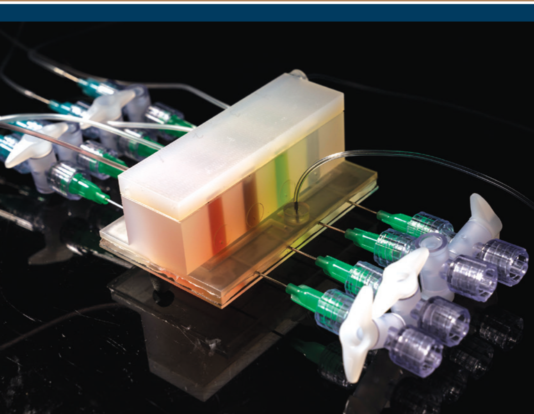
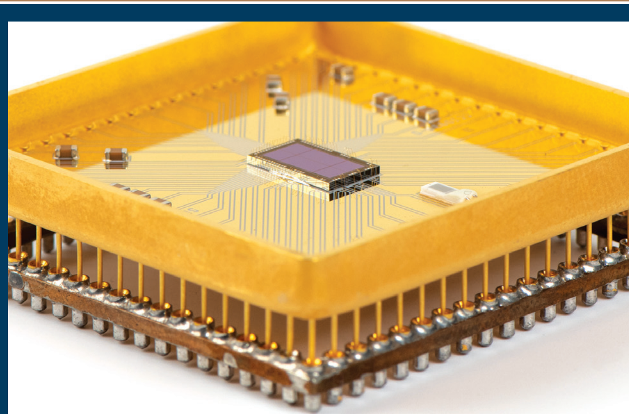
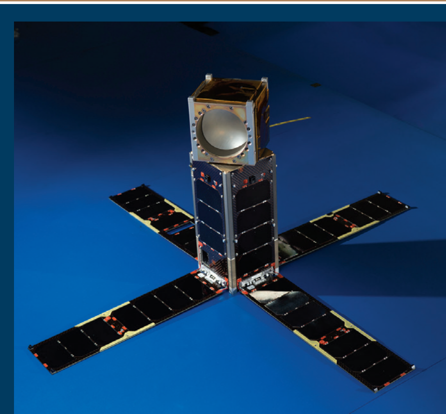
ANNUAL REPORT

2019

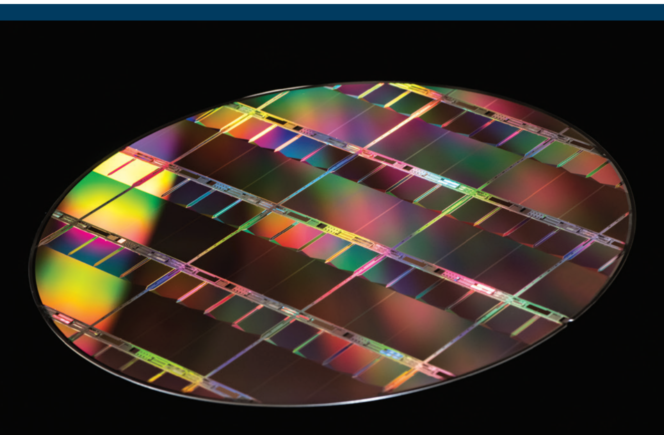


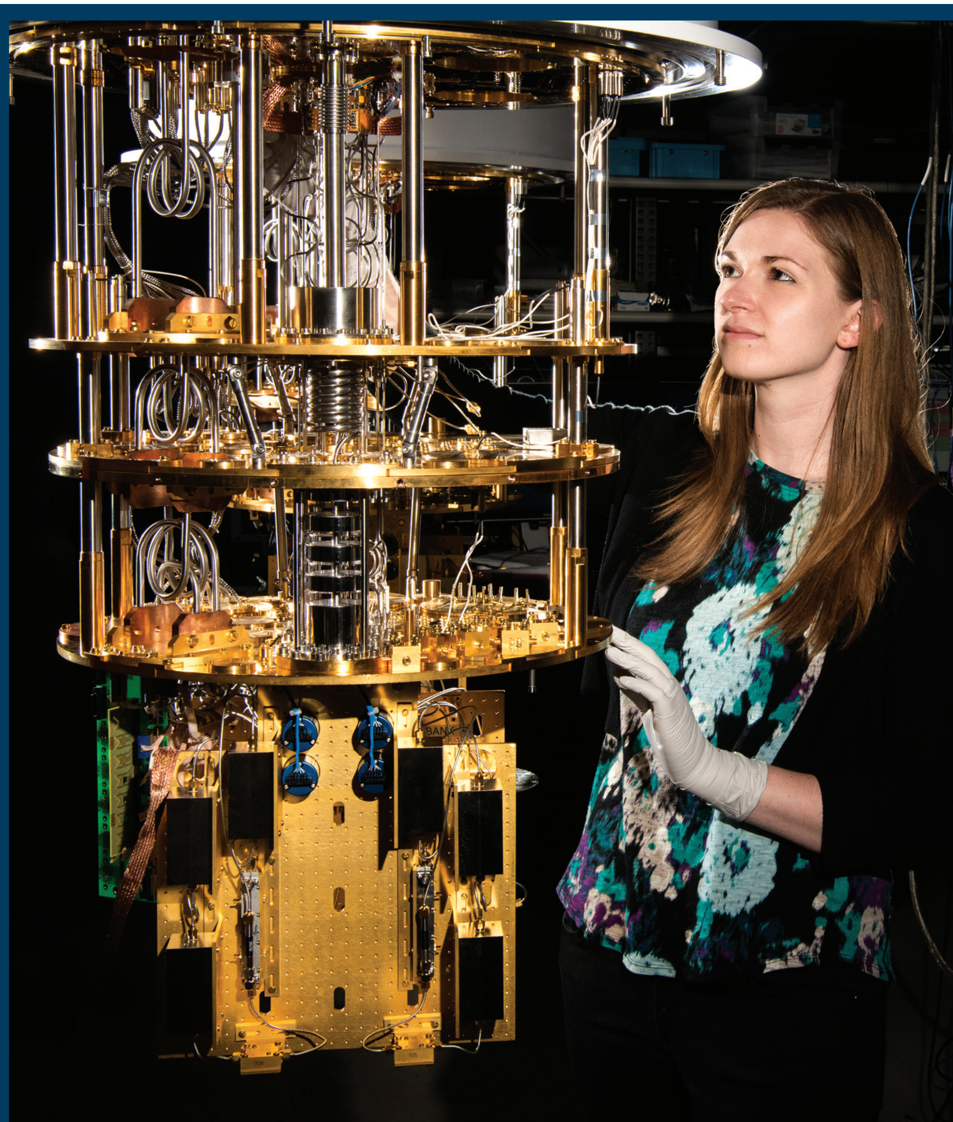




MIT LINCOLN LABORATORY

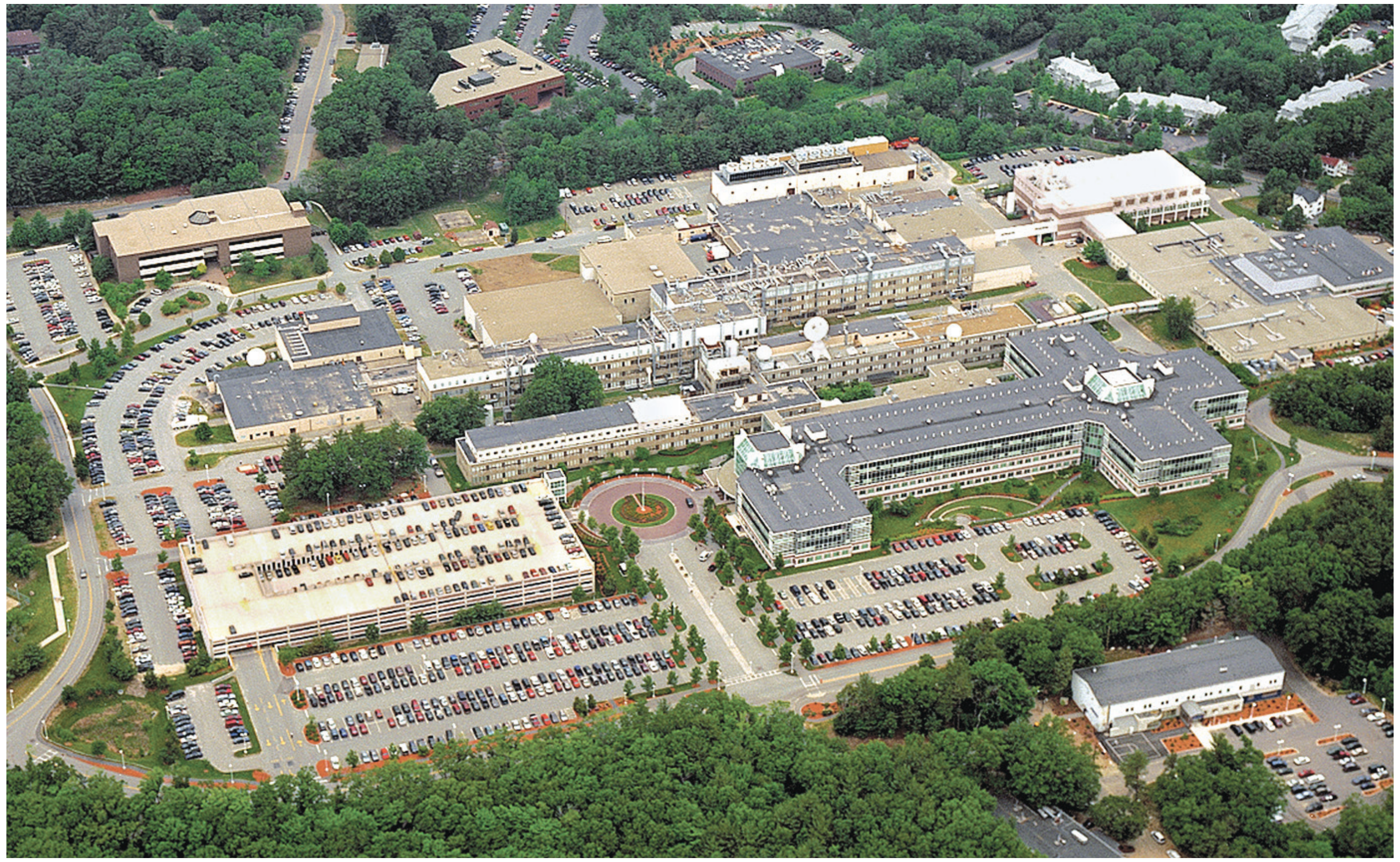
Technology in Support of National Security





Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts



MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2019

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 Research and Development 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 68 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's research and development activities continue to be strongly aligned to the current needs of the Department of Defense, and throughout all mission areas we are exploring technologies that enable significant, new capabilities for emerging problems of national security. One area of promising research is artificial intelligence (AI). Various decision support tools can capitalize on the "thinking" provided by new AI techniques. Researchers at the Laboratory are using AI technology for predicting and avoiding possible aircraft collisions, analyzing video surveillance to detect objects concealed beneath clothing or in bags, spotting suspicious activity in social networks, and responding to electronic warfare threats in a rapid way. A newly established AI group will be coordinating AI efforts across the Laboratory in partnership with researchers from MIT.

Another new field of investigation is quantum information science. Quantum mechanics techniques have the potential to revolutionize communications, computing, and sensing. As part of this effort to harness the potential of quantum physics, we have partnered with MIT's Research Laboratory of Electronics to establish a center dedicated to R&D into quantum technology. In collaboration with MIT, we are testing new quantum-based communications, utilizing a 42-kilometer-long fiber-optic quantum communications link test bed operating between the Laboratory and the MIT campus.

The following highlights are just a few examples of the innovative and important R&D work we are doing.

- We completed the assembly, integration, and testing of six CubeSats for TROPICS, a NASA Earth Venture Instrument program to deploy a constellation of these small satellites equipped with advanced compact microwave sounder technology for providing observations of tropical storms.
- To achieve robust line-of-sight communications, we have developed signal processing algorithms that leverage multiple antennas. Algorithm software and firmware were integrated into a prototype tactical radio system that was successfully flight-tested on operational tactical aircraft.
- Significant enhancements to the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) are enabling the system to realize improved resolution and a sixfold increase in area coverage.
- Under the DARPA ReImagine program, we verified successful operation of a 6.6-billion-transistor, software reconfigurable, imaging readout integrated circuit designed in a 14-nm-node fin field-effect transistor semiconductor process. This chip is the most complex integrated circuit fabricated for the Department of Defense to date.
- Our researchers field-tested a breadboard magnetometer that is based on nitrogen-vacancy centers in diamond. The Laboratory's magnetometer has the potential for higher sensitivity and greater long-term stability than commonly used fluxgate magnetometers. This work represents significant progress toward deployable quantum sensors.
- To enhance the performance of the submarine defense systems, we developed improved sonar automation and signal processing capabilities, and are exploring new techniques that leverage machine learning to classify sonar data.
- Staff in the Defense Fabric Discovery Center are developing a fabric sensor that is highly sensitive to chemical vapors and can alert personnel wearing the fabric to the chemicals' presence. Woven into the fabric are light-emitting diodes and photodiodes that detect the vapors' optical signatures.
- We prototyped a key management system for providing security to military satellite communication systems. The system will be undergoing a large-scale field demonstration to assess its resilience in a realistic threat environment.
- Our staff began installing an advanced chemical-biological test bed in New York City and planning for upcoming testing.

This annual report describes the wide range of our technical work, features many of our collaborative ventures, and summarizes our outreach activities. Our accomplishments continue to be enabled by our strong commitment to technical excellence, integrity, and service to the nation and to our local communities.

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

VALUES

- **Technical Excellence:** The Laboratory is committed to technical excellence through the people it hires and through its system and technology development, prototyping, and transition.
- **Integrity:** The Laboratory strives to develop and present correct and complete technical results and recommendations, without real or perceived conflicts of interest.
- **Meritocracy:** The Laboratory bases career advancement on an individual's ability and achievements. A diverse and inclusive culture is critically important for a well-functioning meritocracy.
- **Service:** The Laboratory is committed to service to the nation, to the local community, and to its employees.

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

MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. L. Rafael Reif
President

Dr. Martin A. Schmidt (left)
Provost

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

MIT Lincoln Laboratory

(Left to right)

Chevalier P. Cleaves
Chief Diversity & Inclusion Officer

Dr. Eric D. Evans
Director

Robert A. Bond
Chief Technology Officer

Dr. Melissa G. Choi
Assistant Director

Dr. Bernadette Johnson
Chief Technology Ventures Officer

Dr. Justin J. Brooke
Assistant Director

Dr. Israel Soibelman
Chief Strategy Officer

C. Scott Anderson
Assistant Director – Operations

ORGANIZATIONAL CHANGES

Justin J. Brooke
Assistant Director

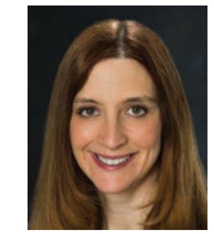
Dr. Brooke served as the Head of the Air, Missile, and Maritime Defense Technology Division from 2014 until his appointment as Assistant Director of Lincoln Laboratory. As Division Head, he led the expansion of the division's R&D into new areas, including maritime defense, establishment of a group focused on undersea systems and technology, counter-hypersonics, and space architectures. He increased the number of large prototyping projects and streamlined sensor data processing pipelines for division programs. An expert in systems analysis, concept innovation, and prototype development, he helped initiate the development of many groundbreaking Laboratory prototypes and led a major Laboratory study that promoted a shift in technology development toward higher-risk, higher-impact programs.

Dr. Brooke served in several leadership roles during his 16-year career at Lincoln Laboratory. He advanced through all levels of group leadership in the Advanced Capabilities and Systems Group, and he was an Assistant Head of the Intelligence, Surveillance, and Reconnaissance (ISR) and Tactical Systems Division, where he oversaw the development of ISR prototypes and strengthened research collaborations with MIT campus. He is also a champion and mentor for inclusion and diversity in the workplace, having co-led the Laboratory's Equity and Inclusion Committee. He is actively fostering practices that ensure a high-performing, collaborative, inclusive organizational culture.

Artificial Intelligence Group Established

To address the rapidly expanding use of artificial intelligence (machine learning) technologies in applications crucial to Lincoln Laboratory's mission areas, the Artificial Intelligence Group was established to coordinate R&D in artificial intelligence across all divisions and in collaboration with the academic community, particularly researchers at MIT. The group will report to the Technology Office, and technical staff of the group will serve term assignments from their mission-specific divisions.

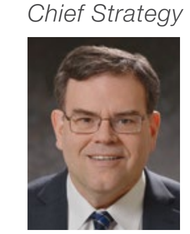
Melissa G. Choi
Assistant Director



Dr. Choi served as the Head of the Homeland Protection and Air Traffic Control Division from 2014 until her appointment as Assistant Director of Lincoln Laboratory. In that role, she oversaw the diversification of the division's portfolio, introducing a biotechnology thrust and establishing a group focused on technology for complex challenges in humanitarian assistance and disaster relief. A nationally recognized expert in system architecture development, she has contributed to several national-level studies conducted by the Defense Science Board and the National Research Council. In 2015, she became a member of the U.S. Air Force Scientific Advisory Board and has served as its vice chair since 2017. She is also a member of the Defense Threat Reduction Agency's Threat Reduction Advisory Committee.

Dr. Choi served in leadership roles in diverse groups in the Laboratory. She was an Assistant Leader of the Advanced System Concepts Group; Leader of the Systems and Analysis Group, directing the Assessment Team supporting the Secretary of the Air Force's Information Dominance Directorate; and Leader of the Active Optical Systems Group, focusing on initiatives in precision geolocation, sensor development, and anti-access/area-denial countermeasures. In 2013, she was named an Assistant Head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division, where she led efforts to develop new system concepts for contested threat environments. She has worked to enhance the Laboratory's organizational culture, serving as a co-lead of the Professional and Community Enhancement Committee and as a key member of the Lincoln Laboratory Women's Network.

Israel Soibelman
Chief Strategy Officer



Dr. Soibelman will serve as Lincoln Laboratory's lead in fostering strategic relationships and outreach, and in developing and coordinating strategic plans and initiatives, both externally with government, academic, and industry partners, and internally across the Laboratory. To this role, he brings 20 years of experience leading Lincoln Laboratory technical programs and several years of working to help the Department of Energy transfer its technology to commercial ventures.

Jesse A. Linnell
Associate Technology Officer

Dr. Linnell brings a broad technical background to his role contributing to the Technology Office's strategic development of the Laboratory's internal R&D investments and to its efforts promoting innovation. He holds advanced degrees in aerospace engineering and has worked on counter–improvised explosive devices, atmospheric modeling for chemical-biological plumes, air defense architectures, and biological detectors.

James M. Flavin
Division Head, Homeland Protection and Air Traffic Control

Mr. Flavin will oversee R&D programs that span a broad range of areas, including surveillance and decision support systems and architectures for air traffic control and safety, homeland air defense and security, border and maritime security, critical infrastructure protection, and humanitarian assistance and disaster relief.

Katherine A. Rink
Division Head, Air, Missile, and Maritime Defense Technology

Dr. Rink brings experience in the integration of advanced air and missile defense and electronic warfare capabilities for the U.S. Navy to this role in which she will be responsible for a portfolio of programs that include new initiatives in maritime defense and Lincoln Laboratory's long-standing work in integrated systems for ballistic missile defense.

James Ward
Associate Division Head, Communication Systems

In this role, Dr. Ward will help direct research and development activities spanning satellite communications, networking, laser communications, and communications-related spectrum operations. Dr. Ward also holds a Lincoln Laboratory Lecturer position with the MIT Department of Electrical Engineering and Computer Science, where he teaches a graduate course in signal processing.

D. Marshall Brenizer
Associate Division Head, Space Systems and Technology

Dr. Brenizer brings to this new role his deep experience in identifying and evaluating threats to the U.S. use of space for military, intelligence, civil, and commercial needs. Since joining the Laboratory in 2002, he has developed a strong understanding of both the sensors and networks used to detect, track, and characterize objects in space and the infrastructure used to operate satellites.

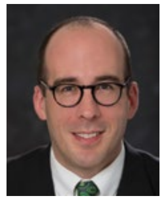
Marc N. Viera
Associate Division Head, Intelligence, Surveillance, and Reconnaissance and Tactical Systems

Dr. Viera will continue to help direct R&D in air vehicle survivability, system-of-system architectures, advanced airborne sensors, and intelligence and decision technologies. He applies a background in Red and Blue Team activities, systems analysis, and prototyping to the division's development of capabilities in advanced infrared and RF systems, electronic warfare, and ISR and tactical architectures.

James K. Kuchar
Assistant Division Head, Homeland Protection and Air Traffic Control

Dr. Kuchar has conducted significant work on technologies for air traffic safety and air traffic management. In his prior role as Leader of the Air Traffic Control Systems Group, he also led programs aimed at reducing environmental impacts for commercial aviation, assessing effectiveness of proposed next-generation ATC procedures, and applying machine learning techniques to air traffic management.

Thomas G. Macdonald
Assistant Division Head, Communication Systems



Dr. Macdonald has experience in a wide range of satellite and terrestrial communications programs, including networking for mobile military forces, laser communications, and space communications architectures. During his career at the Laboratory, he served as the Leader of three different groups within the Communication Systems Division and held a technical leadership position in the Air Force under the Intergovernmental Personnel Act.

R. Louis Bellaire
Deputy, Technology Ventures Office

Dr. Bellaire will support efforts to facilitate the rapid transfer of advanced technology into and out of Lincoln Laboratory for the benefit of national security. During his career at the Laboratory, he has had extensive experience in missile defense radars, big data analytics, and systems for processing geospatial and image data. He previously served as the Leader of the Intelligence and Decision Technologies Group.

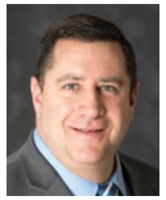
Robert D. Loynd
Executive Officer to the Director and Chief of Staff

Mr. Loynd brings experience in higher education administration and military leadership roles to his new position. Prior to joining Lincoln Laboratory, he was the Director of Executive Education at The Fletcher School of Law and Diplomacy at Tufts University, as well as Vice President and Director of European Operations at the University of Maryland University College. Previously, he served a career in the U.S. Marine Corps, retiring as a colonel in 2015.

Marc D. Bernstein
U.S. Air Force Acquisition Chief Scientist

In this Intergovernmental Personnel Act assignment, Dr. Bernstein supports the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics and the U.S. Air Force Acquisition Chief Architect. Formerly the Associate Director of Lincoln Laboratory and a previous head of the Air and Missile Defense Technology Division, Dr. Bernstein has extensive experience in the management of R&D programs and strategic planning for long-term technology advancement.

Scott J. Mancini
Assistant Department Head, Security Services



Mr. Mancini has supported the Information security for both collateral and compartmented programs at Lincoln Laboratory. To his new role, he brings experience in directing security compliance and forensics operations in information technology.

MIT LINCOLN LABORATORY FELLOW

The Fellow position recognizes the Laboratory's strongest technical talent for their sustained outstanding contributions to both Laboratory and national-level programs.

David C. Shaver

Dr. Shaver is recognized for his contributions to advanced microelectronics and sensor technology and systems. During his career at Lincoln Laboratory, he fostered innovation and technical excellence, creating programs in photon-counting technology, advanced focal planes, silicon microelectronics, and trusted electronics. Through his leadership of the Submicrometer Technology Group in the late 1980s, he promoted the development, demonstration, and transition of 193-nm optical lithography technology to the worldwide semiconductor industry. As Assistant Head of the Solid State Division, he was instrumental in establishing the Microelectronics Laboratory as a national resource.

Dr. Shaver served as the Head of the Solid State Division (renamed Advanced Technology Division in 2010) from 1994 until July 2012. During this time, the work within the division evolved into a strong driver of advancements in many system-related programs. From 2012 until 2019, he was on an Intergovernmental Personnel Act assignment within the Defense Advanced Research Projects Agency.

He is a Fellow of the IEEE, received the Optical Society's E.H. Land Medal, and holds seven U.S. patents.

Derek W. Jones
Assistant Department Head, Security Services

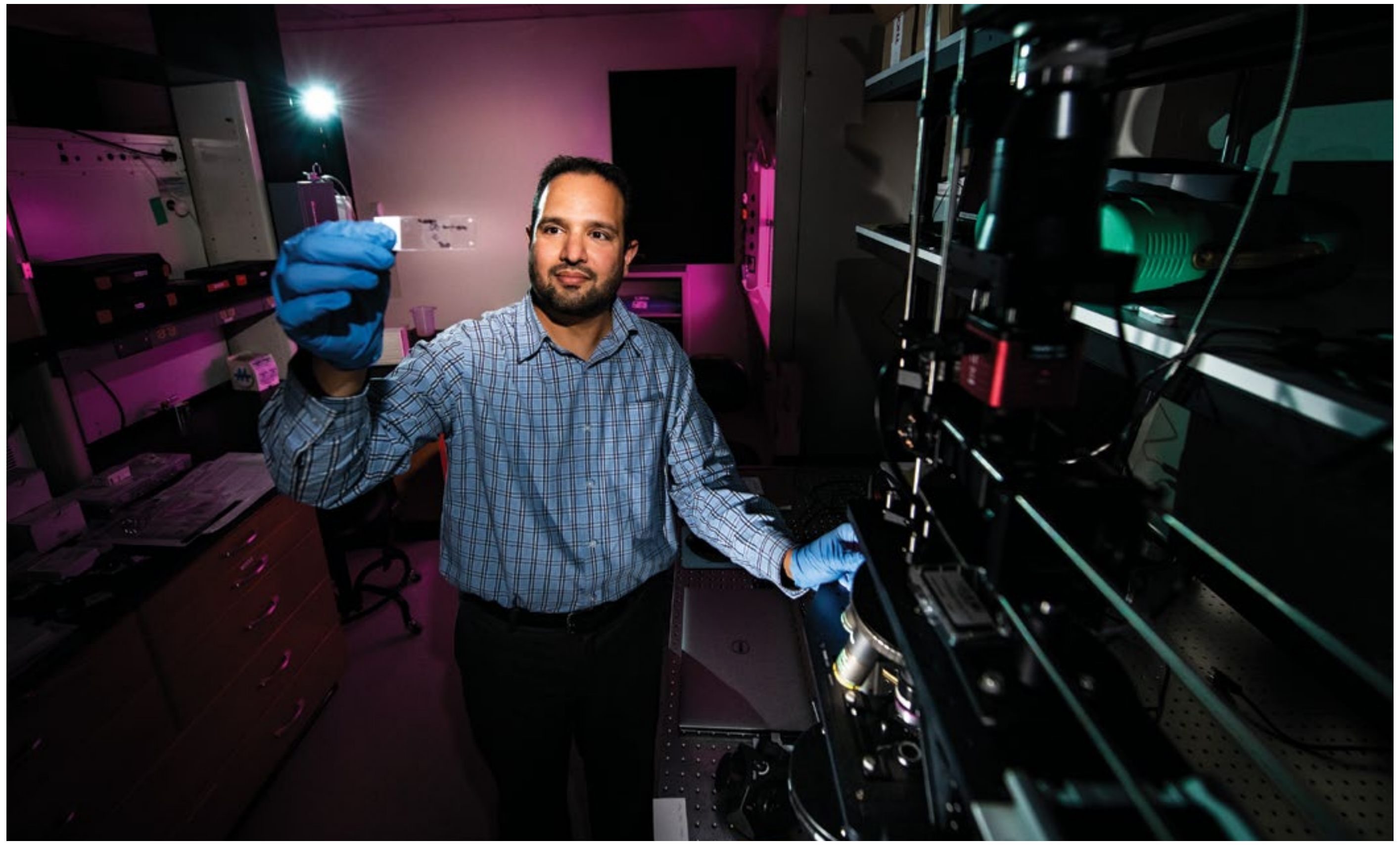
Mr. Jones, formerly the manager of government security and operations, will continue to oversee Lincoln Laboratory's collateral security program, direct communications security services, and supervise remote field site operations.

Robert J. Boston
Assistant Department Head, Security Services

Mr. Boston, who directed Lincoln Laboratory's physical security program, will have responsibility for the Laboratory's round-the-clock security forces, the Security Operations Center, and the Lincoln Laboratory Emergency Preparedness Program.

TECHNOLOGY INNOVATION 9

Joyce Tam is using the Technology Office Innovation Laboratory's (TOIL) recently acquired 3D printer for fabricating metal components in stainless steels, tool steel, and more. This new printer will increase TOIL's capabilities in the rapid production of innovative prototypes and will promote new design techniques.



Siddharth Samsi holds a microscope slide containing a brain tissue sample. The sample will be imaged using the hyperspectral and quantitative phase imager system, at right, set up in the Biophotonic, Electric, Acoustic, and Magnetic Measurement Lab.

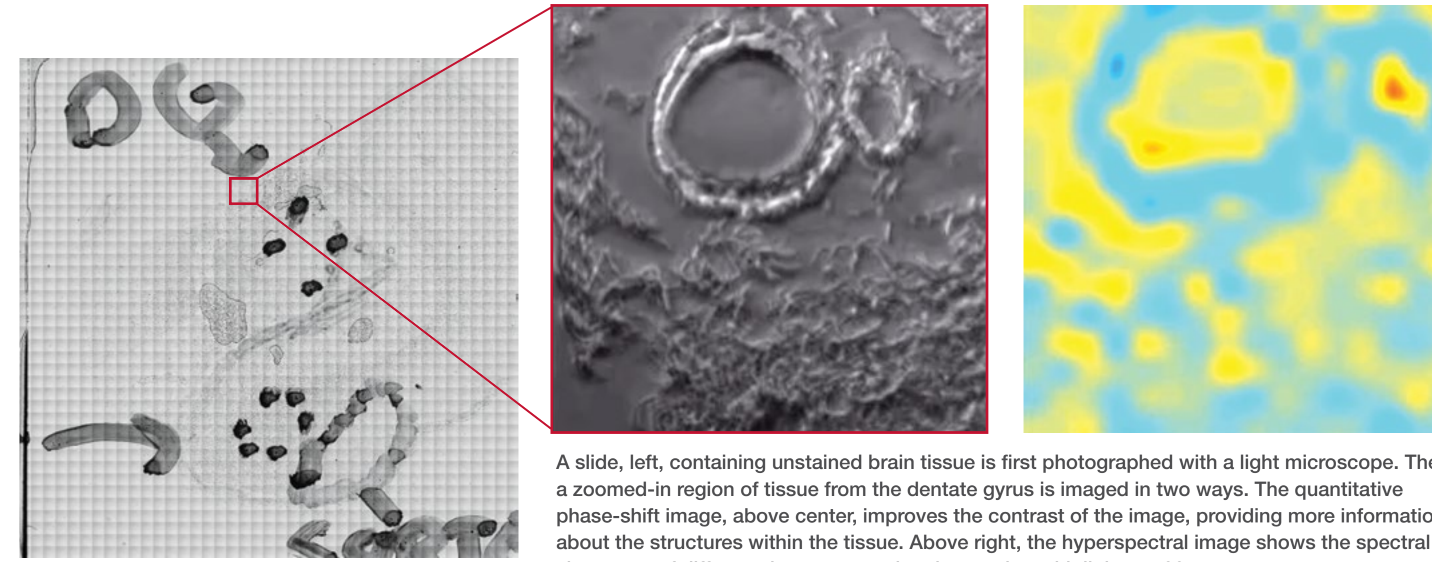
Advanced Imaging and Artificial Intelligence May Shine New Light on Tissue Analysis

Advanced imagers developed at Lincoln Laboratory have enabled scientists to study far reaches of the universe. The Laboratory's expertise in imaging technology is now being applied to study the much closer, but still elusive, molecules in the human brain. Staff are combining novel imagers and artificial intelligence (AI) algorithms to analyze cell and protein structures in brain tissue. These tools could help scientists understand how Alzheimer's disease manifests in the brain.

The research is being conducted in the Biophotonic, Electric, Acoustic, and Magnetic Measurement (BEAMM) Lab that opened in 2019. This Biosafety Level 2 facility, which supports the study of human tissue, is a space for experimenting at the interface of technology and biological materials. This tissue-imaging project is one of the first to use the BEAMM Lab.

The motivation for the project stems from challenges in studying brain tissue samples, specifically those from Alzheimer's patients. The current method of tissue analysis uses various stains to create contrast in otherwise transparent biopsies—the stain sticks to certain proteins and helps make tissue characteristics visible. But staining characteristics can vary widely across institutions, depending on the protocols, age of the stains used, and other human factors. These differences make it difficult to automate the image analysis of the stained samples, a process that helps eliminate subjectivity, improve diagnoses, and speed treatment development.

The researchers wondered: Can advanced imaging and AI eliminate the need for staining altogether? They built a single imaging system that combines a microscope with a quantitative phase imager and hyperspectral imager. The phase imager shines light onto the tissue and its various cell structures. These cell structures bend and refract the light uniquely—the refractive index of the cell nucleus is different from that of the cytoplasm, for example—forcing the light waves to be out of phase with each other. These phase shifts can be measured and depicted in an image as darker or brighter areas, making it possible to distinguish between cellular structures that look the same when unstained.



A slide, left, containing unstained brain tissue is first photographed with a light microscope. Then, a zoomed-in region of tissue from the dentate gyrus is imaged in two ways. The quantitative phase-shift image, above center, improves the contrast of the image, providing more information about the structures within the tissue. Above right, the hyperspectral image shows the spectral signatures of different tissue types when interacting with light at 400 nanometers.

Laboratory engineers designed this hyperspectral and quantitative phase imaging microscope. Using these two imaging methods, researchers may study and quantify tissue structures without needing to apply various stains to the sample.

