diffraction, resolution decreases with distance from the sensor, so high-resolution seafloor maps currently require sending sensors deep into the ocean. A potential solution is to create large sonar arrays, 10 to 100 times larger than modern hull-mounted sonars, by combining many autonomous surface vehicles (ASVs). This fleet of sonar-equipped ASVs would effectively combine to create a sparse-aperture array capable of mapping the deep seabed at a high resolution from the ocean surface.

To demonstrate this concept's feasibility, the Wide-Area Ocean Floor Mapping research team, including MIT researchers, built a series of prototypes. They began with a small-scale sparse-aperture sonar that generated imagery of items in a tank, and then fabricated and sea tested a rigid 8 m × 8 m sparse-aperture array composed of proxies for ASVs. This array showed the ability to produce high-resolution bathymetric imagery in the ocean.

The team's ultimate goal is to enable each ASV to operate individually so that the ASVs can cover a large area but are simpler and less cumbersome to deploy than a system of parts rigidly bound together. To achieve this goal, the team first must prove that the relative position of each ASV can be precisely measured to enable it to map the seabed as if it were a part of such a rigid array. Researchers from the Woods Hole Oceanographic Institution designed and built the first of these ASVs, which the Lincoln Laboratory team then sea tested.

This work has led to and is part of a new, broad initiative at the Laboratory to develop ocean exploration technologies that improve scientists' understanding of the ocean surface, water column, and seabed. The initiative aims to augment existing data sources with targeted, high-quality, low-cost autonomous sensing; develop new sensing technologies that move beyond traditional point sensing to cover large volumes of the ocean; and assimilate multiple types of data to estimate the structure of the uncertainty in ocean predictions in real time.

Integrated Systems

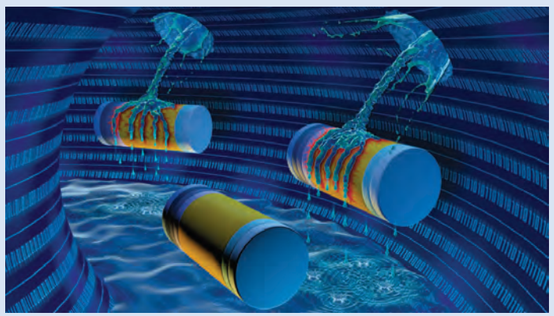
Projects in the integrated systems category bring together scientists and engineers to conduct applied research that accelerates the integration of advanced technologies into systems addressing national security needs. The goal is to demonstrate DoD-relevant system concepts that use novel architectures, recently developed component technologies, and new analytic methods. Scientists and engineers reached key milestones for several projects in 2023:

- Successfully completed the Agile MicroSat low-altitude mission. The satellite reentered the atmosphere after 17 months of on-orbit operations, which included electric propulsion maneuvering, drag modeling, aerobraking-based trajectory control, an artificial beacon–guide star experiment, camera image collection, and several collaborative experiments with ground radars and optical sites. Numerous mission-specific concepts of operation were developed and tested, leveraging heavily automated ground mission–planning algorithms and commercial operations.
- Demonstrated the first-known successful magnetic vector navigation on an aerial platform, enabled by a nitrogen-vacancy diamond magnetometer. Post-processing of flight data validated vector navigation algorithms. This resilient navigation technique successfully transitioned to a sponsored program for demonstration on an operational platform.
- Developed a relative-navigation-system prototype for high-precision tracking of autonomous surface vehicles in a large sparse-aperture sonar array. By integrating data from high-resolution cameras, lidars, microelectromechanical system inertial sensors, and Global Navigation Satellite System receivers, the prototype demonstrated a 5 mm relative-position uncertainty more than 85% of the time in calm seas during sea-field testing. This demonstration is a critical step in enabling the full system concept to deliver high-resolution, wide-area mapping of the ocean floor from the surface.

Cybersecurity

The national need to operate in a contested cyber environment requires both secure and resilient systems-of-systems and survivable cyber capabilities. In 2023, the Laboratory continued fundamental research in cybersecurity through the exploration and development of cybersecurity phenomenology, resilient systems, and cyber capability enablers, with emerging emphasis on AI/ML technologies applied to the problem space and to defense of AI/ML systems:

- Developed an enduring hardware-security test platform enabling a unified R&D capability for hardware security techniques, including side channels, trojan defenses, environmental phenomenology–based attacks, and hardware bridging.
- Continued developing survivability technologies to enhance the ability of offensive cyber operations to minimize mission risk with techniques such as environmental keying and secure computation for deconfliction.
- Created mathematical principles to measure the risk and ensure the security of AI models used for cyber anomaly detection and threat hunting. The technology is being used to assess current U.S. government traffic-analysis tools.
- Generated a module to enhance industry-standard approaches for embedded systems, allowing critical DoD components to operate according to zero-trust principles. An initial proof of concept was developed, and field testing will begin in FY24.



In a cyber poisoning attack, an adversary manipulates a model's training data to ensure that the model produces the attacker-desired output on test data. Laboratory researchers are aiming to develop simulated poisoning attacks against cyber-ML systems so that system developers can investigate the impact of such attacks against their systems and mitigate any vulnerabilities.

INVESTMENTS IN EMERGING TECHNOLOGY

Promoting research into technologies of growing importance to national security and the development of engineering solutions for projects in Lincoln Laboratory's relevant mission areas

Advanced Devices

Work in advanced devices focuses on developing novel components and capabilities to enable new system-level solutions to national security problems. Advanced devices span a wide range of fundamental technologies, including RF technology, lasers, advanced computing, imagers, detectors, and microsystems. Project teams realized the following accomplishments in 2023:

- Continued developing energy-efficient superconducting circuits for AI/ML–based microelectronics to address the increasing demand for neural networks. In FY23, a three-neuron network was tested, demonstrating bipolar analog multiplication, binary stochastic multiplication, analog division, square-root operations, and Boolean functions.

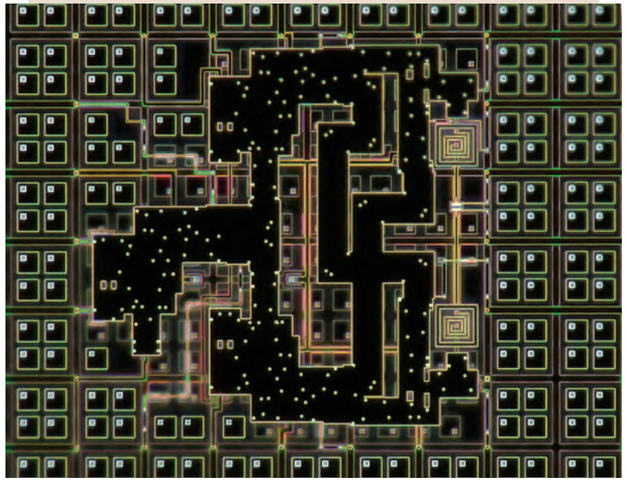
- Demonstrated new midwave infrared (MWIR) absorber layers, a critical step toward realizing high-sensitivity, low-noise MWIR focal plane arrays for a persistent, global ISR capability.

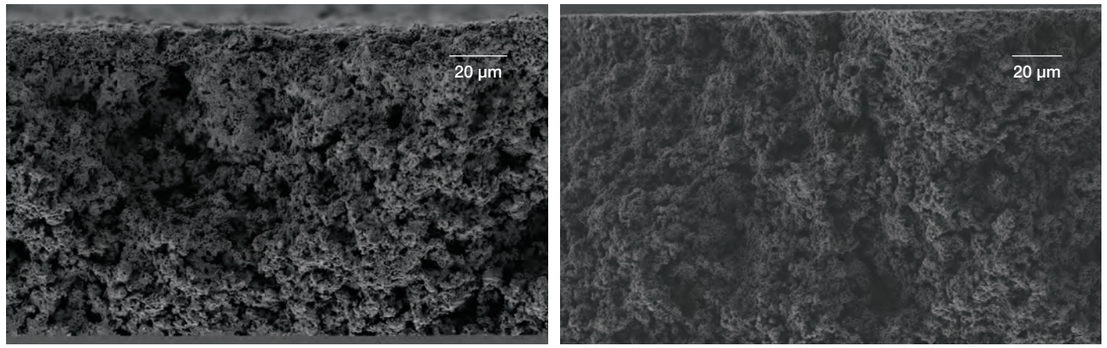
- Designed germanium-based readout circuitry to realize high-frame-rate imagers with subelectron read noise. By integrating active pixel components into the germanium detector layer, this approach overcomes noise limits of traditional imagers, with a design scalable to multimegapixel formats.

Advanced Devices

BioLogic Program

The BioLogic program aims to create scalable components for artificial neural networks. These components will perform computational operations with superconducting circuits that mimic brain functions more closely than traditional semiconductor technology approaches. Shown below is a top-down view of one of these circuits, which is fabricated in a multilayer process. Most of the active circuitry is contained beneath the top ground plane, and the scattered dots are vias down to other layers of the circuitry.





Scanning-electron-microscope images show a material optimization process to improve packaging materials for millimeter-wave RF circuits in 5G applications and beyond. The composite films from initial spray-coating experiments had unexpectedly high porosity (left), which can cause critical failures. The process was improved to result in more densified films (right).

Advanced Materials and Processes

This research area seeks to invent materials and processes to dramatically shorten the time for developing and transitioning materials, and to leverage these methods to develop sensing, computing, imaging, and manufacturing capabilities for the nation. Researchers made the following developments:

- Developed a new paradigm to accelerate the design and maturation of materials with novel properties. Significant advances in ML have accelerated material property prediction from months to seconds. A recent focus has been rapid experimental verification of hypersonic materials, leveraging techniques from the pharmaceutical industry.

- Developed printable composite materials that are enabling cost-effective radiation shields, 3D-integrated RF electronics, and space-compatible electronic packaging. These materials are compatible with commercial cleanrooms.

- Demonstrated superconducting electronics based on Josephson junctions and niobium nitride, instead of CMOS transistors and copper interconnects. Analysis showed that this architecture enables two-orders-of-magnitude savings in switching power, even with the required cryogenic infrastructure. The team has transitioned the technology to a sponsor looking to apply it to power-hungry AI engines.

- Pursued R&D of a rechargeable battery in a textile-fiber form factor. If successful, this capability will enable a new class of microelectronics no longer limited by the size and shape of their power sources. The functional fiber and smart textile area continues to grow at the Laboratory.

Quantum System Sciences

Quantum information science is a fusion of quantum mechanics and information theory—two foundational fields underpinning modern technology—that could yield transformative new types of sensors, computers, and interconnects. The Technology Office investment in quantum system sciences is democratizing access to qubit platforms at the Laboratory and across the United States, accelerating impact with quantum devices born from rigorous system-driven design, and enabling next-generation advances through quantum theory, with the following advancements:

- Developed a superconducting qubit platform bringing together high-coherence qubits, integrated crossover elements for signal routing, and flip-chip technology. This advanced platform is being leveraged for a program that provides partner organizations with devices fabricated at the Laboratory to support scientific inquiry at their home facilities.

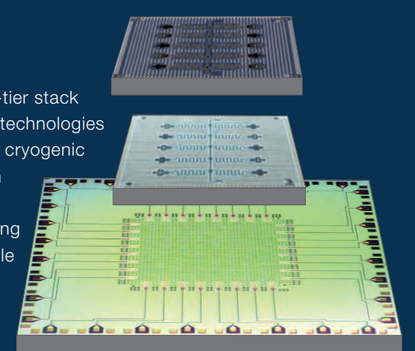
- Developed scalable quantum memory modules based on silicon-vacancy centers in diamond to move delicate quantum states between systems. In collaboration with Harvard University and MIT, the Laboratory performed the world's first demonstration of a quantum interaction with a nanophotonic quantum memory across a deployed telecommunications fiber. A central part of this demonstration was the scalable quantum memory modules.

- Applied magnetic microscopy for quantum sensing applications. Wide-field magnetic microscopy using nitrogen-vacancy centers in diamond can produce magnetic movies, which are magnetic-field maps with high spatial and temporal resolution. A Laboratory-developed microscope recorded high-speed movies of currents in microelectronic test devices and demonstrated tunable-frequency imaging from direct currents up to 100 MHz. The technology is being translated to cryogenic temperatures to advance superconducting computing.

Quantum System Sciences

Three-Tier Stack Platform

The Laboratory has developed a three-tier stack platform that optimizes 3D-integration technologies for use with superconducting qubits at cryogenic temperatures. This integration platform has demonstrated connectivity for multiple types of qubits while maintaining qubit performance. It will provide flexible control and readout options for qubits as superconducting quantum technology continues to evolve.



>> *Investments in Emerging Technology, cont.*

Autonomous Systems

While autonomous systems have improved dramatically in recent years, technology gaps remain in enabling robots or robotic teams to make complex decisions and in seamlessly integrating robots with human supervisors and teammates. To address these gaps, the Laboratory has concentrated applied research on intelligent perception and decision-making algorithms; human-machine teaming, with a particular focus on trust and explainability; and rigorous approaches for verifying and validating closed-loop systems. In 2023, Laboratory teams pursued the following R&D in autonomy:

- Addressed needs for improving autonomous situational awareness in outdoor and underwater environments. The lack of interpretable feedback in these environments limits the effectiveness of autonomous systems. The team developed topologies and hierarchies of abstract environmental objects, from which meaningful scene graphs depicting the unstructured outdoor domain can be constructed. In the underwater domain, one effort is pursuing collaborative navigation between an autonomous underwater vehicle and a human diver.

- Advanced correct-by-construction and explainable mixed-integer logic-based approaches to policy selection, whether to improve autonomous adversarial game playing or robot training by demonstration. Laboratory staff are participating in Army, Navy, and DoD competitions that pit teams and tactics against each other to demonstrate relative advantages in disparate DoD-relevant missions.

- Collaborated on a unified and comprehensive multidomain, multidisciplinary demonstration. This demonstration is part of an overarching thrust to integrate individual technologies—such as those for perception, verifiable planning, and human-machine teaming—to enable a truly autonomous system.

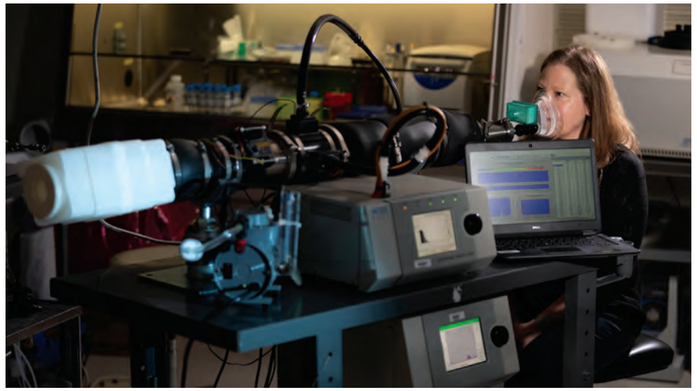
Biomedical Sciences and Technologies

This research area focuses on biotechnology development for national security, operationalization and threat assessment, human and team performance optimization, and advancement of diagnostics and therapeutics delivery. In 2023, several milestones were reached:

- Designed knitted cell scaffolds from bioabsorbable yarns. The scaffolds match the mechanics of a range of soft tissues to enable high levels of cell survivability, by mimicking the ability of soft tissue to “uncrimp” before stretching. These new knitted meshes represent an improved method for handling skin loss from blast or burn injuries.

- Completed a quantum biology study to determine the potential of leveraging externally controlled electron-spin-dependent biochemical reactions for DoD applications. This study identified a multi-institution research strategy to address key questions necessary to advance the field of quantum biology and solutions to national security challenges.

- Developed a real-time, closed-loop test bed for neurofeedback with wireless electroencephalography, including algorithms for training neural decoders to estimate brain state. A study conducted with the neurofeedback system showed participants’ attentional ability to block out unwanted stimuli improved over the course of a single-hour session. The platform and algorithms will help enable applications including rehabilitating those with brain injuries and improving cognitive function.



Exhaled breath could be a rich source of biomarkers indicative of metabolic and disease state. Above, Trina Vian provides breath to a sampling manifold coupled to multiple instruments to characterize exhaled aerosols. This system can support studies investigating disease diagnosis, transmission, and control.

TECHNOLOGY HIGHLIGHT: Autonomous Systems

The MAESTRO program is working to improve the intelligence and safety of robots in complex real-world environments. The team recently traveled to Jervis Bay, Australia, to test their algorithms on autonomous marine vessels, working with Five Eyes partner nations.

Safe and Verifiable Reinforcement Learning for Autonomous Systems

The Multi-Application Explainable and Safe Temporal Logic for Reward-Based Objectives (MAESTRO) program focuses on making robots smarter and safer in real-world environments. MAESTRO is developing AI verification and validation techniques for multiagent reinforcement learning deployed at the tactical edge. These techniques allow multiple problem-solving strategies to be combined during a robot’s mission to help the robot adapt to a dynamic environment and never-before-seen adversarial behaviors. MAESTRO also layers multiple AI safety techniques from the field of formal methods to provide strong safety guarantees on the AI agents’ collective behaviors. Together, these AI techniques allow MAESTRO’s robots to overcome a diverse set of challenges with limited training data by synthesizing novel and verifiable zero-shot strategies.

In October 2023, the MAESTRO research team traveled to Jervis Bay, New South Wales, Australia, to deploy autonomous uncrewed surface vessels (USVs) alongside the United Kingdom, Australia, and other U.S. collaborators as part of the Five Eyes technical cooperation program.

The robot teams competed head-to-head in a capture-the-flag tournament in which each research group used a different approach to generate robot team strategies. The MAESTRO team helped develop the interface and infrastructure used for training and deploying the AI pilots on the USVs. The competition produced a large amount of data that can be leveraged to improve autonomous systems. This event was the first successful multinational Five Eyes deployment of AI-versus-AI robotic teams in a competitive marine environment. Future deployments will incorporate aerial and land-based assets to simulate a holistic harbor-defense scenario.

The MAESTRO research team has published papers, transitioned capabilities to programs at DARPA and the Office of the Secretary of Defense, and hosted an open-source marine capture-the-flag competition in collaboration with the Naval Research Laboratory and the United States Military Academy at West Point. The MAESTRO program also maintains close collaborations with Boston University, Lehigh University, and MIT.

>> *Investments in Emerging Technology, cont.*

Critical Infrastructure Technologies

Investments in these technologies support foundational research and infrastructure development to meet national challenges in critical infrastructure protection and resiliency. Such challenges include air and ground transportation, land border and maritime security, and DoD energy needs such as remote power, advanced energy storage, and in situ resource harvesting. Projects span research in advanced sensors and architectures, signal processing, data fusion, and decision support, and the development of prototypes and experimental test beds. In 2023, staff engaged in diverse projects, such as the following:

- Demonstrated an initial test bed capability for geospatial track-based data (e.g., data from aircraft, ships, and vehicles). The test bed could reduce time and workload in acquiring manually labeled track data, verifying ML output on track data, and enabling sense-making of unsupervised ML output. This effort has led to FAA sponsorship and will scale up the test bed's ability to process and visualize significantly more tracks for other use cases.

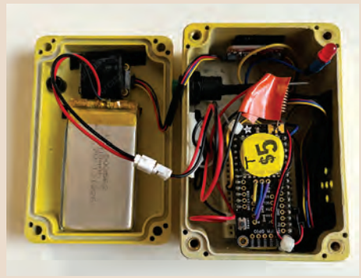
- Completed development of a test bed to assess the benefits of autonomy on advanced air mobility traffic flows and received NASA funding to leverage the test bed to develop use cases for assessing system-wide safety and contingency management.

- Began validation and industry engagement activities for a capability to increase the range of wind and turbulence sensing from Doppler lidar using a new signal processing approach.

- Continued development and risk reduction of alternate power systems, including a portable hydroelectric generator and aluminum-water synthesis of hydrocarbon fuels. These systems provide opportunities to reduce current dependence on the fuel chain while mitigating intermittence issues and energy-storage requirements of weather-based renewable energy technologies. Initial testing and power generation in a flow tank have been conducted, in addition to fundamental chemistry to identify challenges.

Critical Infrastructure Technologies

Increasing Situational Awareness During Power Outages



The COP-in-a-Box, (COP short for common operating picture), is a sensor platform for increasing situational awareness during power outages. This system leverages inexpensive sensors in an automatically configurable mesh network with a range of up to 0.5 miles, to provide real-time inputs of generator operation, power status, and fuel levels. This system could be applied to inform disaster response actions or to monitor infrastructure. Below, Eric Harmon sets up a COP-in-a-Box at the Joint Base Cape Cod Energy Resilience Readiness Exercise in August 2023.

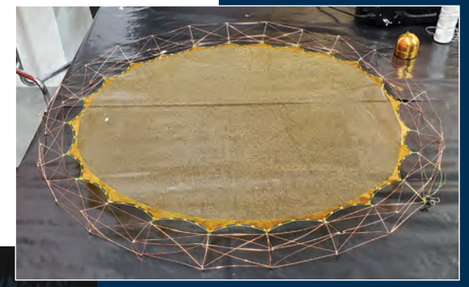
Engineering Research

The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of advanced prototype systems. The engineering research area invests in new tools, processes, and technologies to enable improved capabilities with broad applicability to Laboratory mission areas and specific technology domains. In 2023, researchers moved forward on several projects within this portfolio:

- Demonstrated the ability via additive manufacturing to fabricate in situ composite-fiber reinforcements in any orientation in polymer matrix materials.