Simultaneously, the hyperspectral imager picks up photons that return to the detector after being reflected, scattered, and absorbed by cells in the tissue. The photons' interaction with the cells depends on the wavelength of light, spanning from 400 to 2500 nanometers, and on the molecular composition of the tissue it hits. In the resulting hyperspectral image, the cell structures will have unique spectral signatures.

Artificial intelligence algorithms can then be used to analyze these hyperspectral and quantitative phase imaging data. Researchers in the Lincoln Laboratory Supercomputing Center (LLSC) are building models that use deep neural networks to automatically detect cell patterns known to be significant to Alzheimer's diagnoses, to count cells, and to identify cell and protein types. This work is benefiting from the new TX-GAIA system, installed at the LLSC in 2019, that is optimized for training and running deep neural networks.

The Laboratory team and pathologists at Massachusetts General Hospital have begun studying brain tissue samples from Alzheimer's patients. Specifically, they are imaging two culprits suspected of causing Alzheimer's: beta-amyloids, protein compounds that clump together in the brain tissue, and tau proteins that degrade to become tangles within the brain's neurons. They hope the imaging data and analysis tools will enable new insights into the disease.

Laser Communication System Beams Messages Directly to a Person's Ear

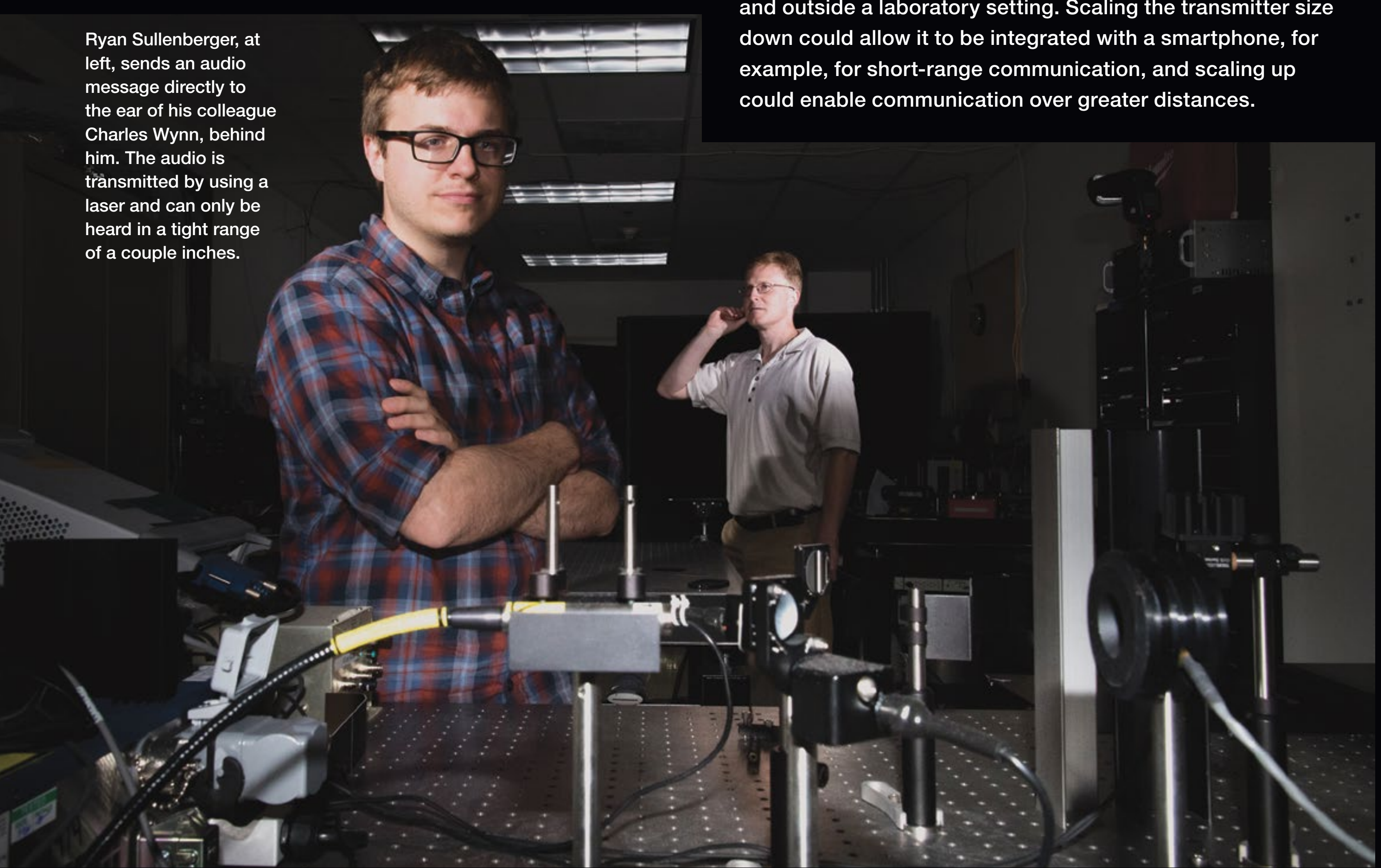
Lincoln Laboratory researchers developed a way to use laser beams to send audible messages directly to a specific person's ear from a distance. The technique relies on the photoacoustic effect in which the absorption of light by a material produces sound. The material in this case is water vapor, hanging in the air near a person's ear. The researchers found that at the infrared wavelength of 1907 nanometers, water vapor absorbs light strongly enough for the photoacoustic effect to still work even in environments with low humidity.

Using an eye- and skin-safe thulium laser at that wavelength, their prototype system can transmit sounds at 60 decibels—the volume of a typical conversation—to the ear of a targeted person standing about eight feet away. The communication can only be heard within a tight range of a couple of inches. If other people were to cross the laser beam's path, they could not overhear the message and instead would simply block the message from reaching its recipient.

The system works by using a rotating mirror to sweep the laser beam in an arc. The message is encoded in the length of these sweeps, which are translated to audible pitches once sound is produced. The speed at which the mirror rotates determines at what particular distance from the transmitter the sound can be heard. Depending on that speed, light at a point down the beam (ideally where the target is standing) will sweep back and forth at the speed of sound. Once the sweeps hit Mach 1, a strong audio signal is produced.

Among its potential security applications, the technology could be used to send a direct warning to people of an active shooter or to stay out of dangerous or restricted areas. It could also have more mainstream uses, such as watching TV or listening (headphone-less) to music without disrupting others who are very close by.

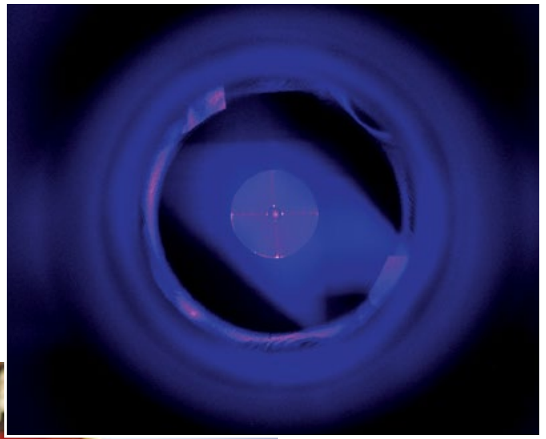
The researchers are planning to demonstrate their photoacoustic communication method at different ranges and outside a laboratory setting. Scaling the transmitter size down could allow it to be integrated with a smartphone, for example, for short-range communication, and scaling up could enable communication over greater distances.

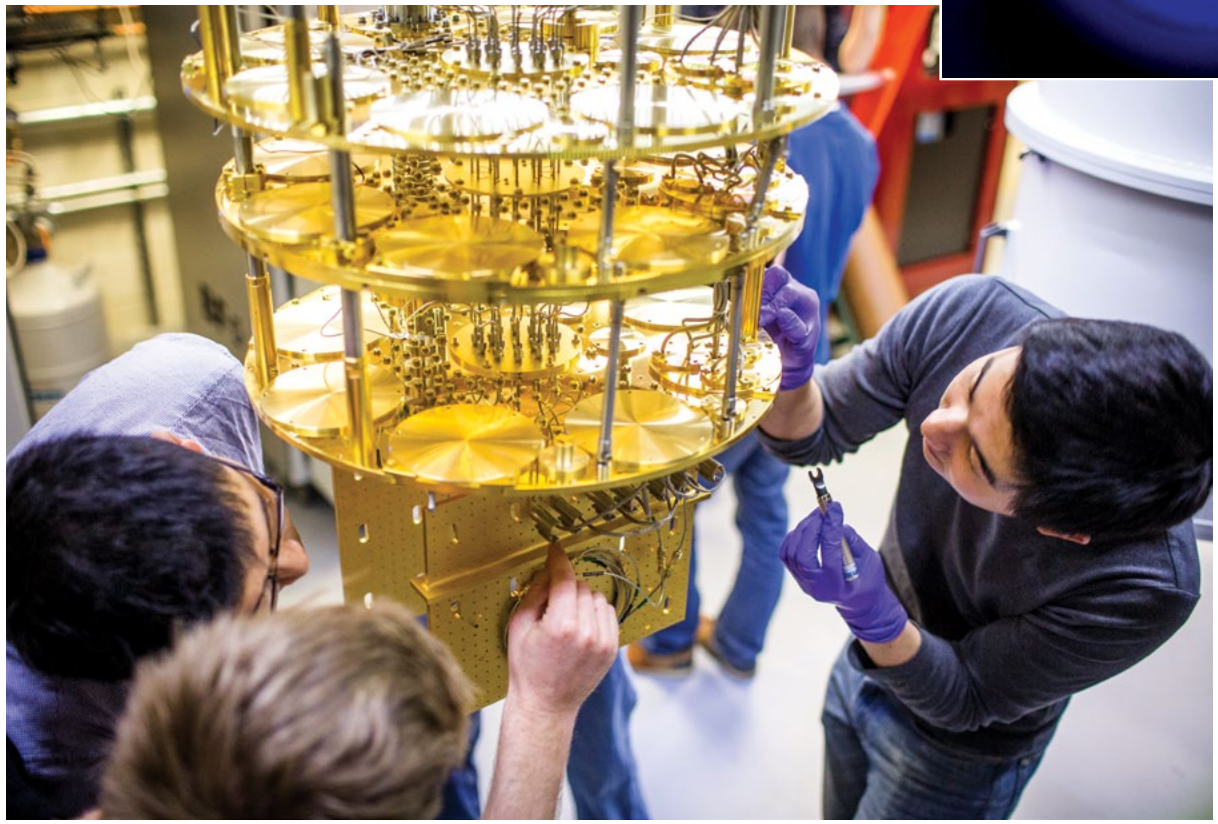


Ryan Sullenberger, at left, sends an audio message directly to the ear of his colleague Charles Wynn, behind him. The audio is transmitted by using a laser and can only be heard in a tight range of a couple inches.

A New Partnership Leads Quantum Engineering Forward

Quantum engineering is an emerging discipline that bridges quantum physics and traditional engineering. To lead this new field, Lincoln Laboratory and the MIT Research Laboratory of Electronics (RLE) established the MIT Center for Quantum Engineering (CQE) in 2019. The center is headquartered at RLE and facilitates collaboration across campus, industry, and government to help realize the promise of quantum technologies.





Above, the small circular cloud at the center of this image contains calcium atoms cooled to a few milliKelvin. The cooled atoms are accelerated toward an ion-trap chip, as part of the Laboratory's research into developing a trapped-ion quantum computer. At left, students at the Research Laboratory of Electronics (RLE) adjust a dilution refrigerator, which is used to cool qubit circuits to cryogenic temperatures.

The building blocks of these technologies are quantum bits, or qubits, which unlike classical bits can represent both 0 and 1 simultaneously. In classical systems, each sequence of bits is represented and manipulated separately, so more time or more parallel copies of hardware are required to process each additional bit sequence. Quantum systems, however, use qubits to represent and manipulate a superposition of many sequences of bits at the same time, using a single copy of the hardware. At the CQE, researchers are using superconducting circuits, trapped ions, photons, nitrogen-vacancy centers, and other technologies as the qubits that are manipulated and controlled in systems for computation, simulation, networking, and sensing.

Laboratory staff members are participating in the CQE as appointed RLE principal investigators. In the past year, the Laboratory and campus collaborators have demonstrated several approaches for advancing integrated quantum circuits, including technologies for trapped ions that manipulate optical and electrical signals on chip and processes for fabricating complex superconducting qubit and control circuitry. Systems for quantum networking, which facilitate the transmission of information between physically separate quantum processors, have reached the testing phase. One such system is a 42-kilometer-long fiber-optic quantum network test bed now in operation between Lincoln Laboratory and the MIT campus.

Beyond pioneering research efforts, the CQE will also educate a rising generation of quantum engineers by designing MIT undergraduate, graduate, and professional development curricula. The center also established the Quantum Science and Engineering Consortium to connect blue-chip corporations, start-ups, and venture capital firms with MIT quantum researchers.

Above, during testing in August and September 2019, the team launched 12 high-altitude balloons with communication payloads. The testing began in the early morning hours at an air center in Roswell, New Mexico. Below, during the Military Utility Assessment of the system, members of the U.S. Marine Corps operated the ground terminals installed in passenger vans in which the Laboratory had set up computers, radios, and laptops for the operator interface and control.

Stratospheric Balloon Swarms Are Being Used for Resilient Communications

Since 2013, Lincoln Laboratory has been developing and testing concepts for using high-altitude balloons as beyond-line-of-sight (BLoS) communication relays. Today's BLoS communications primarily rely on satellites; however, there are emerging concerns that these satellites alone may not be sufficient in some situations. Rapid deployment of alternative communications nodes may be needed to support BLoS communications.

Balloon-borne communication relays offer several advantages. A helium-filled, latex weather balloon can reach an altitude as high as 100,000 feet. From its perch in the stratosphere, high above weather phenomena and all air traffic, the balloon has a coverage footprint greater than 600 miles in diameter. Each balloon, along with the helium needed to carry it to altitude, can be purchased for only a few hundred dollars. Combined with a small but capable payload, the overall system costs much less to build than other alternatives. The low cost also allows replacement relays to be launched as needed to maintain coverage.

Controlling the flight path of the balloons is one challenge in using this relay system. Lacking any kind of propulsion, the balloons move wherever the wind takes them. This problem is addressed by using altitude control systems that vent gas and drop ballast; by catching different winds at different altitudes, the balloon's flight path can be controlled to some extent.

One of the greatest difficulties in using balloon-based platforms for military communications is assuring the system's ability to operate in the presence of intentional or unintentional radio frequency (RF) interference. To solve this problem in particular, Lincoln Laboratory developed new technology employing a swarm of high-altitude balloons to emulate a large antenna array in the stratosphere. The key to this technology is advanced beamforming algorithms that work in the extreme delay and Doppler conditions created by the spacing and motion of the balloon swarm. These techniques not only enable operation in interference but also support efficient use of the RF spectrum by permitting multiple users to operate simultaneously over the same spectrum, in this case using the algorithms to suppress unwanted co-channel interference.

The Laboratory's relay system uses custom lightweight balloon payloads that can operate in the cold environment of the stratosphere and support high-quality relaying of ultra high frequency (UHF) communications signals. Ground terminals were built to support the computationally intensive beamforming processing. These terminals use a combination of software-defined radios, field-programmable gate arrays, and central processing units.

Lincoln Laboratory has conducted more than 10 flight campaigns and flown more than 50 balloon payloads to mature and demonstrate this technology. The most recent work in testing the balloon-based system has been a part of a Joint Capability Technology Demonstration supported by the Office of the Secretary of Defense, U.S. Strategic Command, U.S. Indo-Pacific Command, U.S. Special Operations Command, U.S. Air Force, and the U.S. Marine Corps. In September 2019, a Military Utility Assessment of the system was conducted with 12 balloons launched from Roswell, New Mexico; ground terminals were set up at BLoS ranges and staffed by Marines operating the Lincoln Laboratory systems. This flight test achieved successful relay communications in the presence of strong interference. The U.S. Marine Corps is starting the process to transition the system into operational use.

For the testing, four ground terminals were configured across New Mexico, demonstrating the system's capability over ranges spanning hundreds of kilometers. High-gain receive antennas, such as the one above, were part of the ground terminal setup.

Before sunrise, team members began preparing the 12 balloon payloads that launched from Roswell, New Mexico. The payloads are housed in a styrofoam case with their antennas suspended to allow system checkout prior to launch.

Technology Investments

The Technology Office manages Lincoln Laboratory's strategic technology investments and helps to establish and grow technical relationships outside the Laboratory. The office is responsible for overseeing investments in both mission-critical technology and potentially impactful emerging technology. To maintain an awareness of emerging national security problems and applicable technologies, the office interacts regularly with the Under Secretary of Defense for Research and Engineering and other government agencies. The office collaborates with and supports university researchers, and aids in the transfer of technology to the U.S. government and to industry. The Technology Office also works to enhance inventiveness and innovation at the Laboratory through various investments and activities that promote a culture of creative problem solving and innovative thinking.

LEADERSHIP
Mr. Robert A. Bond, Chief Technology Officer (center)
Ms. Anu Myne, Associate Technology Officer (right)
Dr. Jesse A. Linnell, Associate Technology Officer (left)

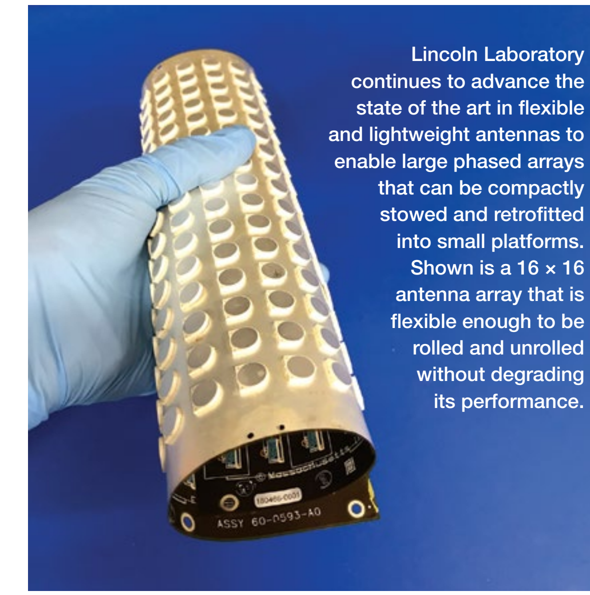
INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

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

Radio Frequency Systems

Research and development in RF systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. New developments focus on next-generation phased arrays, wideband and compact systems, and advanced algorithms. Among the significant projects in 2019 are

- Research in robust RF systems that make use of cryptographic techniques to jam adversaries' signals while remaining resilient to friendly emissions.
- Development of the Micro-sized Microwave Atmospheric Satellite (MicroMAS-2), a CubeSat built and operated by Lincoln Laboratory. Launched on 12 January, MicroMAS-2 demonstrated in April the first-ever microwave sounding data from a CubeSat measuring temperature, water vapor, cloud parameters, and precipitation.



Lincoln Laboratory continues to advance the state of the art in flexible and lightweight antennas to enable large phased arrays that can be compactly stowed and retrofitted into small platforms. Shown is a 16 × 16 antenna array that is flexible enough to be rolled and unrolled without degrading its performance.

TECHNOLOGY HIGHLIGHT

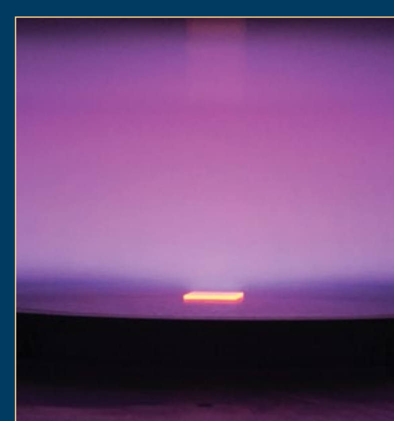
Diamond Magnetometer

Solid-state spin systems are an increasingly favored platform for developing quantum sensing technologies. In particular, magnetometry using nitrogen-vacancy (NV) centers in diamond has been the subject of intense experimental effort. To date, however, academic demonstrations of NV-based magnetometers have not realized the theoretically promised device sensitivities necessary to compete with existing sensor capabilities.

The collaborative MIT and Lincoln Laboratory quantum magnetometry team has overcome two significant barriers: lack of ideal diamonds and low sensitivity. Through tailored diamond growth, the Lincoln Laboratory team has engineered quantum-grade diamonds beyond ordinary gemstones to ideal synthetic diamonds fabricated not for cut, clarity, and color but for quantum capability. The nitrogen and vacancies introduced into these manufactured diamonds during growth and processing have exquisite capability to sense magnetic fields, and the Lincoln Laboratory diamonds exhibit long-lived quantum coherence for high-sensitivity measurements.

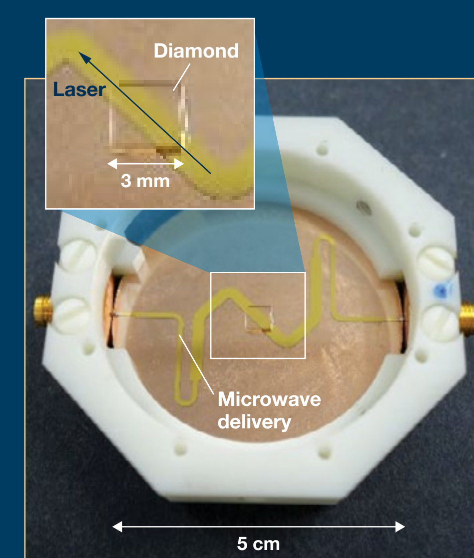
The diamond itself is only the first step to making a sensor. Careful control of quantum states through lasers and microwave fields is needed to realize the full sensing potential of this solid-state system. Advances in machine learning and readout techniques have enabled physics-based sensor development tailored to applications of interest.

Together, these advances are enabling a unique class of magnetometer with quantum stability and a vector measurement tied to fixed, solid-state axes. The diamond and sensor improvements are critical to transitioning this technology from laboratory demonstrations to target applications, such as localization of magnetic signals, magnetic navigation, and brain-machine interfaces.



Diamond Engineering

The diamond seed crystal glows orange as it is heated to hundreds of degrees in a plasma. As diamonds are grown, alterations to the carbon lattice with carefully designed defects create quantum systems, which can be tailored for precision sensing.

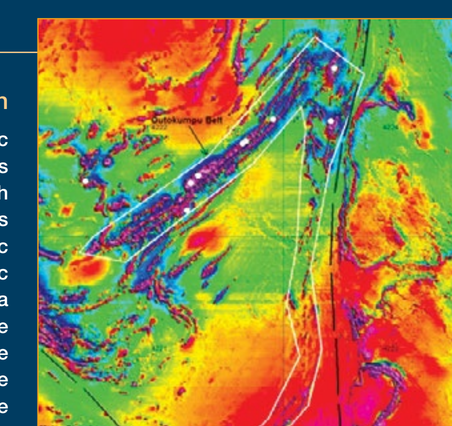


Quantum Magnetometry

The image shows a commercial gemstone in a ceramic resonator. This device is used to test novel excitation techniques that enable sensors with higher sensitivity and lower power.

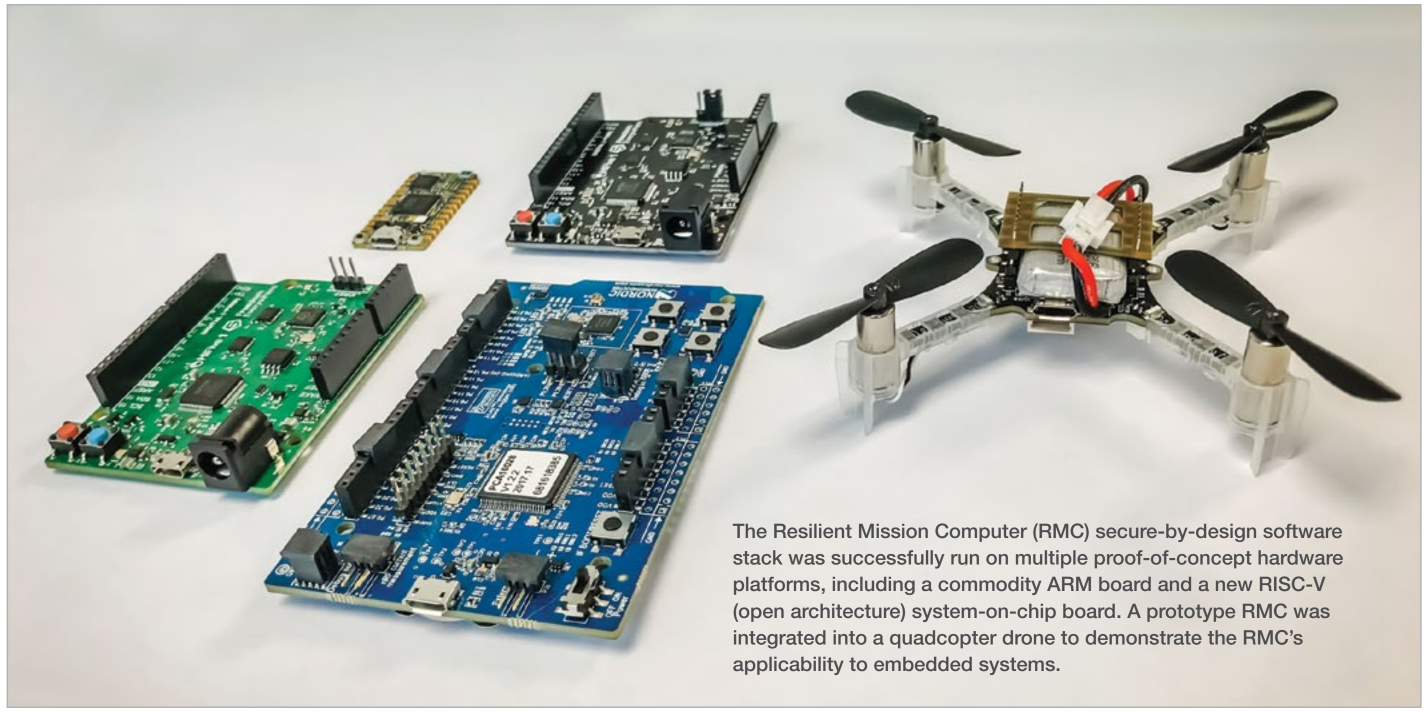
Mission Application

By using magnetic anomaly maps available through geosurvey companies or the National Oceanic and Atmospheric Administration, a unique fingerprint of the magnetic field may be employed to determine location and navigate without the need for GPS.



>> Investments in Mission-Critical Technology, cont.

Cyber Security



The Resilient Mission Computer (RMC) secure-by-design software stack was successfully run on multiple proof-of-concept hardware platforms, including a commodity ARM board and a new RISC-V (open architecture) system-on-chip board. A prototype RMC was integrated into a quadcopter drone to demonstrate the RMC's applicability to embedded systems.

All U.S. government agencies, including the Department of Defense (DoD), must defend against diverse cyber attacks. Applied research at Lincoln Laboratory is working to make the cyber world as secure and resilient as possible. Lincoln Laboratory performs advanced cyber security research to develop a deeper understanding of security issues addressing all aspects of the problem space, from secure hardware architectures and data handling to innovative algorithms that enable capabilities not previously possible. In 2019, Lincoln Laboratory continued fundamental research in cyber security through tools development, algorithm work, and operational implementations. Examples include

- Development of tools designed to discover software vulnerabilities on embedded devices.
- Collaborative work with Australia on the applications of artificial intelligence and machine learning to improve mission assurance in the cyber domain.
- Development of technologies that allow multiple parties to share results of computations while maintaining the privacy of the data.

Integrated Systems

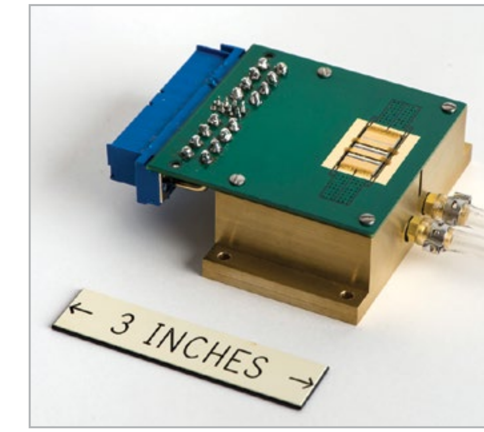
Scientists and engineers conduct applied research to accelerate the integration of advanced technologies into game-changing systems for national security. The goal is to demonstrate DoD-relevant system concepts that use novel architectures, recently developed component technologies, and new analytic methods. Prototypes being developed in 2019 include

- A constellation of picosatellites, called wafersats, that leverage highly integrated manufacturing and semiconductor fabrication methods. A wafersat has all of the space-qualified electronics and connectivity to act as a fully functional satellite bus. Each wafersat will cost between $5K and $10K, will use an electrospray ion thruster to maneuver, and will communicate to coordinate swarm-based and other configurations.
- An agile microsatellite capable of maneuvering at very low orbits. The research team will flight demonstrate an agile 6U CubeSat that utilizes microelectric propulsion; navigation and sensor payloads with very low size, weight, and power usage; and novel guidance and control algorithms.

Optical Systems Technology

Research into optical systems technologies is central to enabling future mission capabilities in intelligence, surveillance, reconnaissance, and communication. The goal of this research is to fill critical technology gaps in emerging DoD threat areas and emphasizes research in ladar, high-energy lasers, imaging systems, optical communications, and novel optical components and technology. In 2019, efforts include

- Utilizing the advantages of precise optical timing to allow distributed radar systems to process signals coherently.
- Developing advances in lasers, including coherently combined lasers for high-energy applications, blue-green lasers for undersea operation, and eye-safe lasers for lidar transmitters.
- Collecting phenomenology measurements for foliage-penetrating ladar to understand more fully the fundamental limits and utility of the technology.
- Exploring long-distance inverse synthetic aperture ladar imaging of orbital and suborbital objects to enable centimeter-scale resolution of fast-moving targets.

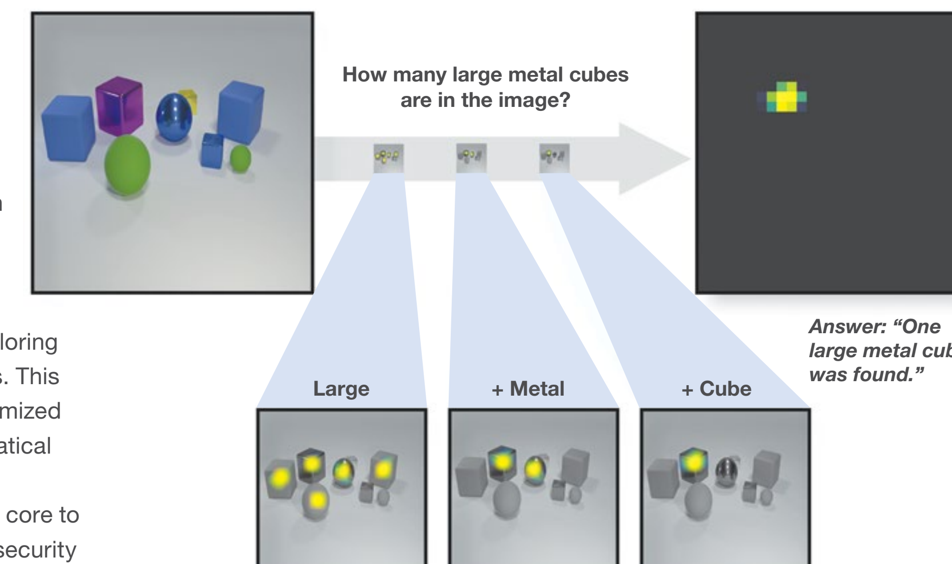


The above efficient, semiconductor-based phased array LED-based laser transmitter system has a modular architecture that can be scaled to high powers. This prototype 2 × 50 array device is capable of 30 W/cm^2 raw power.

Information, Computation, and Exploitation

Research in the information, computation, and data exploitation (ICE) domains addresses challenges posed by the increasing growth in data used for national security and intelligence operations. Research topics range from data conditioning, advanced computing, algorithms, and human-machine teaming. The application of artificial intelligence algorithms to ICE missions promises breakthrough capabilities. Novel projects undertaken in 2019 include

- New algorithm techniques that measure the influence of individual nodes on the rest of the network. These techniques were evaluated for effectiveness in detecting and characterizing online propaganda activities and their associated networks, with potential application to countering influence operations.
- An integrated computing ecosystem for exploring very large-scale graph-based data analytics. This ecosystem has an advanced processor optimized for the acceleration of sparse-data mathematical computations and an easy-to-use software architecture. Sparse-data computations are core to big-data analytics used to explore national security problems, such as foreign influence operations.
- Machine learning algorithms that perform human-level perceptual tasks while providing transparency and insight into their operations and allow users to understand the machine's thought process. This insight helps designers debug and improve algorithms, builds understanding of the algorithms, and increases trust in the machine.



Lincoln Laboratory has developed a state-of-the-art question-and-answer algorithm and user interface for responding to natural language queries and interpreting semantics about complex images. The Transparency-by-Design system answers a visual reasoning question by breaking it down to a chain of subtasks. The response to each subtask is shown in heat maps highlighting the algorithm's focus of attention. This process allows analysts to see the system's "thought process" as it parses and answers questions about the image.