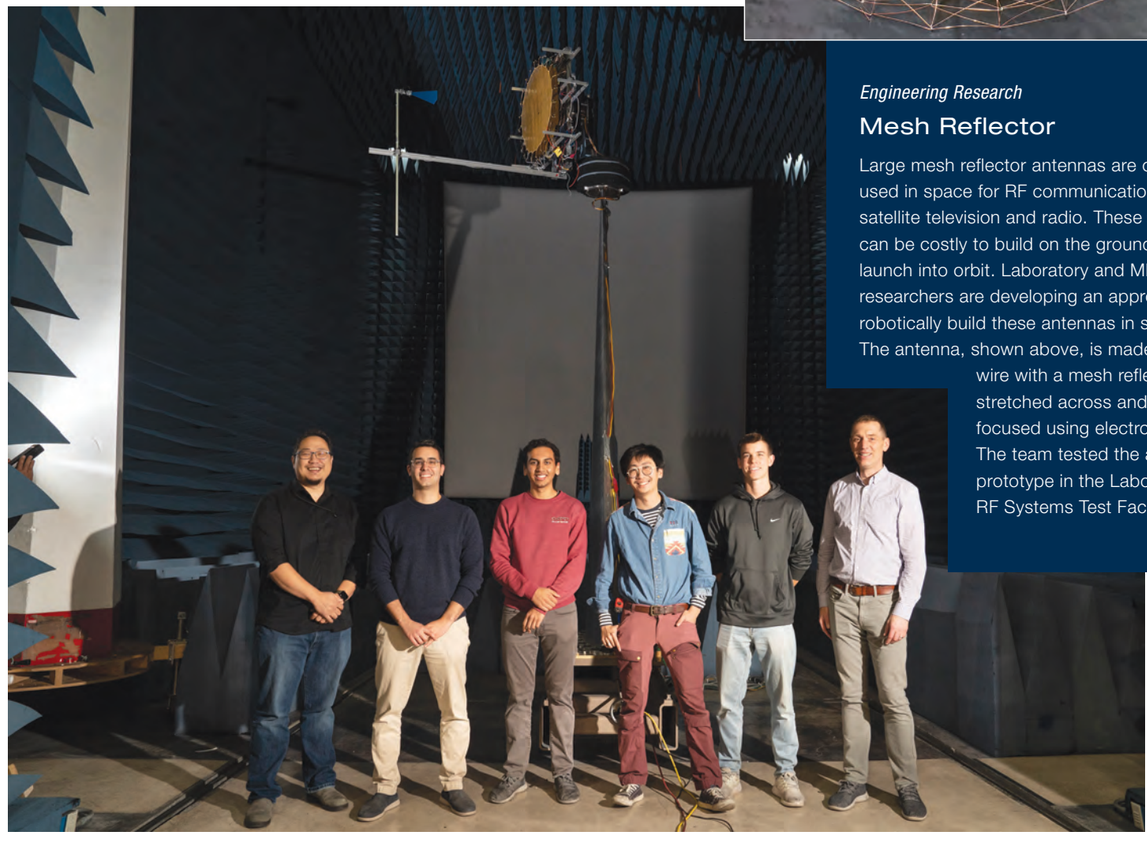
- Completed a sensitivity analysis showing that optical telescopes designed using free-form optical surfaces have significantly improved optical performance, as compared to telescopes designed using polynomial and aspheric surfaces, while possessing similar alignment and environmental tolerances.

- Developed a novel optical window mount for hypersonic vehicles. A set of flexures prestresses the mount to enable it to survive in extreme environments.



Engineering Research

Mesh Reflector



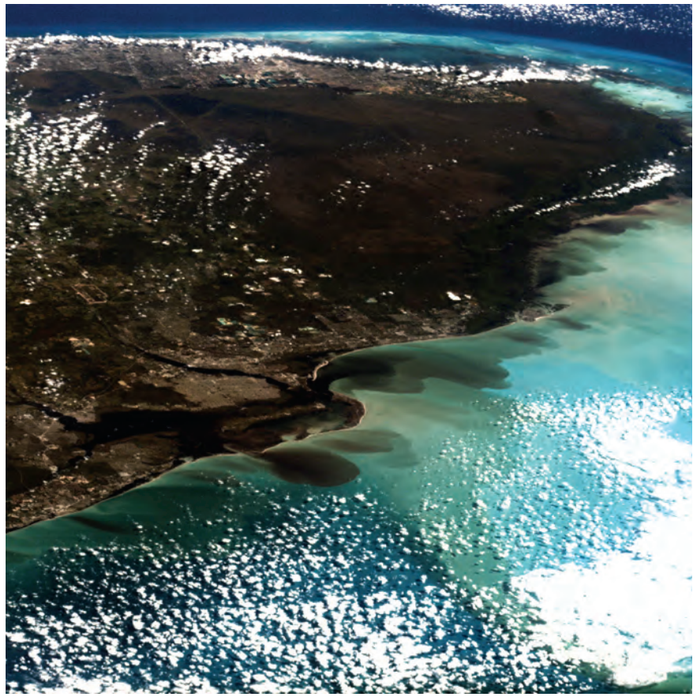
Large mesh reflector antennas are commonly used in space for RF communications and satellite television and radio. These systems can be costly to build on the ground and launch into orbit. Laboratory and MIT researchers are developing an approach to robotically build these antennas in space. The antenna, shown above, is made of bent wire with a mesh reflector stretched across and is focused using electrostatics. The team tested the antenna prototype in the Laboratory's RF Systems Test Facility.

>> *Investments in Emerging Technology, cont.*

Humanitarian Assistance and Disaster Relief

Investments in this mission area emphasize system prototypes and architectures in sensors, analytics, and decision support systems. In 2023, research thrusts included disaster forecasting and early-warning systems, remote assessment and situational awareness technologies, decision-making tools and analytics, disruption-resilient communication, new methods for disease surveillance, and technologies for supporting community resilience and combatting human exploitation:

- Continued efforts to apply predictive analytics techniques to domestic wide-area search-and-rescue squad data. When combined with geospatial analytical methods, these techniques could help first responders quickly determine how many resources to deploy and where to assign them.
- Performed assessments of differential privacy, in which computer science techniques are applied to sensitive datasets such that statistical information can be derived from these data without compromising private details of data contributors.
- Continued evaluation of system requirements and the commercial solution space for space-based remote sensing architectures to support disaster response decision-making. One project is leveraging the Laboratory-developed Agile MicroSat to test on-demand Earth imaging soon after a natural disaster.



This image taken by the Agile MicroSat captures the aftermath of Category 4 Hurricane Ian, which made landfall in Southwest Florida in September 2022. The brown areas of water show post-storm debris and contamination washed out to sea by the tidal surge driven by hurricane-force winds.

Laboratory researchers are building a test bed to evaluate technology and concepts of operation for countering influence operations.

Technology for Counter–Influence Operations

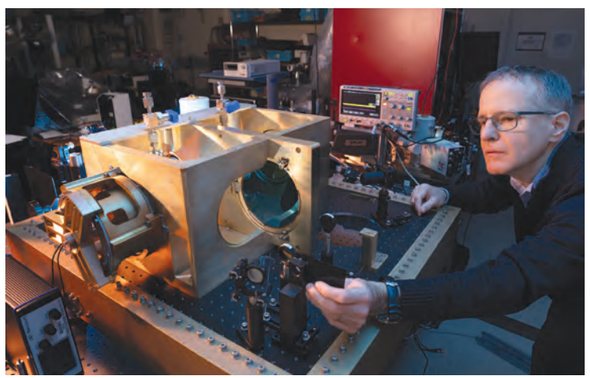
In response to malign influence operations (IO) launched by the nation's adversaries, the Laboratory is prototyping components and systems designed to improve the U.S. ability to counter adversaries who seek to influence the nation's population in covert or clandestine ways. This portfolio made progress in three ongoing projects:

- Implemented an AI-assisted system that permits rapid discovery and clustering of narrative content over millions of documents with only a few hours of human effort. This advancement can help operators develop courses of action to best reduce IO impact.
- Developed automatic approaches for verifying that text messages were authored by the same person, achieving a 10% equal error rate across several social media datasets. This work can help identify inauthentic online personas created by malign foreign actors.
- Integrated enhanced data collection into the Counter–IO Testbed and Evaluation Range, an environment to allow quantitative testing of IO-related tools, evaluation of operator performance, and hosting of exercises.

Climate Initiative

Climate change is recognized by the DoD as a major threat to global stability and national security. In 2022, the Technology Office established a climate initiative R&D portfolio, bringing together the Laboratory's multidisciplinary expertise in systems analysis, sensing, AI, data analytics, prototyping, and decision support. Key research thrusts include the following:

- Greenhouse gas emission–reduction technologies: the Laboratory is at the forefront of developing green computing strategies that apply to high-performance computing centers around the world. To reduce the impacts of aircraft on climate change, the Laboratory is collaborating with MIT on an aircraft-rerouting decision support tool to minimize contrails.
- Climate- and greenhouse gas–sensing capabilities: a Laboratory team rapidly designed and prototyped a wide-area, high-resolution sensor to detect methane leaks. Additional sensors being prototyped include a polarimetric bistatic lidar for aerosol typing, a novel sensor network for detecting change in Arctic sea ice, and a compact salinometer for use in an ocean-sensing fiber system.
- Models and adaptation: one program is producing probabilistic tornado predictions to potentially increase warning time for local populations. The program is leveraging the world's largest severe weather database, SEVIR, which was developed with funding from the Department of the Air Force–MIT AI Accelerator.



A novel optical sensor will enable standoff, high-sensitivity detection of methane, a potent greenhouse gas. The sensor, which will be mounted in aircraft, is designed to pinpoint locations of natural gas leaks along pipelines or drilling areas.

ARTIFICIAL INTELLIGENCE AT THE LABORATORY

Lincoln Laboratory's commitment to advancing AI spans across its mission and technology domains, with the Technology Office taking a central role in coordinating Laboratory-wide AI initiatives.

- Established in 2018, the AI Technology Group, under the Technology Office's direction, has made significant strides in progressing AI research to tackle complex national and global challenges. In 2023, the group focused on the acceleration of AI technology, development of capabilities for trusted AI, and advancement of vanguard and state-of-the-art AI solutions. The group focuses on developing an interoperable set of software for rigorous AI model test and evaluation, with capabilities that span model performance, data perturbations, adversarial attacks, and dataset analysis. These capabilities are applied toward generative AI, large language models, and human-machine teaming. Through advancements in knowledge-informed machine learning, an AI-enabled experimental design pipeline has been used to generate antibody sequences for medical countermeasures and discover new materials.
- The Laboratory hosted the Recent Advances in Artificial Intelligence for National Security (RAAINS) workshop, engaging a diverse audience in topics such as AI computing architectures and paradigms; algorithmic approaches advancing the AI frontier; physics-informed methods with applications in scientific discovery, sensor signal processing, and Earth science; and AI for humanity. The RAAINS workshop also included courses on generative AI, AI ethics, test and evaluation of AI systems, counter–influence operations, AI for cyber, and human–machine teaming.
- Collaborations are ongoing under the Department of the Air Force–MIT AI Accelerator, which is producing AI solutions for improving Air Force operations and addressing DoD needs. Fifteen projects span a range of AI research domains and applications. For example, one project demonstrated the use of physics-informed neural networks to enable magnetic-sensing navigation of an aircraft. Technology from another project is supporting the complex task of developing practical training schedules for Air Force personnel. A third project has developed a new type of AI called a liquid neural network and with DARPA has demonstrated its use for autonomous aircraft flight. All of these projects demonstrate the Laboratory's commitment to cutting-edge AI research and its practical applications, fostering advancements with broader implications for national security and beyond.

INVESTMENTS IN INNOVATIVE RESEARCH

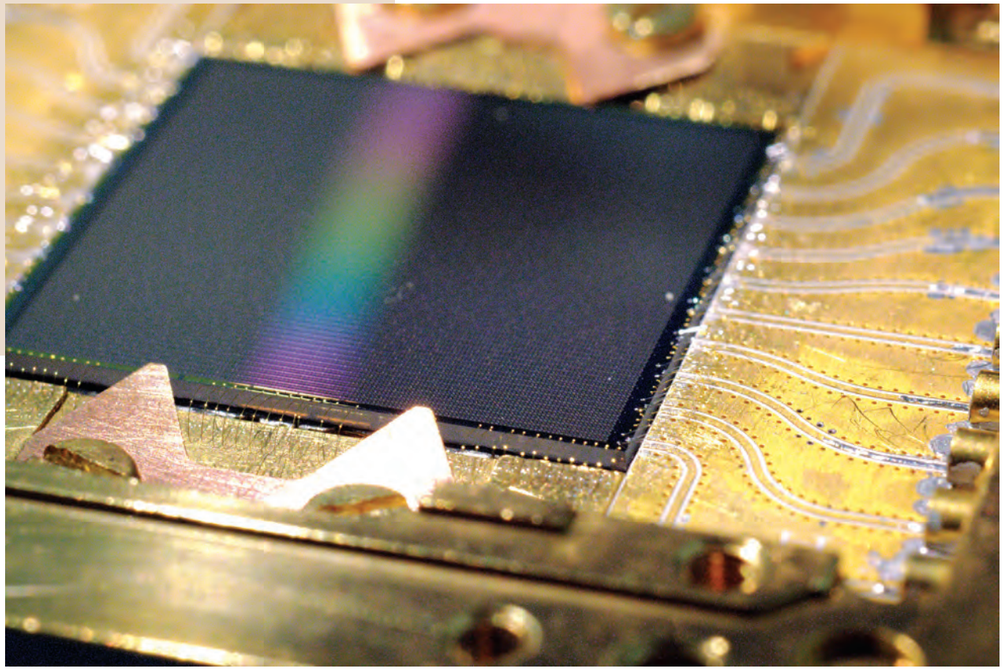
Providing support for R&D into foundational concepts and their applications in new systems

Seedlings

Through investments in Technology Office Seedling projects, staff can pursue innovative technology ideas and feasibility demonstrations. Seedlings encourage exploration of radically new approaches and technologies that could benefit Lincoln Laboratory's mission space.

Advanced Concepts Committee

The Advanced Concepts Committee (ACC) provides funding and technical and programmatic guidance for the development of basic and applied technology concepts that address important technical problems. The ACC funds a breadth of highly innovative, high-risk research that, if successful, has the potential to significantly impact the Laboratory's mission areas.



Advanced Concepts Committee

Microwave Kinetic Inductance Detector Array

This microwave kinetic inductance detector array, fabricated in the Microelectronics Laboratory, utilizes superconducting resonators to resolve the color of a single photon while maintaining its spatial resolution, allowing the array to provide a spectral image from a very dark scene. The 20-kilopixel array can image from the ultraviolet to the shortwave-infrared range without noise but needs to be cooled to very cold temperatures (< 1 K).

FOSTERING INNOVATION AND COLLABORATION

Encouraging staff to discover and develop innovative technology by engaging in technical interchange meetings, conferences, seminars, and Technology Office challenges

Invited Speakers

In 2023, the Technology Office hosted several virtual and hybrid seminars aimed at sparking curiosity, creativity, and collaboration at the Laboratory. Covering a range of topics and perspectives, the seminars provide opportunities for staff to learn about new and interesting subjects from leading experts.

The Hon. Robert Behler describes the unique characteristics of the SR-71 aircraft in his lecture, "Flying the SR-71 in Extreme Environments."

- Mariana Matus, cofounder and CEO of Biobot Analytics, discussed how wastewater intelligence can provide inclusive data on disease burden and trends, and can help communities prepare for outbreaks.
- The Hon. Robert F. Behler, who most recently served as the Director of Operational Test and Evaluation for the DoD until January 2021, used vignettes from declassified missions to explain the SR-71 "Blackbird" aircraft's high-Mach, high-altitude, and high-bank-angle flying qualities.
- Jelena Notaros, assistant professor in the MIT Department of Electrical Engineering and Computer Science, presented work on developing novel silicon-photonics-based platforms for augmented-reality displays, lidar sensing for autonomous vehicles, and free-space optical communications.

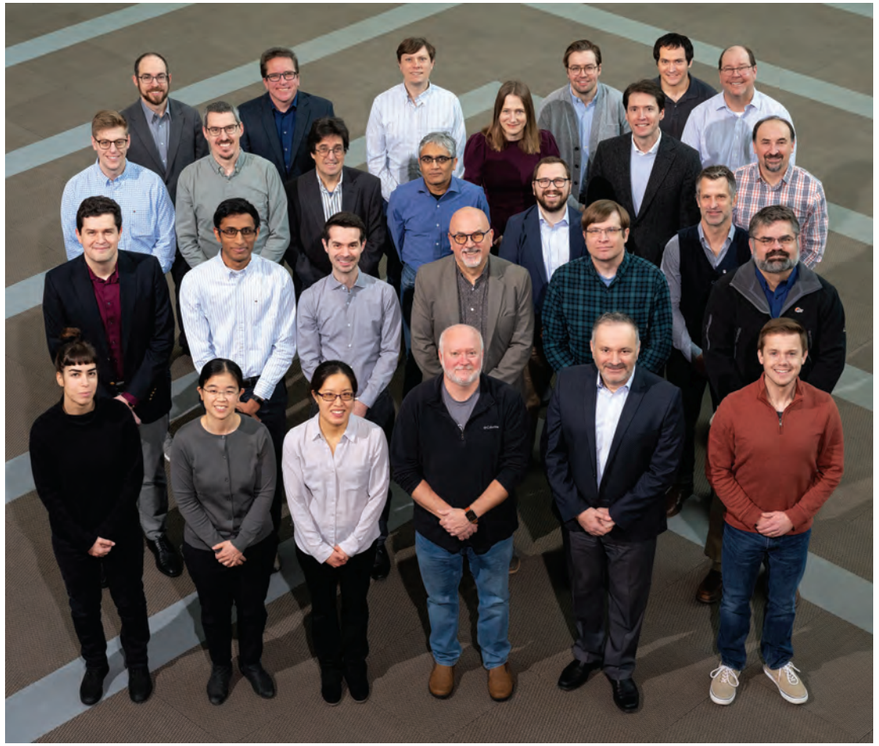
Technology Office Challenges

Each year, the Technology Office invites staff to participate in challenges that explore topics relevant to the nation and the Laboratory's mission areas. In 2023, the Technology Office hosted the Mixed Reality for Augmenting Group Experiences (MIRAGE) Challenge to acquaint Laboratory staff with the available capabilities of an augmented-reality eyewear system. Participating teams were tasked with using the HoloLens 2 and a custom Laboratory-built interactive game to compete in complex challenges and puzzles, in which an operator would wear the HoloLens headset and communicate with a handler and their support team about the course objectives. Participating in the MIRAGE Challenge allowed team members to explore how mixed and augmented reality can enhance their performance to accomplish real-time and complex objectives, and helped them identify ways that they can use this technology to enhance their work at the Laboratory.

MIRAGE Challenge organizers and participants pose in front of the competition course.

R&D 100 Awards

In 2023, *R&D World* magazine presented Lincoln Laboratory with five awards for technologies developed either solely or in partnership with other organizations. The honors included four R&D 100 Awards, which recognize 100 groundbreaking technological innovations developed by research institutes and companies worldwide, and a Silver Medal in a special category that recognizes products for their market-disrupting potential. The awardees are selected each year by an international judging panel composed of editors from *R&D World* and technical experts from academia, industry, and national laboratories. The technologies described below bring up to 86 the total number of R&D 100 Awards that Lincoln Laboratory has received since 2010.



Principal investigators and team members of Lincoln Laboratory's 2023 R&D 100 Award winning technologies.

Joint Communication Architecture for Unmanned Systems Security/Cyber Module End Cryptographic Unit

A compact, National Security Agency–certified device that secures tactical datalinks of unmanned systems processing sensitive information.

LINCOLN LABORATORY TEAM: Benjamin Nahill and David Wilson, project leads; Marc Belanger, Ricky Hardy, Eric Hughes, Roger Khazan, Tim Meunier, and Joseph Sobchuk

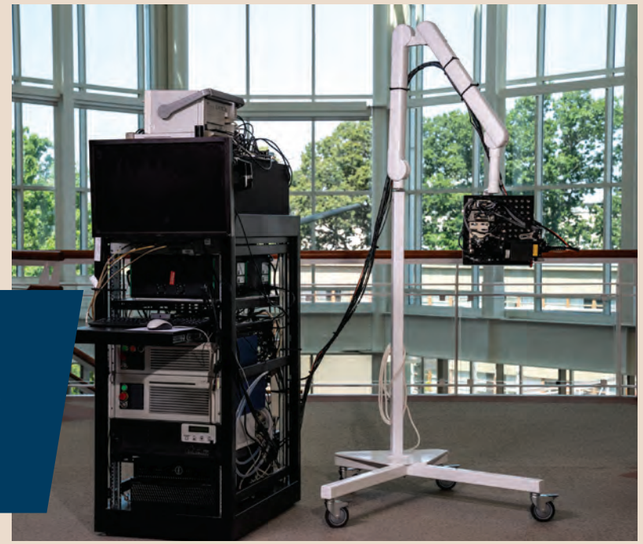
Noncontact Laser Ultrasound for Medical Imaging

A portable system that uses an eye- and skin-safe laser to acquire interior images of human tissue without touching the patient.

LINCOLN LABORATORY TEAM: Robert Haupt, project lead; Brian Boitnott, Bert Green, Rajan Gurjar, Ryan McKindles, Jamie Shaw, Matthew Stowe, and Charles Wynn

2023 R&D 100 SILVER

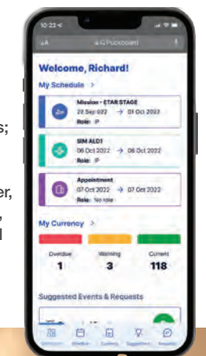
This technology was also the winner of an R&D 100 Silver Medal in the Special Recognition: Market Disruptor category that recognizes entries as game-changing advances in their industries.

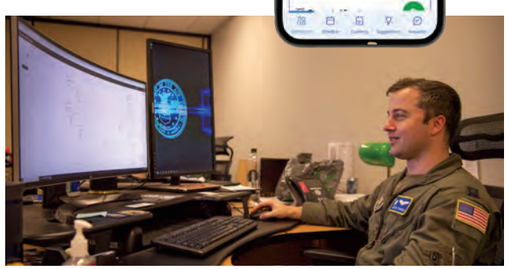


Puckboard

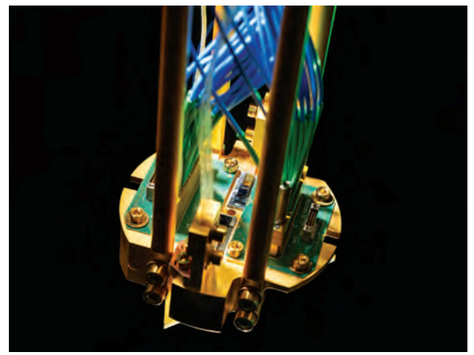
A web-based software application that uses artificial intelligence to optimize scheduling of U.S. Air Force aircrews to mission and training flights.

LINCOLN LABORATORY TEAM: Ronisha Carter, Eric Robinson, and Michael Snyder, project leads; Amy Alexander, Allison Chang, Coralys Colon-Morales, Audrey Haque, Rahul Jain, Jeremy Kepner, Matthew Koch, Nicholas Libertini, Jessamyn Liu, Kyle McAlpin, Paul Metzger, Joseph Mulhern, Jesse Pietz, and Joseph Zipkin





Scalable Photonic Quantum Memory Module



A single unit that combines a photonic interface, loss-error correction, and an architecture able to accommodate multiple memory modules to enable high-rate, high-efficiency quantum networking for computing and distributed sensing.

LINCOLN LABORATORY TEAM: P. Ben Dixon, Scott Hamilton, and David Starling, project leads; Eric Bersin, John Cummings, Dave Kharas, Ryan Murphy, W. John Nowak, and Katia Shtyrkova

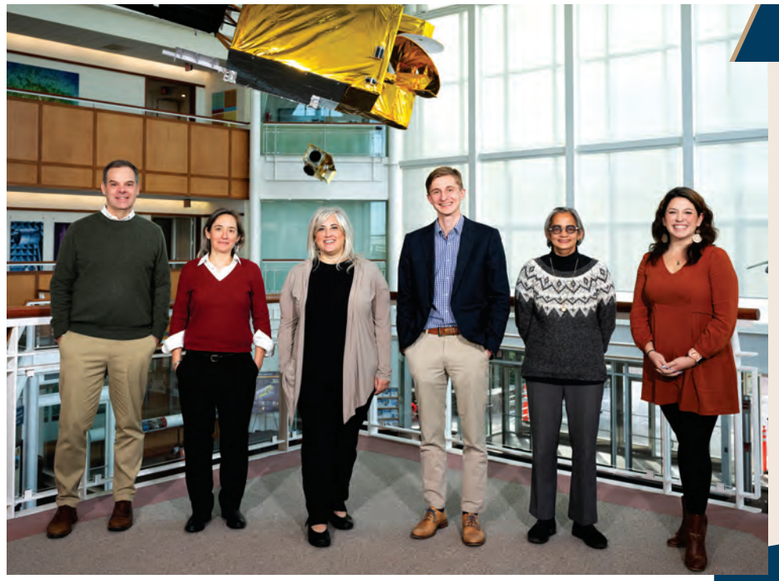
TECHNOLOGY TRANSFER 65

The Optical Terminal Verification Testbed is one of the Lincoln Laboratory testing facilities available to government contractors and industry under a reimbursable test agreement.

Technology Transfer

THE TECHNOLOGY VENTURES OFFICE

The Technology Ventures Office (TVO) provides strategic coordination for technology transfer–related activities at the Laboratory.



LEADERSHIP

(Left to right)

Dr. R. Louis Bellaire
Deputy Technology Ventures Officer

Dr. Teresa Fazio
Ventures Officer

Jennifer Falciglia
Program Manager

Jordan Mizerak
Associate Ventures Officer

Dr. Asha Rajagopal
Chief Technology Ventures Officer

Jessica Wells
Administrative Coordinator

The transfer of its advanced capabilities enabled by unique hardware, leading-edge software, novel component materials, and validated concepts is a core element in Lincoln Laboratory's mission, giving the nation's industrial base access to technologies that can have significant impacts on U.S. national, economic, and societal security.

The TVO

- Assists with sponsor-directed technology transition so that the products of government-funded R&D can be rapidly accessed by others
- Engages industry and the small business community in collaborative R&D to create new markets for Laboratory-developed technologies
- Supports the development of intellectual property (IP) protection strategies that, through commercialization, promote access to Laboratory-developed capabilities
- Accelerates technology transfer by increasing awareness of Lincoln Laboratory technology in the commercial sector
- Provides active support for the transition of Lincoln Laboratory technology into the commercial market through the launch of startup companies

FISCAL YEAR
2023

TECHNOLOGY TRANSFER BY THE NUMBERS

78
Articles in technical journals

94
Papers in published proceedings

50
Patents issued

18
Lincoln Laboratory-hosted conferences

113
Technology disclosures filed

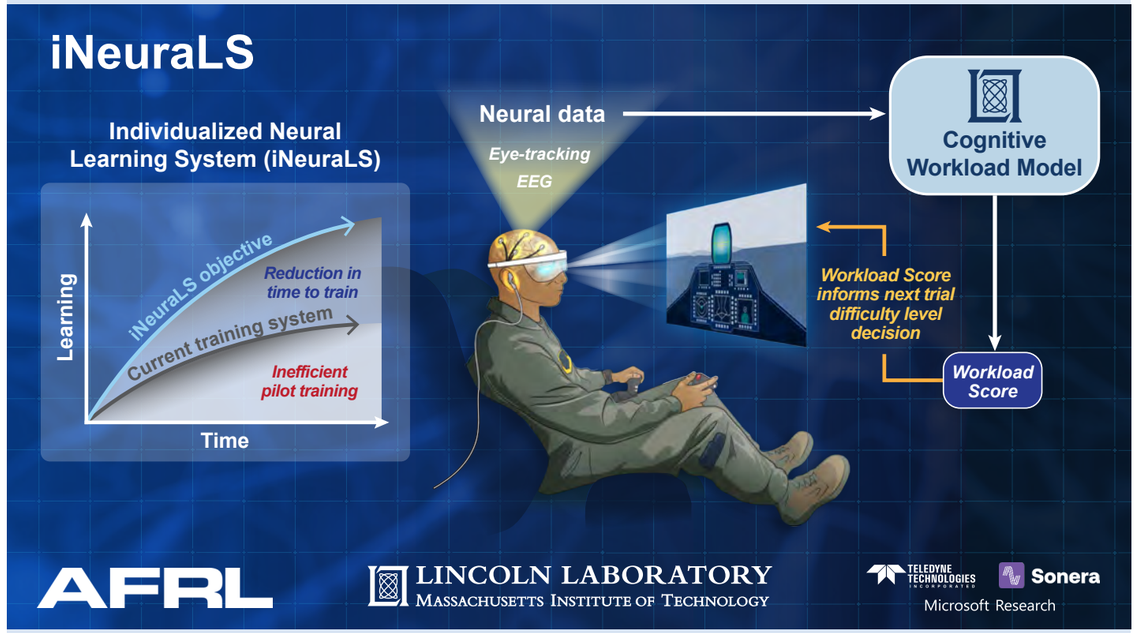
5
R&D 100 Awards
(includes a Silver Medal in the Special Recognition *Market Disruptor Products* category)

SPONSOR-DIRECTED TECHNOLOGY TRANSITION

The TVO team continues to improve the process by which Lincoln Laboratory effectively transfers its technologies to others at the government's request.

- Published guidelines and a simplified transfer agreement process are promoting participation in government-directed technology transfer. A custom database allows the TVO to track and analyze technology transfer activities and trends.
- Consultations with program managers to determine technology transfer intent at program initiation are helping the TVO match programs to industry partners and are encouraging programs to incorporate industry best practices to avoid later barriers to technology handoffs.
- Collaborations with national labs and nonprofit peer institutions are yielding creative solutions for common issues in accomplishing sponsor-directed transfers, such as patent-cost reimbursements and terms of licenses for federally funded research.

SPOTLIGHT: Assessing Pilots' Cognitive Workload



Lincoln Laboratory developed software for the Air Force Research Laboratory's Individualized Neural Learning System (iNeuraLS), a novel augmented virtual learning platform that facilitates rapid skill acquisition through a closed-loop modulation of cognitive states. This software uses electroencephalogram (EEG) and eye-tracking data to generate personalized predictions of a student pilot's cognitive workload. Specifically, the Laboratory's software imports the EEG and eye-tracking data, applies modality-specific preprocessing steps, trains the machine learning model, processes it, and uses AI techniques to generate an assessment of the student's cognitive workload after each trial. Then, the workload assessment is used to inform an appropriate difficulty level for the next trial. The software has been transitioned to Microsoft and Teledyne for integration into the prototype adaptive training systems being designed to accelerate pilot training in a simulator.

COMMERCIAL ENGAGEMENT

Lincoln Laboratory engages with the commercial sector to maximize the economic and societal impacts of its research by transitioning prototype innovations into real-world products. Partnering with industry can foster the creation of new capabilities and markets as businesses share their R&D with Laboratory researchers and adapt federally funded R&D to their product development.

In addition, Lincoln Laboratory engages in partnerships with businesses and defense contractors through

- Reimbursable test agreements that allow companies to use specialized Lincoln Laboratory facilities to evaluate/verify their systems with equipment not available at their own sites
- Commercial Solutions Openings that present small businesses and nontraditional defense contractors with an R&D solicitation and contract award process

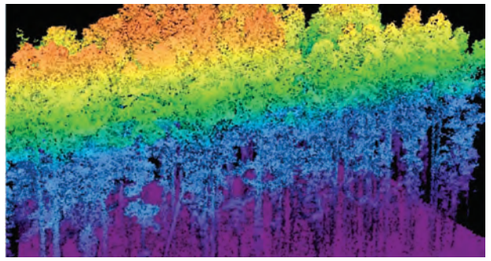
2023 INTERACTIONS WITH COMMERCIAL SECTOR

Mechanism	Benefits	2023
Cooperative Research and Development Agreements (CRADAs) for dual-use or commercial technology development	Allows businesses and the Laboratory to collaborate on new technologies, dual-use products, and innovative processes	**16** CRADAs
Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) direct R&D partnerships with qualified small businesses. Sponsorship of projects for specific government needs can come from diverse sources, e.g., U.S. Army, Navy, Air Force, Defense Advanced Research Projects Agency, NASA	Enables Lincoln Laboratory to contract with small businesses or nontraditional defense contractors in a fast, flexible, and collaborative manner	**31** SBIRs/STTRs
Commercial licensing	Promotes the development and timely delivery of commercial products that leverage innovative government-funded research	**6** commercial licenses and options
Collaboration agreements with nonprofit institutions	Advances early-stage technology development for a wide range of applications	**101** research collaborations
Open-source software distribution	Allows wide utilization of the Laboratory's software and fosters innovation via a collaborative community of users	**28** open-source projects

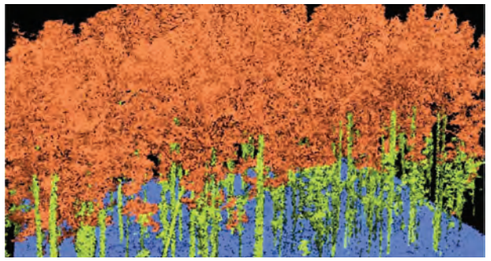
SPOTLIGHT: Accelerating Airworthiness Certification

Under a Missile Defense Agency–sponsored STTR program, Lincoln Laboratory partnered with Istari Digital to develop software for accelerating Federal Aviation Administration (FAA) Airworthiness Certification. To be FAA-certified for flight, aircraft must be free from all aeroelastic instability effects for all configurations and conditions. Tens to thousands of flight-like simulations (digital twins) covering a wide range of conditions are often required to satisfy this requirement. The project team automated the entire aeroelastic stability simulation workflow: generating models, handling high-rate data exchange between tools, and asynchronously communicating with supercomputing resources via an internally developed platform. This end-to-end automation produces high-fidelity results across diverse parametric scenarios. Using the trove of data acquired in this project, developers can train emerging artificial intelligence models to predict aeroelastic tendencies in real-time rather than computing large simulations from scratch for every novel aircraft geometry and flight condition.

This data-driven approach has the potential to expedite system development timelines, lower acquisition costs, expand options for hybrid digital-twin flight testing, and avoid cost-prohibitive modifications after certification—all of which promotes timely transfer of technology to industry. Through a greater understanding of digital twins' capabilities, Istari Digital has become better-equipped to support future contracts with system developers and advance their vision for "digital-first complex systems."



Lidar data are processed into a 3D point cloud.



Algorithm identifies individual tree specs: orange = foliage, yellow = tree trunk, blue = ground.

SPOTLIGHT: Lidar Data for Forest Monitoring

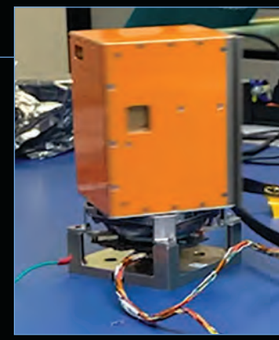
Under a CRADA, a field campaign collected lidar data on 100,000 acres of forests and cultivated tree plantations in Mississippi. The imagery generated from these data will support research in forest management and cultivation. In this partnership, Lincoln Laboratory worked with the Idaho Forest Group, a commercial lumber producer that specializes in sustainable timber harvesting; the University of Idaho, whose College of Natural Resources has deep experience in forest health and management; and 3DEO, Inc., a Laboratory spinout company that operates lidar systems for wide-area 3D imaging. The team developed prototype machine learning algorithms that enabled the detection of individual trees, allowing researchers to accurately estimate the tree location, height, and diameter at breast height. This experimental campaign gathered data at a variety of tree densities, altitudes, and collection rates to gain accurate assessments of forest health. The collection results are driving the development of innovative approaches for long-term land and forest management and for the sustainability of the forestry business.

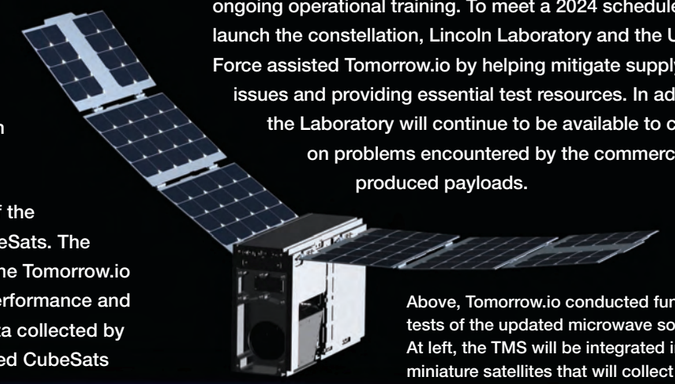
SPOTLIGHT: Extreme Storm Data from the Tomorrow.io Microwave Sounder

Lincoln Laboratory and Boston-based Tomorrow.io have entered into a CRADA to transfer technology the Laboratory developed for the NASA TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) Earth Venture mission. In support of the TROPICS program, Lincoln Laboratory developed a miniaturized microwave sounder that, when integrated on a low-cost, commercial small satellite (CubeSat), acquires measurements of temperature, humidity, and precipitation within tropical storms. The TROPICS constellation makes hourly revisit observations from space, expanding scientists' understanding of the rapid evolution of tropical storms. In spring 2023, a constellation of four CubeSats in the TROPICS mission yielded valuable data on the dynamics of intensifying hurricanes.

The CRADA will facilitate the adaptation of the current TROPICS payload to updated CubeSats. The design of the updated payload, renamed the Tomorrow.io Microwave Sounder (TMS), will improve performance and manufacturability. Tomorrow.io will use data collected by a planned constellation of 18 TMS-equipped CubeSats to generate forecasting models purchasable by public and private organizations needing time-sensitive monitoring of extreme storms.

In addition to providing Tomorrow.io with designs, software, and procedures for test assembly, integration, and calibration, the Laboratory will support Tomorrow.io with ongoing operational training. To meet a 2024 schedule to launch the constellation, Lincoln Laboratory and the U.S. Air Force assisted Tomorrow.io by helping mitigate supply chain issues and providing essential test resources. In addition, the Laboratory will continue to be available to consult on problems encountered by the commercially produced payloads.





Above, Tomorrow.io conducted functional tests of the updated microwave sounder. At left, the TMS will be integrated into miniature satellites that will collect data on emerging storms.

INTELLECTUAL PROPERTY MANAGEMENT

The TVO works closely with MIT's Technology Licensing Office to protect federally sponsored intellectual property (IP). MIT is one of the world's leading institutions in IP disclosures and patents.

Intellectual Property Disclosures

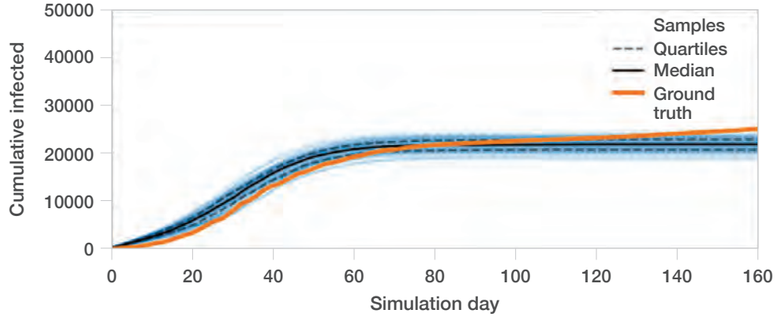
In fiscal year 2023, 595 technology disclosures were submitted by MIT researchers; Lincoln Laboratory was responsible for about 16% of these. Lincoln Laboratory also had 53 patent applications and 50 issued patents in fiscal year 2023. Copyright-protected software and non-software technical data, a growing area to which staff across the Laboratory can contribute, made up 60% of all disclosures in 2023. With the addition of 28 new projects in 2023, the Laboratory's open-source portfolio grew 20%.

SPOTLIGHT: Spinout—Generation NYX

In March 2023, Stephanie Foster and Joaquin Avellan founded Generation NYX to elevate the innovation and accessibility of the open-source Next-Generation Incident Command System, developed by Lincoln Laboratory to address the communication challenges faced by multiple agencies simultaneously responding to crises. Under the brand name PROTECT, Generation NYX provides real-time, collaborative solutions that facilitate efficient information sharing and coordinated responses between crisis management professionals. With a dual focus on domestic and international operations, Generation NYX actively supports state and national governments, with an emphasis on civil protection.

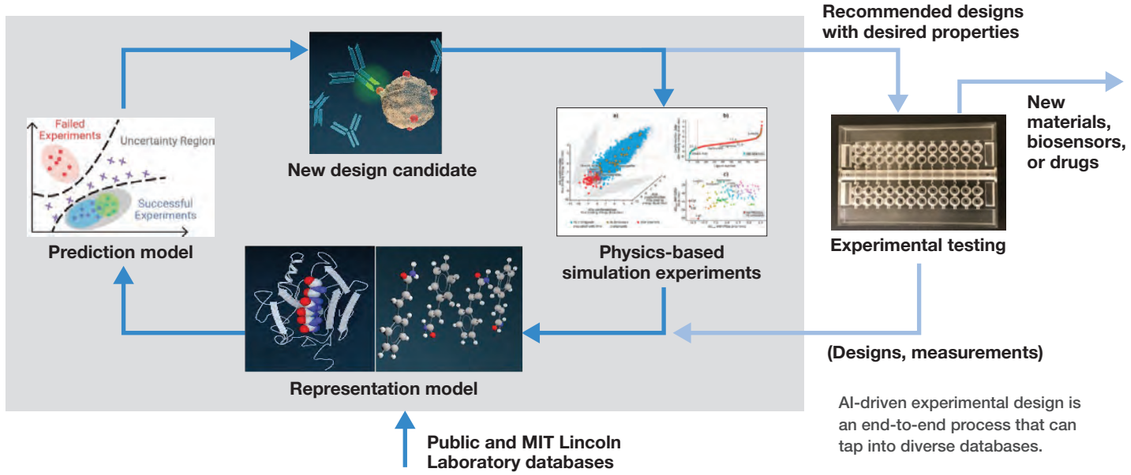
SPOTLIGHT: Predicting Disease Spread with GraphSEIR

GraphSEIR is an open-source, network-based disease-simulation library. Written in Julia, the library uses the SEIR (Susceptible, Exposed, Infected, Recovered) model to simulate disease progression across a population network and probabilistic programming methods to fit model parameters to real-world, reported disease data. Unlike libraries that can only be used with simple simulators, the GraphSEIR library accommodates detailed disease simulators that can model heterogeneous, community-based interactions at varying geographic locations. Lincoln Laboratory in collaboration with Northeastern University has demonstrated that GraphSEIR improves the fit of disease parameters to real data in multiple geographies as compared to simulations that do not model detailed, heterogeneous population-interaction patterns. Because computer simulations for tracking epidemics are used for predicting where and when people will become infected, identifying which factors contribute to or slow disease spread, and testing if various interventions save lives, GraphSEIR's incorporation of network effects and robust fitting to real-world data makes it an impactful tool in disease responses.