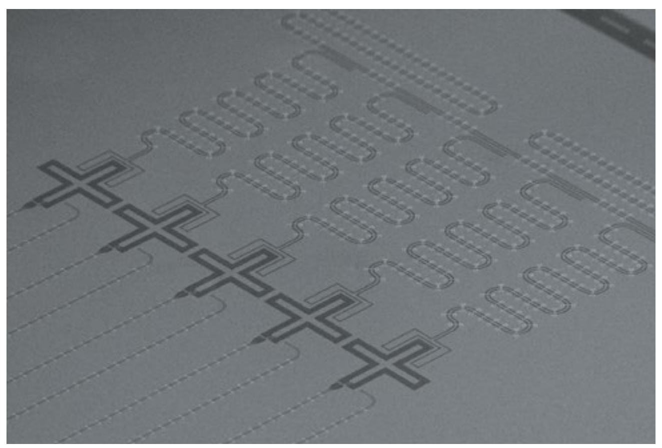
INVESTMENTS IN EMERGING TECHNOLOGY

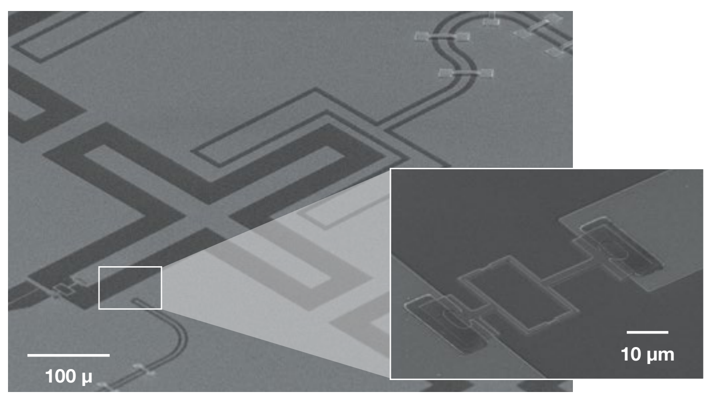
Promoting research into technologies of growing importance to national security and the development of engineering solutions for projects in Lincoln Laboratory–relevant mission areas

Quantum Systems and Science

Quantum systems are eliciting increasing interest from commercial and defense sectors. The Technology Office is investing in emerging quantum applications, such as sensing, communications, computing, and algorithms. In 2019, significant progress has been made on the following:

- Algorithms that can do linear algebra exponentially faster than classical computers.
- Continued improvements in two quantum approaches to computation—superconducting qubits and trapped ion qubits—with the goal of building the control mechanism to scale up to several hundreds of qubits.
- New, highly efficient methods of quantum sensing readout for magnetometers based on nitrogen vacancies in diamond.
- Quantum communications for secure data exchange over long distances and high data rates. This year, quantum communication protocols were demonstrated across a 43-kilometer fiber-optic link.





Quantum systems based on a small number of superconducting qubits (20 to 40) have been demonstrated in laboratories around the world, but these systems are not readily scalable because of their planar geometries. This year, Lincoln Laboratory demonstrated a multi-qubit system based on a 3D geometry that was designed to enable scalable implementations of future quantum computers. The Laboratory is working to integrate a three-tier stack of chips that has on the top chip high-coherence qubits spatially separated by an interposer layer from a readout, and on the bottom an interconnect chip. The superconducting through-silicon-via interposer chip must be thick to maintain isolation but tightly integrated to enable dense circuitry. These requirements call for vias that are much deeper than they are wide and have superconducting metal coatings.

Energy

Research in this area supports DoD energy needs and the sustainability and reliability of the national power grid. This year's work includes activities to address challenges ranging from novel power devices up to power grid system architectures. Examples of 2019 projects include

- Research into novel and advanced power-storage devices, including nanobatteries, structural supercapacitors, and high-performance batteries tailored for specific applications.
- Exploration into ways to make the regional power grid more resilient by increasing situational awareness and coordination between the electrical and natural gas industries.

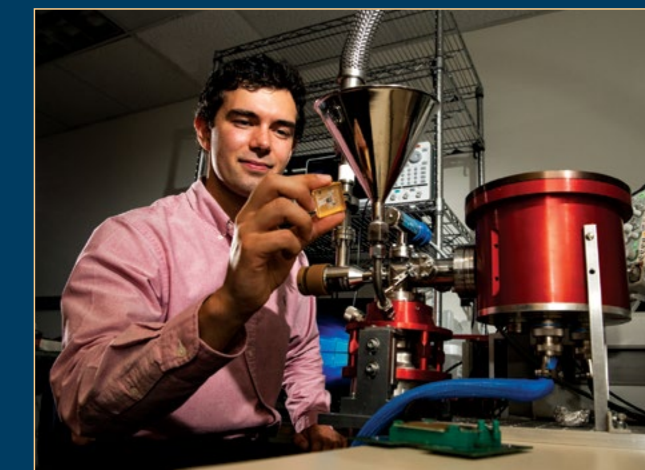
Lincoln Laboratory has worked to further the development of a structural supercapacitor. These multifunction structures are highly desirable for systems constrained by size, weight, and power, and are relevant in the domains of communications, autonomous vehicle power, and power supply for soldier equipment.

TECHNOLOGY HIGHLIGHT

Advanced Imagers at Lincoln Laboratory

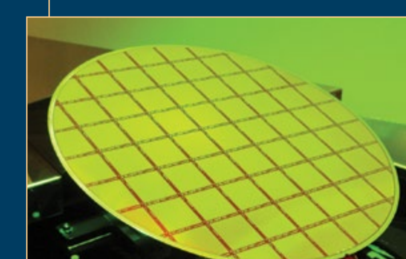
Lincoln Laboratory is at the forefront of the development of advanced imager technology to solve critical national security challenges. The Laboratory's innovations span from the growth of new detector materials, to the design and fabrication of new imager arrays, to the development of the world's most advanced readout circuits, and to the integration and packaging of cameras for prototype systems and field demonstrations.

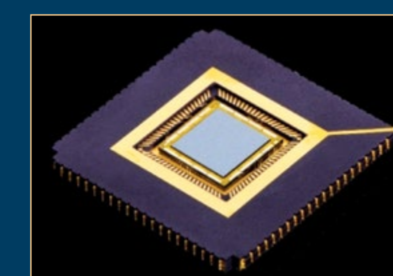
In recent years, particular areas of development have been low-noise charge-coupled devices (CCDs), robust large-format photon-counting arrays of Geiger-mode avalanche photodiodes (Gm-APDs), a visible silicon digital focal plane array (DFPA), and digital readout circuits for rapid-scanning infrared sensors. In addition to their application for national security, these imagers have found wide use in scientific instruments, such as the Transiting Exoplanet Survey Satellite. Recent accomplishments are highlighted in the following images.



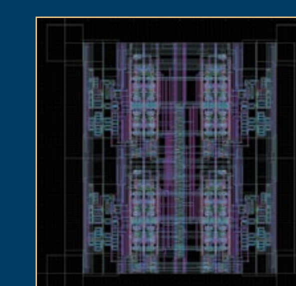
Demonstration of a germanium CCD with sensitivity that spans from the visible through the shortwave infrared and that has enhanced sensitivity to hard X-rays. Here Michael Collins tests a germanium CCD in a cryostat.

Design of a new silicon APD device with the potential to increase dramatically the photon detection efficiency relative to legacy designs.





Development of a new process to build silicon diode arrays mated to DFPAs with $>10^9$ dynamic range.



Design of a new photon-counting readout circuit that leverages DFPA designs to enhance Gm-APD performance.

Advanced Devices

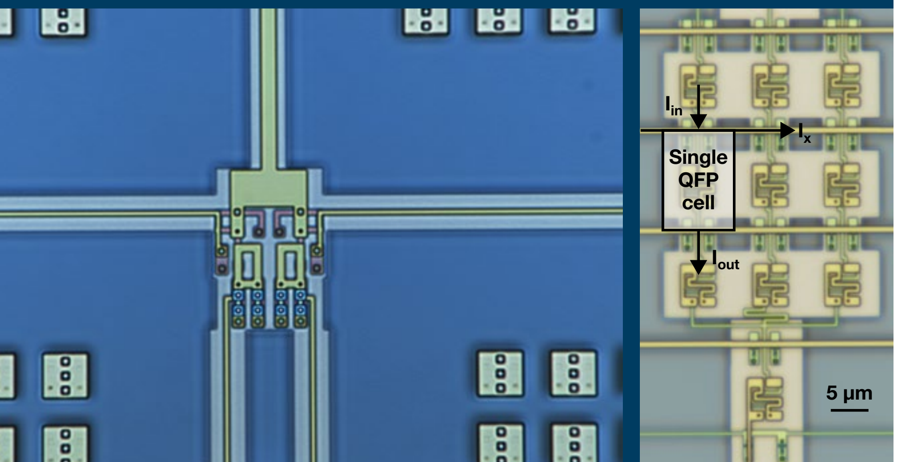
Work in advanced devices focuses on developing novel components and capabilities to enable new system-level solutions to national security problems. Advanced devices span a wide range of fundamental technologies for RF technology, lasers, advanced computing, imagers, and microsystems applications. Groundbreaking projects in 2019 include

- Pioneering work in diamond power transistors that promises to deliver orders of magnitude improvement in low-power computation applications. Diamond offers power, efficiency, and heat removal superior to all other semiconductors and thus can enable radar, electronic warfare, and communication with higher output power.
- Computing that exploits superconducting and low temperatures. This year, improvements were made in miniature cryocoolers and in the advancement of superconducting devices.
- Improvements in photonic integrated navigation-grade accelerometers and gyroscopes that combine the sensitivity of optical measurement with traditional microelectromechanical systems processing. These improvements could have a significant impact on GPS-denied navigation.
- Continued work on fundamental advancements of optical systems to support future mission capabilities.

>> Investments in Emerging Technology, cont.

TECHNOLOGY HIGHLIGHT

Quantum Flux Parametron Neural Networks



Individual quantum flux parametron (QFP) devices are tiled together to form an effective computational neuron, left image. This circuit performs an addition of all input signals, applies a nonlinear activation function to this sum, and outputs the result. The activation functions are intended to mimic a biological neuron, which fires whenever the intensity of the summed inputs is above some threshold value. At right is a tunable weighting element that can scale an input signal by a desired weight.

Researchers at Lincoln Laboratory are building neural networks using superconducting integrated circuits as an alternative to the conventional complementary metal-oxide semiconductor (CMOS)–based chips currently in wide use. Thanks to the properties of superconductors, these devices are expected to operate orders of magnitude faster than their traditional counterparts and dissipate much less energy, even after cooling power is considered.

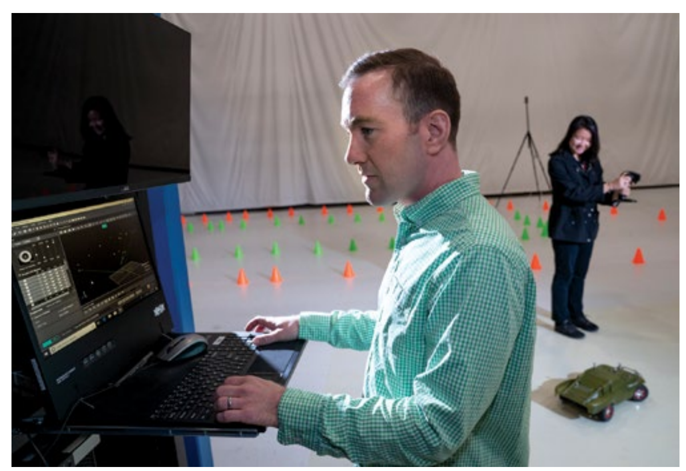
Elementary superconducting circuit elements are well-tailored to low-power multiply and threshold operations, which lend themselves well to efficient neural-network accelerators. The team uses a mixed-signal design to improve power and speed beyond pure digital approaches, but the approach makes use of flux quantization in superconductors to maintain digital fidelity in larger systems.

The program began as a Technology Office seedling and has evolved into an ongoing project involving cycles of design, fabrication, and testing. The team recently designed a tunable cell that allows weights to be stored locally on chip and created basic designs that will be used to verify the device concept before moving the device to a larger scale.

Autonomous Systems

Systems with increasing degrees of autonomy are of growing importance to the DoD and other national security organizations. To address this emerging area, the Laboratory has pursued applied research focusing on decision-making algorithms, autonomous and unmanned platforms, challenges in verification and validation of such systems, and foundational research in autonomy. Novel projects in 2019 include

- The use of advanced machine learning techniques applied to video and imagery to segment and categorize a scene. These categorized scenes can be used for autonomous system reasoning and decision making. This research utilizes deep reinforcement learning trained in a simulated environment and transfers the learned behavior into the real world where training data are scarce.
- Development of a prototype system to map the ocean floor autonomously with a 100-fold greater resolution than that achieved by current systems and coverage rates that are similar to those of existing ship-based mapping systems.

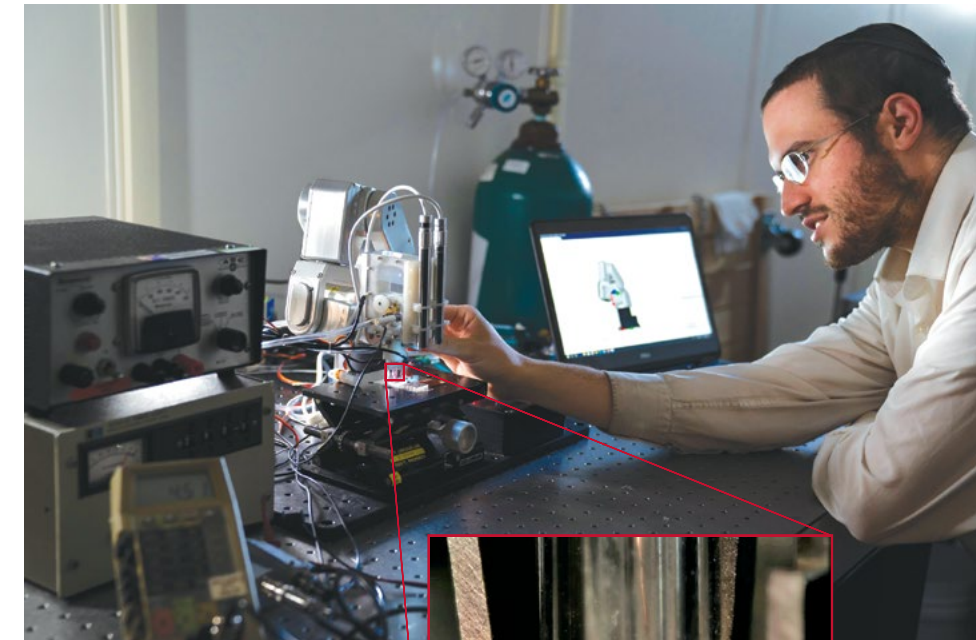
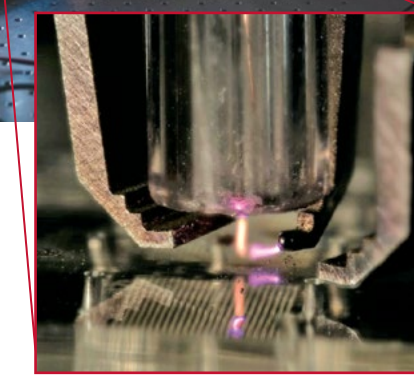


The Lincoln Laboratory Micro Air Vehicle Test Bed facilitates the development of next-generation prototypes by integrating systems across the Autonomous Systems Development Facility, STRIVE Center, and MIT campus to enhance teaming between humans and unmanned aircraft systems. The test bed combines simulation, hardware-in-the-loop testing, and physical test facilities to improve and accelerate the development process.

Advanced Materials and Processes

Research in advanced materials and processes seeks to invent new materials and establish novel processing capabilities to improve sensing, imaging, and manufacturing technologies. Efforts include the development of non-silicon electronic materials, advanced sensors, integrated microsystems, and advanced structures. Project highlights in 2019 include

- The use of phase-change materials to create tunable optical filters. Phase-change metamaterials provide an all-electric, solid-state, thin-film, fast-switching solution that may potentially replace bulky mechanical systems.
- Additive printing of metal matrix composites by using a selective laser smelting process. This technique incorporates novel metal and ceramic mixtures that may dramatically improve structural performance while reducing manufacturing cost and complexity.

The Laboratory is investing in an additive manufacturing process that is capable of printing high-quality functional materials onto a variety of surfaces. This process is accomplished by an atmospheric microplasma sputtering system mounted to a robotic arm to print precision lines and integrated circuit-quality metal interconnects.

Biomedical Science and Technology

Biomedical science and technology research at Lincoln Laboratory focuses on applied research into engineered biosystems, brain science and neurocognition, biological signal and image analytics, and medical decision support. This work investigates technologies needed by the DoD that are unlikely to be developed in the commercial biomedical market and those that leverage the Laboratory's unique semiconductor and device manufacturing capabilities. The 2019 projects include

Lincoln Laboratory has worked to develop a brain-computer interface to enhance the performance of hearing aids. This technology uses a method referred to as auditory attention decoding to determine the attention of the listener. The system then isolates and enhances the acoustic signals of interest.

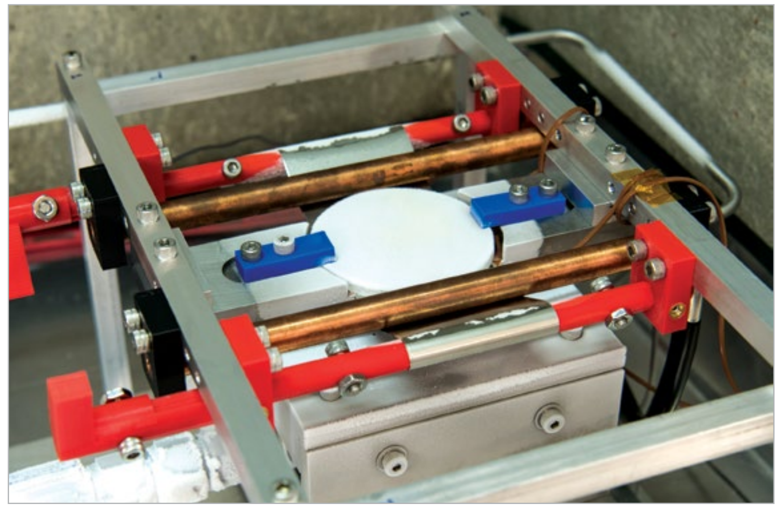
- Development of clinical tools and instrumentation to explore neurological disorders, seeking biomarkers for conditions such as autism and depression.
- Phenomenological experiments that use advanced biosimulants to study the spread of pathogens in public spaces, such as healthcare facilities and mass transit.
- Development of automated medical analysis and decision support tools to aid field-forward medics in diagnosis and treatment.

>> Investments in Emerging Technology, cont.

Engineering

The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of prototype systems. Advancing these capabilities is achieved through investments in several areas of engineering research: design, analysis, and software tools; thermal management technologies; advanced materials and processes; optical technology; and propulsion and power systems. Highlights from this diverse portfolio include

- Research into deployable optical systems based on transmissive diffracting membranes. Membrane optics promise to reduce mass, volume, and cost for imagers for space-based missions.
- Development of a common Lincoln Laboratory autonomy software architecture for CubeSats; the onboard autonomy improves Earth-observing satellites' performance, agility, and reconfigurability.

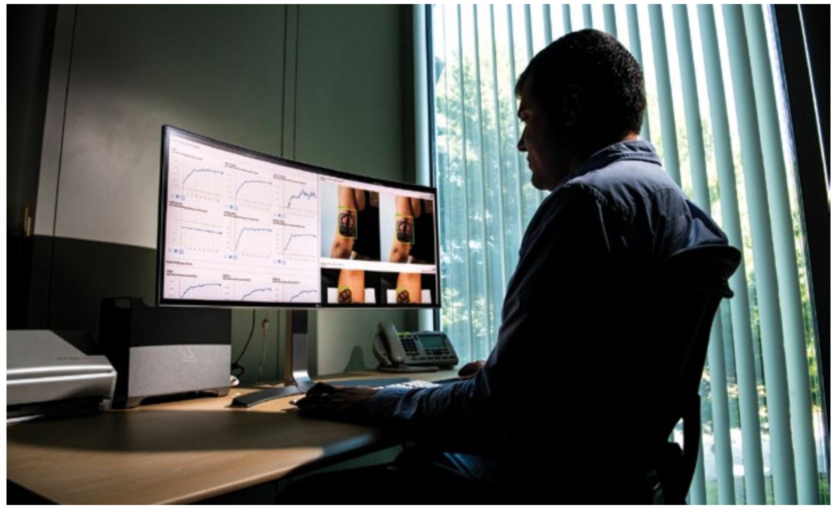


The impingement cooling prototype demonstrated heat-transfer coefficients as high as 20,000 watts per square meter K and temperature control of a high-heat load electronic device to 0°C with a coolant flow rate of less than 0.005 kilograms per second. The experimental setup was machined and built at Lincoln Laboratory's Technology Office Innovation Laboratory.

Homeland Protection, Air Traffic Control, and Humanitarian Assistance and Disaster Relief

Investments in these three areas emphasize foundational research and infrastructure development needed to produce advanced capabilities applicable to a diverse set of critical national security needs. Investments support solutions to national challenges in air and ground transportation, land border and maritime security, chemical and biological defense, critical infrastructure protection, humanitarian assistance, and disaster response. Projects span research in advanced sensors and architectures, signal processing, data fusion, and decision support, as well as the development of experimental test beds and infrastructure needed to explore advanced concepts. Projects highlights in 2019 include

- Development of optimization algorithms to identify high-impact actions and provide real-time recommendations for air traffic control management.
- Development of a smart photovoltaic microgrid to deliver efficient, safe, and inexpensive energy for electric cooking in disadvantaged communities. The technology incorporated power-capacity forecasting, smart power distribution, and novel endpoint utilization.
- Continued work in leveraging airborne hyperspectral imaging to gain situational awareness following a natural disaster. This imaging will provide the ability to classify materials and contaminants at much faster rates than can be done by the traditional manual methods.



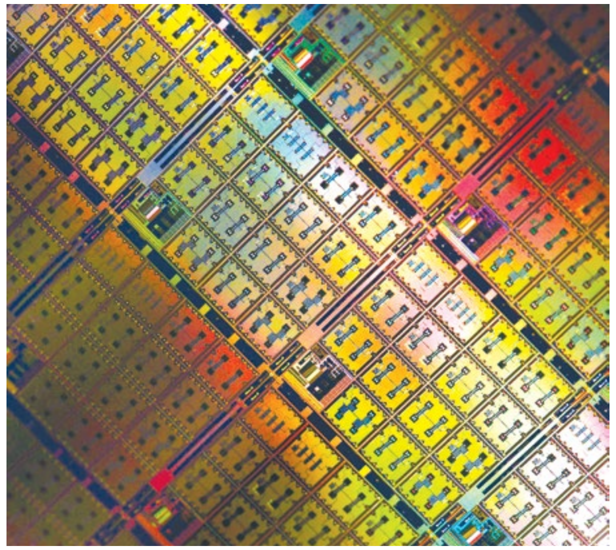
Human trafficking investigators inundated by the time-intensive analysis of large amounts of multimedia evidence often have limited technology to assist in the task. The Exscind collaborative analysis system extracts, enriches, and visualizes information derived from complex evidence data to help investigators more effectively discover connections and identify signs of trafficking. Above, a researcher trains a deep learning algorithm to recognize known trafficking signatures contained in images.

INVESTMENTS IN INNOVATIVE RESEARCH

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

Advanced Concepts Committee

The Advanced Concepts Committee (ACC) provides funding as well as technical and programmatic guidance for the development of advanced concepts that address important technical problems. The ACC funds a breadth of highly innovative, high-risk research that, if successful, has the potential for significant impact on the Laboratory's mission areas. One example from the 2019 portfolio is the development of a low-threshold multiplexed array for neutrino detection.



Neutrinos remain one of the most elusive particles in the Standard Model of particle physics because they are difficult to detect and therefore challenging to study experimentally. In collaboration, the Laboratory and MIT campus developed an array of frequency-based superconducting quantum interference devices (SQUIDs), such that very small recoil energies from neutrino interactions could be detected. Future plans include efforts to integrate such an array to specialized targets made of superconducting metals.

New Technology Initiatives

The New Technology Initiatives supports research and development to prepare relevant Laboratory-developed technologies for transition to the sponsor community and to explore commercialization of select technologies for the benefit of national security and societal well-being.

SEEDLINGS

Through investments in seedling projects, the Technology Office allows staff to pursue novel technology ideas and feasibility demonstrations. Seedlings encourage exploration of radically new approaches and technologies with the potential to enhance Lincoln Laboratory mission areas.

FOSTERING INNOVATION AND COLLABORATION

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

New Collaboration

In a joint agreement between MIT and the U.S. Air Force, a new program called the Artificial Intelligence Innovation Accelerator has been launched to make fundamental investments in artificial intelligence. The goal is to conduct basic research on campus to address broad societal needs and eventually to transition these capabilities to Air Force operations. The initial round of joint research projects between campus and Lincoln Laboratory will be executed in fiscal year 2020. The Technology Office has been working with MIT and the Air Force to define the research agenda.

First RAAINS Workshop

In November 2019, Lincoln Laboratory hosted the inaugural Recent Advances in Artificial Intelligence for National Security (RAAINS) Workshop. This three-day workshop covered the state of the art in key areas of AI, recent advances applied to national security, and future directions in AI that are specifically of interest to DoD and intelligence communities.

Technology Office Innovation Laboratory

The Technology Office Innovation Laboratory (TOIL) is a makerspace that supports the rapid development of proof-of-concept prototypes. TOIL is used for Technology Office–funded projects and general curiosity-driven tinkering. TOIL is designed to foster innovation, collaboration, and creative problem solving. The facility includes 3D printers, a machine shop, a rapid prototyping space, an electronics laboratory, a software engineering facility, and more.

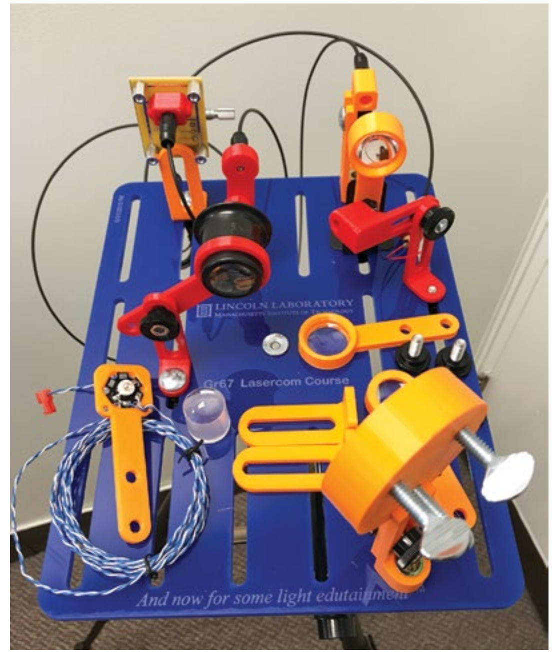
>> Fostering Innovation and Collaboration, cont.

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 2019, the challenge was Build Your Own X. This challenge sought to develop a fun, educational project-based course around a technology area relevant to Lincoln Laboratory's research areas.

Staff used a crowdsourced, web-based tool known as the Idea Incubator to share and develop their course concepts. A downselected subset of the initial concepts was presented at a project pitch and team formation event. The top-rated ideas were then presented to the Technology Office in a more formal proposal presentation.

The two courses selected for implementation were Build Your Own Lasercom and Build Your Own High-Altitude Balloon Carrying Amateur Radio (HABCAR). Build Your Own Lasercom expanded an existing laser communications course to include the addition of a low-cost kit with plastic optics. In the HABCAR course, participants integrated sensors and an amateur radio onto a high-altitude weather balloon. The goal of this course was to demonstrate the HABCAR'S operation with a global circumnavigation flight.



Build Your Own Lasercom focused on decreasing the cost of optical equipment by switching to inexpensive, 3D-printed plastic optics. These parts allow kits to be distributed among a greater number of small teams, thus enabling more people to engage in hands-on building.

Artificial Intelligence Technical Interchange Meeting

In October 2018, Lincoln Laboratory held the first Laboratory-wide technical interchange meeting focused on artificial intelligence (AI). The applicability of AI to national security warranted a new forum to bring together practitioners from across the Laboratory's mission areas. The two-day event provided an overview of each division's activities in AI and a series of "lightning briefs" designed to stimulate discussion and new ideas.

R&D 100 Awards

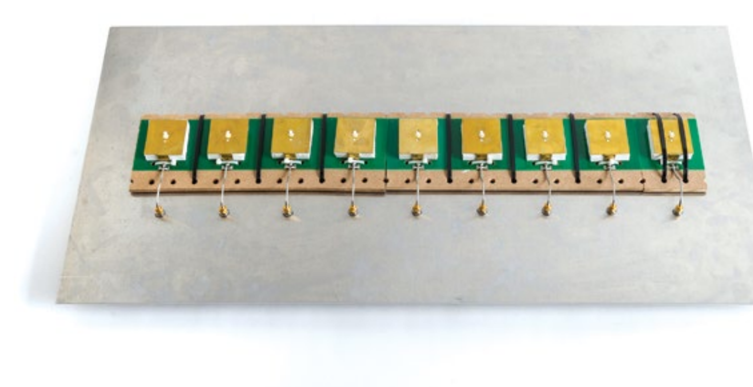
R&D World magazine presented 2019 R&D 100 Awards to 10 technologies developed by Lincoln Laboratory researchers, either solely or in partnership with other organizations. These international awards recognize the 100 most technologically significant innovations introduced during the prior year. From the hundreds of nominees, the winners were selected by a 40-member judging panel composed of editors from several publications owned by the parent company of *R&D World* and technical experts from academia, industry, and national labs.

The principal researchers of Lincoln Laboratory's R&D 100 Award–winning technologies are seen here with Director Eric Evans. Standing, left to right, are Eric Evans, Jeffrey Herd, Jeffrey Palmer, Joseph Cooley, Joseph Lacirignola, Evelyn Mann, Jonathan Doane, Charles Wynn, Jonathan Frechette, Ryan Sullenberger, Johanna Bobrow, Bradley Perry, Paul Juodawlkis, and Pierre Dufilie; kneeling, left to right, are Daniel Herring, David Walsh, William Dupree, Michael Matthews, Gary Shaw, and Jason Plant.

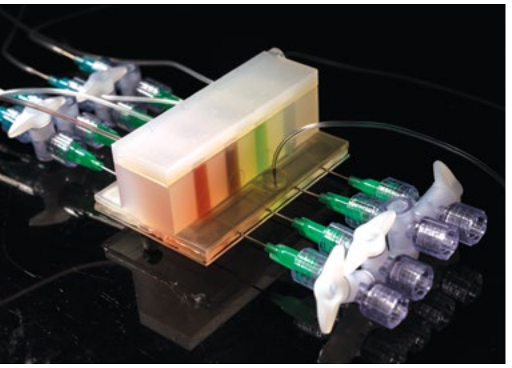
Aperture Level Simultaneous Transmit and Receive Phased Array

The first-ever demonstration of a phased array antenna system that has sufficient isolation to enable practical multi-beam full-duplex communication.

LINCOLN LABORATORY TEAM: Jonathan Doane, project lead; Kenneth Kolodziej and Bradley Perry



>> R&D 100 Awards, cont.



ArtGut

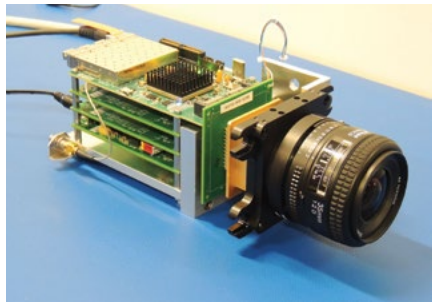
The first in vitro platform that enables researchers to perform high-resolution, physiologically relevant gut microbiome studies.

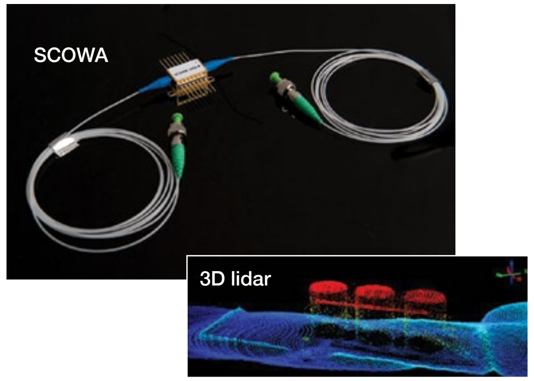
LINCOLN LABORATORY TEAM: Todd Thorsen and David Walsh, project leads; Catherine Cabrera, Peter Carr, James Comolli, Victoria Dydek, Bea Yu, Eric Holihan, Johanna Bobrow, and Catherine Van Praagh

Dual-Mode Imaging Receiver

A camera that integrates the previously disparate functions of high-frame-rate photon-counting imaging and single-photon-sensitive communications into a single optical receiver.