For experiments conducted in Middlesex County, Massachusetts, GraphSEIR obtained distributions of disease parameters that replicate reported infection-count data. The orange line denotes true cumulative infection counts for 160 days starting seven days before March 15, 2020, when initial infection counts represented only 0.5% of the population. Blue lines denote 100 simulations using GraphSEIR, and black lines are the quartiles for the 100 samples.

SPOTLIGHT: AI for Improving Experimental Design



AI-driven experimental design is an end-to-end process that can tap into diverse databases.

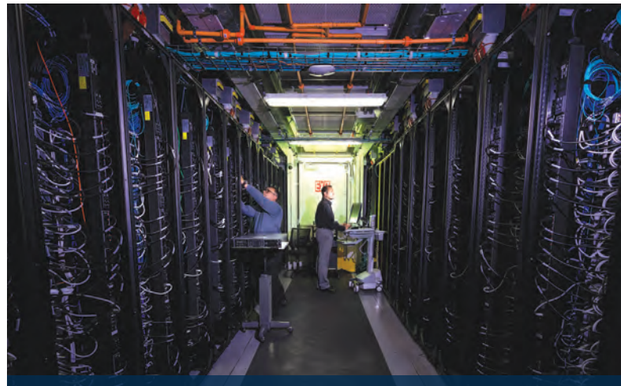
Lincoln Laboratory has been exploring how artificial intelligence (AI) can improve experimental design, i.e., the process of creating research experiments that control variables or parameters in order to evaluate hypotheses. Research and development is often limited by the large number of variables that, especially when considered in combination, can affect technology design of things such as novel materials, medical countermeasures, and climate technologies. Exhaustive evaluation, analysis, and finally optimization of experimental designs thus become infeasible tasks. The fundamental goal of the Laboratory's AI-driven experimental design (AIDED) project is the creation of a modular AI platform, applicable to multiple domains, to enable efficient exploration of a vast design space. To date, Lincoln Laboratory researchers have released an open-source AIDED approach to the rapid, cost-effective design of thousands of antibodies with strong binding affinities to a target pathogen.

SPOTLIGHT: Reducing AI's Energy Consumption

Researchers in the Lincoln Laboratory Supercomputing Center (LLSC) are looking to make AI "greener." The increased reliance on AI for making decisions, solving problems, and analyzing data has significantly increased the carbon footprint of data centers supporting all this high-level "thinking." The LLSC's software suite that reduces the energy costs of developing and employing AI models combines several capabilities:

- Machine learning estimates of a training model's success allow users to redefine model parameters or end the training.
- A configurable utility for evaluating model training under different levels of hardware power consumption guides decisions about limiting hardware resources.
- A software plug-in for setting those limits on the hardware's power usage during AI training and deployment can lead to a 15% reduction in energy use and associated electricity fees.

The suite has been shown to reduce the carbon footprint of AI by as much as 80%. Its availability as open-source software on GitHub may foster both its use and future collaborations on improved energy reduction at data centers.



The LLSC handles enormous data-intense computations driving AI applications. The environmental and financial costs of energy-devouring data centers has led LLSC researchers to explore tools to reduce these costs.

BRIDGING THE GAP BETWEEN DISCOVERY AND IMPACT

The TVO encourages participation in programs that focus on transitioning innovations from an initial concept to a prototype technology and finally to a real-world product. Seminars introducing the fundamentals of entrepreneurship and forums building partnerships enable the move from lab bench to commercial impact.

Building Technical Innovations: Technology Transfer Initiative

The Technology Transfer Initiative (TXI) supports Laboratory staff as they prepare promising R&D for transition into the commercial space and investigate commercial applications. The TXI allocates funding to select projects at a stage of near readiness for a transfer to external sponsorship, the commercial sector, or both. A limited number of small grants help staff rapidly complete a critical technology-transfer-enabling step, for example, finishing the assembly of a device. In fiscal year 2023, 14 projects were funded by the TXI board: each of nine projects was funded for up to $300,000, and five smaller projects were funded as Quick End-Stage Technology Transfer (QuESTT) grants.

Development ruggedization of the prototype Chrisp Compact Visible-Near and Shortwave Infrared (VNIR/SWIR) Imaging Spectrometer is a TXI project.

Building Entrepreneurship and Partnerships

The TVO coordinates staff involvement in entrepreneurial education programs. Courses through MIT's Innovation Corps (I-Corps) Spark explore how inventors can cultivate transferable technology, how customer needs influence research goals, and what the real-world challenges are in starting a tech company. A benefit to I-Corps participants is the identification of dual-use technologies of interest to the commercial sector, thus increasing the potential impact of the Laboratory's novel technologies. Collaboration with I-Corps also helps strengthen the discovery of partners with whom the Laboratory can engage in transferring technology to help fill unmet needs of prospective end users. More than 160 Laboratory staff members have graduated from the I-Corps program.

Lincoln Laboratory researchers participated in the DARPA Perceptually-enabled Task Guidance project to demonstrate how a combination of AI and augmented reality can guide users in performing tasks, like making pour-over coffee, above.

Lincoln Laboratory researchers are encouraged to engage with The Engine, a "tough tech" accelerator spun out of MIT. Through The Engine's ecosystem of entrepreneurs, scientists, engineers, and investors, Laboratory staff offer engineering expertise to help the continuing realization of marketable solutions for the most challenging (toughest) world problems—climate change, human health, and sustainable infrastructure.

To foster engagement with the innovation community, the Laboratory participates in programs sponsored by the Defense Advanced Research Projects Agency (DARPA), the National Security Innovation Network, and In-Q-Tel. A multiyear collaboration between DARPA, a nonprofit called Activate, and the Laboratory enables entrepreneurial fellows to receive funding to conduct research that could lead to new companies developing advanced electronics. Currently, one Activate fellow is embedded at the Laboratory.

OUTREACH ACTIVITIES

The TVO uses several means to engage with commercial companies suitable for R&D collaborations and transition partnerships.

- Membership in organizations promoting technology transfer, such as the Federal Laboratory Consortium (FLC), helps increase awareness of Lincoln Laboratory's transition-ready inventions.
- Participation at conferences and expos introduces industries to the Lincoln Laboratory technologies and facilities available for partnering agreements.
- Technical staff deliver "lightning talks" focused on dual-use technologies, such as artificial intelligence, DNA forensics, cyber-resilient systems, and aviation-safety software.
- The Partner With Us area of the Lincoln Laboratory website provides companies with information about partnerships, whether research collaborations, such as CRADAs and test agreements, or technology licensing opportunities.

Advanced Technology for National Security Workshop

At this workshop held at Lincoln Laboratory, Lou Bellaire, Jennifer Falciglia, Asha Rajagopal, and Teresa Fazio of the TVO showcased the Laboratory's emerging technical advancements to the defense industry.

Federal Laboratory Consortium

Lincoln Laboratory is a partner in the FLC, a nationwide network of more than 300 federal laboratories, agencies, and research centers. The FLC mission is to foster the transition of federally funded technologies into the marketplace. In 2023, the FLC awarded Excellence in Technology Transfer Awards at the national level to two Lincoln Laboratory software products developed to improve security: Keylime and the Forensic Video Exploitation and Analysis (FOVEA) tool suite. Keylime increases the privacy of data and services in the cloud, while FOVEA expedites the extraction of useful information from surveillance videos.

At the 2023 FLC national meeting, Lincoln Laboratory was presented with two Excellence in Technology Transfer Awards. Seen here with the award trophies are Charles Munson, principal investigator for Keylime, left, and Marianne DeAngelus, principal investigator for FOVEA.

Small Satellite Conference

The TVO participated in the international 2023 Small Satellite Conference, which attracted 3,700 attendees from more than 1,000 organizations. At this event in August, the TVO hosted a forum at which the small-satellite (smallsat) community learned about Lincoln Laboratory's current capabilities. For the more than 100 attendees, principal investigators highlighted three Laboratory smallsat programs: TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats), Chrisp Compact VNIR/SWIR Imaging Spectrometer, and TeraByte InfraRed Delivery system.

Looking Ahead

Recognizing the critical role that efficient technology transfer plays in Lincoln Laboratory's national security mission, the TVO will identify new pathways of technology access for the public and private sector. The office will catalog and promote the Laboratory's IP and software assets to increase awareness of the Laboratory's technological capabilities; it will seek to facilitate the rapid licensing of these assets by the small business community; and it will work to expand the resources available for the incubation, acceleration, and translation of the Laboratory's dual-use technologies.

The TVO will also provide the educational resources needed to support efficient transition pathways, and it will partner with academic and federal technology transfer communities to expand its own resource offerings. In addition, the TVO will work to identify transition pathways in the early stages of technology development and to actively find transition partners, both in the private and public sectors, that will help ease the path to technology adoption.

Patents Granted to Lincoln Laboratory Inventors, 1 October 2022–30 September 2023

Passive, Proportional Measurement of Oxygen and Carbon Dioxide Consumption for Assessment of Metabolic Parameters
U.S. Patent 11,464,426; issued October 11, 2022

Apparatus and Methods for Photonic Integrated Resonant Accelerometers
U.S. Patent 11,493,530; November 8, 2022

Neutrally Buoyant Liquid Supply Units for Underwater Vehicles
U.S. Patent 11,498,436; issued November 15, 2022

Liquid Low-Temperature Oxide
U.S. Patent 11,499,234; issued November 15, 2022

Fabrication Method for Endcapped Fiber Laser Pigtails with Sub-micron Virtual Waist Positional Accuracy
U.S. Patent 11,500,158; issued November 15, 2022

Systems, Methods, and Structures for Broadband Phase Shifting for Quantitative Phase Microscopy
U.S. Patent 11,500,187; issued November 15, 2022

Incoherently Combining Lasers
U.S. Patent 11,515,682; issued November 29, 2022

Free-Space Optical Communication System and Methods for Efficient Data Delivery
U.S. Patent 11,522,607; issued December 6, 2022

Reagents for Enhanced Detection of Low-Volatility Analytes
U.S. Patent 11,543,399; issued January 3, 2023

All-Electrical Fully Connected Coupled Oscillator Ising Machine
U.S. Patent 11,552,595; issued January 10, 2023

Superconducting Parametric Amplifier Neural Network
U.S. Patent 11,556,769; issued January 17, 2023

Planar Luneburg Lens System for Two-Dimensional Optical Beam Steering
U.S. Patent 11,579,363; issued February 14, 2023

Passive Wide-Area Three-Dimensional Imaging
U.S. Patent 11,580,694; issued February 14, 2023

Systems and Methods for Optimization of a Data Model Network Architecture for Target Deployment
U.S. Patent 11,586,875; issued February 21, 2023

Photonic Lantern Structures and Devices
U.S. Patent 11,588,292; issued February 21, 2023

High Bandwidth Individual Channel Control via Optical Reference Interferometry Control System Architecture
U.S. Patent 11,588,556; issued February 21, 2023

Propeller Design Systems and Methods
U.S. Patent 11,593,534; issued February 28, 2023

Modular Microjet Cooling of Packaged Electronic Components
U.S. Patent 11,594,470; issued February 28, 2023

Photovoltaic Grid Capacity Sensor
U.S. Patent 11,594,885; issued February 28, 2023

Amorphous Germanium Waveguides for Spectroscopic Sensing and Data Communication Applications
U.S. Patent 11,604,147; issued March 14, 2023

Methods and Systems for Signal Interference Cancellation
U.S. Patent 11,611,423; issued March 21, 2023

Methods and Apparatus for Analog Canceler Tuning Using Neural Networks
U.S. Patent 11,626,966; issued April 11, 2023

End-to-End Deep Neural Network for Auditory Attention Decoding
U.S. Patent 11,630,513; issued April 18, 2023

Methods and Apparatus for True High Dynamic Range Imaging
U.S. Patent 11,632,507; issued April 18, 2023

Multi-antenna Sequential Interference Cancelling Receiver
U.S. Patent 11,632,764; issued April 18, 2023

Method and Apparatus for Determining a Receiver Beam in a Co-existence Cognitive Radio
U.S. Patent 11,637,613; issued April 25, 2023

Identification of Variable Influenza Residues and Uses Thereof
U.S. Patent 11,642,407; issued May 9, 2023

Systems and Methods for Genetic Identification and Analysis
U.S. Patent 11,655,498; issued May 23, 2023

Wide-Area Motion Imaging Systems and Methods
U.S. Patent 11,662,727; issued May 30, 2023

Using Correlation Structure of Speech Dynamics to Detect Neurological Changes
Australian Patent 2014374349; issued June 7, 2023

Forensic Video Exploitation and Analysis Tools
U.S. Patent 11,676,389; issued June 13, 2023

Mitigation of Communication Signal Interference Using Adaptive Transmit Power
U.S. Patent 11,690,090; issued June 27, 2023

Portable Spectrometer for Chemical Sensing
U.S. Patent 11,692,942; issued July 4, 2023

All-to-All Connected Oscillator Networks for Solving Combinatorial Optimization Problems
U.S. Patent 11,698,945; issued July 11, 2023

Qubit Circuits with Deep, In-Substrate Components
U.S. Patent 11,699,091; issued July 11, 2023

Systems, Apparatus, and Methods for Modeling, Monitoring, and/or Managing Metabolism
European Patent (Italy, France, Great Britain, Denmark, Germany) 3,328,276; issued July 12, 2023

Electrospray Devices and Methods for Fabricating Electrospray Devices
U.S. Patent 11,708,182; issued July 25, 2023

Extending Footprint for Localization Using Surface Penetrating Radar (SPR)
China Patent CN110,462,433; issued August 1, 2023

Method and System for Localization of a Vehicle Using Surface Penetrating Radar
China Patent CN110,520,754; issued August 1, 2023

Quantum Measurement Emulation Error Mitigation Protocol for Quantum Computing
U.S. Patent 11,715,026; issued August 1, 2023

Compact Computational Spectrometer Using Solid Wedged Low Finesse Etalon
U.S. Patent 11,733,094; issued August 22, 2023

Water Reactive Materials for Drying Articles
U.S. Patent 11,761,143; issued September 19, 2023

In Vitro Tissue Plate
U.S. Patent 11,767,498; issued September 26, 2023

Efficient Operations

In 2023, Lincoln Laboratory forged ahead with hybrid work. A focus on staff satisfaction and enablement drove efficient operations forward. Progress was made on the Laboratory's multiyear Digital Enterprise Transformation initiative, new capabilities were introduced, existing processes were streamlined, and collaborations were forged with partners across the Laboratory to increase inclusivity, efficiency, and security.

Enhancements to Information Technology and Services

- Augmenting communication and collaboration options. Both the Enterprise Lincoln Collateral Network (ELCN) and the Secret Internet Protocol Router Network received email capability in 2023, and the ELCN gained video teleconferencing ability. Across all Laboratory accounts, a new tag applied to emails from external sources alerts users to remain vigilant.

- Enhancing client-service capabilities. A new client-services provider was secured to streamline and improve services when staff request support via phone, email, or online ticket.

- Upgrading enterprise applications and devices. The Laboratory updated its virtual desktop infrastructure with faster storage abilities, migrated from a legacy document-storage system to SharePoint, and moved to the latest version of Microsoft Office. Life-cycle enforcement of legacy iPhones and iPads was implemented to help keep devices secure.

- Expanding IT services. The rollout of more collaboration rooms and reservable workspaces enabled the Laboratory's hybrid workforce. Enhancements to the intranet included personalized notifications and augmented search and blog capabilities. A new website was released for the Laboratory's Digital Engineering Center, whose mission is to integrate digital technology for the efficient development of prototypes.

- Developing storage and backup abilities. Backup-as-a-Service was introduced to offer quick, on-demand access to secure data-backup capabilities. Storage-as-a-Service was also augmented with a self-service, cost-effective capability enabling infrequently used or archived data to be stored securely offsite.

- Expanding security processes. The Laboratory continued its journey toward zero-trust capabilities by enhancing remote-access processes. Single-sign-on certificates were retired where necessary, and a way to pause patching to protect in-progress tests was offered. A new framework and dashboard for vulnerability reporting increased transparency into the Laboratory's vulnerability posture.

Collaboration Spaces Support Hybrid Teams

New collaboration rooms opened at the Laboratory's Katahdin Hill facility. The renovated spaces include four large Zoom-enabled rooms, 11 new hoteling offices, and a closed area with collaboration spaces for classified discussions. The updates allow for improved flexibility and teamwork in a hybrid workplace.

Shawn Ohler, who leads the research group that will be using the spaces, said that the new areas will "allow his team to be more productive and collaborative, and will have a positive overall effect on team activities." Pictured above, Ohler and Lincoln Laboratory Director Eric Evans discuss the features of one of the collaboration rooms, which includes large screens for videoconferencing.

Progress in Digital Enterprise Transformation

The Digital Enterprise Transformation (DET) is a multiyear effort to modernize Laboratory operations. The Laboratory has established key objectives in striving toward improved operational efficiency:

1. Advance a culture of ownership, accountability, and continuous improvement within core operations processes.

2. Enable Laboratory staff with new capabilities aligned with a digitally mature organization.

3. Simplify and improve core business processes.

4. Inform decisions with data-driven insights, and rely on metrics and key performance indicators to identify challenges and successes.

5. Establish an enterprise architecture that is scalable and adaptable to changes in the operating environment.

In 2023, key progress was made on several DET initiatives:

- Portfolio and project management. The Laboratory launched an initiative analyzing portfolio and project management. This initiative reviewed how current processes address the needs of the Laboratory's evolving sponsor and information requirements. Focus areas examined resource allocation, cost estimation, and scheduling. The next phase of the initiative will investigate simple, scalable, and flexible capabilities that meet the needs of all program types.

- Opportunity and connection management. Nearly 100 Laboratory staff and leaders tested a pilot of a customer relationship management platform. The platform is aimed at strengthening sponsor and partner relationships, enhancing business development, improving collaboration, and growing the visibility of technology transfer activities.

- Business process management. A team leading improvements in business process management continued to collaborate with process owners and stakeholders to discover, model, analyze, measure, improve, and optimize work practices. The team focused on processes for removing surplus equipment, using a new conflict-of-interest portal, and improving access to special networks.

- Group office portal. The Laboratory is implementing a centralized and personalized portal to provide group leaders and line managers with timely, relevant, and actionable insights, enabling data-driven decisions to better support research and operations. The first iteration of this portal was launched in 2023, with future enhancements and capabilities to be introduced bimonthly.

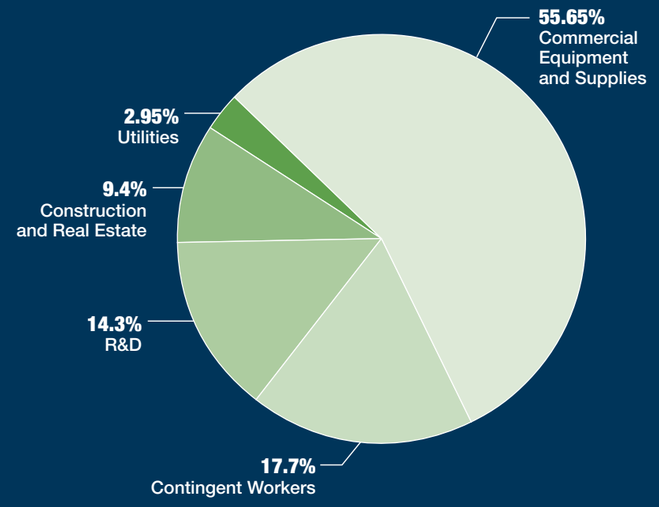
Digital Twin Software Debuts

An Operational Digital Twin website was created to help simplify business practices and visualize workflows within the Laboratory. A "digital twin" is a software program that mirrors the state of either a person, asset, or organization to aid business ventures. Access to the Operational Digital Twin can help project managers define requirements, easily access systems and processes, and gain a high-level view of the capabilities and products available at the Laboratory.