LINCOLN LABORATORY TEAM: Gary Shaw, project lead; Cindy Fang, Jonathan Frechette, Matthew Gregory, Pablo Hopman, George Jordy, Thomas Karolyshyn, Anthony Kryzak, Jeffrey Little, Alexander McIntosh, Joseph Racamoto, Andrew Siegel, Eric Simpson, and Richard Younger



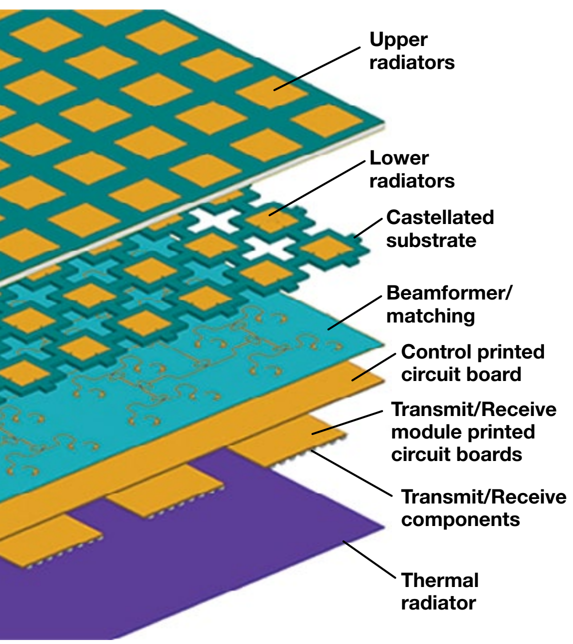


Gas Mapping LiDAR™

A sensor, built by Bridger Photonics and enabled by Lincoln Laboratory's slab-coupled optical waveguide amplifier (SCOWA), that remotely detects, locates, and quantifies methane leaks and oil and gas infrastructure status.

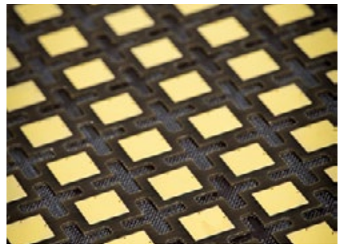
LINCOLN LABORATORY SCOWA TEAM: Paul Juodawlkis, project lead; Chris Heidelberger, John Liddell, Ryan Maxson, Antonio Napoleone, and Jason Plant. BRIDGER PHOTONICS TEAM LEAD: Michael Thorpe

Lightweight Deployable Array Panels for Space

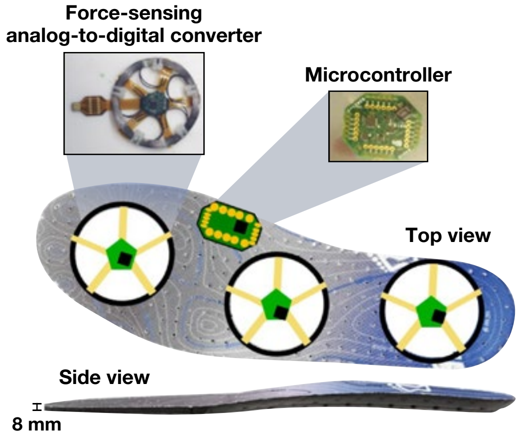


Panels for space-based communications and remote sensing systems that have minimized weight and size to lower launch costs by reducing fuel needs and increasing capacity to accommodate more systems per launch.

LINCOLN LABORATORY TEAM: David Conway and Pierre Dufilie, project leads; Lawrence Artz, Daniel Baumgartner, David Bragdon, Deanna Dysert, Janusz Majewski, Edward Martin, and Mark Silver



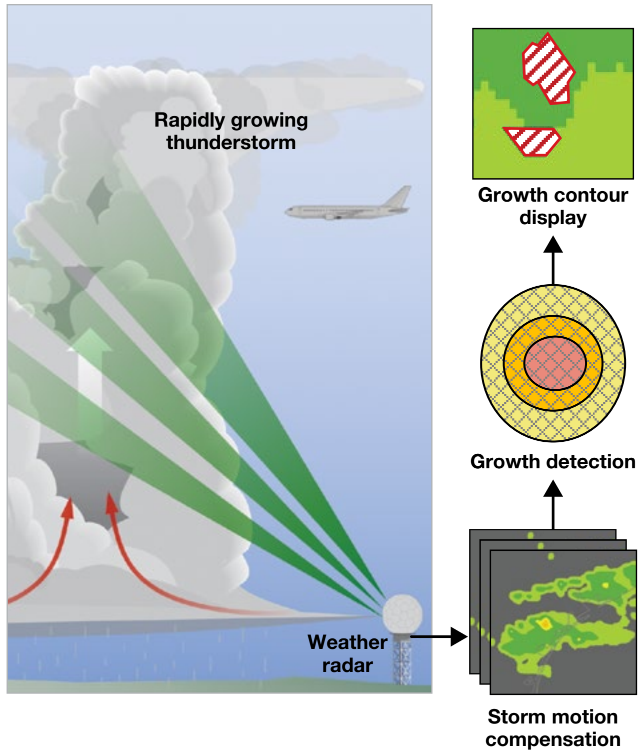
Mobility and Biomechanics Insert for Load Evaluation



Biomechanical sensors that are built into a shoe insert and small ankle package to measure a user's weight and lower leg movements to help guide decisions about load-bearing and gait.

LINCOLN LABORATORY TEAM: Joseph Lacirignola, project lead; Kate Byrd, Paula Collins, David Maurer, Erik Metzger, Jeffrey Palmer, Ninoshka Singh, and Whitney Young

Rapid Convective Growth Detector



A system that uses tilt-by-tilt processing of weather radar data to identify and display regions of hazardous storm growth 10 times faster than other weather sensors.

LINCOLN LABORATORY TEAM: William Dupree and Evelyn Mann, project leads; Derek Eberle, Danielle Morse, John Morgan, Kathleen Nahabedian, Gregory Rappa, and Marilyn Wolfson

Tactical Microgrid Standard Open Architecture

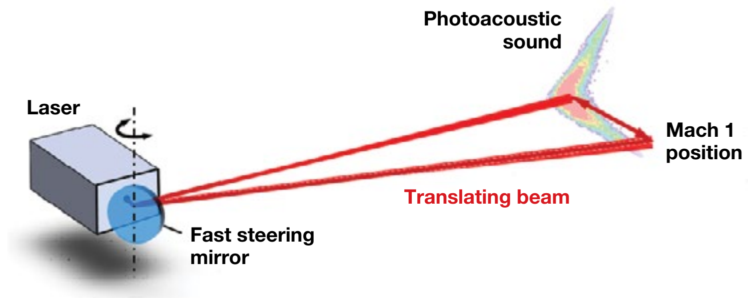
An architecture that was developed by a Department of Defense-led consortium of government, industry, and academic partners to provide an interoperability standard for highly modular, resilient, scalable, and mission-specific microgrid solutions.

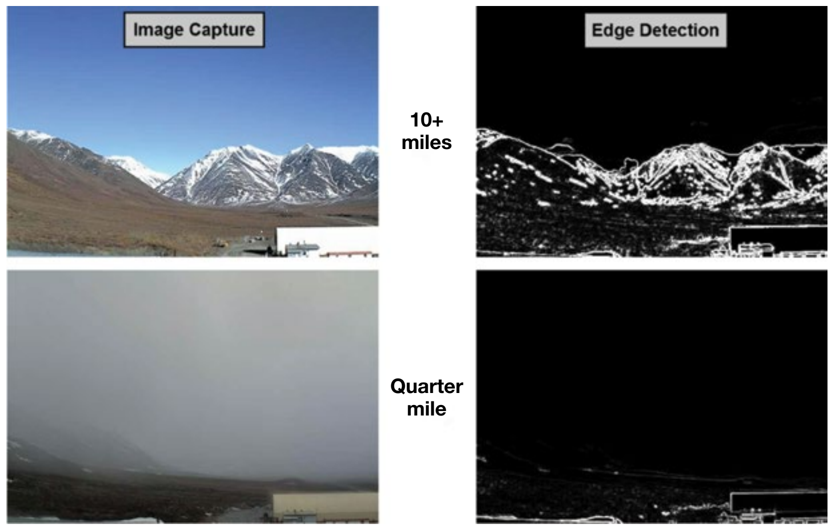
LINCOLN LABORATORY TEAM: Daniel Herring, project lead; Joseph Cooley, Aaron Gawlik, Shelly Hazard, Jason LaPenta, Erik Limpaecher, Raymond Paradiso, Brandyn Schult, Geoffrey Stilwell, and Scott van Broekhoven. CONSORTIUM PROJECT LEADS: Thomas Bozada, U.S. Army; Chris Garick, Humber-Garick; Ellery Blood and Scott Manson, Schweitzer Engineering Labs

Targeted Acoustic Laser Communication

A system that uses laser photoacoustics to create audible messages in a person's ear, enabling secure and remote communications with the individual of interest and no one else.

LINCOLN LABORATORY TEAM: Charles Wynn and Ryan Sullenberger, project leads; Sumanth Kaushik and Yaron Rachlin





Visibility Estimation through Image Analytics

A software system, developed by the Laboratory in partnership with the Federal Aviation Administration, that provides air traffic managers and pilots with an inexpensive, yet effective, way to automatically extract from camera images vital data about meteorological visibility.

LINCOLN LABORATORY TEAM: Michael Matthews, project lead; Robert Hallowell. FAA LEAD: Jenny Colavito

Technology Transfer

Technology transfer is a critical element of Lincoln Laboratory's mission. Since its inception in 1951, the Laboratory has generated more than 1,000 patents and launched more than 100 startup companies to leverage and commercialize inventions developed under federal funding.

Most of Lincoln Laboratory's R&D projects result in some form of technology transfer—to government agencies, the commercial sector, and academia. The mechanisms for these transfers include the delivery of hardware, software, algorithms, or advanced architecture concepts to government sponsors or their designated partners; the dissemination of concepts via Lincoln Laboratory technical reports, publications in professional journals, and presentations at conferences and workshops; collaborative research via Small Business Innovative Research (SBIR) or Small Business Technology Transfer (STTR) projects, and Cooperative Research and Development Agreements with industry and not-for-profits; and patent filing, copyright protection, and licensing activities.

FISCAL YEAR 2019 TECHNOLOGY TRANSFER BY THE NUMBERS

92 Articles in technical journals	**116** Papers in published proceedings	**72** Patents issued
12 Lincoln Laboratory–hosted conferences	**83** Technology disclosures filed	**10** R&D 100 Awards

THE TECHNOLOGY VENTURES OFFICE

In 2018, Lincoln Laboratory established the Technology Ventures Office (TVO) to provide strategic coordination for technology transfer activities across the Laboratory

The TVO's primary objective is to facilitate the rapid transfer of advanced technology into and out of Lincoln Laboratory for the benefit of national security. This office, working with others across the Laboratory and at MIT proper, focuses on three areas:

- Managing and tracking sponsor-directed technology transition to industry and others
- Engaging with a wide variety of advanced-capability companies, including small and nontraditional defense contractors
- Developing an intellectual property (IP) strategy that maximizes the availability of the Laboratory's inventions for military and economic competitiveness

TECHNOLOGY VENTURES OFFICE
Dr. Bernadette Johnson, Chief Technology Ventures Officer (center)
Dr. R. Louis Bellaire, Deputy, Technology Ventures Office (left)
Jennifer A. Falciglia, Administrative Staff (right)

SELECT TECHNOLOGY TRANSITIONS

Emergency Response System

North Macedonia is adopting the Next-Generation Incident Command System as its official crisis management system. The software system enables all emergency agencies in the country to be digitally unified, allowing for simplified coordination of disaster response services. Lincoln Laboratory is working with NATO to implement the system in additional southeastern European countries.

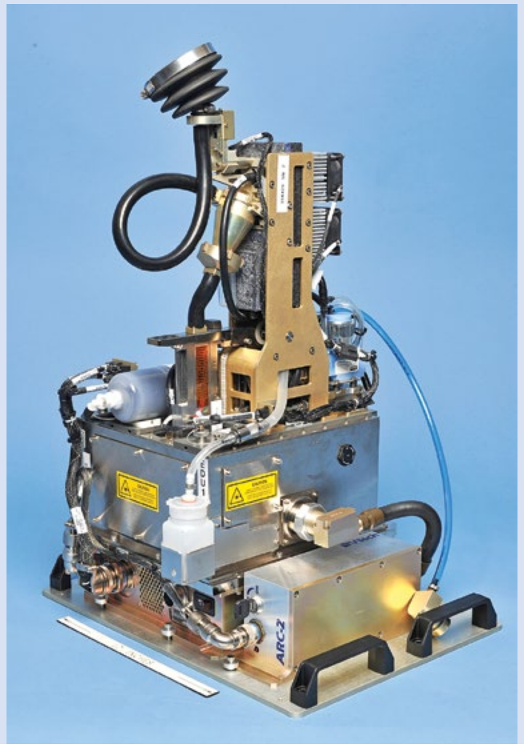
Emergency responders test NICS during a NATO field exercise in Bosnia and Herzegovina.

Signal Processing Algorithms

Signal processing algorithms for antenna beam pattern shaping, developed under U.S. Army sponsorship, were transitioned to multiple industry vendors. These algorithms have been demonstrated through on-orbit testing of current satellite systems to enhance the strength of user signals and are applicable to future satellite communication designs.

Subsystems for Laser Communications

The Laboratory is working with CACI International Inc. to transition laser communication modem designs as part of NASA programs to deploy laser-communication terminals on the International Space Station and the Orion spacecraft.



Rapid Agent Aerosol Detector

The Rapid Agent Aerosol Detector (RAAD), the trigger for the government's Joint Biological Point Detection System, is being transferred to Chemring Sensors & Electronics Systems as part of the Enhanced Maritime Biological Detection program. The RAAD rapidly detects airborne biological warfare agents, such as anthrax, by measuring properties of individual aerosol particles as they flow through the instrument. The sensitivity of the RAAD to detecting biological warfare agents is critical because the trigger sets the sensitivity for the entire system. Furthermore, the trigger has to detect the biological agent aerosol very rapidly to enable the system to collect a sample for identification before the aerosol has floated downwind. Systems that monitor for bioagents are used to warn people of hazards so they can minimize exposure or take steps to avoid contamination altogether.

At left, in this external view of the Rapid Agent Aerosol Detector, a 12-inch ruler is provided for scale.

>> Technology Transfer, cont.

Commercial Engagements

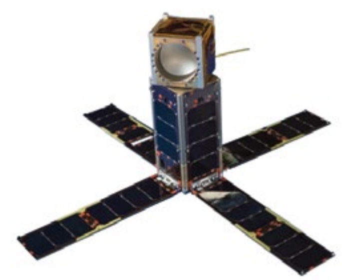
In 2019, Lincoln Laboratory conducted collaborative research and development with 15 companies under Cooperative Research and Development Agreements (CRADAs), which are R&D partnerships funded by industry to advance dual-use or commercial technologies; 46 collaborative agreements with not-for-profit institutions; and an additional 26 sponsor-supported collaborative research efforts with MIT campus departments. These agreement types are an established means of transferring technology developed in federal laboratories to the commercial sector. Lincoln Laboratory also executed 16 SBIR/STTR–supported projects under sponsorship from multiple government agencies.

In addition, the Laboratory introduced a modified version of the Commercial Solutions Opening contracting vehicle to engage more flexibly with small and nontraditional companies who can help solve challenging problems for the Laboratory's diverse sponsor base.

Innovation–Corps (I–Corps™) Spark Program

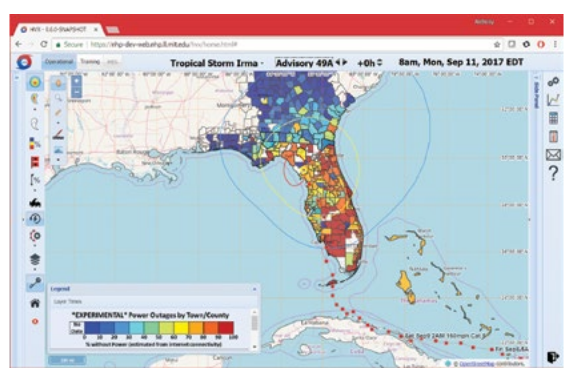
In FY2019, MIT began offering to staff members at Lincoln Laboratory a variation of the Innovation–Corps (I–Corps™) Spark Program, which was originated by the National Science Foundation. The objective of this new 10-week program is to accelerate the translation of research into practical applications. Already, 32 Laboratory employees conducted more than 100 informational interviews with external stakeholders, strategic partners, and commercial entities to discuss transfer possibilities for eight technologies developed by the Laboratory. Through this program, participants expanded their entrepreneurial skills and improved their program-development acumen by exploring the national security, commercial, and societal potential of their new technologies, expanding their professional networks, and gaining valuable feedback on the utility of their inventions.

I–Corps™ Program Featured Technology: *Miniaturized Radiometer*



A small, low-cost radiometer (left) was developed for use on microsatellites that could be deployed in a constellation to monitor atmospheric conditions within storms.

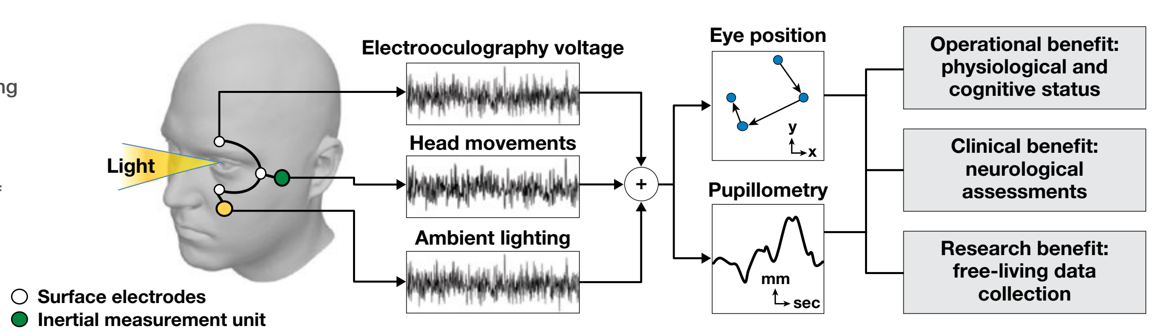
I–Corps™ Program Featured Technology: *Decison Support Tools*



Tools for predicting the power outages caused by severe storms help emergency personnel plan the deployment of repair crews.

I–Corps™ Program Featured Technology: *Medical Diagnostics—Wearable Eye-Tracking Device*

A lightweight, wearable eye-tracking device can enable the assessment of the neurological and cognitive function of service personnel in the field.

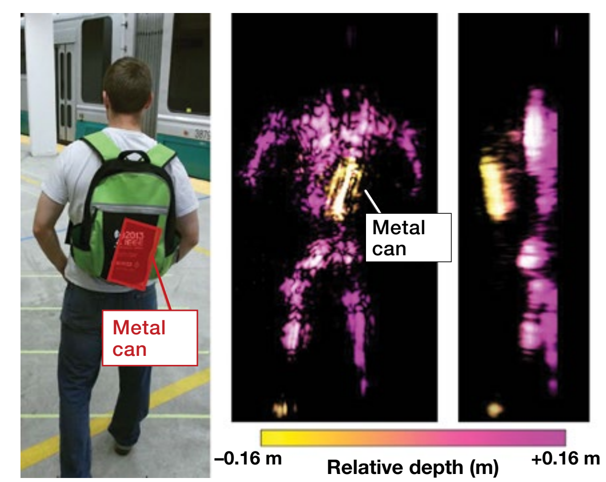


Intellectual Property Management

Approximately 10 to 15 percent of MIT's annual technology disclosure count derives from inventions at Lincoln Laboratory, and about one-third to one-half of those result in granted patents. About 20 percent of the Laboratory's technology disclosures are software-based and afforded copyright protection by MIT. A significant fraction of this software is distributed through open-source repositories or government-controlled repositories for the benefit of other researchers and global user communities. In 2019, MIT executed seven licenses on technologies developed at the Laboratory.

This computer rendering shows the HEXWAVE system in use at a sports stadium. Photo: Liberty Defense

For example, Liberty Defense Technologies, a startup in Atlanta, Georgia, secured an exclusive license from MIT for patents related to active millimeter-wave radar imaging technology. Liberty Defense Technologies' system, HEXWAVE, produces high-fidelity, real-time imagery and uses machine learning to detect metallic and nonmetallic firearms, knives, and explosives. The system is being developed to be openly deployed from a kiosk through which pedestrians walk or built covertly into infrastructure surrounding building entrances. The immediate application for the HEXWAVE systems is monitoring public venues for concealed weapons. The technical, contracting, and licensing staff responsible for this technology transfer activity received a Federal Laboratory Consortium (FLC) Northeast Regional Excellence in Technology Transfer Award.



Above, the Laboratory's prototype microwave imaging system identified a metal can inside the subject's backpack. At right, Lincoln Laboratory researcher William Moulder is scanned by the microwave imaging system when it was tested at a transportation center.

Featured Spinout Company

In 2019, two former Lincoln Laboratory employees formed a company named JetCool to market an innovative way to cool high-power, power-dense electronic devices. Their patent-pending twist on microjet cooling uses small jets of high-velocity fluid to cool a device. Instead of passing fluid over a device's surface, as in typical heat sinks or cold plates, microjets are aimed directly at the surface, producing a heat-transfer coefficient 10 times greater than can be achieved by competing approaches. In June 2019, JetCool won the title of Next Top Startup at the 2019 International IEEE Microwave Symposium.

>> *Technology Transfer, cont.*

U.S. Patents Granted to Lincoln Laboratory Inventors, 1 October 2018–30 September 2019

Cognitive Radio Method and Apparatus for Achieving ad hoc Interference Multiple Access Wireless Communication
U.S. Patents 10,091,798 and 10,299,281; issued 2 October 2018 and 21 May 2019

Zero Cross-Talk Geiger-Mode Avalanche Photodiode Arrays
U.S. Patent 10,109,671; issued 23 October 2018

Interconnect Structures and Methods for Fabricating Interconnect Structures
U.S. Patent 10,121,754; issued 6 November 2018

Assessing Disorders Through Speech and a Computational Model
U.S. Patent 10,127,929; issued 13 November 2018

Methods, Systems, and Apparatus for Global Multiple-Access Optical Communications
U.S. Patent 10,128,949; issued 13 November 2018

Qubit and Coupler Circuit Structures and Coupling Techniques
U.S. Patent 10,134,972; issued 20 November 2018

Methods and Apparatus for True High Dynamic Range (THDR) Time-Delay-and-Integrate (TDI) Imaging
U.S. Patent 10,142,567; issued 27 November 2018

Accurate Timing Distribution by High-Frequency Radio
U.S. Patent 10,148,345; issued 4 December 2018

Ingestible Devices and Methods for Physiological Status Monitoring
U.S. Patent 10,149,635; issued 11 December 2018

Wave Damping Structures
U.S. Patent 10,151,074; issued 11 December 2018

Mechanical Memory Transfer
U.S. Patent 10,153,382; issued 11 December 2018

Message Fractionation and Physical Layer Channel Assignment for Multiuser Detection-Enabled Wireless Communication
U.S. Patent 10,159,004; issued 18 December 2018

Symmetric Micro-Optic Module
U.S. Patent 10,168,538; issued 1 January 2019

Limited Execution of Software on a Processor
U.S. Patent 10,169,251; issued 1 January 2019

Fuse-Protected Electronic Photodiode Array
U.S. Patent 10,177,181; issued 8 January 2019

Systems and Methods for Single Device Authentication
U.S. Patent 10,182,040; issued 15 January 2019

Four Spin Couplers for Quantum Information Processing
U.S. Patent 10,187,065; issued 22 January 2019

Multi-fin Flared Radiator
U.S. Patent 10,193,237; issued 29 January 2019

Shielded Through Via Structures and Methods for Fabricating Shielded Through Via Structures
U.S. Patent 10,199,553; issued 5 February 2019

Apparatus, Methods, and Systems for High-Power and Narrow-Linewidth Lasers
U.S. Patent 10,203,285; issued 12 February 2019

Network of Extremely High Burst Rate Optical Downlinks
U.S. Patent 10,205,521; issued 12 February 2019

Integrated Optical Blocking Filters for Compact Single-Photon Sensitive X-ray Imaging Detectors
U.S. Patent 10,206,637; issued 19 February 2019

Compact Steerable Transmit Antenna System
U.S. Patent 10,211,531; issued 19 February 2019

Directional Force Sensing Element and System
U.S. Patent 10,222,278; issued 5 March 2019

Physical Layer Encryption Using Out-Phased Array Linearized Signaling
U.S. Patent 10,225,039; issued 5 March 2019

Adaptive Digital Cancellation Using Probe Waveforms
U.S. Patent 10,225,112; issued 5 March 2019

Methods and Apparatus for Recording Impulsive Sounds
U.S. Patent 10,225,672; issued 5 March 2019

Devices and Methods for Sensing Targets Using Photothermal Speckle Detection
U.S. Patent 10,228,284; issued 12 March 2019

Multi-layer Semiconductor Structure and Methods for Fabricating Multi-layer Semiconductor Structures
U.S. Patent 10,229,897; issued 12 March 2019

Stacked Patch Antenna Array with Castellated Substrate
U.S. Patent 10,236,593; issued 19 March 2019

Methods and Apparatus for Deployable Sparse-Aperture Telescopes
U.S. Patent 10,241,293; issued 26 March 2019

Interconnect Structures and Semiconductor Structures for Assembly of Cryogenic Electronic Packages
U.S. Patent 10,242,968; issued 26 March 2019

Printed Circuit Board Assembly with Foam Dielectric Material
U.S. Patent 10,249,943; issued 2 April 2019

Method and Apparatus for On-Chip per-Pixel Pseudo-random Time Coded Exposure
U.S. Patent 10,250,831; issued 2 April 2019

ISA Extensions for Synchronous Coalesced Accesses
U.S. Patent 10,255,070; issued 9 April 2019

Method and Apparatus for Remote Imaging
U.S. Patent 10,261,297; issued 16 April 2019

Methods and Systems for Optical Beam Steering
U.S. Patent 10,261,389; issued 16 April 2019

High-Fidelity Systems, Apparatus, and Methods for Collecting Noise Exposure Data
U.S. Patent 10,264,999; issued 23 April 2019

Methods and Apparatus for Additive Manufacturing of Glass
U.S. Patent 10,266,442; issued 23 April 2019

Timely Randomization Memory Protection
U.S. Patent 10,268,601; issued 23 April 2019

Paramagnetic Tree Coupling of Spin Qubits
U.S. Patent 10,275,718; issued 30 April 2019

Multiloop Interferometers for Quantum Information Processing
U.S. Patent 10 283,693; issued 7 May 2019

Multipolarized Vector Sensor Array Antenna System for Radio Astronomy Applications
U.S. Patent 10,283,877; issued 7 May 2019

Flexible and Implantable Glucose Fuel Cell
U.S. Patent 10,297,835; issued 21 May 2019

Cryptography and Key Management Device and Architecture
U.S. Patent 10,305,870; issued 28 May 2019

Imaging Systems and Methods for Immersive Surveillance
U.S. Patent 10,306,186; issued 28 May 2019

Timely Address Space Randomization
U.S. Patent 10,310,991; issued 4 June 2019

Method and Apparatus for Secure Communication
U.S. Patent 10,311,243; issued 4 June 2019

Distributed Airborne Beamforming System
U.S. Patent 10,312,984; issued 4 June 2019

Printed Circuit Board Assembly with Air Dielectric
U.S. Patent 10,321,557; issued 11 June 2019

Method and Systems for Enhanced Ontology Assisted Querying of Data Stores
U.S. Patent 10,324,964; issued 18 June 2019

Methods and Systems for Pre-symptomatic Detection of Exposure to an Agent
U.S. Patent 10,332,638; issued 25 June 2019

Reagents for Enhanced Detection of Low Volatility Analytes
U.S. Patent 10,345,281; issued 9 July 2019

Equalization of Receiver
U.S. Patent 10,348,345; issued 9 July 2019

Digital Readout Method and Apparatus
U.S. Patent 10,348,993; issued 9 July 2019

Methods and Systems for Near-Field Microwave Imaging
U.S. Patent 10,353,067; issued 16 July 2019

Cross-Talk Suppression Filters in Geiger-Mode Avalanche Photodiodes
U.S. Patent 10,361,334; issued 23 July 2019

Focal Plane Array Processing Method and Apparatus Related Applications
U.S. Patent 10,362,254; issued 23 July 2019

Variable Thermal Resistance
U.S. Patent 10,365,670; issued 30 July 2019

Methods and Apparatus for Array-Based Compressed Sensing
U.S. Patent 10,367,674; issued 30 July 2019

Systems, Apparatus, and Methods for Laser Amplification in Fiber Amplifiers
U.S. Patent 10,374,379; issued 6 August 2019

Apparatus and Methods for Power Efficient Multi-format Optical Transmission
U.S. Patent 10,374,723; issued 6 August 2019

Sleeved Coaxial Printed Circuit Board Vias
U.S. Patent 10,375,838; issued 6 August 2019

Cryogenic Electronic Packages and Methods for Fabricating Cryogenic Electronic Packages
U.S. Patent 10,381,541; issued 13 August 2019

Interconnect Structures for Assembly of Semiconductor Structures Including Superconducting Integrated Circuits
U.S. Patent 10,396,269; issued 27 August 2019

Four Spin Couplers for Quantum Information Processing
U.S. Patent 10,396,801; issued 27 August 2019

Multipolarized Vector Sensor Array Antenna System for Search and Rescue Missions
U.S. Patent 10,416,268; issued 17 September 2019

Semiconductor Structures for Assembly in Multi-layer Semiconductor Devices
U.S. Patent 10,418,350; issued 17 September 2019

Simultaneous Transmit and Receive with Digital Phased Arrays
U.S. Patent 10,419,062; issued 17 September 2019

Dynamic Video Summarization
U.S. Patent 10,424,341; issued 24 September 2019

Methods and Systems for Time-Encoded Multiplexed Imaging
U.S. Patent 10,425,598; issued 24 September 2019

Efficient Operations

As business operations grow in complexity and technology evolves, Lincoln Laboratory continues to introduce efficiencies, simplify operations, and increase its workforce's capabilities.

Members of the Efficiency Improvement Team represent each of the Laboratory's departments and divisions. The team meets monthly to review current process improvements, future initiatives, and operational updates.

Continual Efficiency Improvements

The Efficiency Improvement Team accepts constructive ideas from the Laboratory community for reducing operational overhead or improving processes. Feedback is gathered through the team's website, where employees can submit suggestions, see examples of efficiency projects, and check in on the team's progress.

The team works in tandem with the Business Transformation Office (BTO), which supports the Laboratory's journey to becoming a more digitally mature organization. The BTO is championing a new initiative called the Digital Enterprise Transformation, which involves reviewing and streamlining processes and introducing new tools and technology to improve efficiency and save costs.

In 2019, the BTO and Efficiency Improvement Team worked with representatives across the Laboratory's departments to help implement efficiency improvements, including the following:

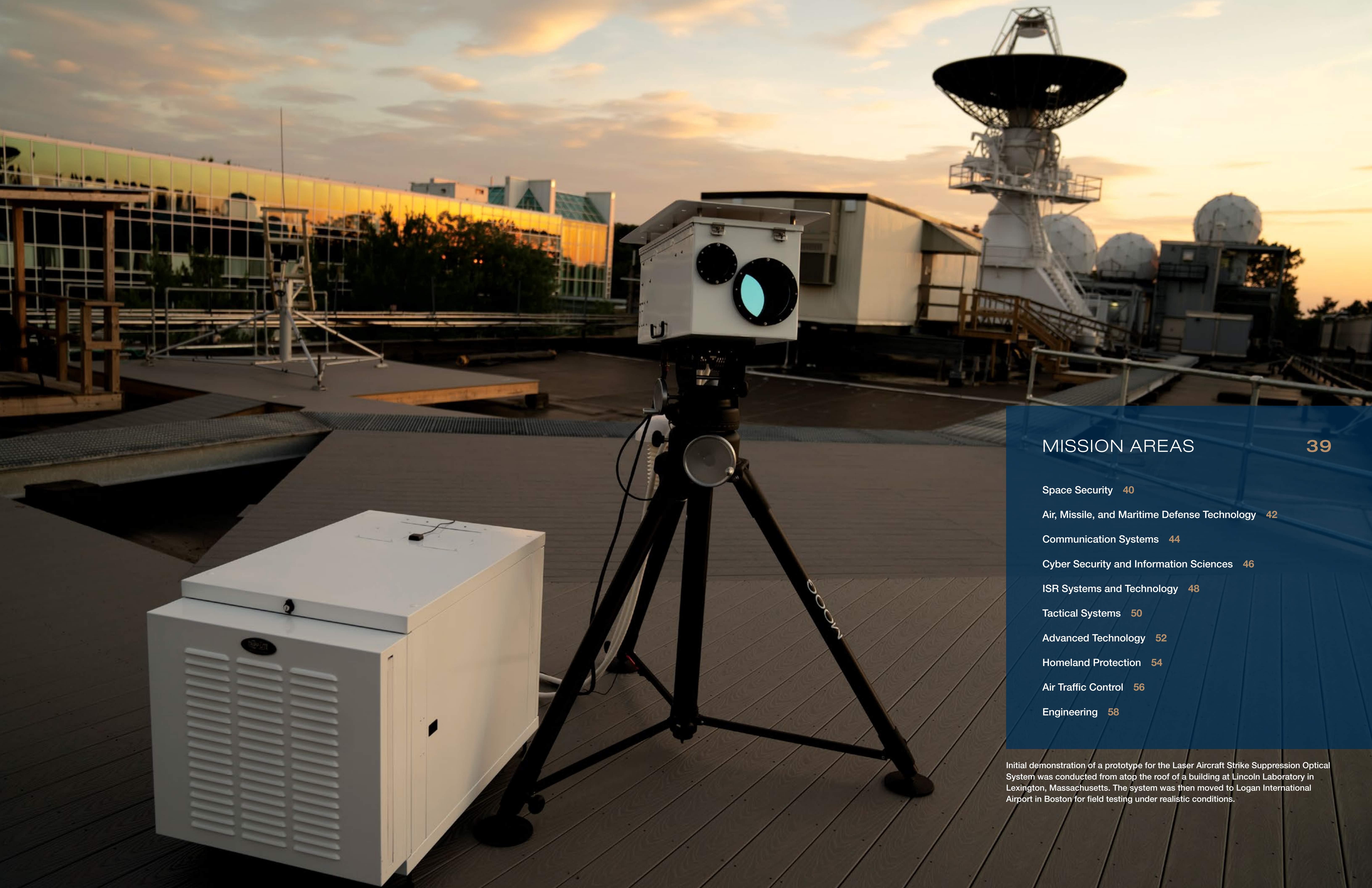
- The Laboratory launched a major modernization to update the SAP business data systems and provide upgraded tools and a new master data architecture.
- Human Resources implemented a new onboarding program that starts new hires on the same weekday, streamlines the background investigation and badging process, brings new hires through tours and orientations, and assigns each new hire a guide to further help the person acclimate to the Laboratory's culture.
- The Financial Services Department launched the SAP Concur tool that allows staff to digitally plan their travel, make reservations, and submit expenses.
- Knowledge Services established a centrally managed process that requires all departments and divisions to write, review, and share procedures in the same way. As part of this process, all procedure owners now review their procedures annually.
- The Director's Office raised group leaders' approval limits from \$10,000 to \$50,000 for the acquisition of products and services.
- The Security Services Department developed computer-based training that users can access at their desktops and that is tracked in the Laboratory's Learning Portal. Online training has reduced scheduling conflicts that previously pushed training off for months. The department also replaced an inefficient paper-based process that burdened technical staff with 7,000 paper forms annually, improving the department's ability to electronically approve, track, and generate foreign travel and foreign contacts reporting.
- The Contracting Services Department rolled out a new function called the External Workforce Services that streamlines the hiring and supervision of subcontractors at the Laboratory, making it easier for hiring managers to bring in the help they need. The department also improved procurement tools to reduce staff time and frustration. These improvements included streamlining purchasing-card validation processes, developing procurement quick cards and training modules, co-locating contracting staff to assist division business managers with major procurements, and simplifying administrative procedures. In addition, the department streamlined its annual mandatory export compliance training, reducing time spent fulfilling the requirement from more than 40 minutes to less than 15 minutes per individual.