Economic Impact

Lincoln Laboratory serves as an economic engine for the region and the nation through its procurement of equipment and technical services. During fiscal year 2023, the Laboratory issued subcontracts with a total value of $515.5 million including businesses in all 50 states and Washington, D.C. The Laboratory purchased $275.5 million in goods and services from New England companies, with approximately $193 million in contracts awarded to Massachusetts businesses. The Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

Procurement by Business Category (FY2023)



**Estimates from $515.5M, total FY23 spend*
– Includes orders to MIT – $8M
– Figures are net awards less reductions

Top Procurement Awards by State (FY2023)

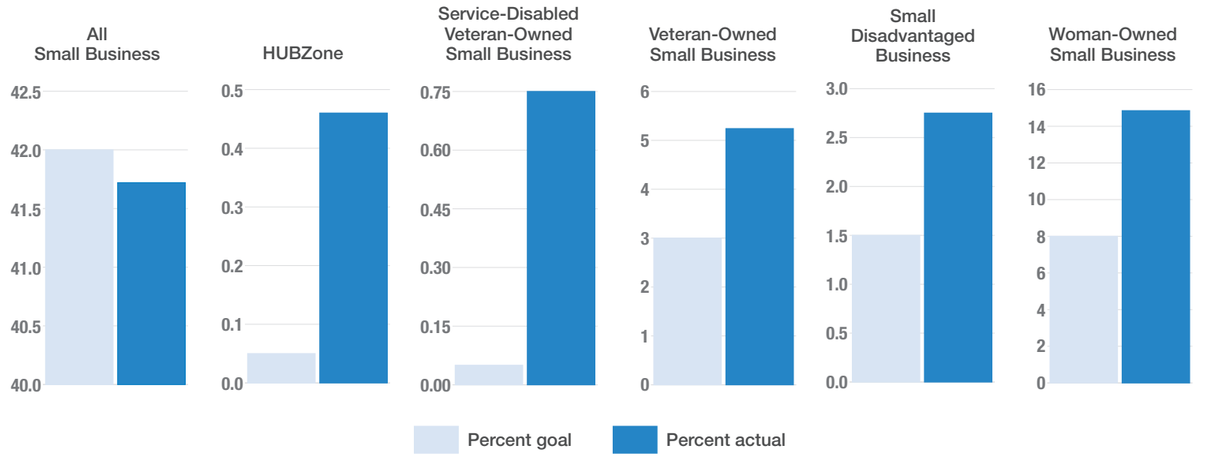
STATE	$ MILLION
Massachusetts	193
New Hampshire	68.5
California	49.3
Texas	34.9
Virginia	25
Oregon	14
Connecticut	11.7
All Other	119.1
Total*	515.5

**Includes orders to MIT – $8M*

Small Business Office

Small businesses—which supply construction, maintenance, fabrication, and professional technical services in addition to commercial equipment and material—are significant beneficiaries of the Laboratory's outside procurement program. In 2023, more than 41% of subcontracts were awarded to small businesses of all types, and the Laboratory exceeded its goals for engagement with small businesses in underrepresented or disadvantaged categories. The Laboratory's Small Business Office is committed to an aggressive program designed to afford small businesses the maximum opportunity to compete for purchase orders.

Percentage of Spending by Small Business Category (FY2023)



LABORATORY INVOLVEMENT

Interns participating in the 2023 Summer Research Program convene in the Laboratory's lobby. The annual program offers undergraduate, graduate, and military students hands-on research experience.

Research and Educational Collaborations

PHOTONIC FIBERS FOR TEXTILE RECYCLING

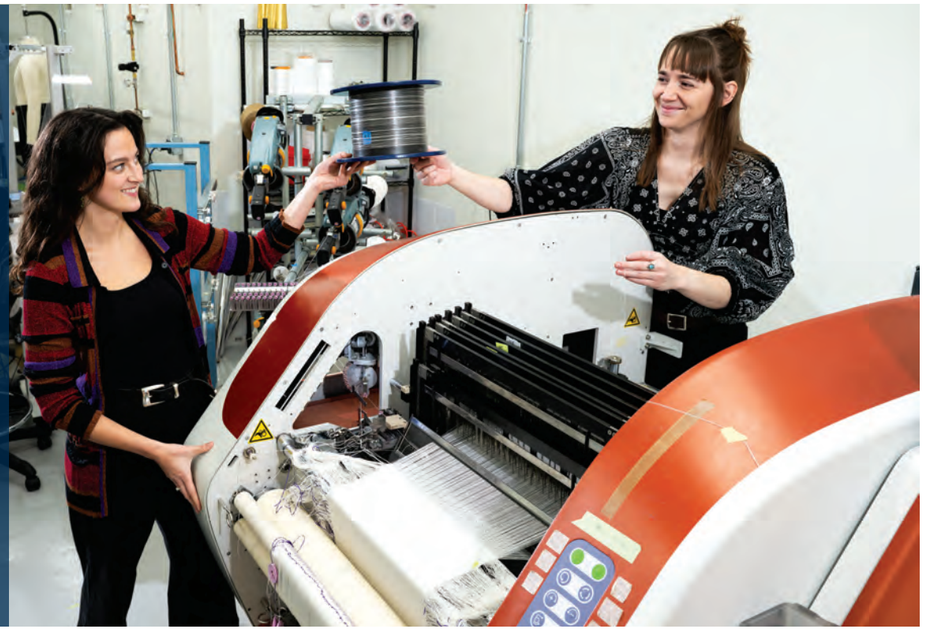
In the United States, an estimated 15 million tons of textiles end up in landfills or are burned every year. This pileup is partly due to the difficulties of recycling textiles. They first must be sorted by fabric type, and labels are often worn away or missing.

To improve this sorting process, a team of materials scientists from the Laboratory's Defense Fabric Discovery Center and the University of Michigan developed fibers with engineered light reflectivity. When woven into textiles, these photonic fibers can serve as scannable, durable labels.

The team constructed the fibers to contain more than 50 alternating layers of acrylic and polycarbonate. Though each individual layer is clear, the pairing of the two materials reflects and absorbs light at specific, periodic ranges of wavelengths—creating a unique optical barcode in each fiber. This barcode can then be assigned to a corresponding fabric type, one symbolizing cotton, for example, and another polyester. Once a textile reaches a recycling facility, an infrared detector would read the optical barcode, identifying the fabric.

University of Michigan postdoctoral researcher Brian Iezzi scans and measures photonic fibers in a fabric. Photo: Marcin Szczepanski

The team has applied for patent protection on their technology and are evaluating ways to implement it in textiles. The researchers are also thinking about how such fibers might tackle other environmental problems in the textile industry, like toxic waste from dyes. While the fibers used in this study are designed to be reflective at wavelengths invisible to the eye, a similar process can be used to make fibers with shimmering colors.



Emily Holtzman and Erin Doran, who work in the Defense Fabric Discovery Center, load a spool of photonic fiber into an industry loom, which weaves the fiber into textiles. Such fibers could function as indelible labels to easily sort fabrics for recycling.

ICE FRACTURING ON LAKE SUPERIOR

Laboratory researchers Benjamin Evans and David Whelihan visited Michigan Technological University's Great Lakes Research Center (GLRC) to deploy a system of sensors used to collect acoustic, seismic, and weather data related to ice-fracturing events.

Last year, Evans and Whelihan visited the Arctic to pursue this research for the U.S. Navy during its biennial Ice Exercise (ICEX). After returning from Alaska, they began analyzing their data and refining their system design. In ICEX's off-year, they hoped to get back out on the ice to continue building upon what they had learned. Lake Superior in the winter presented a strong parallel to the Arctic while being much more accessible. The GLRC team helped the Laboratory researchers scout locations for their fieldwork, ending up on a patch of Huron Bay ice.

The sensor data capture a vertical view of atmospheric effects, allowing scientists to see how factors above and below the water surface interact to affect ice breakup. The Laboratory team's goal is to deploy this system widely across the Arctic to study ice loss as climate change accelerates.

Above, David Whelihan, left, and Benjamin Evans inspect a spool of fiber embedded with temperature and depth sensors before they lower the spool into the water. At left, Lincoln Laboratory and GLRC researchers test locations for data collection on Huron Bay ice. Photos: GLRC

Leaders from Air Command and Staff College, from left to right, Lt. Col. Brian Hellesto, Col. (Ret.) Jeff Reilly, and Lt. Col. Sean Atkins meet with Daniel Strassler at the Laboratory to learn about the programs to which their students will be contributing.

EDUCATION FOR JOINT ALL-DOMAIN STRATEGISTS

The Laboratory kicked off a new educational collaboration with Air Command and Staff College at Air University, the U.S. Air and Space Forces' center for professional military education. In the collaboration, students in the Joint All-Domain Strategist Graduate Program are embedded within project teams at the Laboratory. Students in this graduate program practice critical-thinking skills required for strategic operations and are likely to one day hold command positions. The experience at the Laboratory will help expose the students to the art of the possible when faced with technical challenges.

>> *Research and Educational Collaborations, cont.*

U.S. Air Force and Army cadets learn about robotic systems in the Laboratory's Autonomous Systems Development Facility.

INNOVATIVE IDEAS IGNITE IN STUDENTS

All eyes were on the robot-dog pacing the Laboratory's Autonomous Systems Development Facility. The robot was just one technology—among small drones, autonomous mapping vehicles, and virtual-environment simulators—set up for cadets to interact with. Over the coming school year, they would be applying such technologies to challenges facing the U.S. Special Operations Command (USSOCOM) for a program called SOCOM Ignite.

SOCOM Ignite connects military students with research scientists and Special Operations Forces to address SOCOM's pressing technology challenges while ushering in a new generation of technology-savvy officers and operators. In its fourth installment in 2023, the program brought in more than 80 cadets from across the nation's service academies and Reserve Officers' Training Corps (ROTC) programs to participate.

Laboratory researchers serve as technical mentors for Ignite. To kick off the program in September, they offered new "innovation incubator" courses that taught the basics of machine learning and autonomy, two topics of high interest to SOCOM. Following those sessions, a formal ceremony invited SOCOM leaders to discuss the impact of the program on the command's mission.

After the opening ceremonies, the cadets traveled to MIT campus for a weekend-long hackathon, where SOCOM operators presented them with more than a dozen Ignite challenges. Cadets then formed teams to begin brainstorming concepts, working firsthand with Special Operations Forces and Laboratory technical experts to refine their ideas.

SOCOM Ignite 2023–2024 kicked off at Lincoln Laboratory with more than 80 cadets from 19 universities working on solutions for specific Special Operations Forces challenges.
Photo: SOCOM Public Affairs Office

SOCOM Ignite mentor Jordan Sinoway demonstrates a variety of small sensors, such as infrared cameras, that can be outfitted on small drones.

The challenges covered diverse needs. One challenge was to develop a way to deploy air tags from small uncrewed air vehicles (UAVs) onto ground vehicles. Another sought algorithms and hardware to enhance autonomous UAV flight indoors. A biotechnology challenge called for methods to improve the storage and delivery of blood in a tactical environment.

"The hackathon experience was inspiring. It was great to see such a large number of cadets coming from different institutions attend and have a desire to conduct meaningful research," said Jack Perreault, a SOCOM cadet whose challenge was to apply computer vision and speech recognition to enhance the process of triaging casualties.

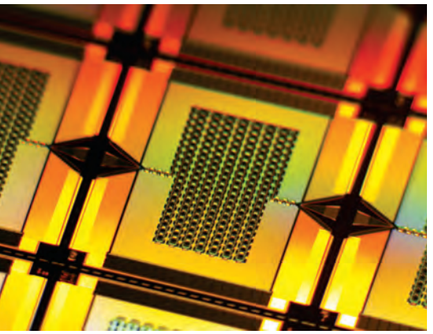
After the opening weekend, cadets continue to work on their concepts and develop prototypes throughout the school year. Lincoln Laboratory and various SOCOM components then take on some cadets as interns or military fellows to continue their research. Perreault is one such military fellow, now developing his SOCOM solution at the Laboratory while pursuing a master's degree at Boston University. "Getting insight on how our technical skills can help enable operators to achieve their missions has left the greatest impact on me overall," Perrault said.

A U.S. Air Force cadet operates a small robotic vehicle that creates a 3D lidar map of its surroundings in real time.

>> *Research and Educational Collaborations, cont.*

A BOOST FOR QUANTUM SIGNALS

A wide-ranging team of researchers from Lincoln Laboratory and MIT, including the MIT Research Laboratory of Electronics and Center for Quantum Engineering, developed a superconducting parametric amplifier that can achieve quantum "squeezing" over much broader bandwidths than those achieved by other designs. When a quantum system, such as a qubit, is read out, squeezing decreases the noise affecting one variable while increasing the noise affecting another. Though the total amount of noise remains the same, the noise is effectively redistributed. Researchers can then make accurate measurements by looking only at the lower-noise variable. This new broadband device may enable scientists to read out quantum information much more efficiently, leading to faster and more accurate quantum systems.



The superconducting parametric amplifiers pictured above are the first to demonstrate quantum squeezing over a broad bandwidth of up to 1.75 GHz. Previous amplifiers have generally achieved bandwidths of only 100 MHz or less.

EXOSKELETON RESEARCH AT THE STRIVE CENTER

A study participant wearing an exoskeleton approaches a yellow light within a simulated city intersection.

Lincoln Laboratory's Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center opened its doors to collaborators supporting exoskeleton research. The STRIVE Center houses technology that can be used to simulate environments to study human motion.

Laboratory researchers are working with Prof. Leia Stirling, formerly at MIT and now at the University of Michigan, on the development of fluid, intuitive exoskeletons—wearable devices designed to augment human movement. Caleb Jeanniton, a PhD student advised by Stirling, visited the STRIVE Center to conduct a series of human-factors tests. The tests aim to investigate how wearing an ankle-supporting exoskeleton impacts a person's decision to cross a street during a yellow light.

For the tests, volunteer subjects were immersed in a 360-degree virtual environment simulating a city scene. Participants walked through the scene on a force-measuring treadmill while wearing the exoskeleton and motion-capture markers. Researchers use the markers to reconstruct the forces and angles of the person's joints and the direction the person was looking as they decided to cross the street.

The results will have broader implications for how human-machine interfaces influence decision-making and task performance, according to Brian Baum, the STRIVE Center's research manager.

MILITARY FELLOWS PROGRAM

Every year, the Military Fellows Program offers military officers pursuing graduate degrees or advanced education the unique opportunity to engage in R&D at the Laboratory. Fellows are directly involved in developing capabilities important to national security, and, in turn, Laboratory staff benefit from the officers' unique insights. Since the program's start in 2010, more than 300 Fellows have worked alongside Laboratory staff mentors. Twenty-three Fellows worked at the Laboratory for the 2022–2023 session of the program, and 20 Fellows are continuing their research at the Laboratory from 2023 to 2024.

Military Fellow and MIT student Sam Karlson worked with the Laboratory's Quantum Information and Integrated Nanosystems Group on nitrogen-vacancy diamond magnetometry. In May, he presented his research to attendees during an appreciation luncheon for Military Fellows, Lincoln Scholars, and their mentors.

Military Fellow Sam Karlson presents his work on nitrogen-vacancy diamond magnetometry at a luncheon for participants in the Laboratory's educational programs.

"Working here has been a great opportunity. My supervisors have been very helpful integrating me into the group research projects, and the Lincoln Laboratory setup makes it really easy to collaborate and network with different researchers in different groups. Working here has exposed me to lots of the amazing research projects going on," Karlson said.

The Military Fellows Program seeks to provide hands-on experiences that augment the skills Fellows have gained in the classroom and in the military. Nolan Pearce is a Military Fellow pursuing a master's degree at Northeastern University in electrical and computer engineering, specializing in wireless communications. He worked in the Laboratory's Tactical Networks Group on R&D related to low-probability-of-intercept and low-probability-of-detection waveforms. Pearce described his work at Lincoln Laboratory as an excellent complement to his graduate school studies in engineering: "I can work on cutting-edge applications here and supplement them with theory that I learn at school. Often, the topics that I research at Lincoln Laboratory are based on fundamental classes I'm taking simultaneously. Balancing school and research is hard, but it offers a great advantage to grasp the basics while seeing advanced applications. The mentorship and opportunities available through the Laboratory also offer another avenue for exploring options within military life."

An equally important component of the Military Fellows Program is the interpersonal aspect, with Fellows forming connections with their Laboratory staff colleagues and mentors. Fellows gain valuable insight and experience working and interacting with subject-matter experts, and their Laboratory colleagues can offer a glimpse into what a career in the Fellow's field of interest could look like.

"The staff in the Advanced SATCOM Systems and Operations Group has been incredibly helpful, kind, and knowledgeable and has helped expand my view of the field of communications, especially in space. People have dropped what they are doing to help me or explain concepts to me, and that sort of mentorship has really inspired me to learn more in the field. I have a new appreciation for the technologies that Lincoln Laboratory develops," said Jon Copley, a Military Fellow who processed and analyzed data collections from satellites.

>> *Research and Educational Collaborations, cont.*

WORKSHOPS AND SEMINARS

Lincoln Laboratory hosts workshops and seminars where experts present research into emerging technologies. In 2023, Lincoln Laboratory returned to hosting primarily in-person workshops. Below, 90 military officers and Department of Defense civilian employees attended the 2023 Defense Technology Seminar in March to discuss evolving military challenges. Guest speakers included Dr. Matthew Daniels, Assistant Director of the White House Office of Science and Technology Policy for Space Security & Special Projects, and General Paul Silva, USAF (Ret.), 10th Vice Chairman of the Joint Chiefs of Staff. Participant reviews repeatedly stated: "best seminar I have ever attended."

2023 Schedule of Lincoln Laboratory Workshops

MARCH

27–31 Defense Technology Seminar for Military Officers

APRIL

11–13 Advanced Technology for National Security Workshop

MAY

2–4 Space Control Conference

9–11 Air Vehicle Survivability Workshop

24–25 Lincoln Laboratory Communications Workshop

31–1 JUNE Cyber Technology for National Security Workshop

JUNE

6–7 Biotechnology and Resilient Human Systems Workshop

13–15 Air, Missile, and Maritime Defense Technology Workshop

JULY

26–28 Malware Technical Exchange Meeting

OCTOBER

24–26 Advanced Prototype Engineering Technology Symposium

NOVEMBER

7–9 Anti-Access/Area Denial Systems and Technology Workshop

13–16 Recent Advances in Artificial Intelligence for National Security

DECEMBER

1 Defense Technology Seminar for Military Fellows (One Day)

12–13 Advanced Prototype Engineering Technology Symposium

2023 Off-site Workshops

The Laboratory coordinates off-site workshops with partnering organizations. Laboratory involvement may be co-chairmanship of events, technical leadership of sessions, or co-sponsorship. Many of the off-site workshops were offered virtually.

February 14
Artificial Intelligence for Cyber Security Workshop

June 19
MultiEarth Workshop

August 15–16
Graph Exploitation Symposium

September 25–29
IEEE High Performance Extreme Computing Conference

October 9–11
IEEE International Workshop on Wearable and Implantable Body Sensor Networks

November 14
Air Traffic Control Workshop

November 15–16
IEEE International Symposium on Technologies for Homeland Security

Zero Trust Symposium

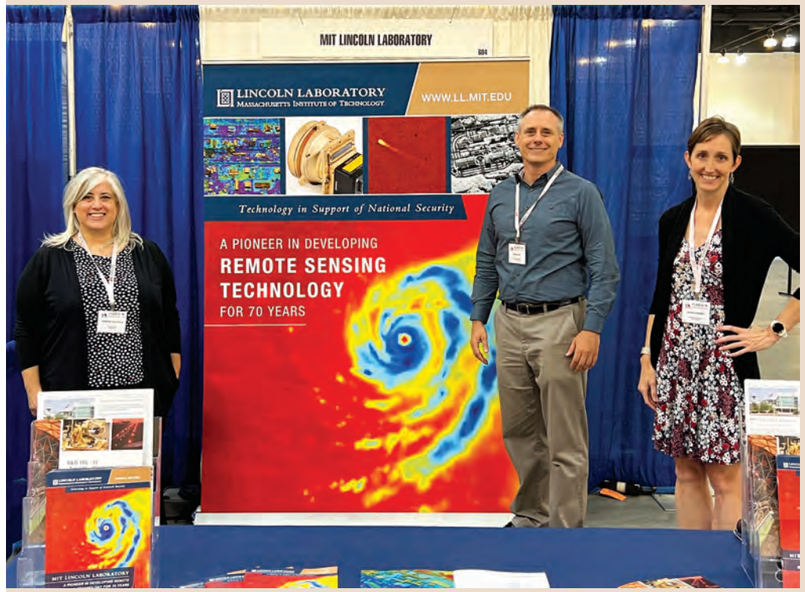
In April, more than 1300 cybersecurity experts and practitioners gathered virtually for the inaugural Zero Trust Symposium, an event emphasizing the cultural shift needed to reach a new cybersecurity norm. Lincoln Laboratory, Defense Acquisition University, and the U.S. DoD Zero Trust Portfolio Management Office sponsored and co-hosted the event.

The Honorable John Sherman, DoD Chief Information Officer, served as keynote speaker for the Zero Trust Symposium.

Air, Missile, and Maritime Defense Technology (AMMDT) Workshop

The 2023 AMMDT Workshop attracted attendees from the Services, the Office of the Secretary of Defense, the Intelligence Community, research centers, national laboratories, and academia. The two-day workshop outlined challenges posed by emerging threats and enumerated potential architectural and technology solutions for defense of the homeland, U.S. interests, and deployed forces worldwide. Presentations were well-received by the audience. The presentation on the Laboratory's deployment of over-the-horizon radar technology concluded with a standing ovation.

Laboratory leadership, session chairs, and speakers—including keynote speaker, Laura DeSimone, Executive Director of the Missile Defense Agency—gather during the AMMDT Workshop.



International Geoscience and Remote Sensing Symposium (IGARSS)

From left to right, Laboratory staff Jennifer Falciglia, Vince Leslie, and Laura Kennedy hosted an informational booth at IGARSS. The conference provides a platform for sharing knowledge and experience on recent developments and advancements in geoscience and remote sensing technologies, particularly Earth observation, disaster monitoring, and risk assessment. Lincoln Laboratory attends IGARSS and has multiple papers accepted every year; however, 2023 marked the first time the Laboratory has recruited at the event.