Enhancements to Information Services

The Information Services Department (ISD) achieved efficiency gains in six areas that impact daily Laboratory activities.

- Voicemail enhancements. Upgrades such as call-forwarding from a desktop phone to a cell phone, soft phones that allow a computer to take a call dialed to a desktop extension, and voicemail delivery directly to an email inbox are making it easier for employees to reach each other.
- Virtual desktop infrastructure. This infrastructure allows staff to work from server-hosted desktops, saving staff time by not requiring them to install updates or security patches and automatically backing up their data. In 2019, ISD rolled out a virtual desktop infrastructure that focused on administrative personnel needs.
- Intranet homepage redesign. The Laboratory's new intranet homepage is modern and mobile friendly. An improved calendar and notifications interface allow staff to easily find information relevant to them.
- Enterprise software catalog. An internal website provides a list of all Laboratory-supported software and any information available about the software, from direct-download links to developer websites.
- Collaborative editing. A new application lets employees edit documents online in tandem with teammates, saving time spent waiting for others to edit and allowing employees to make cooperative decisions in real time.
- Badge photo enablement. Employees lacked a way to visually recognize new collaborators, so ISD added employee badge photos to communication tools such as email.

The Information Services Department (ISD) hosts quarterly ISD Connection Events. All employees are invited to meet ISD specialists and learn about the latest services.



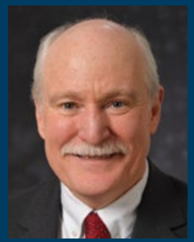
MISSION AREAS

Initial demonstration of a prototype for the Laser Aircraft Strike Suppression Optical System was conducted from atop the roof of a building at Lincoln Laboratory in Lexington, Massachusetts. The system was then moved to Logan International Airport in Boston for field testing under realistic conditions.

Space Security

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

Leadership

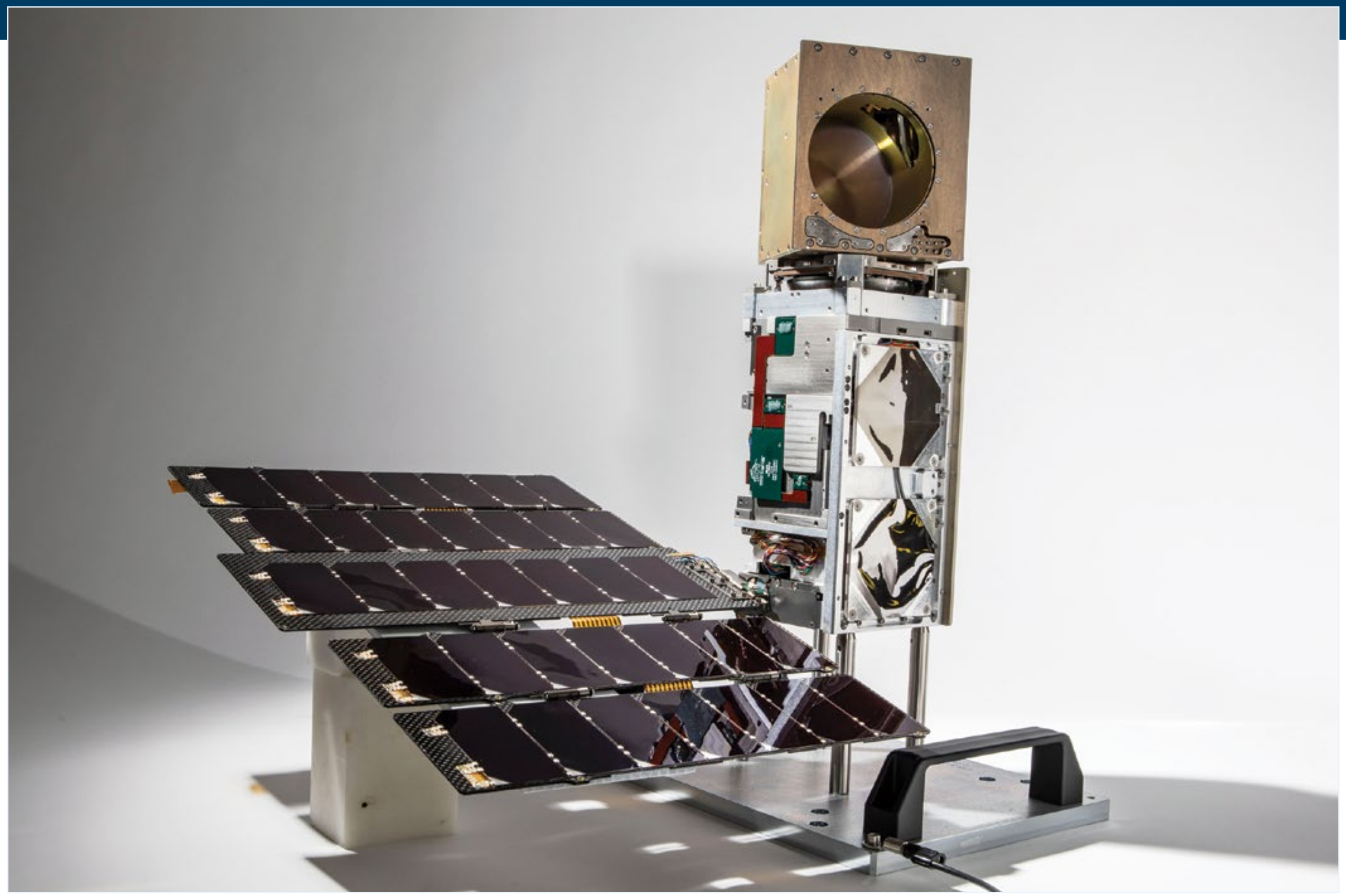


Dr. Grant H. Stokes
Division Head

Mr. D. Marshall Brenizer
Assoc. Division Head

Mr. Lawrence M. Candell
Asst. Division Head

Mr. Craig E. Perini
Asst. Division Head



The TROPICS CubeSat is shown with its solar array deployed. All six of the CubeSats have successfully completed space vehicle environmental testing.

Principal 2019 Accomplishments

- The Space Surveillance Telescope has been assembled and integrated at the Naval Communication Station Harold E Holt (HEH) in Australia, following completion of the new telescope enclosure at HEH. Post-assembly testing will continue, with first light expected in early 2020.

- TROPICS, a NASA Earth Venture Instrument program, is a constellation of 3-U CubeSats with advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. Six TROPICS CubeSats completed assembly, integration, and testing, and are in storage awaiting launch manifest.

- Under the Situational Awareness Camera Hosted Instrument (SACHI) program, Lincoln Laboratory is developing two identical hosted-payload space situational awareness sensors to fly on two Japanese QZSS (Quasi-Zenith Satellite System) satellites. SACHI leverages ORS-5 (SensorSat) sensor technologies to provide a rapid development and delivery sensor system. The systems requirements and preliminary design reviews for SACHI were completed, and the critical design review is planned for mid-2020, with deliveries scheduled for early and mid-2022.

- A portfolio of activities continues to deliver critical space domain awareness information and tools to the National Space Defense Center in Colorado. In addition, the Laboratory is leading an effort to modernize the networking, data architecture, and processing capabilities of legacy space surveillance sensors to improve the timeliness of tactical missions. An initial prototype was completed, with additional prototypes and technology transition to industry planned for 2020.

- Systems and mission analyses motivated the development of new concepts leveraging advanced technologies to set the direction for the Space Rapid Capabilities Office, the Space Development Agency, and the Space Enterprise Architect at the Air Force Space Command. These offices are working to develop more resilient space architectures with initial prototype capability development efforts beginning in 2020, with deliveries in 2023.

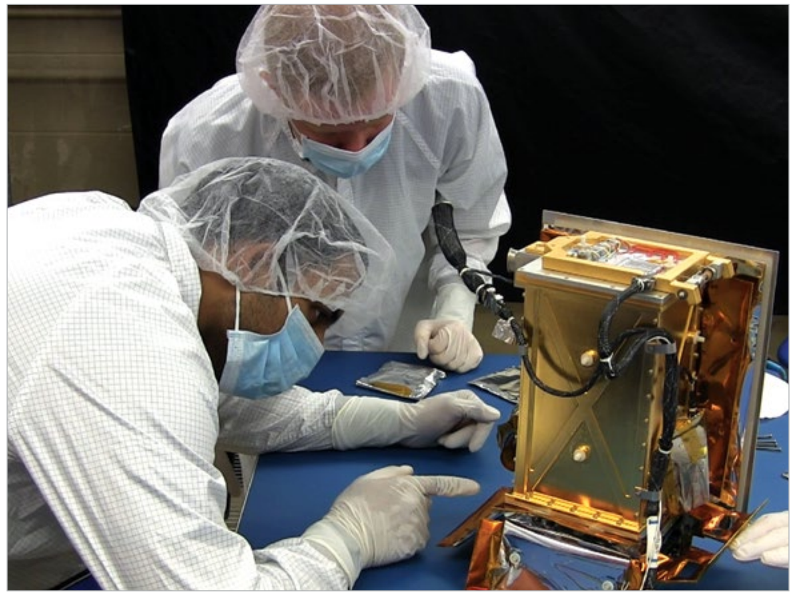
Future Outlook

Resilience of the nation's space enterprise is a significant national security issue as the reliance of the military on space systems to deliver tactical warfighting effects continues to grow. Improved space situational awareness, and responses on tactical timelines, will be the foundation for increasing the survivability of space systems. In addition, space systems will need to be made fundamentally more resilient to potential adversary actions.

Major Laboratory focuses are information extraction and integration, and decision support. Development of a truly netcentric, multidomain architecture, with the agility to discover and incorporate new data sources and services on short timelines, is critical to evolving the warfighting capability that can respond in the time frames required to support space survivability efforts.

Regolith X-ray Imaging Spectrometer (REXIS)

REXIS, an instrument on board NASA's OSIRIS-REx spacecraft, was built by MIT students for the purpose of imaging X-ray fluorescence emitted by an asteroid so that scientists can determine the elements present and their abundance on the asteroid surface. REXIS uses charge-coupled imaging devices developed and fabricated by Lincoln Laboratory. OSIRIS-REx, which is surveying the asteroid Bennu ahead of a sample collection in 2020, has already made key discoveries, including finding hydrated minerals and observing particle plumes. Bennu, originally discovered by the Laboratory's LINEAR project in 1999, is a 500-meter near-Earth asteroid.



Air, Missile, and Maritime Defense Technology

Investigating system architectures, prototyping pathfinder systems, and demonstrating these advanced, integrated sensor systems that are designed for use on tactical air and maritime platforms to provide defense against missiles and other threats

Leadership

Dr. Katherine A. Rink
Division Head

Dr. William J. Donnelly III
Asst. Division Head

Dr. Aryeh Feder
Asst. Division Head

Over-the-horizon radar (OTHR) may potentially support long-range surveillance of the polar region but is hindered by interference induced by the Aurora Borealis. To study the performance of clutter mitigation algorithms, the Laboratory designed, developed, and deployed a full-scale, OTHR to North Dakota.

Principal 2019 Accomplishments

- Lincoln Laboratory continued to develop advanced sensors and algorithms to ensure robust performance of the Ballistic Missile Defense System (BMDS) against missile threats that might employ intentional and unintentional countermeasures. The Laboratory-developed BMDS Analysis Enclaves were used during dedicated and target-of-opportunity tests to evaluate the effectiveness of these advancements.

- The Laboratory supported the successful FTG-11 flight test of the Ground-based Midcourse Defense System. This test marked the first salvo interceptor launch and the most complex, comprehensive, and operationally challenging test executed by the Missile Defense Agency.

- Using data collected during the U.S. Navy's 2018 Ice Exercise, the Laboratory investigated the effects of the rapidly changing Arctic on underwater acoustic propagation and noise. Initial planning has begun for the experiments at Ice Exercise 2020.

- To enhance the performance of the submarine combat system, the Laboratory developed improved electronic warfare, sonar automation, and signal processing capabilities. New approaches being explored for the classification of sonar data leverage novel artificial intelligence and machine learning.

- The Laboratory provided Department of Defense leaders with analytical assessments of boost-phase missile defense technology, including air and surface-based kinetic interceptors and directed energy options.

- The Laboratory delivered recommendations to the U.S. Navy community to inform the development of advanced electronic warfare technologies and shipboard systems to counter advanced threats against the fleet.

- Development continues on algorithms for real-time assessment of electronic warfare decoy performance and on discovering these algorithms' operational effectiveness by using serious game environments.

- Lincoln Laboratory continued to demonstrate a small-form-factor advanced sensor prototype. This prototype is the basis for an airborne test bed currently in development.

Future Outlook

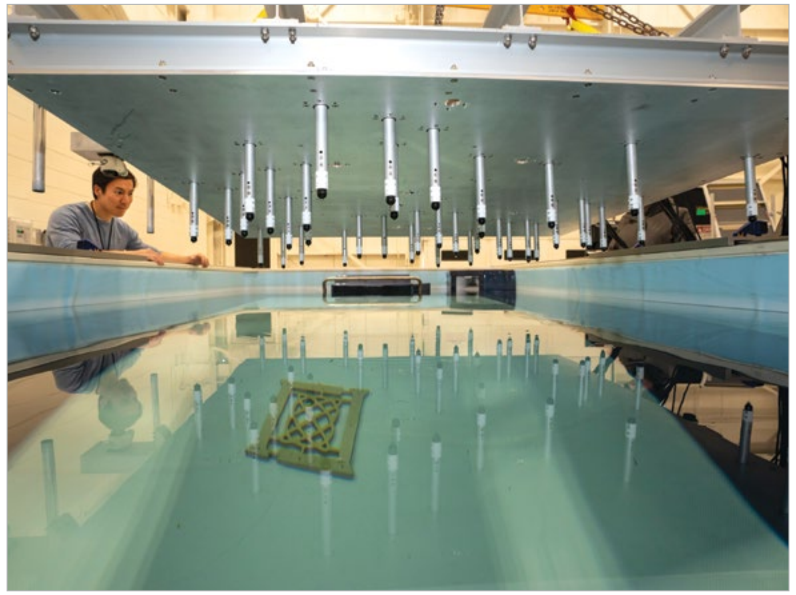
Hypersonic threats pose an emerging threat to the United States and its allies. Lincoln Laboratory is working with the Missile Defense Agency to define a defense architecture and develop advanced technologies to counter these threats.

The Laboratory will emphasize system analysis and advanced concept development to ensure U.S. dominance in the undersea domain. The focus on technologies for unmanned undersea vehicles includes R&D in advanced sensors, high-capacity energy systems, and algorithms for autonomy.

To deter aggression in regional conflicts, forward-deployed forces may benefit from longer-range, cross-domain engagement webs, enabled by new sensing and engagement paradigms. The Laboratory is defining distributed architectures and developing sensor prototypes to support such engagements.

Sparse Aperture Sonar Technology Test Bed

Less than 15 percent of the ocean floor has been mapped by surface vessels using 12-kHz depth sounders in combination with large hydrophone arrays. Surface-based techniques, which can achieve 100-meter resolution in the deep ocean, are limited by the available aperture on the ship hull. Lincoln Laboratory's aquatic test bed, at right, is being used to design a novel surface-based, distributed multiple-input, multiple-output sparse aperture sonar. The goal is to support surface-based topographic mapping of the deep ocean floor with a resolution two orders of magnitude higher than is currently achievable. The team is employing a scaled system, operating at 200 kHz, to prototype the advanced signal processing techniques.



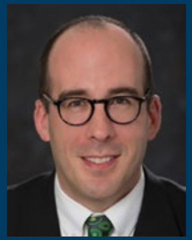
Communication Systems

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. J. Scott Stadler
Division Head

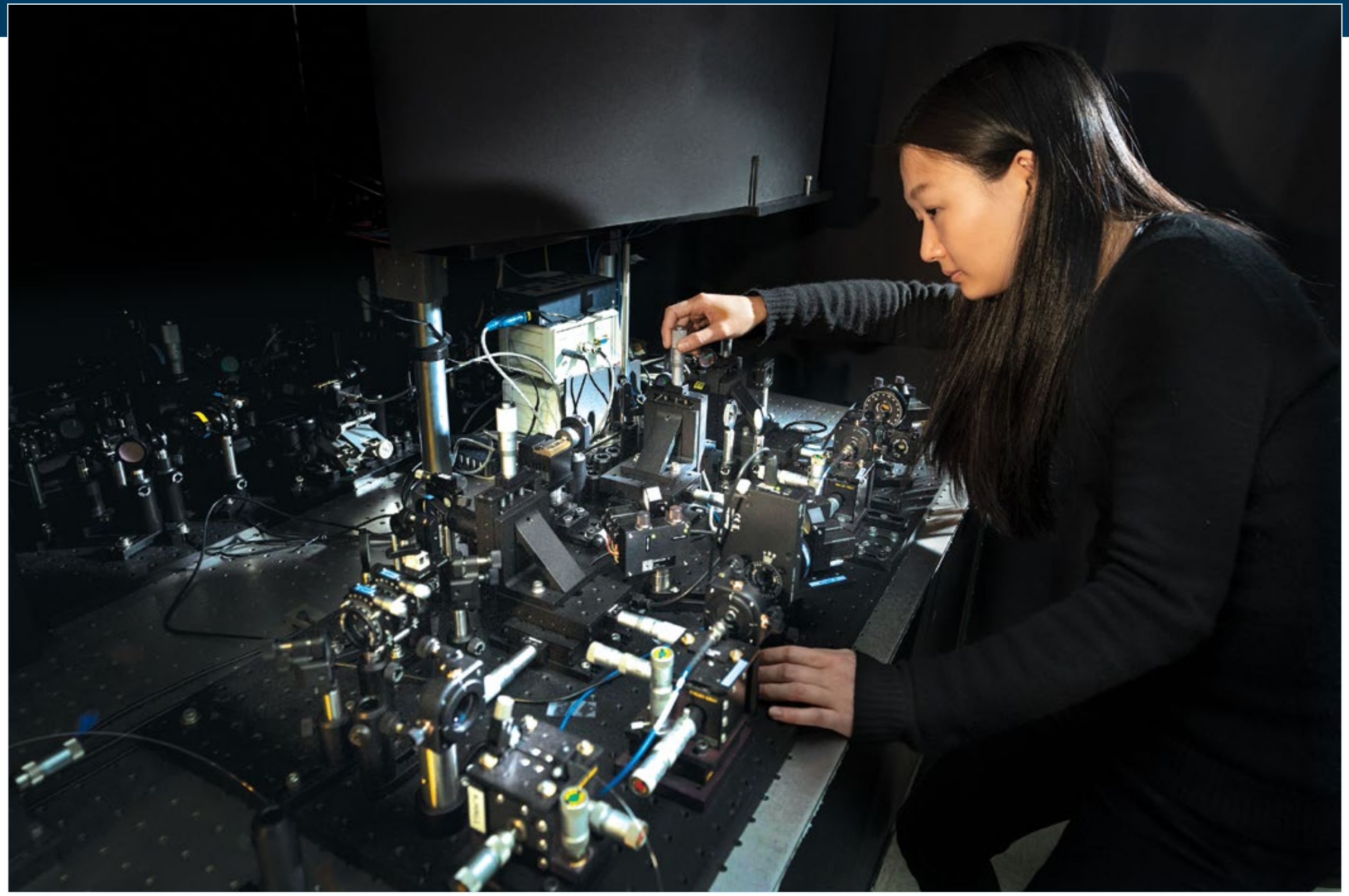

Dr. James Ward
Assoc. Division Head


Dr. Thomas G. Macdonald
Asst. Division Head


Dr. Don M. Boroson
Laboratory Fellow


Dr. David R. McElroy
Principal Staff


Mr. Joseph J. Scozzafava
Principal Staff



Catherine Lee performs an entanglement swap measurement by using two spontaneous downconversion sources that generate entangled photon pairs at gigahertz rates. High-rate entanglement distribution is required to enable distributed quantum sensing, timing, and computing applications.

Principal 2019 Accomplishments

- Lincoln Laboratory developed a prototype data distribution architecture that enables dynamic mission execution across disparate networks. The approach, based on content-aware networking, was adopted for a government reference architecture that will form the foundation for future Air Force development activities. The software is being delivered to government organizations for integration and experimentation.

- A new protected satellite communication (SATCOM) waveform and system architecture prototyped by the Laboratory was transitioned to industry. Performance and interoperability testing of industry modems was conducted in the Laboratory's system integration facility. Over-the-air experiments with operational commercial and military communication satellites provided data for refining the architecture.

- The Laboratory demonstrated bidirectional undersea optical communications between two remotely operated vehicles in a pool and wave tank. Critical technology for ensuring secure undersea communications include an active laser beam pointing, acquisition, and tracking system, and a wide-dynamic-range photon-counting modem.

- The Laboratory supported checkout of an Advanced Extremely High Frequency satellite launched by the Air Force. Initial contact with the satellite was established from the Laboratory's SATCOM Performance Operations Center. Staff conducted on-orbit calibration of the communication antennas and end-to-end link performance testing, and supported inclusion of the satellite into the operational constellation.

- To achieve robust line-of-sight communications, Lincoln Laboratory developed signal processing algorithms that leverage multiple antennas. Algorithm software and firmware were integrated into a prototype tactical radio that was successfully flight-tested on operational tactical aircraft.

- To develop technology for quantum information transmission, the Laboratory and MIT Research Laboratory of Electronics are operating a test bed that integrates high-rate entanglement sources and superconducting single-photon detectors. Demonstrations of high-rate, high-visibility entanglement swap were conducted as a step toward quantum state teleportation.

Future Outlook

The Laboratory will continue to develop free-space optical communications technology and system capabilities for space exploration and potential national security applications.

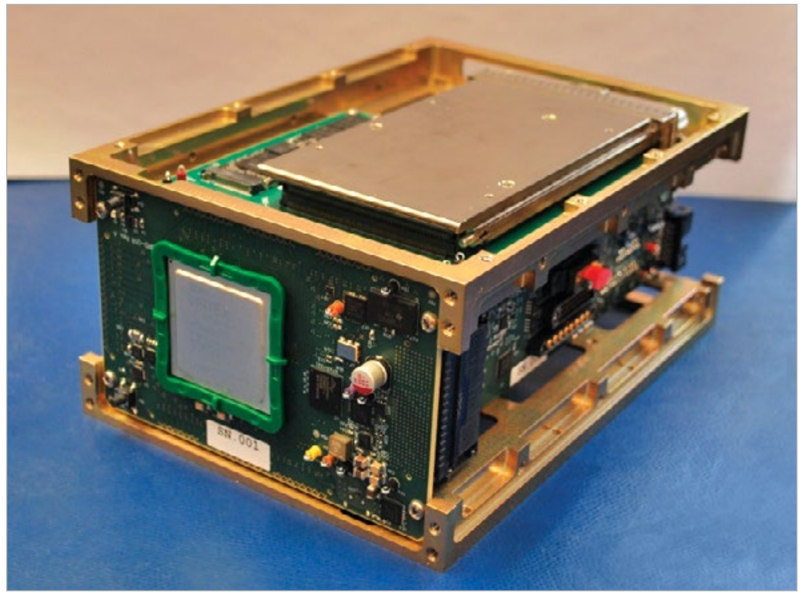
The Laboratory will develop new architectures and prototypes of space and ground systems to support enhanced networking among land, maritime, and air platforms and space systems.

Antenna, waveform, and signal processing technology will be developed to provide reliable communications in congested spectrum environments and to enable multifunction communication and sensing capabilities.

The Laboratory will partner with MIT to pursue technology for a scalable quantum network that will enable enhanced communications, sensing, timing, and computing.

Small Satellite Lasercom Terminal

To support high-rate data dissemination needs of NASA science missions, Lincoln Laboratory designed a small satellite optical communications terminal. The terminal's high-speed digital electronics include a large (2 terabyte) buffer with fast read/write capability, two 100 Gbps fiber-optic transceivers for optical transmission of data from the spacecraft to the ground terminal, and a state-of-the-art field-programmable gate array that implements an automatic repeat request protocol over the optical links between the space and ground terminals to provide error-free data delivery. This prototype is scheduled to launch in 2020 for NASA's TeraByte InfraRed Delivery (TBIRD) demonstration program.

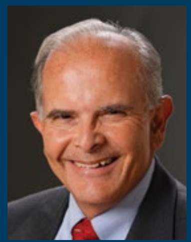


Cyber Security and Information Sciences

Researching, developing, and evaluating 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



Mr. David R. Martinez
Assoc. Division Head

Dr. Marc A. Zissman
Assoc. Division Head

Dr. Jeremy Kepner
Laboratory Fellow

Under the Department of Defense Joint Communications Architecture for Unmanned Systems program, the Laboratory developed an architecture and hardware security module prototypes, such as the one pictured above, for securing communication with small unmanned systems.

Principal 2019 Accomplishments

- Lincoln Laboratory delivered to the Cyber National Missions Force, through the U.S. Cyber Command, a software-based analytic tool for detecting credential misuse in virtual private network connections. The tool enabled operators and analysts to quickly visualize threats and improve their situational awareness of operational networks.

- The Lincoln Laboratory Supercomputing Center collaborated with the MIT Computer Science and Artificial Intelligence Laboratory to found the MIT–Air Force AI Accelerator, which will leverage the expertise and resources of MIT and the Air Force to enable rapid prototyping, scaling, and application of artificial intelligence systems.

- The Laboratory developed a novel language model–based system for detecting human trafficking indicators and activities. This system provides a new capability for law enforcement to rapidly identify advertisements and organizations that are suspected of human trafficking.

- Under an Air Force military satellite communications program, the Laboratory prototyped a key management system and delivered it to the Air Force Space and Missile Systems Center, Aerospace Corporation, and several contractors to support a large-scale field demonstration and serve as a technical underpinning for the eventual live capability.

- The Joint Artificial Intelligence Center (JAIC) tasked the Laboratory with developing and applying a methodology to select national and service-level AI initiatives for JAIC to start in fiscal years 2020 and 2021. The Laboratory provided selection criteria, outlined classes of AI that apply to military objectives in the National Defense Strategy, and worked with industry, military users, and combatant commanders to develop initial project investment areas for JAIC to consider.

- To enable collaboration among U.S. agencies and foreign partners, the Laboratory developed a framework for rapidly prototyping secure multiparty computation applications, which allow different parties to compute results on collective data while ensuring that the data remain private. This framework was used to prototype secure solutions for joint analyses of cyber activity across multiple organizations.

Future Outlook

Lincoln Laboratory will research, prototype, and evaluate adversarial-AI and counter-AI technologies to increase performance, robustness, and user trust of these technologies.

Resilience of microelectronics is a significant national security issue. The Laboratory is growing its portfolio of work to address supply-chain vulnerabilities. This work includes the development of technologies to secure against vulnerabilities, test and evaluation methodologies, and end-to-end architectures.

The Laboratory will leverage technology to protect from cyberattacks supervisory control and data acquisition systems typically found in power plants and other industrial control systems. Efforts will also be made to enable the simulation of large industrial control systems and to provide improved instrumentation to detect cyber intrusions.

Netprof

The 300th Military Intelligence Brigade (Linguist) used the Laboratory's automatic speech recognition (ASR) application, Netprof, during their annual Polyglot Games, a series of language skill events designed to challenge a linguist's functional and operational language capabilities. Netprof's fine-grained ASR models give feedback for individual spoken sounds, allowing a language learner to focus on specific pronunciation areas. Netprof was expanded to include the new functionality of timed quizzes for competition, a feature used both by the 300th Military Intelligence Brigade and the Defense Language Institute Foreign Language Center.

ISR Systems and Technology

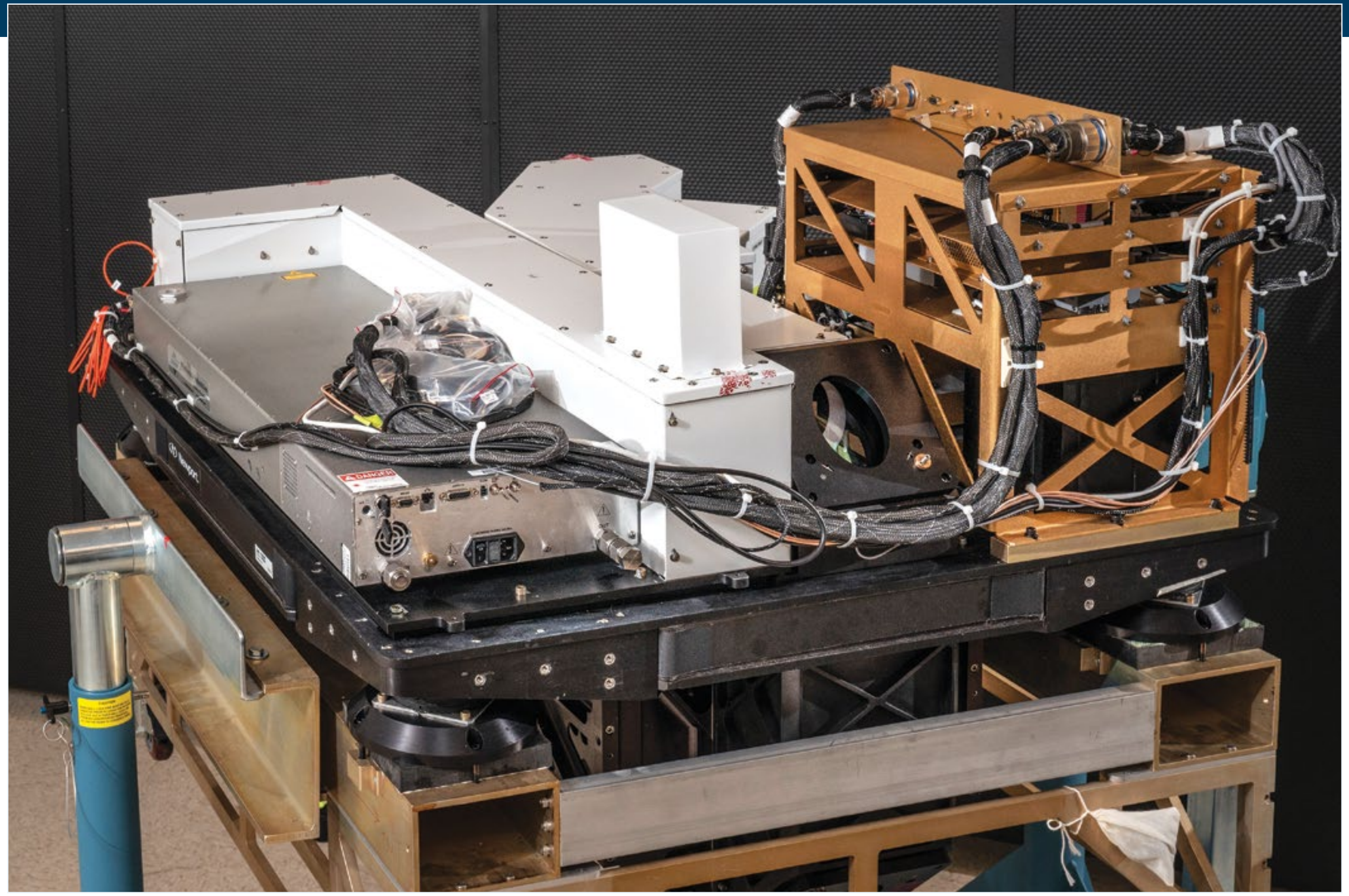
Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

Dr. Robert T-I. Shin
Division Head

Dr. Marc N. Viera
Assoc. Division Head

Dr. Richard M. Heinrichs
Asst. Division Head



Upgrades to the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) ladar imaging system are aimed at enhancing the system's resolution capability and increasing its area coverage rate sixfold.