Awards and Recognition

2022 MIT Lincoln Laboratory Technical Excellence Awards

Dr. Joseph P. Campbell, for outstanding contributions and leadership in human-language technology, pioneering developments in speech processing, expertise in biometrics, innovations in machine learning, and effective technology transition to government. Campbell's efforts have significantly impacted the nation's intelligence, warfighting, and law-enforcement capabilities.

Dr. Brian A. Telfer, for sustained, outstanding achievements and leadership in developing radar and biosignal processing and machine learning technologies. His research and development efforts are counted among the Laboratory's top contributions in multiple mission areas, ranging from missile defense to human health and performance.

2022 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Lulu Liu, for innovation and leadership in the development of electro-optic technologies for next-generation directed energy and remote sensing systems. Over the past five years, Liu has proven be a prolific and innovative researcher, a successful program developer, and an exceptional leader.

Dr. Curt M. Schieler, for leadership in developing next-generation optical communication technologies. Schieler has the unique ability to combine deep theoretical insights with strong hardware development skills. His contributions have significantly impacted the future direction of optical communications both within the Laboratory and in the broader community.

2022 MIT Lincoln Laboratory Best Paper Award

Dr. Timothy M. Braje and **Dr. Martine M. Kalke** for their paper "Adversary Safety by Construction in a Language of Cryptographic Protocols," published in the *Proceedings of the 2022 IEEE 35th Computer Security Foundations Symposium*, August 2022. Co-authors include Alice R. Lee (Technische Universität Wien), Andrew Wagner (Northeastern University), Benjamin Kaiser (Princeton University), Daniel Park (Rensselaer Polytechnic Institute), Dr. Robert K. Cunningham (University of Pittsburgh), and Prof. Adam Chlipala (MIT Computer Science and Artificial Intelligence Laboratory).

2022 MIT Lincoln Laboratory Best Invention Award

Dr. Steven T. Smith, **Dr. Edward K. Kao**, **Dr. Danelle C. Shah**, and **Dr. Olga Simek**, for their invention "System and Technique for Influence Estimation on Social Media Networks Using Causal Inference." The team also includes co-inventor Professor Donald Rubin from Harvard University.

Dr. Steven R. Gillmer, **Erin Doran**, **Emily Holtzman**, and **Ariel M. Sandberg**, for their invention "Stretchable Knitted Cell Scaffolds." The team also includes co-inventor Professor Ming Guo from MIT.

2023 AIAA Fellows

Left to right, **Dr. Robert T-I. Shin** and **Dr. Leena Singh** were selected into the 2023 class of Fellows for the American Institute of Aeronautics and Astronautics (AIAA). Fellows are elected for their accomplishments in important engineering or scientific work, or for their outstanding contributions to the arts, sciences, or technology of aeronautics or astronautics.

2024 AIAA Associate Fellows

Left to right, **Dr. Gabriele Enea** and **Dr. Ryan Fontaine** were named Associate Fellows of the AIAA. Associate fellowships are awarded to individuals who have accomplished important engineering or scientific work and those who have made outstanding contributions to the field of aeronautics or astronautics.

AIAA International Cooperation Award

Dr. Vincent A. Orlando received an International Cooperation Award from the AIAA for his 40-plus years of sustained technical innovation, standards development, and international harmonization of aviation surveillance system technology. This award is given to those who have recently contributed to the application of scientific and mathematical principles that result in a significant accomplishment or event.

Federal Laboratory Consortium Technology Transfer Awards

Lincoln Laboratory received Excellence in Technology Transfer Awards from the Federal Laboratory Consortium for two software products developed to improve security: Keylime and the Forensic Video Exploitation and Analysis (FOVEA) tool suite. Keylime increases the security and privacy of data and services in the cloud, while FOVEA expedites the process of reviewing and extracting useful information from existing surveillance videos.

Keylime, an open-source software, is enabling organizations to secure sensitive cloud data. The FOVEA is a suite of analytic tools that makes it easier for investigators to review surveillance video footage. Shown at left is a portion of the system's interface.

AIAA Missile Systems Award

The AIAA presented **Mark A. Weiner** with a Missile Systems Award for his significant national contributions to the development of surface-to-air and air-to-air missile systems and countermeasures through rigorous analysis and testing of radar and seeker technologies. Weiner received the award at the AIAA DEFENSE Forum, a yearly event that provides a venue for leaders from government, military, industry, and academia to advance and accelerate innovation.

Appointment to the Air Force Scientific Advisory Board

In 2022, the Secretary of the Air Force appointed **Dr. Vyshnavi Suntharalingam** as vice chair of the Department of the Air Force Scientific Advisory Board. Board members consist of the nation's top civilian scientists and engineers.

2023 Royal Aeronautical Society Fellow

Dr. Thomas Sebastian became a Fellow of the Royal Aeronautical Society. The society is dedicated to driving innovation in aeronautical art, science, and engineering globally. Fellowships are awarded to individuals who have made outstanding contributions and reached a high position in an aerospace or aerospace-related profession.

Military Sensing Symposia Fellow

Dr. Frank C. Robey was elected as a 2022 Military Sensing Symposia (MSS) Fellow. Fellows are selected for their technical accomplishments and significant contributions as an engineer, scientist, or technical leader to the military sensing community.

Appointment as Program Chair of NDSS Symposium

Dr. Hamed Okhravi was appointed by the steering committee of the Network and Distributed System Security (NDSS) Symposium to serve as its program chair for a two-year term, from 2025–2026. The NDSS Symposium is a leading security forum that fosters information exchange among researchers and practitioners of network and distributed system security. Through the collaborative sharing of top-tier research on systems security, the NDSS Symposium helps the community members make the Internet more secure.

IEEE Region 1 Technological Innovation Award

Dr. Laura Brattain was named a recipient of the IEEE Region 1 Technological Innovation Award. The award recognizes individuals for their significant patents, discovery of new devices, development of applications, or exemplary contributions to industry or government. IEEE Region 1 consists of about 40,000 IEEE members from New England and the Mid-Atlantic states, and only a handful of these members are selected each year for this significant award.

>> *Awards and Recognition, cont.*

National Medal of Technology and Innovation

Left to right, former Lincoln Laboratory researcher Eric Swanson, along with colleagues David Huang and James Fujimoto, was awarded the National Medal of Technology and Innovation by President Joe Biden. They received the award for their invention of the optical coherence tomography technology that uses light waves to enable noninvasive eye imaging. Swanson worked on this technology while serving as an associate group leader at the Laboratory.

2023 AFCEA 40 Under Forty Award

Left to right, **Dr. Lin Li** and **Kevin Creedon** were among the 2023 40 Under Forty winners chosen by Armed Forces Communications and Electronics Association International (AFCEA). Each year, AFCEA selects 40 individuals under the age of 40 to receive this award for their significant contributions in a technical science, technology, engineering, or mathematics field.

AFCEA Cyber Edge Writing Contest Award

The first-place prize of the Cyber Edge Writing Contest was awarded to **Richard Skowyra**, **Samuel Mergendahl**, and **Roger Khazan** from the Laboratory along with Joseph "Dan" Trujillo from the Air Force Research Laboratory for their article titled "Holding the High Ground: Defending Satellites From Cyber Attack." Held annually by AFCEA's *SIGNAL Magazine*, the contest aims to spread knowledge from cyber thought leaders to the 30,000 members of AFCEA.

DAF-MIT AIA Challenge Award

A **Lincoln Laboratory team** was awarded the 2022 Department of the Air Force–MIT Artificial Intelligence Accelerator Challenge Award for their development of the Multimodal Learning for Earth and Environment (MultiEarth) Challenge. The goal of the MultiEarth challenge was to bring together the Earth science, environmental science, and multimodal representation learning communities to examine new ways to leverage technology for environmental monitoring.

2022 Superior Security Rating

Awarded to **Lincoln Laboratory** by the U.S. Air Force for the 17th consecutive year. The rating represents the Laboratory's commitment to safeguarding sensitive and classified information.

2023 MIT Excellence Awards

Serving our community: **Roslyn R. Wesley** and **Timothy J. Meunier**; *Outstanding contributor*: **Dennis C. Hamel** and **Dr. Sarah E. Willis**.

Herman R. Salmon Technical Publications Award

Thomas Washington, who is a pilot at the Flight Test Facility, won the 2023 Herman R. Salmon Technical Publications Award for his paper titled "Technique for Determining Takeoff Performance of Modified Part 25 Aircraft." The Society of Experimental Test Pilots grants this award to the best article published in *COCKPIT Magazine* during the year. Below, Washington (right) accepts his award.

2023 Cultivating Leadership, Achievement, and Success Awards

Employee Resource Group Excellence Award
Stephanie A. Mosely

Equity Award
Julie A. Arloro-Mehta

Outstanding Mentor Award
Trina P. Miller and **Dr. Thomas F. Quatieri**

Leadership Award for Advancing Organizational Culture
Dr. Mabel D. Ramirez

Peer Award for Cultural Impact
Dr. Elizabeth N. Fucetola

Best in CLAS Award
Dr. Bernadette Johnson

Strength in Unity Award
Staff from the Lincoln Laboratory Native American and Indigenous Peoples Affinity Group—**Dr. Joseph A. Belarge, Ryan D. Burrow, Consuelo G. Cuevas, Dr. Francesca D. D'Arcangelo, Benjamin Gregory Kazimer, Dr. Craig A. Keim, Grace R. Kessenich, Alfredo G. Martinez, Dr. Stephen J. Uftring, Hannah Walters, Alexandra R. Wright,** and **Elena C. Zorn.**

HIRE Vets Gold Medallion Award

Lincoln Laboratory was awarded the Gold Medallion Award by HIRE Vets in 2023. The HIRE Vets Medallion Awards recognize companies that are committed to the employment, retention, and professional development of veterans. This is the Laboratory's fourth consecutive year of receiving the Gold Medallion.

Participant in AnitaB Top Companies for Women Technologists

The **Laboratory** has been recognized as a participant in the AnitaB Top Companies for Women Technologists benchmarking program. AnitaB.org is an organization that aims to "connect, inspire, and guide women in computing and organizations that view technology innovation as a strategic imperative." The program compares companies to each other to let them know how each organization's gender breakdown stacks up against others of similar size.

Disability Inclusion Award

Lincoln Laboratory was recognized in the 2023 Disability Equality Index Report as one of the best places to work for disability inclusion. The recognition is given by the nonprofit Disability:IN, a leading resource for business disability inclusion worldwide, and the American Association of People with Disabilities. The Laboratory joins two other federally funded research and development centers, Argonne National Laboratory and Sandia National Laboratory, in this honor.

From left, Sharon Clarke, the Human Resources Department's employee relations and leaves manager, and Sarah Larson, the deputy director of the Human Resources Department, accepted the award on behalf of the Laboratory.

2023 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Left to right, Alicia A. LaDuke, Linda D. Madden, Sengsouriya "Keto" Sysong, and Brent H. Purington were honored at the 2023 MIT Lincoln Laboratory Administrative and Support Excellence Awards event.

Administrative category: **Alicia A. LaDuke**, for her exemplary oversight of critical release review submissions and management of major Laboratory events and outreach programs; **Sengsouriya "Keto" Sysong**, for employing creative technical solutions and effective collaboration to improve the Laboratory's critical computing infrastructure.

Support category: **Linda D. Madden**, for her exceptional administrative support to the Counter-Weapons of Mass Destruction Systems Group and dedication to fostering a supportive and inclusive work culture; **Brent H. Purington**, for being an exemplar aircraft mechanic in the Flight Test Facility and for going beyond his duties to ensure the success of the Laboratory's programs.

DIVERSITY AND INCLUSION 95

GEM students and Director Eric Evans celebrate the 2023 GEM Fellowship.

Diversity and Inclusion

THE OFFICE OF DIVERSITY AND INCLUSION

In 2018, the Office of Diversity and Inclusion (ODI) was established at Lincoln Laboratory. Its vision is to deliver a transformational competitive advantage to the Laboratory by becoming the national security industry exemplar in strategic diversity and inclusion (D&I) leadership and application. The ODI seeks to maximize individual and organizational performance and effectiveness by incorporating holistic D&I operations across people, business, and R&D systems and processes.

LEADERSHIP

(Left to right)

Alex Lupafya
Deputy Chief Diversity and Inclusion Officer

Emilee Selvitella
Administrative Coordinator

Amanda Martinez
Principal Diversity and Inclusion Officer

Bonnie Walker
Principal Diversity and Inclusion Officer

Brittney Odoi
Principal Diversity and Inclusion Officer

Chevy Cleaves
Chief Diversity and Inclusion Officer

A diverse workforce and an inclusive culture are vital to Lincoln Laboratory's technology mission. Leveraging the diversity of the nation it serves is advantageous for the Laboratory in solving the nation's hardest technical problems. The organization evolves and advances when the combined talents and unique views of many come together in an environment in which individuals with many critical skillsets are empowered to be their best. Employees thrive when their views, experiences, and knowledge combine to progress creativity, and when the ability to rapidly develop technology is made possible by a work environment in which employees are embraced for what they can do and for who they are. Diversity and inclusion elevate productivity, effectiveness, collaboration, and innovation.

The ODI offers many resources and events for the Laboratory community, including seminars that cover a variety of topics, such as healthcare disparities; leadership development offsites, where staff can learn how to lead more effectively while centering inclusivity; study groups; and Laboratory-wide educational and cultural initiatives.

Employee Resource Groups

Lincoln Laboratory's employee resource groups (ERGs) provide opportunities for connection between employees and support to staff members during the transitions they make as they advance in their careers. From helping new staff acclimate to the Laboratory's work environment, to encouraging professional development, to facilitating involvement in community outreach activities, the groups below help promote the retention and development of employees.

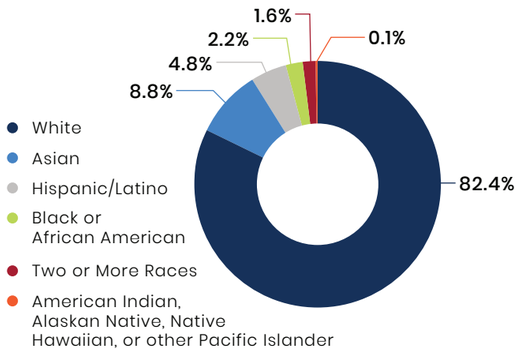
- **Lincoln Employees' African American Network (LEAN)**
  LEAN addresses issues faced by current and prospective African American employees, and participates in recruiting, community outreach, professional development seminars, and external networking.
- **Lincoln Laboratory ACCESS (LLACCESS)**
  LLACCESS supports Laboratory employees with disabilities to create work environments that are accessible, comfortable, ergonomic, and inclusive.
- **Lincoln Laboratory Hispanic Latinx Network (LLHLN)**
  LLHLN fosters awareness of Hispanic culture and promotes networking and professional development for its members.
- **Lincoln Laboratory New Employee Network (LLNEN)**
  LLNEN is a social networking group for new hires to help them transition into the Laboratory culture.
- **Lincoln Laboratory Out and Proud Network (LLOPEN)**
  LLOPEN provides a forum for the LGBTQ+ community at the Laboratory and strives to make an environment in which LGBTQ+ employees can thrive and feel comfortable.
- **Lincoln Laboratory Veterans' Network (LLVETS)**
  LLVETS recognizes Laboratory employees who are U.S. veterans, supports veterans transitioning from the military, provides outreach to local active-duty troops and veterans, and informs members of activities and legislation affecting veterans.
- **Lincoln Laboratory Women's Network (LLWN)**
  LLWN promotes the recruitment, retention, and achievement of women employees and provides a forum for them to share experiences, strategies for success, and resources.
- **Pan-Asian Laboratory Staff (PALS)**
  PALS promotes and builds awareness of the variety of Asian cultures present at the Laboratory and offers opportunities for its members to congregate and share experiences.
- **Recent College Graduates (RCG)**
  RCG is a networking group for new employees transitioning from college life. Activities include social networking events and trips, community involvement, and peer-to-peer technical presentations.

WORKFORCE DEMOGRAPHICS

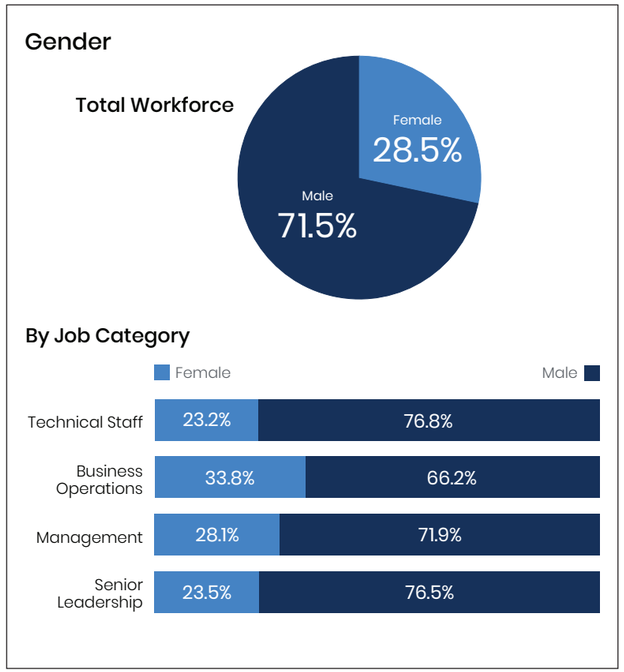
Recognizing the importance of transparency and accountability around D&I, the Laboratory shares these workforce demographics, which reflect the Laboratory's employee population as of December 31, 2023.

Self-Reported Data

Race and Ethnicity



Gender



Career Level by Race and Ethnicity

	White	Asian	Hispanic/ Latino	Black or African American	Two or More Races	AIAN and NHPI*
Technical Staff Assistant Staff, Associate Staff, and Full Technical Staff	79.0 %	11.9 %	5.2 %	1.5 %	2.2 %	0.2 %
Business Operations IT Staff, Specialist, Security Officer, Technician, Facilities and Finance Staff	85.5 %	5.9 %	4.9 %	2.6 %	1.0 %	0.1 %
Management Group Leader, Sector Manager, Division and Department Business Manager	84.0 %	8.7 %	2.2 %	3.8 %	1.3 %	0.0 %
Senior Leadership Director, Assistant Director, Division and Department Heads	82.4 %	11.8 %	2.9 %	2.9 %	0.0 %	0.0 %

*American Indian, Alaskan Native, Native Hawaiian, or other Pacific Islander

D&I: IT TAKES ENGAGED AND ACCOUNTABLE LEADERSHIP

Maximizing the organizational benefit of D&I takes the proactive support of management and the involvement of thought leaders from across the Laboratory.

Lincoln Laboratory is fortunate to have such a team of individuals dedicated to D&I goals:

- The Executive Diversity and Inclusion Council is co-chaired by Lincoln Laboratory Director Eric Evans and Chief Diversity and Inclusion Officer Chevy Cleaves. The council represents a best practice designed to provide strategic oversight of, organizational support for, and accountability regarding D&I transformation while establishing and solidifying the Laboratory's position as an employer and partner of choice. The council is composed of 15 representatives across divisions, departments, offices, and levels.
- Fifteen members make up the Diversity & Inclusion Champions, one representing each division and department. This best practice supports coordination, strategic communications flow, alignment, and transformation through select senior leaders in each department and division.
- Each of the nine members of the Cross-Cultural Executive Sponsors for Employee Resource Groups shares experience as a leader, strategist, and innovator with an employee resource group, helping advise and shape pathways that foster an inclusive, welcoming environment across the Laboratory.

LEADERSHIP PROGRAMS

Conexión

Conexión provides a 10-month executive mentorship and leadership program for early and mid-career professionals with a demonstrated track record of performance in business, education, and government.
Mentees are matched with accomplished mentors with multisector executive experience.

The Partnership, Inc.

The Partnership offers leadership development programs and consulting services for organizations in all sectors. The ODI provides opportunities for Laboratory staff members to participate in the following programs:
Early Career Associates, Mid-Career Fellows, Mid-Career, BioDiversity Fellows, Next Generation Executive, and C-Suite.

CONFERENCES

EmERGe

ERGs are vital to Lincoln Laboratory's mission of fostering a diverse and inclusively led workplace because they let employees connect, learn, and have discussions in a safe environment. In 2023, Laboratory leaders and ERG members attended the Seramount EmERGe conference. This conference is one of the only conferences in the nation that focuses on best and emerging practices for ERGs and their leaders. This year's event hosted keynote speeches from academic scholars and leaders who spoke about society's most pressing current issues. Working group sessions brought ERG leaders together to meet and exchange ideas, and at the "best practices" sessions, leaders learned strategies for elevating the impact of their ERGs for their colleagues and organizations.

Leaders from the Laboratory's employee resource groups and the Office of Diversity and Inclusion are shown attending the 2023 Seramount EmERGe conference in New York.

>> D&I: It Takes Engaged and Accountable Leadership, cont.

Massachusetts Conference for Women

The Massachusetts Conference for Women provides connection, motivation, networking, inspiration, and skill building for thousands of women each year. High-profile presenters and dozens of expert speakers lead workshops and seminars on the issues that matter most to women, including personal finance, business and entrepreneurship, health, work/life balance, and more. The conference offers opportunities for business networking, professional development, and personal growth. The 19th annual Massachusetts Conference for Women was held on December 14, 2023, at the Boston Convention and Exhibition Center. Coordination and planning by LLWN and Human Resources with support from the ODI made it possible for more than 200 Laboratory staff members to attend the conference this year.