Principal 2019 Accomplishments

- Lincoln Laboratory developed deep-learning algorithms that achieved breakthrough performance in detecting objects within radar imagery, thereby augmenting a national capability to exploit sensor data from this critical modality.
- Researchers continue to develop the Transparency by Design artificial intelligence system, which not only achieved state-of-the-art performance on interpreting images on the basis of a plain text query but is also capable of describing the logic behind its decisions.
- A successful counter–unmanned aircraft system field campaign employed novel sensing technology that promises a game-changing capability for wide-area, day and night detection in challenging clutter environments.
- The Laboratory is finishing the development and integration of a next-generation airborne sensing capability that is scheduled to be deployed in the U.S. Southern Command's area of responsibility in 2019. The system, which employs an advanced Geiger-mode avalanche photodiode camera, will provide a sixfold increase in area coverage, improved high-resolution data, and significantly enhanced real-time onboard processing.
- Lincoln Laboratory demonstrated a novel distributed MIMO radar system that integrates a third-party active electronically scanned array with the Laboratory's open-architecture Airborne Radar Test Bed to image maritime targets.
- Collaborating with researchers at MIT campus and the Massachusetts General Hospital, Lincoln Laboratory technical staff developed a novel noncontact laser ultrasound technology that may be a low-cost and portable solution for medical imaging of bone injuries in the field.
- Lincoln Laboratory developed an integrated ecosystem for exploring very large-scale, graph-based data analytics. This ecosystem comprises an advanced processor optimized for the acceleration of sparse mathematical computations and a software architecture structured for ease of use by data analysts. The prototype system has been used to explore important national security problems, such as foreign influence operations.

Future Outlook

Lincoln Laboratory will provide analysis and prototyping in support of future U.S. Air Force multi-domain command and control architectures powered by advanced battle management systems.

The Laboratory will continue to innovate in artificial intelligence, machine learning, and rapid software development for national security by prototyping and then transitioning its novel architectures and algorithms to government and/or industry.

Artificial intelligence–enhanced algorithms, multisensor data fusion, and real-time signal processing systems will enable new intelligence, surveillance, and reconnaissance capabilities for challenging domains and missions.

Airborne Radar Test Bed

The Airborne Radar Test Bed is a flexible open-architecture radar system well suited to demonstrate next-generation system concepts, novel algorithms, and advanced RF technology. Two variants of the test bed at right are currently flying and have participated in 10 sponsored programs, logging more than 100 flights and collecting nearly one petabyte of data. Initial real-time processing was demonstrated in 2019, and this capability will be expanded in 2020. In the near future, the test bed will also upgrade the antenna system by adopting the Laboratory's dual-band, dual-polarization, low-cost panel technology.

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

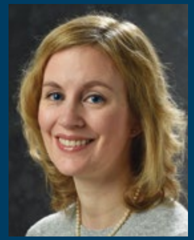
Leadership

Dr. Robert T-I. Shin
Division Head

Dr. Marc N. Viera
Assoc. Division Head

Dr. Richard M. Heinrichs
Asst. Division Head

Dr. Josh G. Erling
Group Leader



Dr. Janet T. Hallett
Group Leader

The Airborne Seeker Testbed team poses in front of the Gulf Stream II aircraft. The plane is modified to carry a variety of instrumented sensors to assess the performance and limitations of Air Force aircraft.

Principal 2019 Accomplishments

- Lincoln Laboratory researchers continue to conduct systems analyses, laboratory testing, and flight-system data collections that inform assessments of the performance and limitations of Air Force aircraft against current and future threats. These assessments include investigations of missile system performance, electronic attack and electronic protection, and RF and advanced infrared kill chains.
- The Laboratory's open architecture technology was employed to enable a joint Army–Air Force sensor-to-shooter interoperability demonstration. This technology creates new opportunities for machine-to-machine artificial intelligence to dramatically increase operational capabilities in multidomain environments.
- Software researchers developed an initial resilience infrastructure with which they demonstrated concepts for data access and synchronization to support logistics systems for advanced U.S. fighter platforms.
- The continued development of advanced, small autonomous systems included successful closed-loop flight tests to demonstrate vision-based navigation algorithms applicable to GPS-denied environments.
- In multiple U.S. Air Force and Department of Defense field tests, Lincoln Laboratory continued to demonstrate prototype software systems to aid decisions, reduce errors, and speed up operations.
- Lincoln Laboratory formed a new Army Blue Team to provide the Army Rapid Capabilities and Critical Technologies Office with targeted analysis and rapid prototyping across a wide variety of Army missions.
- In its R&D work on a novel radar concept for Army vehicle protection, Lincoln Laboratory is conducting phenomenology measurements at multiple test ranges. Researchers evaluated the potential for the radar to integrate a communication capability that could enable the high-bandwidth, short-range communications required for the Army's future unmanned ground vehicles.

Future Outlook

Lincoln Laboratory will continue to support the Air Force by performing systems analyses, prototyping systems with advanced capabilities, and demonstrating capabilities through measurement campaigns. This R&D work will investigate the ability of systems to operate in a contested environment, with a particular emphasis on operation in the Pacific and European theaters.

The Laboratory will increase its impact on the Army's modernization priorities through the prototyping and analysis of advanced systems and capabilities.

Working with partners in the Army and special operations communities, the Laboratory will expand the development of novel RF sensors and autonomous systems, and directly transition these to the warfighter.

Integrated Ka-band Radar Instrumentation System

The Integrated Ka-band Radar Instrumentation System (IKARIS) is a podded system, seen at right, carried by a Gulfstream G-II airborne test asset. The IKARIS achieved initial operating capability in November 2018 after a three-year development period. It has made initial measurements of tactical aircraft to enable a better understanding of the propagation, scattering, and clutter phenomena at Ka band. Over the next decade, IKARIS will provide valuable flight test data that will inform the development activities of various Department of Defense programs.

Advanced Technology

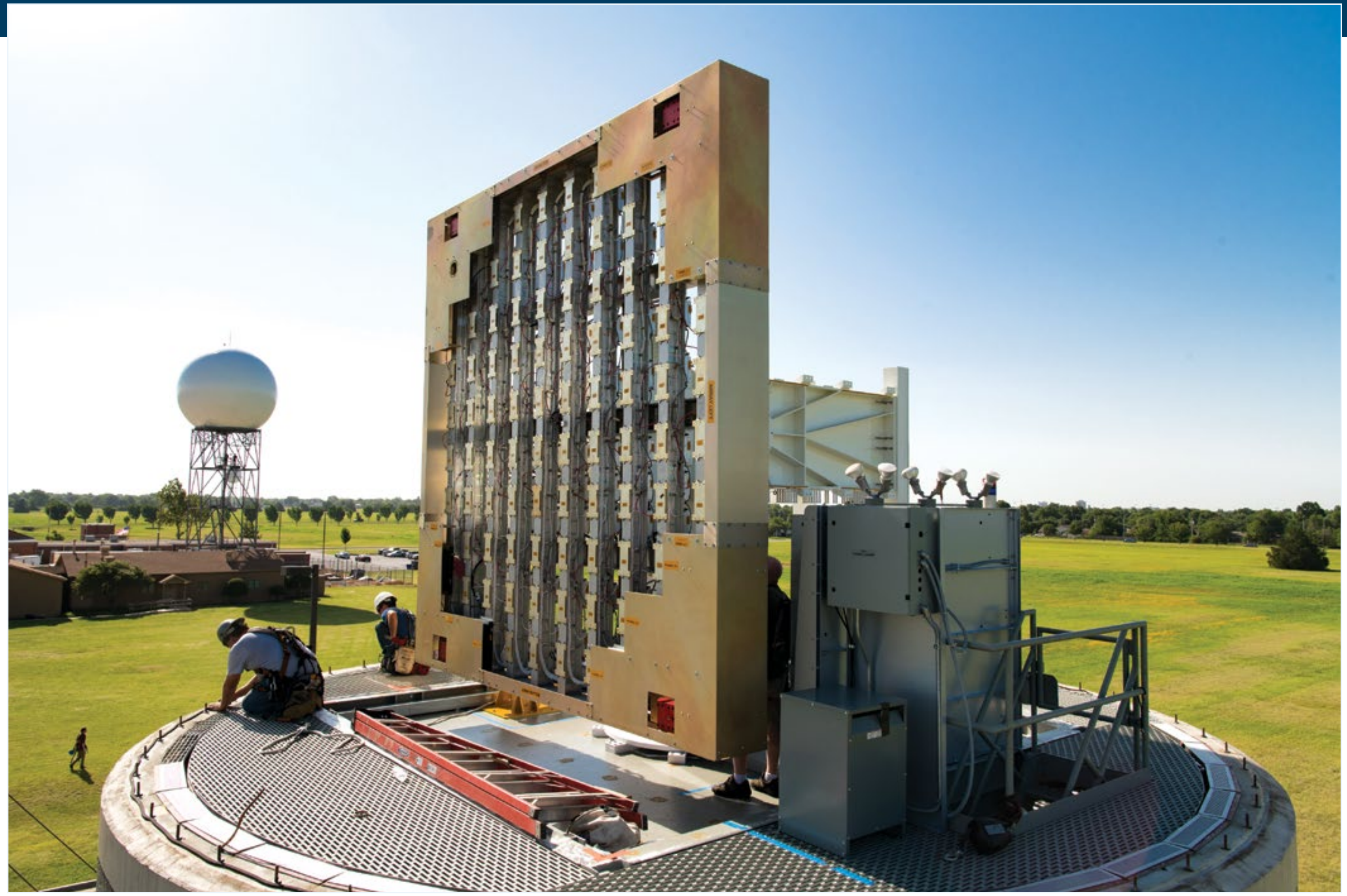
Leveraging solid-state electronic and electro-optical technologies, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

Leadership

Dr. Robert G. Atkins
Division Head

Dr. Craig L. Keast
Assoc. Division Head

Dr. Mark A. Gouker
Asst. Division Head



The Multifunction Phased Array Radar (MPAR) Advanced Technology Demonstrator is undergoing tests in Norman, Oklahoma, at the National Weather Radar Testbed. The MPAR is a candidate for a new nationwide system that will combine the separate sensors used for tracking aircraft and weather events.

Principal 2019 Accomplishments

- Under Defense Advanced Research Projects Agency funding, Lincoln Laboratory's work to develop microhydraulic actuators increased. This technology mimics the actuation of human muscle by applying an electric field to electrodes that force water droplets inside the actuator in one direction, causing motion. The Laboratory produced linear and rotary actuators that exceed the efficiency and power density of human muscle.
- An ultrastable laser was demonstrated that is suitable for use in deployed systems. Traditional approaches to stabilizing a laser have relied on the use of bulky cavities housed in a controlled vacuum environment, but these cavities do not function under the vibrations and temperature variations present in fielded systems. Using a new technique based on stimulated Brillouin scattering, the Laboratory produced a laser with a 20-hertz linewidth that functions in an unshielded environment. The laser's first use will be as a key component in a deployable optical atomic clock that is under development.
- Germanium-based charge-coupled-device (CCD) imagers passed a significant milestone with the demonstration of a 128-by-128-pixel array. This technology has sensitivity and noise performance as good as state-of-the-art silicon-based CCDs, while greatly extending the imager's spectral range, from the soft X-ray to the near infrared. Future work is focused on producing megapixel-class imagers.
- On paper, diamond is the ultimate material for high-power electronic applications. Its high thermal conductivity and high breakdown voltage should produce transistors with 10 times higher power handling than state-of-the-art gallium nitride transistors. The Laboratory has begun to develop this potential and demonstrated a transistor with world-record power density.
- Significant progress was made toward deployable quantum sensors, with the field testing of a breadboard magnetometer. The sensor is based on nitrogen-vacancy quantum defect centers in diamond, which have potential for higher sensitivity and greater long-term stability measurements than commonly used fluxgate magnetometers.

Future Outlook

Growth in quantum information systems technology will continue. Laboratory technology will exploit the strong vertical integration from materials growth to prototype quantum systems for several potential applications.

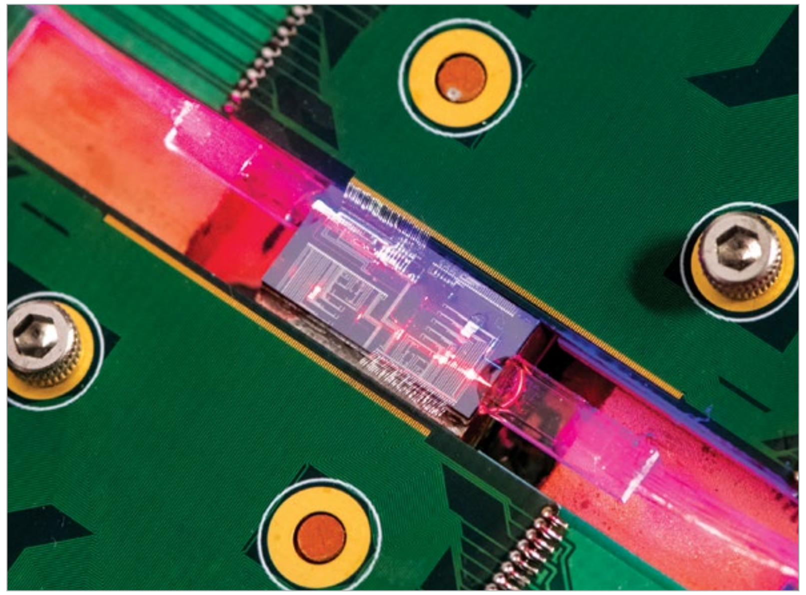
The Laboratory continues to develop high-energy laser technology and supporting sensor systems.

Work has begun on components for several NASA programs, including an optical communication link for the Psyche mission, a lidar for the Europa Lander concept, and detectors for the Lynx X-ray Observatory concept.

The Laboratory is innovating a new generation of imaging technology and photon detectors. This work includes gaining a broader spectral response with germanium detectors and more sophisticated on-chip processing to synthesize information from the sensor.

Photonic Integrated Circuits

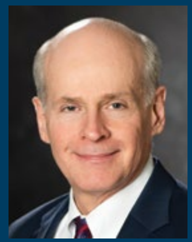
The sophistication of photonic integrated circuit technology was demonstrated with a device that performs signal processing in the microwave frequency regime. This silicon nitride–based circuit, pictured at right, contains more than 80 photonic components to create a bandpass filter with 43 gigahertz of bandwidth, minimal insertion loss, a less than 5 gigahertz transition band, and 30 decibel loss in the stop band. The technology contains mature designs for many optical components, including couplers, power dividers, ring resonators, modulators, and phase shifters. Off-chip electronic bias circuits tune the characteristics of the optical components to optimize the microwave filtering characteristics.



Homeland Protection

Innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from human-made and natural disasters

Leadership



Mr. James M. Flavin
Division Head

Dr. James K. Kuchar
Asst. Division Head

Mr. Edward C. Wack
Asst. Division Head

Laboratory staff tested a prototype system at Boston Logan International Airport; the system allows law enforcement to rapidly locate individuals who are using handheld lasers near airports to disrupt the vision of pilots in flight.

Principal 2019 Accomplishments

- Under Department of Homeland Security (DHS) Science and Technology Directorate (S&T) sponsorship, Lincoln Laboratory developed technologies for detecting concealed threats at future Screening at Speed checkpoints, designed for secure, high-throughput passenger and bag screening in airports.
- A land-based surveillance system for northern border land and waterway security was developed for Customs and Border Protection and has been transitioned to industry for future deployment and sustainment.
- The Laboratory established a prototype system, an integration facility, and test sites to enable the development of technologies to counter unmanned aerial systems in urban environments.
- The Laboratory continued to expand its work applying artificial intelligence (AI) and machine learning to solve critical biomedical challenges, such as improved detection of injuries with ultrasound and AI-enabled semiautonomous trauma treatment tools for field-forward care.
- Key milestones were achieved in the Laboratory's development of advanced DNA forensics methods, algorithms, and systems and in the transitioning of these developments to the FBI for testing and assessment.
- In collaboration with academic, industry, and Department of Defense partners, the Laboratory expanded its focus on assessing, restoring, and enhancing human performance by developing innovative exoskeleton prototypes. This R&D leverages the unique combination of sensors and virtual reality technologies available at the Sensorimotor Technology Realization in Immersive Virtual Environments Center.
- Advanced capabilities successfully transitioned to the FBI Laboratory and Terrorist Explosive Devices Analytical Center included ones for enabling improved attribution of improvised explosive threats from terrorist networks.
- Laboratory staff tested a particle measurement system in the Czech Republic during outdoor hazard assessment and characterization trials.

Future Outlook

Protecting critical infrastructure and reducing contraband activities within air, land, and maritime domains will require novel sensors and advanced decision support architectures. The Laboratory will provide systems analysis, assess technology, and develop prototypes to fill capability gaps.

Improving humanitarian assistance and disaster response activities will motivate the development of new technology, such as information-sharing architectures, sensors, and analytics for decision making.

The Laboratory will continue to develop system architectures, including biometrics and forensic technologies, for chemical and biological defense.

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

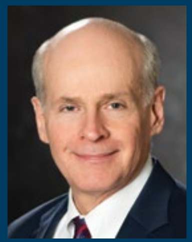
Chemical-Sensing Fabric

Laboratory researchers are developing a fabric sensor that is highly sensitive to chemical vapors and can alert personnel wearing the fabric to the vapors' presence. The sensor is made by embedding light-emitting diodes (LEDs) and photodiodes into fibers that are then woven into a fabric, as shown at right. A substrate on top of the fabric containing dye changes colors when exposed to a chemical agent, altering the amount of light (emitted from the LEDs and reflecting off the dye) that the photodiodes in the fabric absorb. The sensor has accurately detected ammonia and formaldehyde. The team's goal is to develop a fabric patch that can identify all chemical warfare agent classes and many toxic industrial chemicals.

Air Traffic Control

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

Leadership



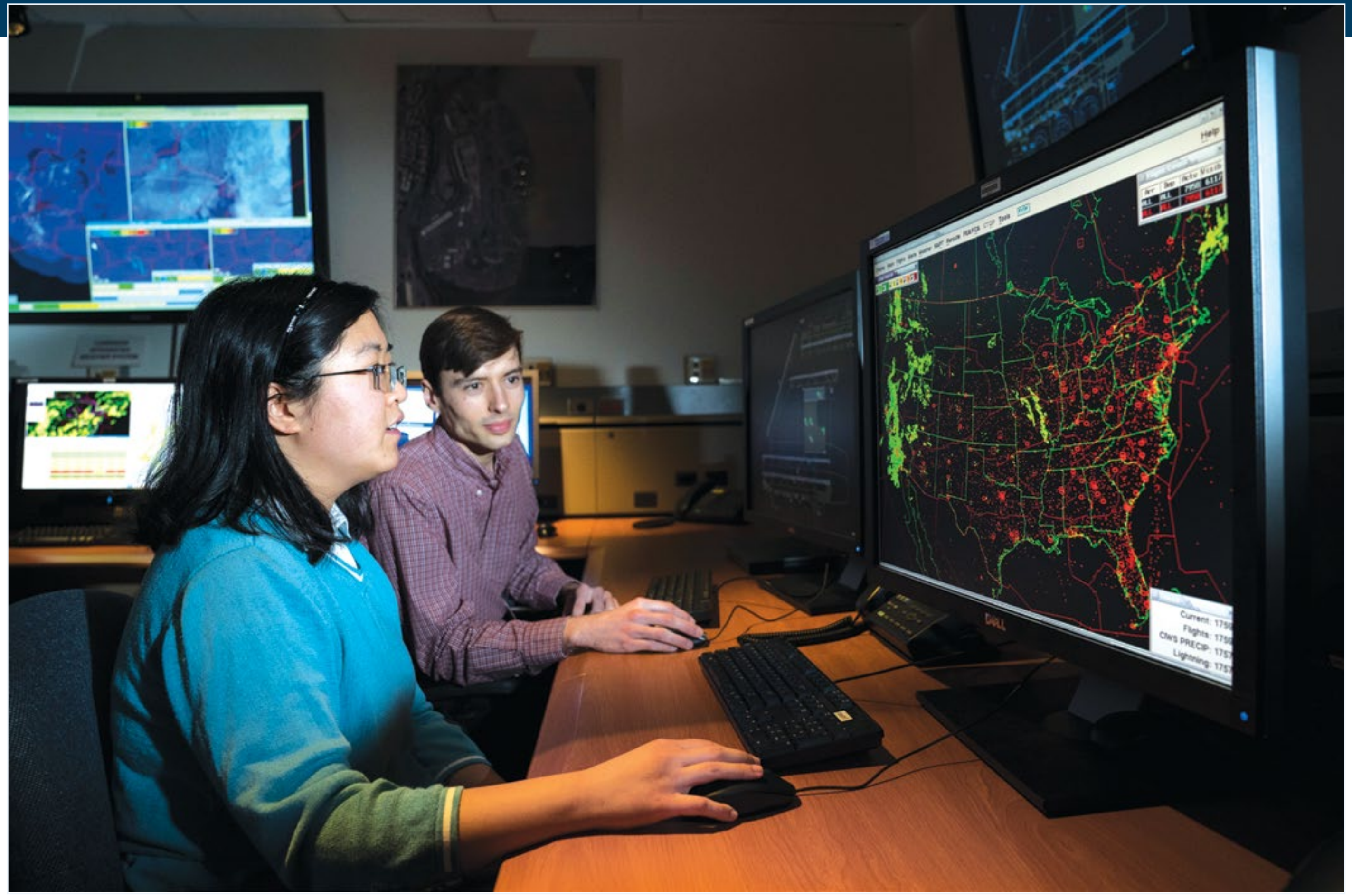
Mr. James M. Flavin
Division Head

Dr. James K. Kuchar
Asst. Division Head

Dr. Marilyn M. Wolfson
Laboratory Fellow

Dr. Tom G. Reynolds
Group Leader

Dr. Gregg A. Shoults
Group Leader



Researchers evaluate the Laboratory's aviation weather systems technology. Advances in radar signal processing and weather algorithms provide nationwide 0–8-hour forecasts to aid in routing air traffic around thunderstorms.

Principal 2019 Accomplishments

- Lincoln Laboratory completed another successful demonstration of the Small Airport Surveillance Sensor at Bedford Airport and initiated technology transfer with the Federal Aviation Administration (FAA).

- The Laboratory continued technology transfer from its reference implementation of the Next Generation Weather Processor (NWP) to the FAA. The NWP integrates multiple weather systems into a single aviation weather display. Laboratory-developed algorithms enable enhanced hazardous weather detection and air traffic management decision support.

- The Airborne Collision Avoidance System X (ACAS X) for manned aircraft received the 2019 American Institute of Aeronautics and Astronautics Dr. John C. Ruth Digital Avionics Award and is proceeding toward worldwide deployment. The Navy's Triton program adopted a variant of ACAS X for large unmanned aircraft systems (UAS). Development of small UAS variants and urban air mobility applications has begun.

- The Offshore Precipitation Capability (OPC) uses lightning, satellite, and meteorological model data to depict radar-like storm coverage beyond the range of land-based weather radars. The OPC continues to be used as an operational prototype at five FAA air traffic control centers. Under the Air Force's Global Synthetic Weather Radar program, the Laboratory is extending OPC to provide global real-time weather products, including a 0–12-hour forecast.

- Activities are ongoing in air traffic management decision support for the FAA and industry. Specialized weather impact mitigation technologies developed by the Laboratory are being transitioned into operations at Delta Air Lines and NAV CANADA.

- The Laboratory continues to develop and apply methodologies for cyber threat identification and mitigation for the nation's ground-based air traffic control infrastructure and aircraft systems.

- Development of data management and visualization tools for key performance indicators, flight data analysis for predictive maintenance, and novel optimization methods for tanker planning continue for the U.S. Transportation Command.

Future Outlook

Lincoln Laboratory will enhance the development of Next Generation Air Transportation System concepts, including trajectory-based operations, collision avoidance, and weather impact mitigation.

Cyber security efforts will address the identification and mitigation of potential vulnerabilities in aviation systems. Innovation in improved weather capabilities will focus on sensing technology, data dissemination and processing architectures, and algorithms for managing airspace capacity.

The Laboratory's support for the integration of new entrants into the National Airspace System will include developing standards, safety evaluation methods, threat avoidance algorithms, and real-time prototypes for unmanned aircraft systems, space operations, and urban air mobility.

Airborne Collision Avoidance System X

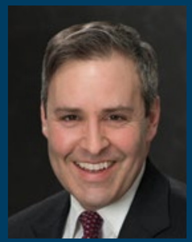
Lincoln Laboratory initiated the Airborne Collision Avoidance System X (ACAS X) under internal funding in 2008 to improve flight safety and reduce nuisance collision alerts. The FAA has funded ACAS X development since 2009. The Laboratory has served as the logic development lead in the FAA design team to produce a family of collision avoidance systems for manned aircraft (ACAS Xa), large unmanned aircraft (ACAS Xu), and small unmanned aircraft (ACAS sXu). At right, a researcher examines an ACAS Xa installation on a Lincoln Laboratory Flight Test Facility aircraft.

Engineering

Employing expertise in electrical, mechanical, structural, thermal, aeronautical, optical, and control systems engineering to build, integrate, and test prototype systems for application in space control, energy, communications, and autonomy

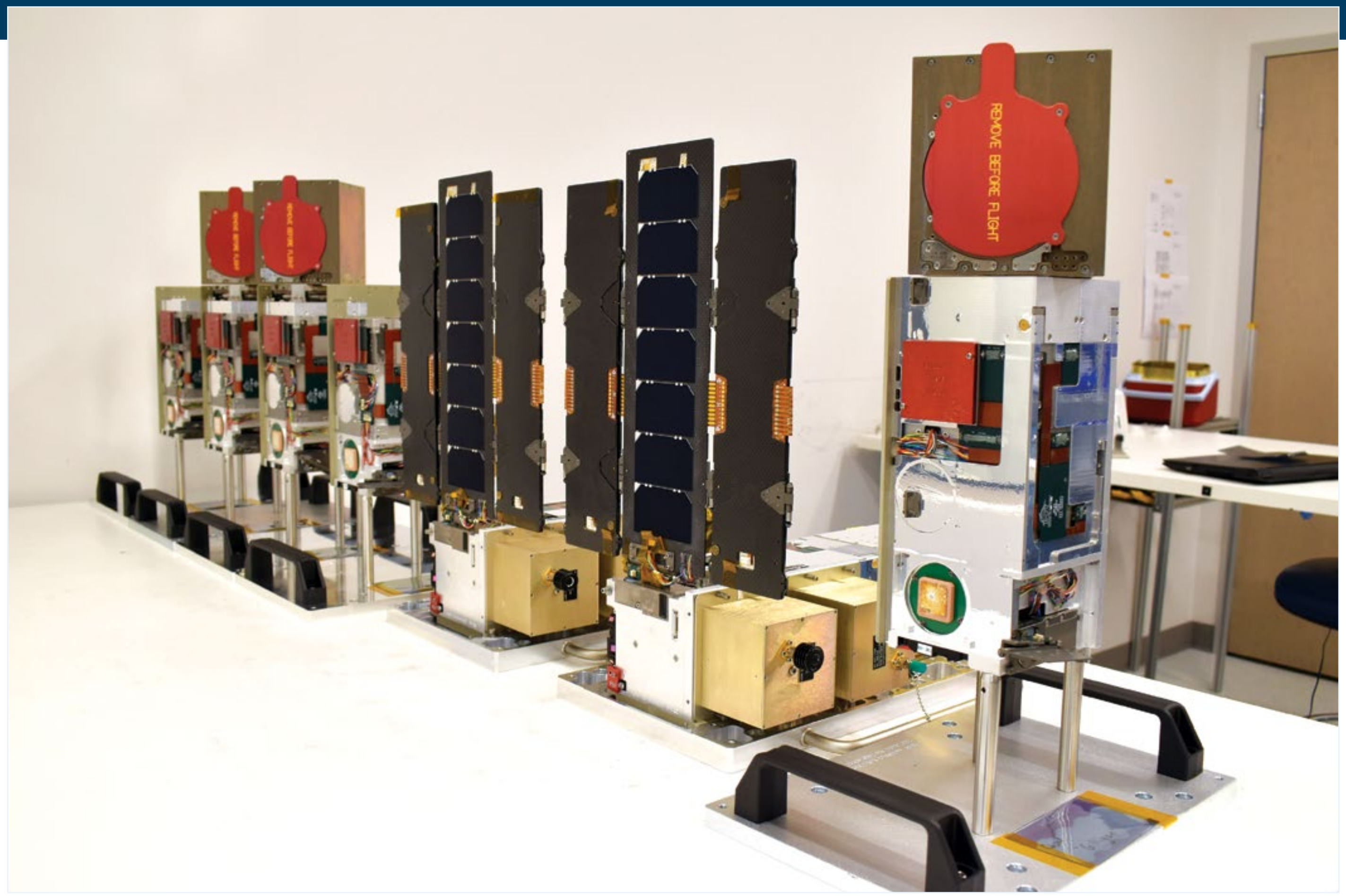
Leadership

Dr. Michael T. Languirand
Division Head



Dr. Ted David
Asst. Division Head

Vicky M. Gauthier
Asst. Division Head



The TROPICS (Time-Resolved Observation of Precipitation structure and storm Intensity with a Constellation of Smallsats) constellation of 3U CubeSats will provide rapid revisit passive microwave sounding in the 90–200-gigahertz frequency range for improved characterization and prediction of tropical storms.

Principal 2019 Accomplishments

- Lincoln Laboratory is making a significant investment in model-based engineering (MBE) as part of a digital transformation initiative to enable more efficient prototype system development. The first phase established a common database for information and fully digitized processes for design and fabrication using a product life cycle management tool.
- The Laboratory developed a chamber to perform semiautomatic testing on full 200-millimeter wafers at temperatures below 5 Kelvin with magnetic flux density nulling less than 1 μTesla. The chamber supports research at the Microelectronics Laboratory on superconducting integrated circuits, which are a promising solution to ever-increasing high-performance computing demands.
- Flight system subassembly designs were completed for laser communication terminals that will fly on the International Space Station and the Orion space vehicle. Critical design reviews were held, and the designs were released for fabrication.
- TROPICS, the first CubeSat-enabled NASA science mission, was developed to provide tropical storm characterization for weather prediction. The Laboratory led the design, building, integration, and testing of six space vehicles for TROPICS.
- A groundbreaking optical design capability that allows freeform optical surfaces to be incorporated and optimized in optical system designs was developed. This capability helped improve the performance of conventional systems and enabled missions that were previously unachievable with conventional optical systems.
- The Laboratory assisted the Department of Defense (DoD) in testing the energy resilience of three Army and two Air Force installations by developing an Energy Resilience and Readiness Exercise framework to safely disconnect the installations from commercial electrical power systems. The DoD tested backup capabilities and interdependent missions and infrastructure for up to 12 hours. Mission owners identified interdependencies between missions and other tenants, identified misconfigured backup systems, and tested a force deployment during an outage.

Future Outlook

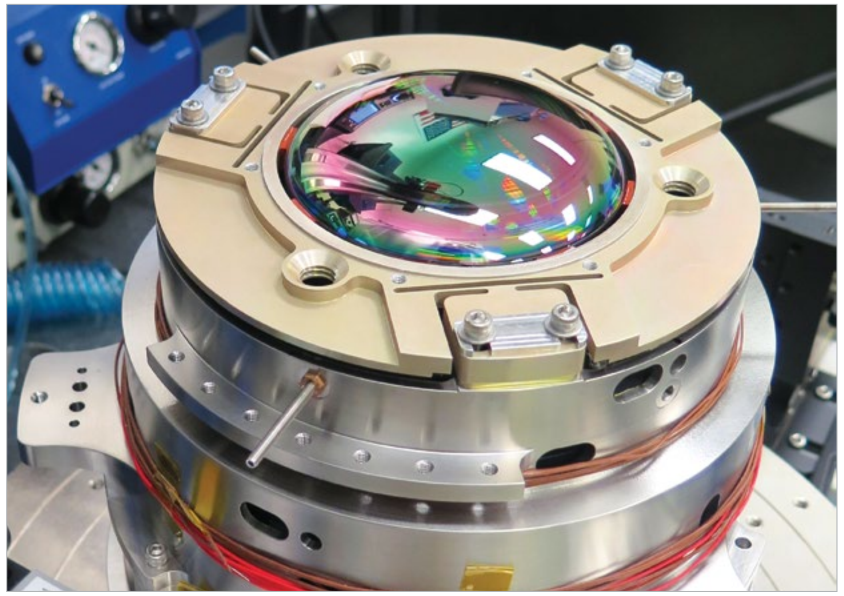
The new Engineering Prototyping Facility will house engineering staff and fabrication, assembly, and test capabilities, and will replace aging facilities that are no longer adequate to support the wide range of Laboratory prototyping. Engineering staff will work with the Air Force on specifications for the building.

Research will continue on advancing the Laboratory's prototyping tools, including autonomy software for small satellite constellations, additively manufactured composite materials, propulsion systems for small satellites, advanced thermal management, new techniques to align complex optics, and unmanned air vehicle design and analysis tools.

Model-based systems engineering and integrated analysis capabilities will be incorporated into MBE as part of the digital transformation initiative.

Chickadee Sensor

The Chickadee prototype is a midwave infrared ultrawide field-of-view imaging sensor developed for use in a small satellite constellation. The sensor is the widest field-of-view optical system ever built at the Laboratory and has the widest known field of view of any infrared imaging system. It is the lowest f-number fisheye lens ever built, is the first imaging infrared system known to be aligned to single micron tolerances, and enables imaging performance over the ultrawide field of view in a very compact package. The Chickadee prototype has undergone initial environmental testing and will continue performance evaluation in 2020.



LABORATORY INVOLVEMENT

In summer 2019, Lincoln Laboratory employed more than 200 interns from colleges and universities across the country. The interns worked in technical groups on projects that complemented their studies.

Research and Educational Collaborations

INTERN INNOVATIVE IDEA CHALLENGE

At the final competition of the fourth annual Intern Innovative Idea Challenge, the team who created ENVOY (Enabling Natural-language Versatility and Opportunity) was named the first-place winner. ENVOY is a system that enables American Sign Language users and English speakers to communicate in real time. This year, 24 teams that involved more than 70 summer interns submitted ideas for solving a wide range of problems. From these 24 concepts, six were downselected to be presented to the judges, a panel of technical experts. Second-place went to a brace capable of monitoring and mitigating hyperextension in the wearer's joints. Garbots, above, a system that "sweeps" trash made of microplastics from the surface of a river, was named the third-place winner. The winning teams were invited to return to Lincoln Laboratory next summer to continue developing their systems.

The panel of expert judges for the Intern Innovative Idea Challenge included, left to right, Lincoln Laboratory Director Eric Evans; Katherine Rink, Head of Lincoln Laboratory's Air, Missile, and Maritime Defense Technology Division; Sergeant Eric Ross of the U.S. Army Special Operations Command; Bernadette Johnson, the Laboratory's Chief Technology Ventures Officer; and Robert Bond, the Laboratory's Chief Technology Officer.

SMART PHOTOVOLTAIC MICROGRIDS FOR COOKING IN DISADVANTAGED COMMUNITIES

Every day, billions of households in disadvantaged communities across Africa, India, Asia, and South America burn biomass fuel—that is, firewood or charcoal—to cook meals. This method of cooking leads to more than four million deaths per year attributed to illnesses caused by indoor air pollution from biomass cooking. Lincoln Laboratory is working with Columbia University and the Global Alliance for Clean Cookstoves to develop and pilot smart photovoltaic (PV) microgrid technology that will help communities adopt and accept electric cooking.

An infrared sensor measures the temperature of food inside a rice cooker, triggering a controller to shut off power when a certain temperature is reached.

The team's smart PV system connects a microgrid, powered by solar panels, to homes. Algorithms distribute power in a prioritized fashion to homes that have signed up to cook at a particular time. If there is excess power at any time, the system alerts other customers immediately if they wish to sign their home up next. Excess power can also be used to activate cell phone charging stations.

The team is also focusing on delivering safe, simple, and efficient cooking appliances, such as rice cookers, to these communities. Inexpensive rice cookers, which lack controls to cook foods to a specific temperature, constantly draw power even when food is at a boiling temperature. To address this energy waste, the team developed a new controller, connected to a temperature probe or infrared sensor inside the cooker, that turns off power to the appliance once it senses that the food has reached the target temperature. The smart PV power distribution system then redirects energy from that appliance to another household, greatly increasing efficiency.

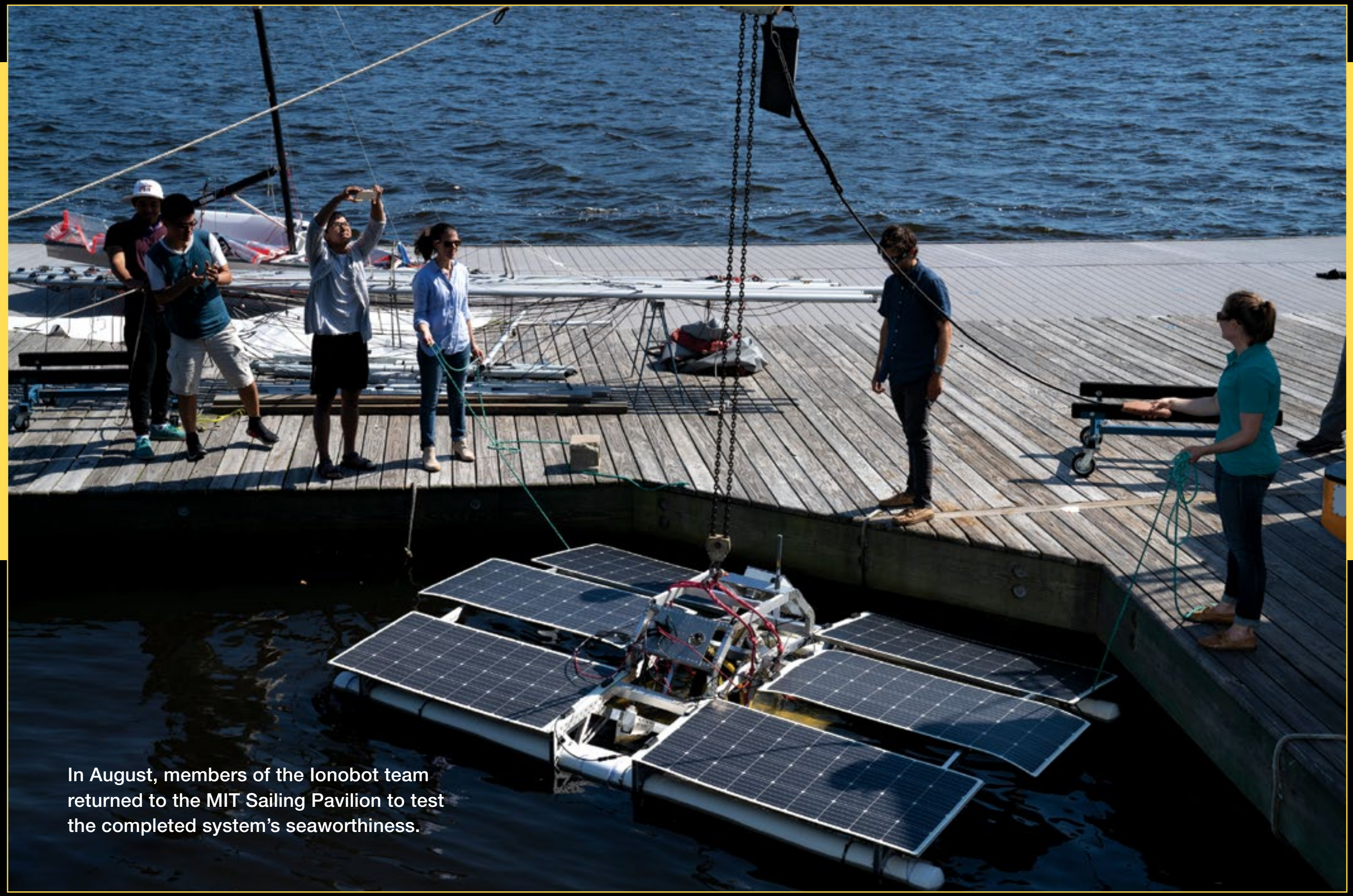
MEDIC-AIDE

Researchers from Lincoln Laboratory are collaborating with a physician from Massachusetts General Hospital's Trauma Research Laboratory to investigate the application of artificial intelligence (AI) techniques to the decision making of doctors and medics who are working at field-forward military installations. The medical personnel deployed in the field are often called upon to treat urgent-care cases as well as routine, familiar medical problems. The wide array of traumas that may occur out in the field strains the resources and expertise of the limited number of medics or doctors assigned to a base. An automated diagnostic tool that advises on treatment options would be a valuable "partner" for these medical practitioners.

The envisioned Medic-AIDE (i.e., AI for Decision Emulation) tool would apply AI algorithms to the task of correlating information of varying types (text, medical images, medical codes) from multiple sources (databases, scans, clinicians' reports) into decision options. Complicating the creation of such a decision support system is the development of a method that estimates the effectiveness of each option so that the "best" treatment can be recommended, along with a confidence score that estimates the uncertainty in the predictions. The main step to obtaining a well-calibrated estimate hinges upon developing an algorithm to train a model that can form opinions on predictions and capture data variations. The research team is developing models of expert decision making and applying them to trauma care. Their algorithm was used to train a classification model to categorize electrocardiogram waveforms as normal or atypical (in this case atrial fibrillation) rhythms. This method demonstrated performance better than the state-of-the-art techniques.

Future work will focus on models for various medical decisions—prescribing therapeutics, weighing surgery options, estimating the need for transfusions, and performing fast search in electronic health records. Medic-AIDE could transform the training for and execution of field medicine.

SPOTLIGHT: BEAVER WORKS CAPSTONE PROJECT



In August, members of the Ionobot team returned to the MIT Sailing Pavilion to test the completed system's seaworthiness.

Students from the spring 2019 Engineering Systems Development course, their professor Douglas Hart (third from left kneeling), and Lincoln Laboratory Ionobot program manager Jessica Brooks (standing right) posed for a photo on test day.

Ionobot

Undergraduates in the two-semester course sequence Engineering Systems Design and Development, offered by the MIT Department of Mechanical Engineering, designed, built, and tested a marine platform, called Ionobot, that will carry a sensor for measuring the dynamics of the ionosphere, the ionized layer of the atmosphere that extends 50 to 600 miles above Earth's surface.

The sensor system, developed by Lincoln Laboratory, addresses the need for measurement systems, called ionosondes, that can operate from sea-based locations to accurately measure fluctuations in the ionosphere above the ocean. These naturally occurring fluctuations can cause communication disruptions and inaccurate GPS localization as the electromagnetic waves interact with the ionosphere.

In the fall 2018 semester, Lincoln Laboratory Ionobot program manager Jessica Brooks of the Air, Missile, and Maritime Defense Technology Division challenged the students with baseline requirements for the design of the autonomous vehicle that could carry the payload (i.e., the sensor). This platform must

- Provide at least 2.5 kilowatt hours of power per day, and store health and status data on the platform for the duration of the mission
- Autonomously navigate within an hour to a GPS location no further than 2 kilometers from shore
- Maintain for one week its position within 50 to 100 meters of its assigned GPS location
- Send and receive communications to and from a ground station no further than 2 kilometers away

The students added their own requirements to meet constraints imposed by the ocean environment and their facilities. The platform needed to be

- Robust to remain operational in the roiling ocean
- Self-righting in the event of a capsize
- Able to fit through Beaver Works doors and to be transported via an SUV

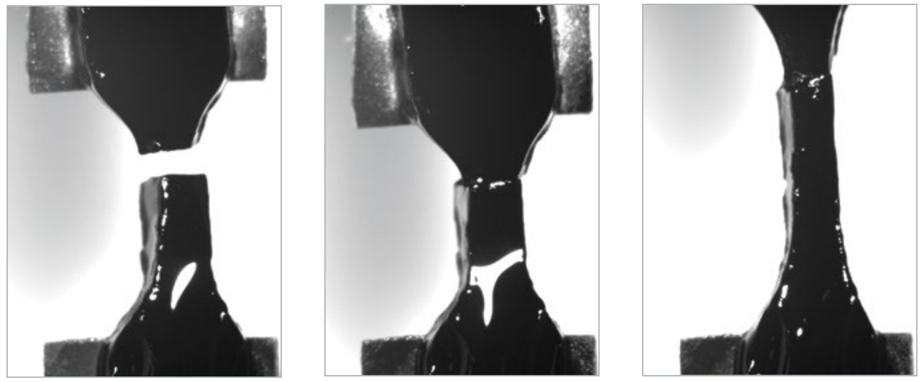
The resulting design was a vehicle equipped with two pontoons and a sunken hull that doubles as a keel to act as an unstable pendulum to provide a self-righting capability if the vehicle were to capsize in rough seas. The upper structure carries the solar panels that provide power, two motors that drive the craft, and communications equipment that reports health and status back to base operations. The submerged hull is watertight and provides a casing for the vehicle control electronics, power storage, and payload.

During the spring 2019 semester, the students in the development phase of the course built and tested the Ionobot. In late April, they hauled the disassembled Ionobot to the MIT Sailing Pavilion on the Charles River, reassembled the autonomous vehicle, and conducted checkout testing, including buoyancy tests, without the payload or the electronics. After some modifications over the summer, the operational Ionobot was launched in August and met all of its test criteria. This important milestone demonstrated the concept for future program efforts.

Ionobot owes its success to the dedicated team of people working on the program. The students were highly innovative and singularly focused on delivering a working prototype at the end of the year. This rapid prototyping goal obliged the students to learn to trade designs quickly and sometimes re-engineer a design after failure. Mentors from Lincoln Laboratory and MIT guided students through what was for many of them their first hardware project. Jean Sack from the Laboratory's Engineering Division served as the keystone mentor, from the project's introduction in the Beaver Works classroom until the setting sun on the very long final test day on the Charles River. She will teach the design-and-build course sequence in fall 2019, challenging student teams to create either an undersea exploration platform or an emergency medication-cooling system.

>> *Research and Educational Collaborations, cont.*

SELF-HEALING MATERIALS FOR VIBRATION DAMPING



The composite material, fractured at left, completely self-heals in five minutes at room temperature.

Vibrations limit the life span and functionality of systems, for example, causing stress fractures in aircraft wings and blurring images from a camera. Materials used today specifically in microsystems are unable to endure repeated stresses, limiting their overall performance.

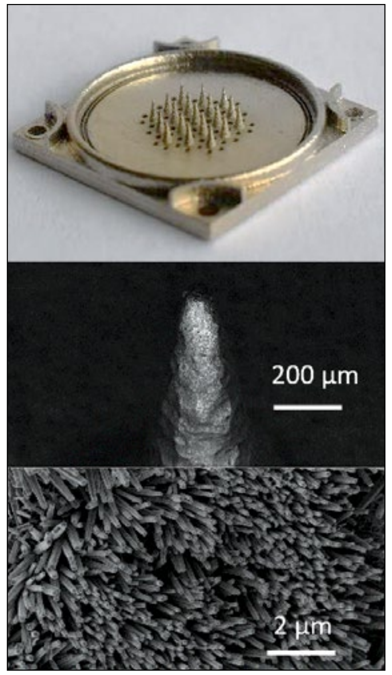
Scientists from Lincoln Laboratory and the MIT Department of Materials Science and Engineering are developing new materials that could be tailored at the molecular level to dissipate vibrations in microsystems. The materials are chemically inspired by nature, taking cues from the threads that keep mussels attached to rocks amidst the pounding of ocean waves. These structures automatically reassemble, or self-heal, when broken. While bio-inspired hydrogels that can self-heal have previously been developed, these materials are limited in application because they require water to self-heal. The scientists are aiming to replicate this self-healing ability in composite materials made of metal ions and nanoparticles bonded with polymer gel, whose chemical nature allows it to repair itself in response to damage.

These materials could be tuned to vibrate at specific frequencies to counteract the vibrations incurred on a system. By measuring the frequency at which the system, or part of a system, vibrates, a composite material could be customized with different metal ions, such as iron and cobalt, that will absorb the range of vibrational frequencies. These materials could then be engineered into the system, for instance as mounts for stabling micro-optics. The end goal of the program is to create a suite of materials that can survive repeated external stresses to enable a next generation of enhanced microsystems.

LOW-COST HIGH-VACUUM PUMP

Researchers at Lincoln Laboratory and MIT's Microsystems Technology Laboratories are experimenting with the design of a small, high-vacuum pump that will use an array of additively manufactured (i.e., 3D printed) "needles" to spray an ionized, nonvolatile liquid into a chamber, generating ample air movement that will result in the creation of a vacuum. The ultimate goal of the project is to develop a low-cost vacuum pump that will enable a portable mass spectrometer to achieve high-performance chemical detection.

This new pump design offers an advantage for a mass spectrometer: a working liquid with essentially zero vapor pressure that could facilitate pumping to extremely low pressures. The lower the pressure achieved, the better the spectrometer performs. Currently, most precision spectrometers use large turbomolecular vacuum pumps (or, succinctly, turbopumps) that deliver high-sensitivity detection and accurate identification of chemicals. However, these pumps are expensive because of the fine machining needed to achieve the tolerances required of the turbopumps' high-speed spinning blades that generate the rapid air movement. Turbopumps are also susceptible to malfunction and damage from even slight vibrations. The electrospray concept uses no moving parts, eliminating costly machining and mitigating vulnerability to vibrations, and the needles are manufactured of inexpensive, durable plastic polymer. This novel pump's performance has been evaluated via simulation, and its prototype is being fabricated at MIT for testing at Lincoln Laboratory.



At top is a photograph of electrospray tip array 3D printed from stainless steel and coated with zinc oxide nanowires. In the center and at bottom are electron microscope images of the tips.

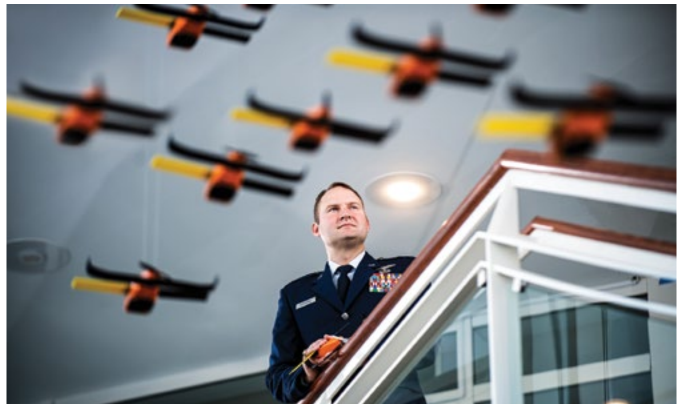
MILITARY FELLOWS PROGRAM

Lincoln Laboratory's Military Fellows Program has been offering military officers unique technical work experiences for nine years. Since the program's start in 2010, a total of 290 military fellows have worked alongside Laboratory staff mentors on developing technologies and capabilities important to national security. Beginning in the summer of 2019, 55 military officers engaged in research at the Laboratory.

Military officers from various service branches engaged in research at the Laboratory under the 2019 Military Fellows Program.

The fellowship program allows military officers to get hands-on experience with technologies that have applications to real-world problems. Lieutenant Colonel John Bergmans has been working in the Cyber System Assessments Group and the Artificial Intelligence Software Architecture and Algorithms Group on small unmanned aerial systems (sUAS) for the Air Force. His research focuses on teaming expendable sUAS, called hounds, with larger manned aircraft, called hunters, to search for mobile targets in highly contested environments.

"I have been able to research emerging technologies and potential solutions to a multitude of Air Force problem sets. It is incredible to have access to all of these researchers under one roof during my year as a fellow," Bergmans said.



"I have gained a unique understanding of the inner workings of a federally funded research and development center and how to leverage the exquisite prototyping capability that the Laboratory brings to bear."

Lieutenant Colonel John Bergmans, U.S. Air Force

Fellows find that their time at the Laboratory helps them expand their thinking outside of their traditional military training. "The Lab has a proven culture of innovation, and this year provides a mechanism to bring that spirit of innovation and best practices back to the Marine Corps," said Lieutenant Colonel Francisco Caceres, who worked in the Laboratory's Cyber-Physical Systems Group. "I think this experience will make me a better leader for our Marine Corps as we tackle the tough work of designing the future forces and their necessary capabilities."

>> Research and Educational Collaborations, cont.

WORKSHOPS AND SEMINARS

The workshops and seminars hosted by Lincoln Laboratory cover a wide range of topics. At these events, Laboratory experts and nationally prominent guest speakers share their research into emerging technologies.

Fifty-three military officers and Department of Defense civilian employees attended the 2019 Defense Technology Seminar in April to discuss evolving military challenges. Six esteemed guest speakers presented seminars on national security and current geopolitical issues.

2019 Schedule of Lincoln Laboratory Workshops

APRIL

3–4 Advanced Technology for National Security Workshop

8–12 Defense Technology Seminar for Military Officers

MAY

7–9 Space Control Conference

14–16 Air Vehicle Survivability Workshop

21–22 Lincoln Laboratory Communications Workshop

JUNE

4–6 Air, Missile, and Maritime Defense Technology Workshop

OCTOBER

1–3 Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

23–24 Advanced Prototype Engineering Technology Symposium

NOVEMBER

5–7 A2/AD Systems and Technology Workshop

13–15 Recent Advances in AI for National Security

19–20 Homeland Protection Workshop Series

DECEMBER

3–4 Cyber Technology for National Security

2019 Offsite Workshops

The Laboratory also coordinates offsite workshops with partnering organizations. Laboratory involvement may be co-chairmanship of events, technical leadership of sessions, or co-sponsorship.

24–25 April
Graph Exploitation Symposium in Dedham, Massachusetts

20–23 May
IEEE Body Sensor Networks Conference in Chicago, Illinois

18–20 June
Cyber Endeavour Workshop in Menlo Park, California

24–26 September
IEEE High Performance Extreme Computing Conference in Waltham, Massachusetts

5–6 November
IEEE International Symposium on Technologies for Homeland Security in Woburn, Massachusetts

Lincoln Laboratory's technical staff often serve as keynote speakers, technology experts, chairpersons, or moderators at national and international conferences, such as the High Performance Extreme Computing Workshop, the Federal Interagency Conference on Traumatic Brain Injury, and the Chief Diversity Officer Summit.

As the program chair for the Association for Computing Machinery's Richard Tapia Celebration of Diversity in Computing in September, David Martinez was a guest speaker. In November, he was the inaugural keynote speaker for the Laboratory's first workshop on Recent Advances in Artificial Intelligence for National Security.

Thomas Quatieri served as keynote speaker for the Speech Science and Technology Conference in December 2018. "I was honored and excited when asked to give a keynote, especially on my research in vocal biomarkers of neurological conditions," Quatieri said.

At the 2019 Grace Hopper Celebration, the world's largest meeting for women technologists, Lincoln Laboratory staff gave presentations on tracking power outages via the Internet of Things, predicting cyber attacks, and uncovering human trafficking networks through text analysis.

Seen here at the 2019 IEEE Radar Conference in Boston are the 2019 Fred Nathanson Memorial Radar Award winner Professor Julie Ann Jackson, second from the left, and several Lincoln Laboratory members who served leading roles in organizing the conference: left to right, Daniel Bliss, formerly of Lincoln Laboratory and now at Arizona State, technical vice chair of the conference; Frank Robey, in charge of plenary sessions; Eric Evans, general chair of the conference; Jennifer Watson, conference vice chair; Jeffrey Herd, publicity chair; and Vito Mecca, an instructor for a tutorial offered at the conference.

The recruiting team that attended the Grace Hopper Celebration met computer science majors for consideration as staff candidates.

For the 2019 IEEE International Symposium on Phased Array Systems and Technology in October, Jeffrey Herd, above, served as the conference chair. His colleague Alan Fenn was the technical program chair, and several Laboratory staff members organized sessions, tutorials, and communications for the event.

Diversity and Inclusion

National Employee Disability Awareness Month

In October 2019, the Lincoln Employees with Disabilities (LED) group celebrated National Employee Disability Awareness Month with a number of events, including the Laboratory's first American Sign Language (ASL) class, which was aimed at helping staff connect with deaf and hard-of-hearing colleagues. More than 80 employees applied to take the class, and participants learned ASL vocabulary needed to discuss technical information. On 30 October, LED hosted its annual luncheon with guest speaker Jaya Narain, one of the founders of MIT's assistive technology hackathon and a doctoral candidate in mechanical engineering at MIT.

Lunar New Year Celebration

Laboratory employees joined in a demonstration of Chinese ribbon dancing for the annual Lunar New Year celebration.

On 5 February 2019, the Laboratory rang in the Lunar New Year with a celebration hosted by the Pan-Asian Laboratory Staff (PALS). Staff gathered to enjoy cultural performances and food from different regions of Asia. Performances included a Chinese lion dance by members of Gund Kwok, an all-women's lion and dragon dance troupe from Boston; a ribbon dance from the New England Chinese Cultural Studio; and an Indian folk dance by MIT Bhangra.

Hispanic Heritage Month Celebration

In October, the Lincoln Laboratory Hispanic/Latino Network invited Natalia Guerrero to deliver a keynote address in commemoration of Hispanic Heritage Month. Guerrero is a researcher at the MIT Kavli Institute for Astrophysics and Space Research and is also the MIT communications lead for NASA's Transiting Exoplanet Survey Satellite (TESS). The keynote address focused on Guerrero's personal story growing up Hispanic-American and TESS's recent achievements. Guerrero's experiences and advocacy of accessible science education resonated especially with Laboratory staff members who grew up as first-generation American college students.

For the Laboratory's Hispanic Heritage Month celebration, MIT researcher Natalia Guerrero shared insights from her personal experiences and technical work.

The 2019 GEM fellows are seen with Chief Diversity and Inclusion Officer, Chevalier Cleaves, far left.

GEM National Consortium

Through partnerships with universities and industries, the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) provides support to students from underrepresented groups who are seeking advanced degrees in science and engineering fields. As an employer member of the National GEM Consortium, Lincoln Laboratory offers paid summer internships to students in the GEM Fellowship Program.

In summer 2019, 18 GEM fellows worked as interns at the Laboratory. These internships gave students a chance to apply their knowledge to real-world projects and to experience the demands of an R&D laboratory. In addition to gaining technical work experience, the fellows were given the opportunity to network with peers and experts in their field. The Laboratory, in turn, met young professionals who are promising candidates for future employment.

"I had a great time working at the Lab, and this was an amazing opportunity to hone previous skills while learning new ones from some of the best and brightest in the field," said GEM fellow Matthew Perez. Perez spent his summer in the Human Health and Performance Systems Group researching acoustic and speech-based biomarkers for identifying and analyzing different neurocognitive conditions, such as aphasia and depression.

"The relationships built up at the Lab are something that I'm sure will have a long-lasting positive impact on my future endeavors, and they are ones that I hope to continue fostering in the future."

Matthew Perez,
2019 GEM fellow

>> *Diversity and Inclusion, cont.*

EmERGe Leadership Summit

Employee research groups (ERGs) are integral to the Laboratory's efforts to support an inclusive working environment. In June 2019, Laboratory ERG leaders attended the EmERGe Leadership Summit, held by Diversity Best Practices in Newark, New Jersey. The summit gathered ERG leaders from around the country for discussion about the importance and impact of ERGs on an organization's success. "Hearing these stories made me realize that here at the Laboratory, we are getting a lot of things right," said Lincoln Laboratory Out Professional Employee Network co-chair Noel Keating, who attended the summit. "The conference provided me with plenty of excitement and enthusiasm to continue to advance our ERGs to the next level."

The leaders of five Laboratory employee resource groups and Chief Diversity and Inclusion Officer Chevy Cleaves, far right, attended the EmERGe Leadership Summit.

Robbin Chapman delivered the keynote speech at the 2019 Martin Luther King Jr. Luncheon.

Martin Luther King Jr. Luncheon

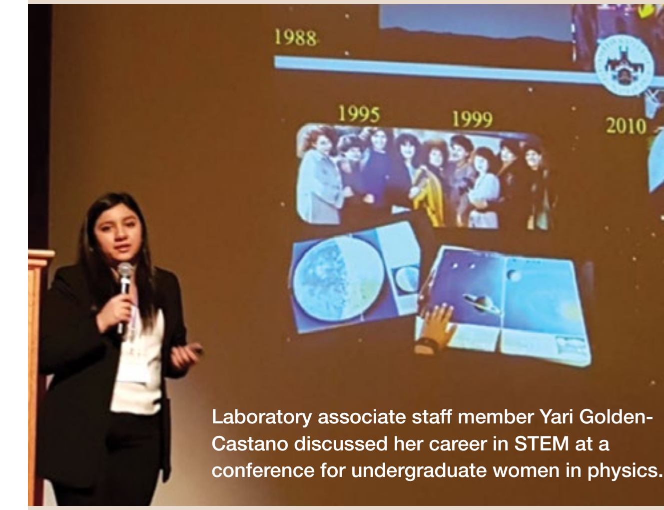
On 13 March, the Lincoln Employees African-American Network (LEAN) hosted the sixth annual Martin Luther King Jr. Luncheon. The event marked the conclusion of LEAN's month-long celebration of Black History Month, which featured technical presentations from staff members and seminars from a variety of guest speakers. The luncheon's keynote speaker was Dr. Robbin Chapman, the Associate Dean of Diversity, Inclusion, and Belonging at the Harvard Kennedy School.

The theme of the event, "Lead, Inspire, Excel: A Call to Service," was designed to call upon every person at the Laboratory to inspire the community toward excellence. To express this theme, LEAN invited Chapman to speak about Dr. King's legacy and leadership style, their impact upon her life, and strategies to make the Laboratory a more inclusive environment.

"Leadership does not rest on just one person but is actually distributed across an entire community. This is an important part of the legacy of Martin Luther King Jr.," Chapman said.

Pride Month

During Pride Month in June 2019, 400 Laboratory members attended the Lincoln Laboratory Out Professional Employee Network's annual ice cream social. The group held three discussion sessions throughout the month, the first of which focused on a talk given by actress and LGBTQ activist Laverne Cox at the 2019 Simmons Leadership Conference. The second discussion addressed various TED Talks focusing on LGBTQ issues, such as how to talk to transgender people and how to fight prejudice in conversation; and the third discussion centered on the documentary, "Driving Equality Across America," in which the stories of LGBTQ Americans were shared through a series of interviews.



Laboratory associate staff member Yari Golden-Castano discussed her career in STEM at a conference for undergraduate women in physics.

Undergraduate Women in Physics Conference

Yari Golden-Castano, an associate staff member in the Laboratory's Systems Engineering Group, shared her story of success in STEM to 240 undergraduate women from across New England who attended the American Physical Society Conference for Undergraduate Women in Physics in January 2019. Golden-Castano discussed her experience as one of the 100 finalists in the Mars One mission program and spoke as part of a panel on diversity and inclusion in STEM to help inspire women pursuing degrees in physics.

Veterans' Appreciation Luncheon and Memorial Day Barbeque

The eighth annual Veterans' Appreciation Luncheon was held at the Minuteman Commons Community Center to recognize veterans at the Laboratory for their service. Approximately 400 Laboratory employees are veterans who have served in wartime and in peace in the National Guard, the Reserves, and active duty. Lieutenant General (Retired) Kevin Campbell delivered the keynote address. GEN Campbell relayed the importance of remembering enlisted service members during their transition to the civilian workforce and commented on the strong history of innovation that he has seen during his relationship with Lincoln Laboratory over the years. He also spoke about how the Laboratory has had a great impact on the lives of many service members.

Cultivating Lincoln Achievement and Success Symposium

The Laboratory held its first Cultivating Lincoln Achievement and Success (CLAS) Symposium in 2018 to help staff learn how to be effective leaders and succeed in their careers. The CLAS symposium returned in 2019 to continue educating staff through panel discussions, speakers, and workshops. Each day's activities covered topics such as what makes a good leader, how to communicate effectively, and why mentorship is important. A closing ceremony and awards presentation recognized staff members for their exceptional leadership and contributions to diversity and inclusion at the Laboratory. Award recipients included Daryl Easler, for the Leadership Award for Advancing Organizational Culture; Samantha Jones, for the Peer (LLInfinity) Award for Cultural Impact; and Hsiao-hua Burke, for the Emeritus Award for Advancing Organizational Culture.

At the Cultivating Lincoln Achievement and Success Symposium, members of the Laboratory's leadership discussed tips for becoming a reliable leader.

Awards and Recognition

2018 Lincoln Laboratory Technical Excellence Awards

Dr. James K. Kuchar, for sustained leadership and technical contributions in the development, integration, and testing of air traffic control and other transportation-related systems, and for innovative work in collision avoidance and risk assessment.

Dr. Michele A. Schuman, for exceptional leadership and a wide range of contributions to the field of radio frequency satellite communications, including system design and analysis, algorithm development, and system integration and test.

2018 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Danelle C. Shah, for her contributions to the research and development of data analytics, machine learning, and artificial intelligence techniques. She has contributed to programs in intelligence, surveillance, and reconnaissance and to technology for humanitarian assistance and disaster relief.

Dr. Thomas Sebastian, for his innovative new concepts in aerospace systems, including micro–unmanned aerial vehicles, thermal management of lasers, and biodefense sensors. He led the development of a low-acoustic propeller for autonomous air vehicles.

2018 MIT Lincoln Laboratory Best Paper Award

Dr. Mark S. Veillette, **Eric P. Hassey**, **Christopher J. Mattioli**, **Dr. Haig Iskenderian**, and **Patrick M. Lamey**, for "Creating Synthetic Radar Imagery Using Convolutional Neural Networks," published in the *Journal of Atmospheric and Oceanic Technology*, December 2018.

2018 MIT Lincoln Laboratory Best Invention Award

Dr. Darrell O. Ricke, **Tara L. Boettcher**, **Philip D. Fremont-Smith**, **Adam M. Michaleas**, **Dr. Martha S. Petrovick**, **Dr. Eric D. Schwoebel**, and **James G. Watkins**, for the invention of the Advanced DNA Forensics System.

2019 IEEE Fellow

Dr. William J. Blackwell, for contributions to atmospheric remote sensing algorithms and instrumentation.

Election to the National Academy of Engineering

Christine Wang's pioneering reactor design concepts shaped a standard tool used today in the compound-semiconductor industry.

Christine Wang was elected to the National Academy of Engineering for contributions to epitaxial crystal growth of III-V compound semiconductors and the design of organometallic vapor-phase epitaxy (OMVPE) reactors.

Dr. Wang's design concepts are incorporated in the major large-scale commercial OMVPE reactor platforms used worldwide for the production of III-V compound semiconductor epitaxial materials needed for lasers, light-emitting diodes, high-efficiency solar cells, and other electronic and optoelectronic devices.

Beyond her work on OMVPE reactors, Dr. Wang has led the use of nonconventional chemical compounds to enable epitaxial growth of antimonide-based III-V semiconductors, has advanced gallium arsenide–, gallium antimonide–, and indium phosphide–based optoelectronic devices, and has contributed to the development of quantum cascade lasers emitting in the long-wave infrared wavelength region.

2020 AIAA Associate Fellows


Dr. Grant H. Stokes, far left, and **Dr. Robert T-I. Shin**, left, were named to the 2020 class of Associate Fellows of the American Institute of Aeronautics and Astronautics, recognizing their careers of notable contributions to the arts, sciences, or technology of aeronautics and astronautics.

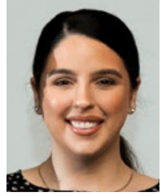
2019 NASA Exceptional Public Service Medal

Dr. Gregory D. Berthiaume received this NASA Agency Honor Award that is presented to a non-government individual who demonstrated sustained outstanding contributions to a NASA project or program. He was recognized for his leadership of Lincoln Laboratory's R&D for the Transiting Exoplanet Survey Satellite (TESS) program.

2019 Boston CIO of the Year ORBIE Award

Robert D. Solis was chosen by the Boston CIO Leadership Association as the 2019 ORBIE Award winner in the nonprofit category. ORBIE Awards recognize chief technology officers who have shown outstanding leadership and whose technology initiatives have made a significant, lasting impact on their organizations.

2019 Cultivating Lincoln Achievement and Success Awards


Daryl A. Easler, left, received the Leadership Award for Advancing Organizational Culture; **Samantha Jones**, center, received the Peer Award for Cultural Impact; and **Dr. Hsiao-hua K. Burke**, right, received the Emeritus Award for Advancing Organizational Culture.

2019 Excellence in Technology Transfer Award

The Federal Laboratory Consortium for Technology Transfer presented Lincoln Laboratory's Microwave Imaging System for Threat Exposure with the 2019 Excellence in Technology Transfer Award for the Northeast region. The technology has been licensed to Liberty Defense Technologies.

2019 Aviation and Space Operations Weather Prize

Dr. James E. Evans was awarded this recognition for lifetime achievement in aviation weather hazard detection, warning, and mitigation by the Friends and Partners in Aviation Weather group of the National Business Aviation Association.

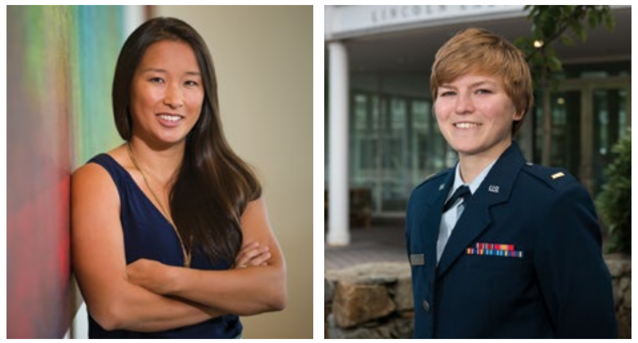
2019 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative staff category: **Marie L. Dow**, for dedication to improving visual communications across the Laboratory and expanding Technical Communication's creative services; **Jason B. Williams**, for addressing graphic arts needs at the Laboratory and continually elevating the design of visual materials for Laboratory staff and events.

Support staff category: **John F. Orthmann**, for his tireless work as a machinist contributing expertise and technical support to multiple projects of significance at the Laboratory; **Terri L. Welch**, for outstanding management of her group's administrative duties and for contributions to the Quantum Communications Workshops.

Recipients of the 2019 Administrative and Support Excellence Awards are, left to right, Terri L. Welch, Marie L. Dow, Jason B. Williams, and John F. Orthmann.

>> Awards and Recognition, cont.

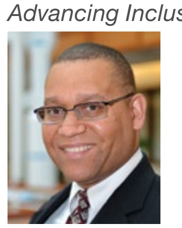


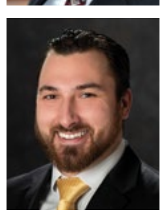
2019 Aviation Week's 20 Twenties Honorees

Jessica Zhu, left, and **Casey Evans**, right, Military Fellows at Lincoln Laboratory, were selected by Aviation Week Network as two of its 20 Twenties, an annual recognition of 20 engineers in their twenties whom the network, in partnership with the American Institute of Aeronautics and Astronautics, identified as making significant contributions to aerospace-related research and engineering.

2019 MIT Excellence Awards

Advancing Inclusion and Global Perspectives: **William H. Kindred**, for sustained efforts to improve diversity and promote inclusiveness at Lincoln Laboratory. He formalized the Laboratory's diversity and inclusion programs, and forged strong relationships with outside associations.





Outstanding Contributor: **Christopher Budny**, for exceptional support to his group's development of technology that enhances crisis management capabilities. His software improves disaster response tools used worldwide.

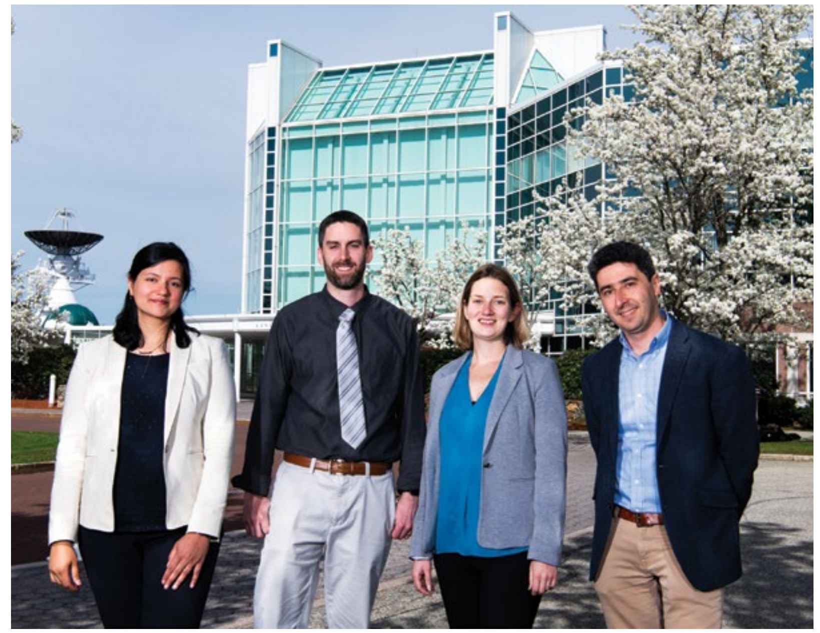
National Fire Control Symposium Outstanding Paper

Dr. Joseph A. Munoz was named the second-place award winner for his paper "Information Denial for Missiles," presented at the 2019 National Fire Control Symposium; he was honored in the Early Career Award category.

2019 AIAA Dr. John C. Ruth Digital Avionics Award

The American Institute of Aeronautics and Astronautics (AIAA) presented this award to the design team for the Advanced Collision Avoidance System X (ACAS X): **Dr. James K. Kuchar** and **Dr. Wesley Olson**, technical staff, and **Dr. Mykel J. Kochenderfer**, consultant, of Lincoln Laboratory; Joshua Silbermann of the Applied Physics Laboratory; and Neal Suchy of the Federal Aviation Administration. The team was recognized for applying machine learning technology, statistical risk assessment, and flight test campaigns to develop ACAS X.

AFCEA 2019 40 Under 40 Awards



Recipients of the AFCEA 2019 40 Under 40 Awards are, left to right, Anu K. Myne, Dr. Mark S. Veillette, Meredith K. Drennan, and Dr. Alexander M. Stolyarov.

Meredith K. Drennan, **Anu K. Myne**, **Dr. Alexander M. Stolyarov**, and **Dr. Mark S. Veillette** were named by the Armed Forces Communications and Electronics Association International (AFCEA International) to its annual list of 40 individuals under the age of 40 who have shown exceptional leadership and innovative use of information technology to advance scientific and engineering work at their organizations.

2019 Fellow of the Royal Aeronautical Society

David Culbertson was elected to the rank of Fellow to recognize his extensive experience and contributions to the profession of aeronautics.

2018 Superior Security Rating

Awarded to Lincoln Laboratory's collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office. This is the 13th consecutive Superior rating for the Laboratory.

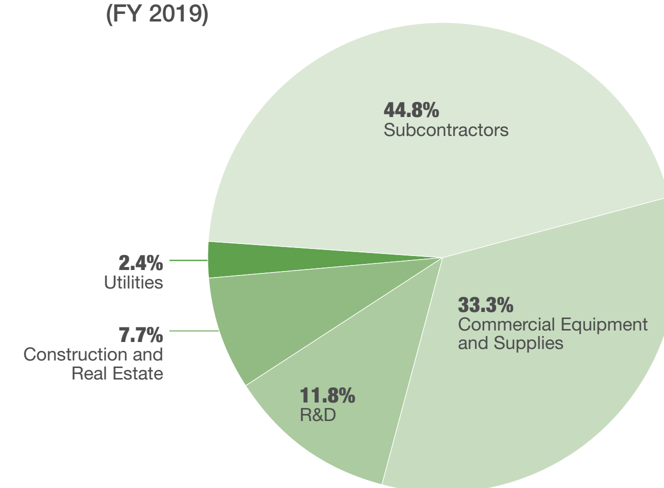
2019 ASTOR Homeland Security Award

American Security Today, a publisher of government and general security news, presented an ASTOR Homeland Security Award in the category of Best Video Analytics Solutions to the Department of Homeland Security Science and Technology Directorate's Office of Mission and Capability Support for the development with Lincoln Laboratory of the Forensic Video Exploitation and Analysis Tool Suite.

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 2019, the Laboratory issued subcontracts with a value of nearly $632.2 million. This figure represents a substantial increase in external spending over the previous fiscal year, with the Laboratory issuing subcontracts to businesses in all 50 states, Washington, D.C., and Puerto Rico. In fiscal year 2019, the Laboratory purchased more than $408.3 million in goods and services from New England companies, with $313.5 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. For fiscal year 2019, the percentage of spending increased across all small business subcategories from the previous year.

Contracted services*
(FY 2019)



**Estimates from $632.2M, total FY19 spend*
– Includes orders to MIT – $7.99M
– Figures are net awards less reductions

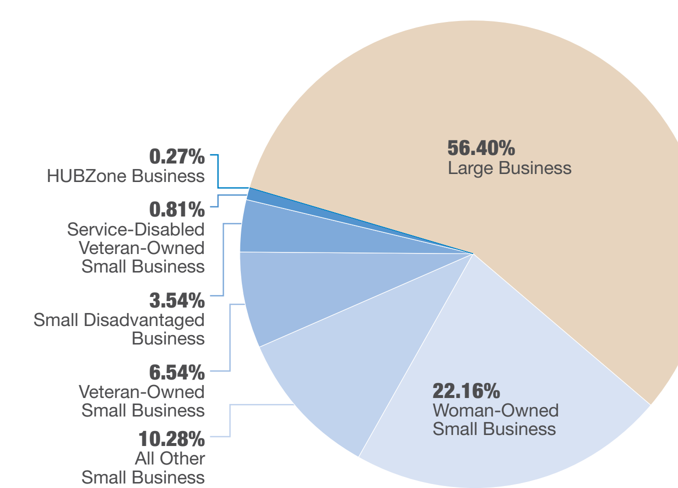
STATE	$ MILLION
Massachusetts*	313.5
New Hampshire	81.4
California	50.9
Virginia	31.6
Texas	25.7
New York	11.3
Pennsylvania	10.6
All Other	107.2
Total*	632.2

**Includes orders to MIT – $7.99M*

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 2019, more than 43% of subcontracts were awarded to small businesses of all types (as reported to the Defense Contract Management Agency). The Laboratory's Small Business Office is committed to an aggressive program designed to afford small business concerns the maximum opportunity to compete for purchase orders.

Contract awards by category of businesses (FY 2019)*



**As reported to the Defense Contract Management Agency (DCMA)*

43.60% Total for all small business

EDUCATIONAL AND COMMUNITY OUTREACH 79

Volunteers gathered at Lincoln Laboratory in November to assist high school girls participating in the G.I.R.L. workshop.

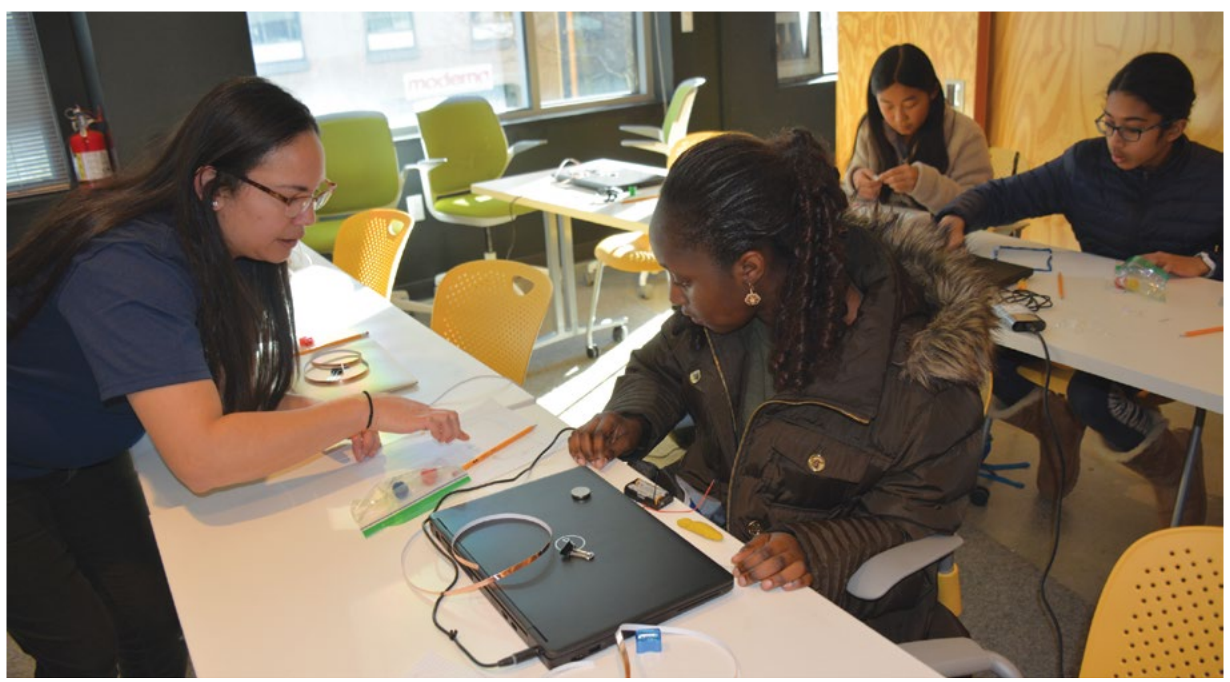
Educational Outreach

BUILD YOUR OWN LIGHTSABER

Volunteers from the Lincoln Laboratory Hispanic/Latino Network (LLHLN) spent Star Wars Day (May 4) at the Latino STEM Alliance's family science festival in Roxbury, Massachusetts. They taught children of all ages how to build a functioning miniature lightsaber. Each lightsaber was made from an LED light, a plastic straw, copper tape, batteries, and a popsicle stick in the same color as the child's lightsaber. The LLHLN volunteers explained the basics of circuitry while helping students to build a basic circuit that would allow them to turn their lightsaber's LED on and off. Eric Chaidez, co-chair of LLHLN, estimated that 60 students came by their Build Your Own Lightsaber booth and that many came back a second time to build another lightsaber. "We wanted to provide STEM for these students whose schools might not offer a strong science or math curriculum," he said.

Building a miniature lightsaber sharpened children's understanding of circuits.

GIRLS INNOVATION RESEARCH LAB



Elisa Kirchheim explains how circuits work to a middle school girl during the G.I.R.L. workshop.

A team of Laboratory staff headed by Yari Golden-Castano offered a new opportunity for young women to learn about science and engineering. The program, Girls Innovation Research Lab (G.I.R.L.), introduced 40 middle school girls from the Boston area to a workshop called Scratch Programming and Intro to Circuits and Electronics. Participants learned about various electronic components while building their own circuits using MIT's Scratch programming language and a Makey Makey board. The course organizers and instructors—including seven Laboratory staff members—helped girls understand the basic programming needed to enable piano keys to change sound, color, and position while responding to different commands. The Laboratory team plans to develop the experience into a standalone workshop across the country to introduce more girls to programming and engineering. They also plan to offer a more advanced version of the program that will use a Playground Circuit Board and Arduino.

Students assemble a radar by integrating all the separate components they built over the course of a week.

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Twenty-four students from across the country completed the Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE)—a two-week radar workshop. Now in its eighth year, the summer course challenges high school seniors to build their own small radar systems as they tackle college-level courses, tour Laboratory facilities, and sample college life while staying in MIT dormitories. The students attend lectures on physics, electromagnetics, Doppler radar, pulse compression, signal processing, circuitry, and antennas. Then they apply knowledge from the lectures as they build their own radar. In addition, they learn how to 3D print components and solder circuit boards. After the radars are completed, the students stage experiments and present a technology demonstration. This is the third year that a teacher has attended the program. Wandesha Traylor, a chemistry and environmental science teacher at Wossman High School in Monroe, Louisiana, participated with the intent of offering the LLRISE program as an extracurricular activity at her school.

"LLRISE incorporates project-based, hands-on learning opportunities," said Kelli Thornhill, an intern in the Communications and Community Outreach Office who helped with LLRISE. "The students accepted into this program gain an understanding of radar technology, but more importantly, they gain an understanding of what the emerging STEM fields look like in both a professional and a college environment."

LLRISE participants show off their radars at MIT Museum to Louie Lopez, (left) Director of STEM at the Office of the Under Secretary of Defense, Research and Engineering. Lopez sponsors LLRISE and a variety of other Lincoln Laboratory outreach programs.

>> Educational Outreach, cont.

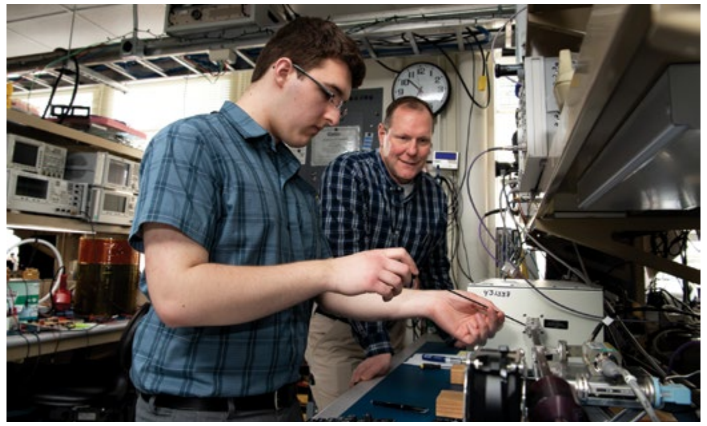
GIRL SCOUT STEM BADGES

A Junior Girl Scout troop of 17 fourth graders from Burlington, Massachusetts, contacted Lincoln Laboratory for help in earning some of the brand-new STEM-based badges now offered by the Girl Scouts of USA. Edward Lyvers led technical staff in developing lectures and hands-on activities and demonstrations that would fulfill badge requirements while introducing the girls to engineering and digital arts. Four STEM workshops were held for the scouts throughout spring 2019:

- Product Designer, led by Yari Golden-Castano, taught girls about entrepreneurship, engineering skills, and real-life product designs.
- Balloon-Powered Cars, led by Allison Norloff, focused on creative problem solving and mechanical engineering.
- Designing Robots, led by Kathleen Nahabedian, taught girls how to use basic engineering skills to build and program robots.
- Digital Photography, taught in two parts—photo taking and digital editing—by Lyvers satisfied part of the Girl Scouts Digital Arts category of the new STEM badge.

Sara-anne Taylor helps a participant with the finer points of building a balloon-powered car to increase the car's speed and balance.

TECHNICAL SCHOOL INTERNSHIPS



John Boughner observes as intern Samuel Harris connects a waveguide to a high-power amplifier to be able to perform bench testing.

Every year, Lincoln Laboratory hires two to three seniors from local technical high schools as interns for the summer. John Boughner in the Advanced SATCOM Systems and Operations Group mentored Samuel Harris, an intern from Minuteman Career and Technical High School in Lexington, Massachusetts. Boughner guided Harris in hands-on testing to ensure high-power amplifiers were operational and in good working condition at both fixed and mobile antenna sites. Boughner enjoyed the opportunity and said, "Being able to mentor a student from a vocational-technical high school and help teach about the high-tech environment we operate in with hands-on work is very gratifying for both the mentor and the student."

EXPLORER POST 1776

From October to May, 15 high school students explored engineering-related fields through a partnership between the Boy Scouts of America and the Laboratory. Explorer Post aims to deliver character-building experiences for 14–20-year-olds to allow them to achieve their full potential in both life and work. The coed group learned about technical topics, engaged in reverse engineering home electronics, created a machine that propels a ping pong ball down a track, and built water rockets. They were challenged to use creative problem-solving strategies to build prototypes and prepare demonstrations of their projects.

"Once a team starts working together, you begin to see the ideas form. The realization that they came up with a solution on their own makes it very rewarding," said Chiamaka Agbasi-Porter, organizer of the Explorer Post program at Lincoln Laboratory. The students said they appreciate the opportunity to visit and tour Laboratory facilities, such as the Microelectronics Laboratory and the Rapid Prototyping Laboratory. "It is awesome to see the equipment and projects that people are working on at the Laboratory and how things come to be," said Liliana Vornehm, daughter of staff member Joseph Vornehm. "I enjoy learning about the facilities and seeing what I might like to do as a potential career."

BEAVER WORKS SUMMER INSTITUTE

In its fourth year, the Beaver Works Summer Institute (BWSI) offered hands-on STEM learning to rising high school seniors through project-based courses. This year, the program admitted more than 250 students from 27 states. This year's BWSI featured 10 courses—Autonomous RACECAR (Rapid Autonomous Complex Environment Competing Ackermann-steering Robots) Grand Prix, Autonomous Air Vehicle Racing, Autonomous Cognitive Assistant, Medlytics: Data Science for Health and Medicine, Build a CubeSat, Unmanned Air System–Synthetic Aperture Radar (UAS-SAR), Embedded Security and Hardware Hacking, Hacking a 3D Printer, Remote Sensing for Crisis Response, and Assistive Technology.

At the Beaver Works Summer Institute final event, teams of students prepare to race autonomous racecars around an obstacle course in the MIT Johnson Ice Rink.

Students from the UAS-SAR course created an image of a covered space with a hidden pattern underneath by flying a small UAS around an enclosed room. The UAS was equipped with a radar that the students built and tested during the course.

One team in the Build a CubeSat course designed and built a prototype of a CubeSat that would inform people responding to oil spills about how to take action quickly and efficiently.

The Autonomous Air Vehicle Racing class completed an obstacle course race made of bridges and rings hanging at different heights in the air. Each team developed algorithms that allowed an Intel drone to autonomously navigate the race course.

The final BWSI event was the RACECAR grand prix which converted MIT's Johnson Ice Rink into an obstacle-filled racetrack. Students programmed RACECARs to navigate the track by using inertial sensors, lidar, and cameras.

This year's program included teams from Mexico and Cape Cod. In addition, teaching assistants from South Korea helped in several BWSI courses and will adopt the BWSI curriculum next year.

RACECAR Crash Course at BWSI

Technical staff member Andrew Fishberg developed an abbreviated RACECAR workshop for middle school students. Fishberg was worried that the BWSI program was reaching students too late in their educations to have maximum impact. "It only gets harder [to teach coding] the later you get to the students," he said. "This was an opportunity for middle school students to be exposed to the basics of programming, computational thinking, computer vision, and robotics." With the help of colleague Eyassu Shimelis and the Timothy Smith Network, Fishberg designed a four-week program to introduce middle schoolers to coding by programming racecars. Two dozen participants learned the basics of coding followed by actual work on a miniature autonomous racecar. "Basically everything they learn turns into the logic to drive the car," Fishberg said. "That application really drives home the learning objectives."

Middle school students learned coding by way of programming miniature autonomous racecars.

>> Educational Outreach, cont.

ROLL ROBOTICS

Robotics Outreach at Lincoln Laboratory (ROLL) is designed to stimulate youth interest in science and technology through hands-on robotics programming. Members of ROLL help to sponsor and coach robotic teams participating in regional and national competitions. The volunteers help children of all ages learn how to program robots to complete challenges specified by FIRST (For Inspiration and Recognition of Science and Technology). Participants in FIRST also perform research on a topic and engage in team-building activities. This year, students worked on space-themed challenges, which focused on problems involving space travel and living on the moon.

The Jr. FIRST LEGO League (Jr. FLL) students, in first to third grade, built a model made of LEGO elements with motorized parts and presented their work at an expo in December. FLL teams, for students in fourth to eighth grade, built an autonomous robot to perform the challenges thoroughly and accurately. FIRST Tech Challenge (FTC) teams consist of high school students who spend hundreds of hours designing their more advanced Android-based robots to perform autonomously and under driver control.

ROLL is just one way that the Laboratory is helping shape the next generation of scientists. “Kids often have a lot of engineering knowledge,” said Hemonth Rao, Jr. FLL team coach. “They just don’t know that they know it.”

During the first Astronomy Night, volunteers assisted budding astronomers in locating a nebula and taking several photos.

ASTRONOMY NIGHTS FOR KWAJALEIN COMMUNITY

While working and living on Kwajalein, Jessica Brooks created the Astronomy Nights program to introduce Kwajalein residents to the wonders of astronomy and foster the relationship between Lincoln Laboratory and the local community. Astronomy Nights are held once a month, as are special events such as scout nights, school events, and camping with the stars workshops, all of which use the Celestron CGX 1100 telescope with star-finder technology and a camera for astrophotography. This outreach team has also hosted an astronomy information booth at local STEM fairs, allowing elementary school students to learn how the telescope works. Sarah Willis indicates that plans are underway to train volunteers to become telescope operators and to add a solar filter capability to the telescope so the community can learn about the sun in addition to the stars.

REPUBLIC OF MARSHALL ISLANDS INTERNSHIPS

During 10 weeks with Lincoln Laboratory staff at the Kwajalein Field Site, two Republic of Marshall Islands (RMI) students, Naomi Mae Napa and Abraham Mea, completed a summer internship in information technology. The interns honed their abilities in computer management, server administration, and computer networking. Together, they used their new skills to build a backup server for Ebeye’s Health Center.

The annual internship program includes observations at and field trips to departments around the garrison. Upon program completion, the interns pursue higher education, volunteer their skills to the local community, or prepare for jobs in the information technology field. Napa plans to pursue a career as a business analyst, solutions architect, or information consultant for the RMI. Mea plans to take Cisco courses on Majuro Atoll. “I want to volunteer and use my repair knowledge, especially at the high schools,” he said. The interns expressed their gratitude, saying it was a very fruitful journey.

Lincoln Laboratory Instructor/mentor Ranny Ranis, left, and interns Naomi Mae Napa and Abraham Mea are this year’s RMI Information Technology Internship Program team.

Community Giving

ALZHEIMER’S SUPPORT

In June, 10 Laboratory cyclists took part in the annual Ride to End Alzheimer’s and raised $21,000—a team record. In September, the Laboratory’s 23-member walk team collected $33,455 and were recognized as the top fundraiser in the 2019 Walk to End Alzheimer’s in the Greater Boston area. Seeing this team’s success, and enthusiasm, Huntsville field site personnel were inspired to participate in their local Walk to End Alzheimer’s and raised $1,400 for the Alzheimer’s Association.

Staff walk and ride to help discover a cure for Alzheimer’s disease.

TROOP SUPPORT

Laboratory employees showed their support for U.S. troops by shipping 160 care boxes of food, toiletries, and clothing to soldiers stationed overseas.

The care packages and handwritten thank-yous included in them are much appreciated by recipients serving far from home.

KWAJALEIN MIA PROJECT

Helping to keep the oceans around the atoll clean, dozens of divers from the Kwajalein Scuba Club spent a day “splashing” for the cause.

Through the Kwajalein MIA Project (KMP), Phillip Davis and others contributed to efforts locating underwater crash sites of World War II aircraft. These sites may be the sea graves of American servicemen currently listed as missing. The team uses sonar to search the ocean floor and locate the sites. There are nine suspected wrecks, four of which have been located by the KMP project. Davis also helped organize an annual harbor cleanup, enlisting the help of Laboratory staff in Kwajalein’s dive community to collect trash from the bottom of the harbor.

STAR SPANGLED 5K

In late May, the Recent College Graduates employee resource group hosted their second annual 5K fun run. The event supported Troops First Foundation, which offers reintegration programs for wounded warfighters. Battle Buddies, which matches canines to wounded military veterans, was the main charity supported by this event. Organizers Emily Joback and Mark Gymiski agreed the day was successful: “We ended up with 104 runners and raised $2,600 for therapy dogs for wounded veterans. We’re so glad to help our veterans!”

Participants enjoy fitness and friendly competition while raising funds for veterans during the Star Spangled 5K.

GOVERNANCE AND ORGANIZATION

Laboratory Governance and Organization

MIT
Dr. L. Rafael Reif
President

Dr. Martin A. Schmidt
Provost

Dr. Maria T. Zuber
Vice President for Research

DoD Joint Advisory Committee
The committee annually reviews the Laboratory's proposal for programs to be undertaken in the subsequent fiscal year and five-year plan.

Dr. Milan Nikolich, Chair
Director of Defense Research and Engineering for Research and Technology

Major General William T. Cooley
Commander, Air Force Research Laboratory

Mr. James F. Geurts
Assistant Secretary of the Navy for Research, Development and Acquisition

Vice Admiral Jon A. Hill
Director, Missile Defense Agency

The Honorable Dr. Bruce P. Jette
Assistant Secretary of the Army for Acquisition, Logistics and Technology

Dr. Will Roper
Assistant Secretary of the Air Force for Acquisition, Technology and Logistics

Dr. Christopher Scolese
Director, National Reconnaissance Office

Dr. Steven H. Walker
Director, Defense Advanced Research Projects Agency

Ms. Kathy Watern
Executive Director, Air Force Life Cycle Management Center

Lincoln Laboratory

Eric D. Evans
Director

C. Scott Anderson
Assistant Director – Operations

Justin J. Brooke
Assistant Director

Melissa G. Choi
Assistant Director

Office of the Director

Israel Soibelman
Chief Strategy Officer

Robert A. Bond
Chief Technology Officer

Bernadette Johnson
Chief Technology Ventures Officer

Robert D. Loynd
Executive Officer and Chief of Staff

Chevalier P. Cleaves
Chief Diversity & Inclusion Officer

Deborah A. Valley
Safety and Mission Assurance Office

Dennis A. Burianek
Business Transformation Office

Kristin N. Lorenze
Program Management Office

J. Michael Menadue
Capital Projects Office

David R. Granchelli
Communications and Community Outreach Office

David Culbertson
Flight Test Facility

David A. Suski
Counsel

Service Departments

Contracting Services
Donald L. Vandeveer

Financial Services
Patricia O'Riordan

Information Services
Robert D. Solis
Chief Information Officer

Facility Services
Joseph Dolan

Human Resources
Brian S. Donahue

Security Services
Shawn S. Daley
Chief Security Officer

Advanced Technology

Robert G. Atkins
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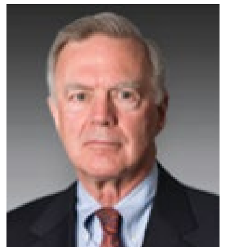

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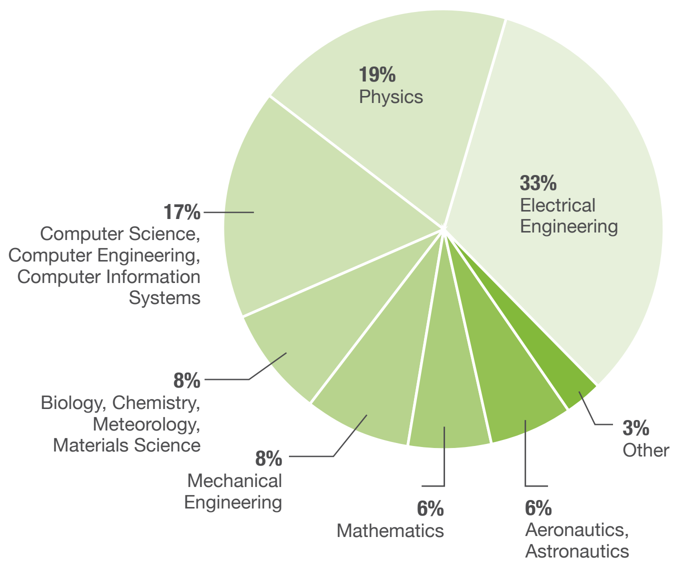
Staff and Laboratory Programs

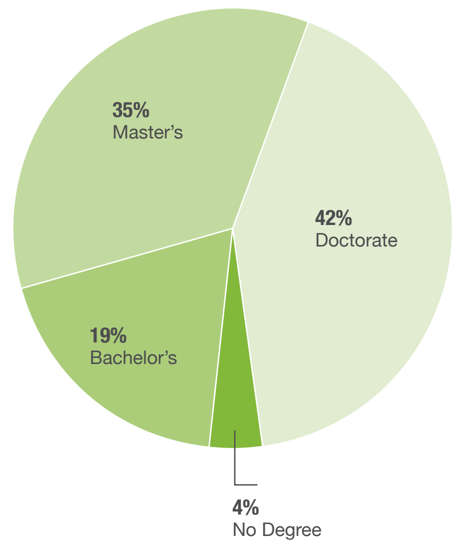
1820	Professional Technical Staff
1247	Support Personnel
479	Technical Support
510	Subcontractors
4056	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline



Academic Degree



Breakdown of Laboratory Program Funding

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