A group of Laboratory staff attending the 2023 Massachusetts Conference for Women gathers for a photo.

The Conference Board

The Conference Board (TCB) is the world's preeminent think tank serving businesses and society since 1916. TCB is an industry-leading research center that offers virtual and in-person conferences, newsletters, community discussions, and insights. TCB uses innovative approaches that challenge people to think critically about real-world challenges by delivering business insights from a non-profit organization that are independent and nonpartisan. Lincoln Laboratory holds a TCB membership that provides Laboratory leaders opportunities for personal development outside of the organization. Resources that Laboratory TCB members have access to include publications, conferences, industry experts, webcasts, podcasts, roundtable discussions, working groups, and an online community of fellow TCB members.

THE CONFERENCE BOARD

Human Capital Center and People 2030 Conference

The Human Capital Center is one of five U.S.-based centers at TCB which provides members with guidance, support, and actionable solutions for optimizing human capital strategies to attract, develop, and retain workers while building a more effective and inclusive work culture. The Laboratory became a member of the Human Capital Center so that its leaders could gain insights about best and emerging practices and how they can be leveraged to support the mission and vision of the Laboratory.

As part of their involvement in the Human Capital Center, the ODI and Laboratory leaders attended the People 2030 conference in November 2023. The conference focused on the future of work and explored the idea that people will be central to creating business value in the coming years. Presentations and workshops provided participants with actionable information on how to make workforce-related decisions that will improve their organizations. Attendees learned how to create inclusion and purpose within a workforce, develop workforce potential, and ensure high levels of productivity through technology, innovation, D&I, and engagement. Laboratory leaders collaborated with each other and people from other organizations to learn best practices for the workplace, and they walked away with new ideas on how to be effective and inclusive leaders.

Laboratory leaders attend the People 2023 conference to learn about workplace best practices and effective leadership.

U.S. Navy Rear Admiral Seiko Okano gives Laboratory employees insight on how to be an effective leader in the present day.

Cultivating Leadership, Achievement, and Success (CLAS) Symposium

Cultivating Leadership, Achievement, and Success (CLAS) is an annual Laboratory-wide symposium focused on fostering leadership, growth, development, and success in an inclusive environment to ensure that all members of the Laboratory community have the tools, resources, and support they need to thrive in their careers. This year's CLAS symposium featured keynote speakers Rear Admiral Seiko Okano, the Program Executive Officer for Integrated Warfare Systems in the U.S. Navy, and Vijay Govindarajan, the Coxe Distinguished Professor at Dartmouth College's Tuck School of Business. Govindarajan presented his theory of the Three Box Solution. He explained that everything an organization does can be put in three boxes: Box One is about managing the present, Box Two is about selectively forgetting the past, and Box Three is about creating the future. This theory focuses on the foundational measures and thinking for driving innovation. Okano discussed what makes a great leader and organization in the 21st century and the importance of change in shaping both.

"The best companies with the best cultures are the ones where the values are very clear and well defined, and the people and the company abide by them," Okano said.

The symposium also included a new course on "Driving Growth, Innovation, and Inclusion Through Psychological Safety" that taught participants about the neuroscience-based habits that create a climate of team psychological safety—the belief that one is allowed to voice one's thoughts, take risks, and make mistakes without being punished or shamed. A virtual lecture given by Daena Giardella, a senior lecturer and faculty affiliate of the MIT Sloan School of Management, offered insight on how fear impacts organizations and teams and how psychological safety is vital for overcoming these barriers to best team outcomes. The CLAS symposium concluded with an awards ceremony and closing remarks from Lincoln Laboratory Director Eric Evans about his perspectives on leadership.

> *"The best companies with the best cultures are the ones where the values are very clear and well defined, and the people and the company abide by them."*
>
> **Rear Admiral Seiko Okano, Program Executive Officer for Integrated Warfare Systems in the U.S. Navy**

>> *D&I: It Takes Engaged and Accountable Leadership, cont.*

OUTREACH

GEM Fellowship Program

A network of leading corporations, laboratories, and research institutions, GEM enables qualified students to pursue graduate education in science and engineering. Lincoln Laboratory has had a committed partnership with GEM for the last 10 years. So far, the Laboratory has supported 154 MS and PhD Fellows, representing a direct investment in critical mentoring and sponsorship. Lincoln Laboratory Director Eric Evans served as the GEM board chairman for two consecutive terms.

GEM Fellows complete internships that provide companies opportunities to access and recruit talented candidates who they may not find otherwise. GEM offers programming on the importance of graduate school and tools for access and successful matriculation. It also produces publications for graduate and undergraduate students, and university and industry administrators to assist in the education process of how to obtain a graduate STEM education.

GEM Fellowships at the Laboratory offer students numerous returns, from networking opportunities to high-level research experience.

The Laboratory's 2023 GEM Fellows gather for a group photo with Lincoln Laboratory Director Eric Evans (front row, far left) and members of the Laboratory's Office of Diversity and Inclusion.

Buddy Program

The Buddy Program, overseen by Human Resources in partnership with the ODI, was launched in 2021 and has been jointly coordinated by HLN and LEAN.

In summer 2023, 40 students opted into the Buddy Program. More than 30 Laboratory staff representing a broad range of groups and departments volunteered to serve as buddies. Matched with one or more interns, each buddy provides professional and developmental support for their assigned interns. Buddies also function as sources of knowledge about Laboratory culture; foster a sense of belonging and community; check in regularly with interns; and serve as liaisons between the intern and Laboratory such as Human Resources, the ODI, and MyLife Services. A former intern described the Buddy Program as "a great support system that helped me feel more connected to the Lab."

Summer interns and Laboratory staff participating in the 2023 Buddy Program commemorate their time together with a photo.

DIVERSITY AND INCLUSION INITIATIVES

REEACT

REEACT, which stands for "Research. Educate. Empathize. Act. Transform," is an ongoing initiative at the Laboratory that the ODI developed in 2020 to help members and leaders of the Laboratory community develop the foundation necessary to build a more diverse and inclusive organization. REEACT has expanded its focus on D&I topics to help the Laboratory develop and create the conditions for sustainable organizational success. The ODI will continue to provide opportunities for engagement that will be available and open to all within the Laboratory community.

The goals of REEACT are to create psychological safety, increase familiarity with new concepts and vocabulary, and foster people's understanding of each other through their interactions. The initiative will work toward fostering familiarity and awareness of different cultures, generations, and functional areas, cultivating the Laboratory's ability to fluidly adapt to change, challenges, and opportunities.

All-Gender Bathrooms (AGBs) White Paper

In recent years, the Laboratory introduced AGBs in its facilities. LLOPEN members Christine Carlino and Noel Keating published a white paper documenting the cultural change–management process, community-based planning, and design standards that went into implementing the AGBs. The paper, titled "Designing for Equity: An FFRDC's Journey to All-Gender Bathrooms," aims to help guide other federally funded research and development centers (FFRDCs) and institutions that may be considering implementing all-gender facilities. The white paper aims to share information with other organizations, including the process the Laboratory went through, best practices and standards it has set as an organization, and the successes the Laboratory has had in working toward a more equitable workplace for all employees.

Shown above is one of the all-gender bathrooms at the Laboratory. These facilities were introduced as part of the Laboratory's efforts to create inclusive spaces for its employees.

INCLUSIVE SPACES

The Laboratory is committed to creating spaces that are comfortable and safe for all employees. These spaces are inclusive of all employees, including those who have special medical requirements, those who need additional privacy, those who are neurodiverse, and those who are of any gender. It is important to remove barriers that cause stress and anxiety, impede privacy, and make it challenging to get work done. This vision supports the creation of a more connected, inclusive, and equitable environment at the Laboratory. The following spaces have been installed or planned as part of the Laboratory's commitment to inclusivity.

Reflection Rooms

A reflection room is located above the Laboratory gym for individuals who wish to engage in structured or unstructured reflection that could include prayer or meditation. The room provides a calming space for individuals who feel overstimulated and need to refocus. The Laboratory's goal is to add additional reflection rooms in the future.

Wellness Rooms

A wellness room is a space to tend to a variety of health needs. The Laboratory is currently working to obtain a single wellness room where the Director of Wellness, Katherine Barlett, can host classes such as fitness, yoga, meditation, and health coaching.

Lactation Rooms

There are currently plans to implement seven lactation rooms at the Laboratory. These spaces will give nursing caregivers the privacy they need.

All-Gender Bathrooms

The Laboratory built several all-gender bathrooms to provide community members of all gender identities and expressions, or those requiring additional privacy, a safe, comfortable, and accessible environment.

EMPLOYEE RESOURCE GROUP ENDEAVORS

Employee resource groups provide cultural learning experiences and support diversity and inclusion initiatives for members of the Laboratory community. They are an important component of the Laboratory's mission to support its employees and foster connectivity and camaraderie. Highlighted here are a few programs and events executed by employee resource groups in 2023.

LLOPEN and LEAN 10-Year Anniversary

Ten years ago, members of the Laboratory's LGBTQ+ community established the ERG that became LLOPEN. In the same year, Black employees established LEAN to further the Laboratory's goal of providing a safe, comfortable, and inclusive workplace for all.

Above left, Lincoln Laboratory Director Eric Evans, center, poses with members of LLOPEN at the annual Ice Cream Social. Above right, the ODI's Principal Diversity and Inclusion Officer Bonnie Walker addresses attendees of this year's Juneteenth-Pride barbeque.

"Celebrating the 10-year anniversary of both LLOPEN and LEAN as ERGs during the combined Juneteenth-Pride event marks a milestone at the Laboratory; it's a time to celebrate the founders of these ERGs, the dedicated people, and their contributions for a decade, and it is a time to celebrate the organization's growth and evolution, and to set new goals and aspirations for the future," said Bonnie Walker, the ODI's Principal Diversity and Inclusion Officer.

During Pride Month in June, LLOPEN and HLN hosted a fireside chat with Gabby Rivera, a queer Puerto Rican author, who talked about her intersectional identity and her experience in contributing to the Marvel Comics universe. Rivera is the creator of America Chavez, a queer Latina superhero. Later in the month, founding members of LLOPEN gathered for a panel discussion about the history of LLOPEN and the role the ERG has played in impacting policy and cultural shifts at the Laboratory.

The Juneteenth-Pride barbeque, co-organized by LLOPEN and LEAN, honored the communities and impact of both ERGs. This event, along with LLOPEN's annual Ice Cream Social later in the month, were planned to bring community members together to lift each other up when times are rough and celebrate together when progress is made. Both events had record attendance, with approximately 400 people at each event.

Asian American and Native Hawaiian/Pacific Islander (AANHPI) Heritage Month

PALS invites staff of any background to learn about and celebrate various Asian cultures by hosting special events throughout the year. May is AANHPI Heritage Month, a time to appreciate Asian American cultures and reflect on the diversity of those working at the Laboratory. PALS' theme for this year's AANHPI month was "Advancing Leaders Through Opportunity." To celebrate that theme, PALS held its first luncheon on May 15 with invited speakers Chris Yu, the Software and Algorithms Engineering Director at Draper Laboratory, and Sung-Hyun Son, the Assistant Head of the Laboratory's Air, Missile, and Maritime Defense Technology Division. Yu encouraged the next generation of engineers to take control of their professional growth and career development by thinking about their goals and continuously learning. He also encouraged everyone to embrace challenges, celebrate the technology age, enjoy the benefits of working in a team environment, and treat people with respect.

Chris Yu, the Software and Algorithms Engineering Director at Draper Laboratory, speaks to Laboratory employees about career development at a luncheon hosted by PALS.

LEAN 4ward Project Podcast

The LEAN 4ward Project Podcast is a podcast produced by LEAN and hosted by Laboratory employees Will Gibbs, Spencer Johnson, and Chiamaka Agbasi-Porter. The podcast was created as a response to a survey that found Laboratory employees felt that there was a lack of connection between one another. To help fix this problem, members of LEAN created the podcast as a safe space for members to have open discussions and healthy dialogue about their experiences, from their successes to triumphs and even failures. A total of eight episodes were released throughout the year featuring in-depth interviews with LEAN community members who shared their personal stories.

Hispanic Heritage Month

HLN and the Lincoln Laboratory Concert Committee hosted Veronica Robles and her all-female mariachi band in celebration of Hispanic Heritage Month, which began in September. Robles is a mariachi singer, musician, and Latin American folkloric dancer and choreographer. She uses arts and culture to bring communities together by raising awareness on the importance of diversity, and she empowers youths by teaching them about their roots and cultures.

Veronica and her band delivered an interactive and educational program of music from many Latin American countries, including Mexico, Peru, and Colombia. Laboratory employees also participated in the program by donning cultural clothing and learning cultural dances. HLN hoped that the sharing of stories during Hispanic Heritage Month would help bridge divides by highlighting common values and fostering greater understanding between people.

Veronica Robles performs the Jarabe Tapatio, a traditional Mexican dance, at a Laboratory event held during Hispanic Heritage Month.

>> *Employee Resource Group Endeavors, cont.*

Veterans Day Recognition Event

In partnership with the ODI, LLVETS hosted their 13th annual Veterans Day Recognition Event in December. U.S. Navy Rear Admiral Robert Gaucher delivered the keynote speech, discussing the Navy's successful integration of women on submarines and its efforts to provide leadership development and career support to its officers. Earlier in the year, the annual LLVETS Memorial Day Barbeque was held at the Laboratory, bringing the community together to honor those who served in the military and gave their lives in service to the nation.

In 2023, Lincoln Laboratory was awarded the Gold Medallion Award by HIRE Vets. The HIRE Vets Medallion Awards recognize companies that are committed to the employment, retention, and professional development of veterans. This is the Laboratory's fourth consecutive year of receiving the Gold Medallion.

Lincoln Laboratory Director Eric Evans, front row second from left, and U.S. Navy Rear Admiral Robert Gaucher, front row center, join for a photo with LLVETS committee members, allies, and active-duty troops.

HOLISTIC DIVERSITY AND INCLUSION LEADERSHIP FOR THE FUTURE

Lincoln Laboratory's workforce and mission areas are continually evolving to maximize their ability to meet the organization's mission—developing technology to meet national security challenges and to help sponsors maintain a competitive advantage. This sentiment supports the guidance captured in several of the most important national strategy documents:

"The success of… our foreign policy will require strengthening the national security workforce by recruiting and retaining diverse, high-caliber talent."
– National Security Strategy

"The Intelligence Community's future success depends on its ability to attract and retain a highly technical and talented workforce that draws on one of our country's unmatched reservoirs of strength: our diversity."
– National Intelligence Strategy

"The complex strategic environment demands a diverse team of people to overcome its challenges and exploit its opportunities. Inclusiveness ensures that we are leveraging the broadest possible set of human resources to produce the maximum number of options. In this way, inclusiveness serves as the power underwriting our agility."
– U.S. Air Force Strategic Master Plan

"Fostering inclusive environments is a multidimensional force multiplier, and we are committed to leveraging its power to the benefit of our stakeholders and the nation."

Chevy Cleaves,
Chief Diversity and Inclusion Officer

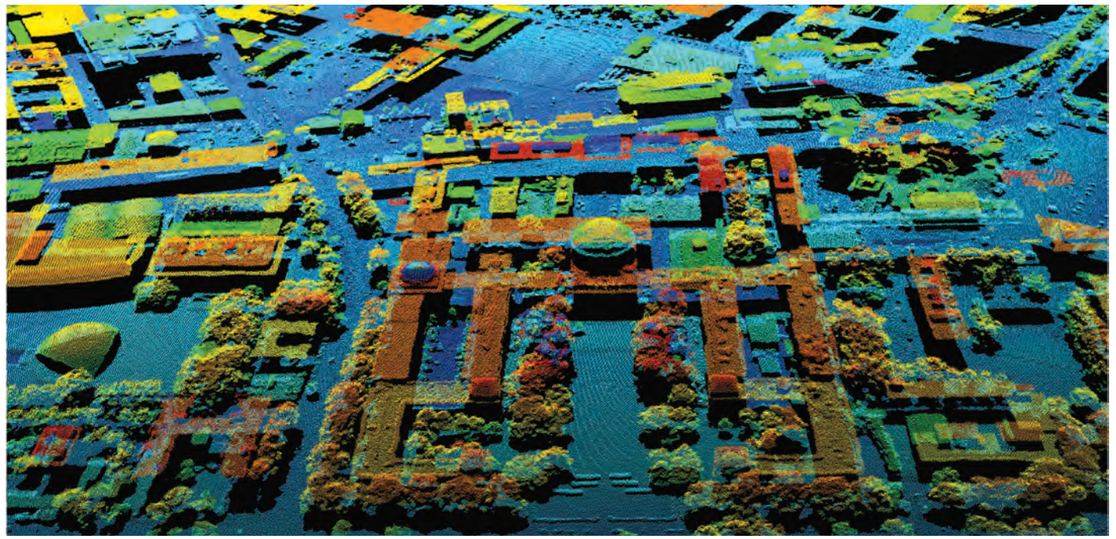
Lincoln Laboratory Spotlight in *Savoy Magazine*

Lincoln Laboratory was featured in a spotlight in the February 2023 issue of *Savoy Magazine*, a leading African American lifestyle magazine that showcases and drives positive dialogue about Black culture. The article described the Laboratory's efforts to foster an environment that drives innovation and belonging for everyone, including the establishment of the ODI in 2018; initiatives such as REEACT that promote dialogue and action among Laboratory community members; and professional/leadership development events for employees, such as the CLAS symposium.

The Laboratory's impact extends beyond the organization, as its mission has always been to develop technologies that meet a variety of needs. The *Savoy* article detailed the Laboratory's work in applying its airborne imaging technology to the humanitarian aid and disaster relief space, particularly in the aftermath of the 2010 earthquake that struck Haiti.

The Laboratory continues to partner with government and nongovernment relief organizations, developing technology to help responders work more efficiently, officials make data-informed evacuation decisions, and survivors find access to life-sustaining resources.

In the past year, Lincoln Laboratory formed the new Biotechnology and Human Systems Division that is responding to global needs for improving human conditions. In this division, programs are using climate change modeling and decision support tools to empower underserved communities, improving the treatment of neurological conditions, and using artificial intelligence to rapidly assess potential therapies for new diseases including COVID-19 treatments. In the midst of the pandemic, Laboratory researchers pioneered a privacy-protecting contact tracing method based on Bluetooth, which Google and Apple have since enabled on millions of smartphones worldwide.



The Airborne Ladar Imaging Radar Testbed (ALIRT) is an airborne laser radar that provides high-resolution and high-accuracy 3D views of terrain. ALIRT has been used to map earthquake-affected regions of Haiti. At left, MIT campus is shown mapped with ALIRT.

EDUCATIONAL AND COMMUNITY OUTREACH 109

G.I.R.L. program participants and mentors gather outside after a day of activities based on forensic science.

Educational Outreach

LLCIPHER

From July 31 to August 4, 21 high school students from across the United States occupied a conference room at the Laboratory's Forbes Road location, where they learned about cryptography through LLCipher. The goal of the program is for students to gain a solid understanding of the fundamentals of cryptography, starting with subjects such as modular arithmetic and the mathematical definitions of security and ending with examples of zero-knowledge proofs and multiparty computation.

Dhir Patel teaches LLCipher students about modular arithmetic and group theory.

Ariel Hamlin served as the lead instructor, supported by David Wilson, Noah Luther, Nicholas Cunningham, Parker Diamond, Hanson Duan, and Dhir Patel.

Jack Whitman—a high school student who plans to study computer engineering in college—found the LLCipher program while looking for an educational opportunity that was relevant to his future studies. "It's [cryptography] a field that I don't know much about, so it was really nice to be able to go from virtually zero knowledge to a point where I can explain it to others," he said.

For Annelise Gross, who is interested in mechanical engineering, cryptography was an entirely new subject. Gross found the program through the Girl Scouts website, which lists opportunities for women in engineering. "My favorite part was on the first day, working with a team to crack codes as fast as possible," she said.

"I love how enthusiastic the students are," said Nicholas Cunningham, who has been involved in LLCipher for six years. "So many of them are happy to learn the material and eager to ask lunchtime questions about cryptographic topics they've heard about in their personal lives."

At the end of the program, the students toured some of the Laboratory's facilities and asked the instructors final questions. "From the questions we got, I think a lot of them plan to keep learning more about the topic," said Cunningham. "I count that as a huge success!"

This year's LLCipher students, instructors, and coordinators take a group photo at the Laboratory's main location on Wood Street.

SEAPERCH

From November to May 2023, a group of high school cadets from the U.S. Naval Sea Cadet Corps Massachusetts Bay Division routinely visited the Laboratory's testing pool located on Hanscom Air Force Base in Lexington, Massachusetts. The cadets were preparing for an international underwater robotics competition called SeaPerch, which challenges participating teams to build an underwater vehicle that could maneuver through an obstacle course and perform tasks such as moving objects and opening a door.

Ronald Ross connected the cadets with the Laboratory. He and Laboratory colleagues Benjamin Evans and David Whelihan secured time at the pool for the students to visit once a month. The cadets were in charge of studying the supplied SeaPerch material and assembling and testing their vehicles. The Laboratory staff served as domain-expert advisors, assisting the cadets in underwater physics and robotics engineering, and providing oversight to prevent safety issues.

According to Lt. Glenn Jones, executive science officer for the Bay Division, SeaPerch is one of many ways to bring STEM opportunities to his cadets. They had competed in previous years but struggled to find a suitable place to practice with their vehicles. "It was an extraordinary opportunity to come to the Lincoln Laboratory facility and garner intellect from individuals like Ron," Jones said.

For cadet Seamus Pilette, who is on track to join the U.S. Marine Corps, participating in the event allowed him to gain a better understanding of all that goes into an engineering project. Cadet Simon Jones joined to learn how to build something from the ground up.

At the Laboratory's testing pool, cadets practice driving their vehicles through hoops placed underwater.

> *"This experience allowed me to witness young future engineers, and it was incredibly satisfying."*
>
> **Ronald Ross, U.S. Naval Sea Cadet Corps Massachusetts Bay Division volunteer**

Eleven teams of cadets prepared for the regional competition at the University of New Hampshire, and five teams placed to partake in the international competition at the University of Maryland, College Park, in May 2024. These five teams were the ones that visited the Laboratory to prepare.

"I spent 28 years as a career submariner. A submariner's ability to operate in harsh environments is enabled by sophisticated technology developed by engineers," Ross said. "This experience allowed me to witness young future engineers, and it was incredibly satisfying." The cadets returned to the Laboratory in the fall to prepare for next year's competition.

>> *Educational Outreach, cont.*

LLRISE

LLRISE is a two-week summer program that challenges high school seniors to build their own small radar systems as they tackle college-level courses, tour lab facilities, and sample college life. The 26 high-achieving students, selected from across the nation, learn about physics, Doppler radar, pulse compression, signal processing, circuitry, and antennas. Then, they apply knowledge gained from lectures as they build their own radar while learning how to code in Python, use a soldering iron, and 3D print an antenna frame. After completing their radars, the students work in groups to develop and stage experiments. The workshop culminates with technology demonstrations of each group's experiment. At the program's end, one student said, "LLRISE taught me that collaboration is the most important soft skill for an engineer to learn."

Instructors included Ryan Bohler, Julian Fontes, David Maurer, Allister Azagidi, David Brigada, Beverly Wong, and Spencer Johnson, many of whom annually assist with LLRISE.

"LLRISE incorporates project-based, hands-on learning opportunities," said Chiamaka Agbasi-Porter, Lincoln Laboratory's K–12 STEM outreach program manager, who created the LLRISE program more than 10 years ago. "The students accepted into this program learn about radar technology, but, more importantly, they gain an understanding of general engineering skills and what a possible career in a STEM field might look like for them." Bohler, who has served as an LLRISE instructor for seven years, maintains that LLRISE is "a good opportunity to help students trying to decide on their college and career plans."

LLRISE participants visit the Haystack radar after building their own radars.

LLRISE FOR TEACHERS

Two secondary education teachers participated in LLRISE, learning the principles of radar and building their own radar systems. They plan to recreate the program at their own schools in Massachusetts and Texas. Monica Albuixech, an instructional technology specialist at Hanscom Middle School at Hanscom Air Force Base in Lexington, Massachusetts, appreciated the opportunity to attend LLRISE and learn course material with the students.

Teachers Stephanie Mendoza of Raul Yzaguirre STEM Scholars Academy and Monica Albuixech of Hanscom Middle School participate in LLRISE to understand the program and determine how it may best fit within their respective curricula.

Albuixech, previously an Air Force Association Teacher of the Year, has set up a makerspace in her classroom to increase student access to STEM technologies. She would like to learn more about robotics, programming, and makerspace technology to create new curricula and increase STEM interest among her students, especially female and other underrepresented-minority students.

Stephanie Mendoza from the Brownsville Raul Yzaguirre STEM Scholars Academy in Brownsville, Texas, where she serves as the 21st-century community learning coordinator, was excited by the prospect of bringing a hands-on engineering-based workshop to students. She strives to encourage women and students of Mexican descent to pursue careers in STEM. Agbasi-Porter said, "Including teachers in the program definitely lends a different dynamic in the classroom. It was great to see them enthusiastically building their radar and thinking about how to incorporate the LLRISE curriculum into their schools."

LLRISE: SPRING BREAK

LLRISE: Spring Break offers an abridged version of the LLRISE summer program to students during their spring break week. This condensed program started virtually in 2021 through a partnership with the Texas Alliance for Minorities in Engineering (TAME), which offers age-specific programs to spark student interest in the sciences and technological careers. LLRISE: Spring Break moved back to an in-person format this year to facilitate recruitment from local schools and partner organizations (e.g., Empower Yourself, John D. O'Bryant School of Mathematics and Science, Pioneer Charter School of Science [Saugus and Everett locations], and Excel Academy Charter Schools).

During LLRISE: Spring Break, held at Beaver Works in Cambridge, Massachusetts, 22 students used scientific problem-solving strategies to experiment with a range radar that they could keep. Participants performed their own experiments with Doppler radar and listened to supplemental seminars in between lectures. They received instruction and mentorship from Ryan Bohler, Julian Fontes, and David Maurer in radar basics, electromagnetic signal processing, radar hardware components, and Python fundamentals. Students practiced hands-on engineering skills by soldering radar antennas (assisted by Allister Azagidi) and assembling radars (assisted by Kevin Warner). David Brigada helped students create and conduct experiments using their self-built radars. After the students presented their experimental results to the class, Roberto Martinez provided tips for résumé writing and building a LinkedIn profile.

Like LLRISE for Teachers, LLRISE: Spring Break accommodates an educator to participate as a student in hopes of that educator subsequently offering the course locally as an extracurricular activity. Dajuan Riley, an educator from Empower Yourself in Brockton, Massachusetts, learned about radar operation and assembly. Riley also owns 3-2-1 Action Clubhouse, where he mentors Brockton youth. He plans to incorporate the LLRISE program at his organization and looks forward to offering it to aspiring makers and engineers.

All students completing the one-week LLRISE were encouraged to apply to participate in the full two-week LLRISE, as well as the Laboratory's one-week cryptography program. Six of the 20 students in LLRISE: Spring Break applied for and were accepted into the LLRISE summer program.

Kevin Warner guides LLRISE students in the finer points of soldering wires to a circuit board in preparation for radar assembly.

>> *Educational Outreach, cont.*

High school students from across the nation explore engineering during BWSI.

BEAVER WORKS SUMMER INSTITUTE (BWSI)

Now in its eighth year, BWSI offers hands-on STEM learning to rising high school seniors through project-based courses. In 2023, the program admitted the highest number of students to date: 370 students in the program at MIT and 30 students at Kwajalein. Courses were conducted on MIT campus at the Beaver Works Center for four weeks and featured a daily speaker from a leader in the field. This year's program featured 13 courses.

A student in the AUV Challenge course submerses her programmed AUV to test its ability to navigate through an underwater obstacle field.

Autonomous RACECAR (Rapid Autonomous Complex Environment Competing Ackermann-steering Robots) — Students learned how to program a small-scale, MIT-designed robotic system using knowledge gained in basic control systems, computer vision, sensing, perception, and elementary navigation and planning.

Autonomous Underwater Vehicles (AUV) Challenge — Students designed, built, and programmed an AUV to navigate an underwater obstacle course, applying real-time decision-making based on feedback from onboard sensors.

Autonomous Cognitive Assistant — Students learned about neural networks, natural language processing, audio data recognition, and coding to develop machine learning applications that leverage audio, visual, and linguistic data.

Medlytics: Data Science for Health and Medicine — Students gained a solid foundation in probability, statistics, coding, and machine learning techniques and applied data analytics to structured data, physiological signals, and medical imagery.

Build a CubeSat — To build a working CubeSat, students learned about payloads, camera performance, power, subsystem integration, mission planning, attitude determination, and flight system debugging.

Microelectronics and Hardware Development — Students gained skills working with circuits, transistors, and digital logic while learning how semiconductors, lasers, and solar panels work.

Unmanned Air System (UAS)–Synthetic Aperture Radar (SAR) — Students learned about radar to control a commercial radar, develop radar imaging software, conduct data collections, and perform data analysis.

Embedded Security and Hardware Hacking — Student teams designed and built a secure system in an attack-and-defense-style exercise, targeting other teams' designs.

Cyber Operations — Students learned cyber operations, including networking, system administration, network defense, digital forensics, and malware analysis.

Quantum Computing — Teams of students designed software implementations of a quantum algorithm and developed a program using the algorithm.

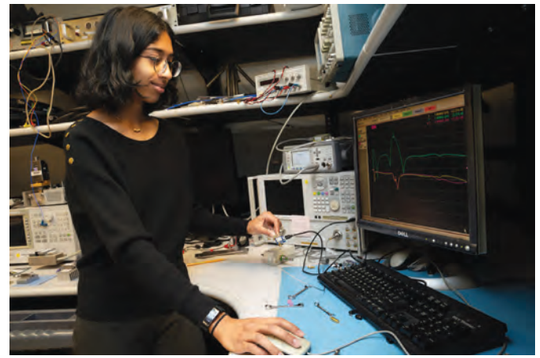
Back to bASICs — Students made their own semiconductors, which were sent to a foundry for fabrication.

Remote Sensing for Disaster Response — Students used imagery from drones, airplanes, and satellites to generate intelligence for disaster relief or humanitarian response.

Serious Game Design and Development with Artificial Intelligence — Students practiced software development, user interface design, game design, and artificial intelligence.

A student in the UAS-SAR course inspects their drone after it completed a radar-equipped flight to map a hidden area inside the MIT AeroAstro building.

HIGH SCHOOL INTERNS



Divya Narayanan is pictured above with a network analyzer, which she uses to characterize the frequency response of an amplifier.

Launched last year, the Laboratory's high school internship program is designed to give high school students the unique experience of doing hands-on work at the Laboratory. This year, the program brought four local interns to work in two divisions.

"The Laboratory's summer high school internship program provides a unique opportunity for local high school rising seniors to experience and explore STEM careers before committing to an area of study in college," said Cheryl Bartolone, Talent Programs Administrator, Human Resources, who helps organize the program. "The program provides students early exposure to careers in STEM as well as a glimpse of Laboratory culture during their six-week paid internship. The program also benefits the Laboratory in numerous ways. Early engagement with young talent builds our recruiting pipeline and we can learn so much from the younger generation. Their energy, passion for STEM, innovation, and eagerness to learn is inspiring!"

The Advanced Satcom Systems and Operations Group brought on Shreya Iyer to be mentored by Richard Chen, John Newey, and Dr. Ryan Shoup. Her project involved translating algorithms into MATLAB to find the most optimal one, which she then translates into VHDL, a language compatible with hardware, and uses to program a field-programmable gate array.

Divya Narayanan worked in the Advanced Concepts and Technologies Group and was mentored by Kristan Tuttle and Philip Zurek. Narayanan used a parabolic antenna to collect and analyze data on neutral hydrogen in the Milky Way galaxy, which will allow her to map the galaxy's shape and spin. "My favorite part of the Laboratory experience was the mentorship. Kristan and Philip had me assemble an antenna and use a network analyzer."

>> *Educational Outreach, cont.*

AEROSPACE ROBOTICS

It Happens Here: Brockton High School's drone program breaking barriers in competition

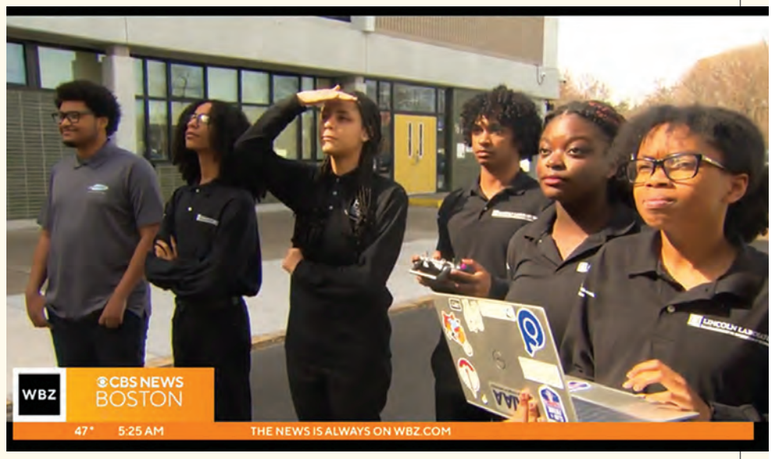
By Levan Reid
CBS Boston, WBZ News

BROCKTON — There's a group of students at Brockton High that are flourishing in the school's drone program. The team's name is the Altitude Angels and they're all about shattering stereotypes. (…)

They're getting ready for the New England Aerospace Robotics Competition. It's a contest that gives high school students the experience in building, programming, and flying drones on a competitive level. This group has been through this last year and took second place. They answered the question of diversity—there are not many teams of color in this competition.

The students are involved in the Empower Yourself non-profit, where the mission is to create critical thinkers for the future. When the drones arrive, they are in pieces. "I thought it was going to take me at least a month to do it but doing it now, it takes me almost a day to finish it," said 10th grader Marcelo Resende. (…)

"To be a part of this group, we are all like a huge family. We all work together so well and we manage to get stuff done," 11th grader Jamya Evans told WBZ-TV. (…) There are not many teams led by young women of color. "It feels really empowering because seeing people like me shows that I can really go out there and do anything," said 11th grader Amieya Cudjoe.



Amieya Cudjoe makes a few programming adjustments to the team's drone, left, and the Brockton Drone team gathers to perform a flight to test the programming updates, above.

> ***"It feels really empowering because seeing people like me shows that I can really go out there and do anything."***
>
> **—Amieya Cudjoe, 11th grader**

The Brockton Drone team has the backing and the mentorship of MIT Lincoln Laboratory.* They encourage the students to push the envelope. So, if one of the drones breaks, no problem. They want the students to exhaust all their ideas. This is the future. Business and companies are in classrooms trying to find the newest and brightest minds, and in this Brockton classroom, the future is extremely bright.

*Johnny Worthy, Idahosa Osaretin, and Donato Kava (formerly of the Lincoln Laboratory) are Brockton alumni who have mentored the Brockton Drone team for two or more years. Under separate programs, Worthy, Osaretin, and Kava visited Brockton Middle School students to show them how to build and launch water rockets, and mentored Brockton High School students in programming mini racecars.

This feature has been adapted from a televised version of the story.

Community Giving

BAKE SALES

National Coming Out Day and National Hispanic Heritage Month

In observance of National Coming Out Day and National Hispanic Heritage Month, the Hispanic/Latinx Network (HLN) and the Out and Proud Employee Network (OPEN) partnered to raise funds for the Gay and Lesbian Alliance Against Defamation (GLAAD).

OPEN co-chairs Sara Canzano and Emily-Anne Genova-Cruz and HLN co-chairs Alfredo Martinez and Elena Zorn collaborated with the Laboratory's Concert Committee to coincide the bake sale with a concert by Veronica Robles and her all-women mariachi band. The Laboratory community was invited to buy a treat and enjoy their purchase while listening to the band. This event raised $1,079, and many Laboratory employees left well fed, both literally and culturally.

Standing at a table filled with bake-sale classics and Hispanic treats, OPEN and HLN members are ready to raise funds for GLAAD.

Zorn was happy with the results of the bake sale and said, "It's great when employee resource groups work together toward a common goal, and even better when baked goods and music are involved!"

ALZHEIMER'S ASSOCIATION

The Lincoln Laboratory Walk to End Alzheimer's Team had 32 members, 12 of whom were first-time participants. The Lincoln Laboratory team was the top fundraising team in the Greater Boston Walk.

Walk to End Alzheimer's

This year, for the first in-person walk since 2020, the 32-member team raised $34,391, ranking them the top fundraising team out of 416 teams in the Greater Boston Walk.

Inspired by the Lincoln Laboratory community's action in this charity, staff at the Huntsville Field Site joined in the Walk to End Alzheimer's in Northern Alabama beginning in 2019. This year, the team led by Denise DeCoster donated $2,184 toward combatting Alzheimer's disease.

Ride to End Alzheimer's

The five members of Team Lincoln that took part in the virtual ride rode a 30-mile route from Lincoln Laboratory to Alewife Station in Cambridge, Massachusetts. Team Lincoln, led by David Caplan, raised $21,135. Referring to the virtual ride, Caplan said, "It was a nearly perfect day with blue skies. A mostly shaded Minuteman Bikeway made for a comfortable ride, despite a blown tire that needed to be fixed en route."

HOLIDAY CARDS FOR VETERANS

Left to right, Michelle Lloyd, Sharon Clarke, and Kyle Denney collect holiday cards for veterans at the VA Hospital in Bedford, Massachusetts.

In December, Lincoln Laboratory Access (LLACCESS), an employee resource group emphasizing accessibility for all in the workplace, partnered with the Lincoln Laboratory Veterans Network (LLVETS) to plan an opportunity for the Laboratory community to sign holiday greeting cards for veterans at the Veterans Administration (VA) Hospital in Bedford, Massachusetts. Those taking part in this effort included Magdaline Bathory, Sharon Clarke, Kyle Denney, and Michelle Lloyd from LLACCESS and Ronald Ross and Mathew Mills from LLVETS. Organizers of the event collected 80 signed cards to deliver to local veterans.

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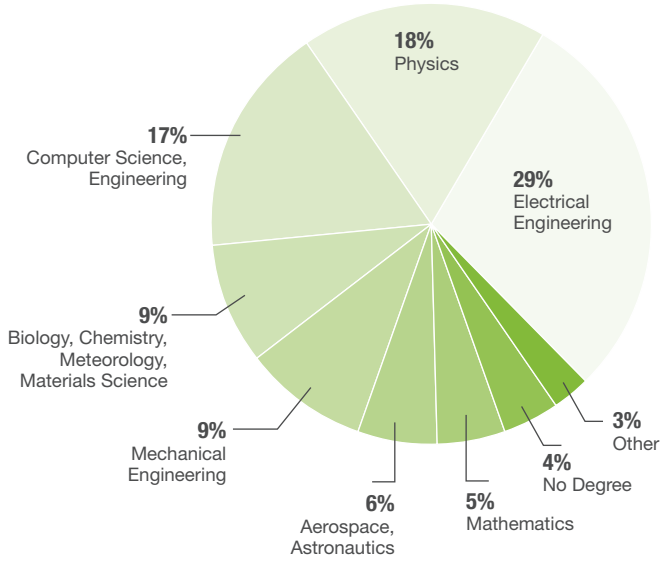
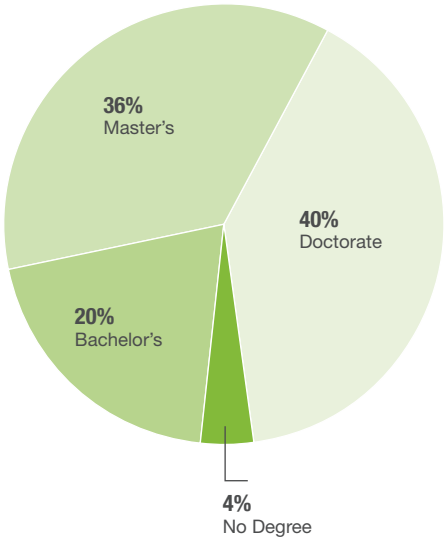


Academic Degree



Breakdown of Laboratory Program Funding

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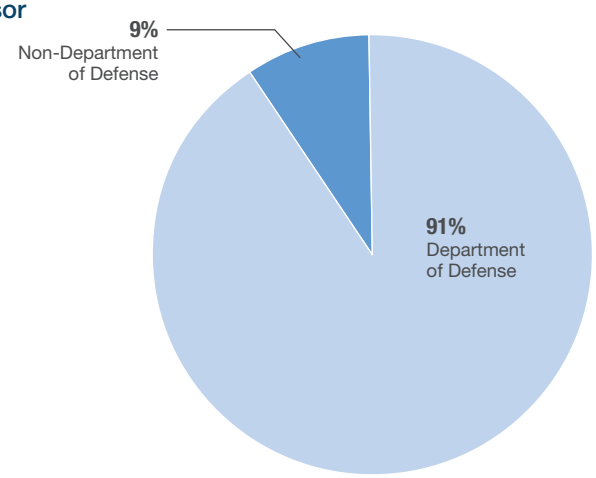

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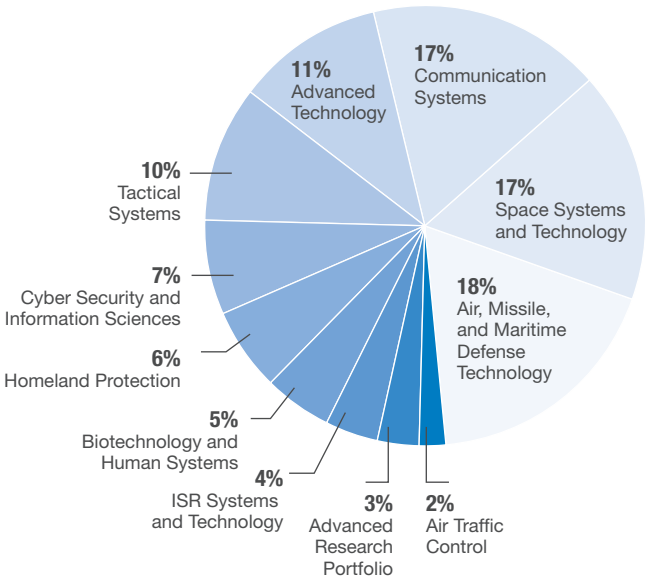

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY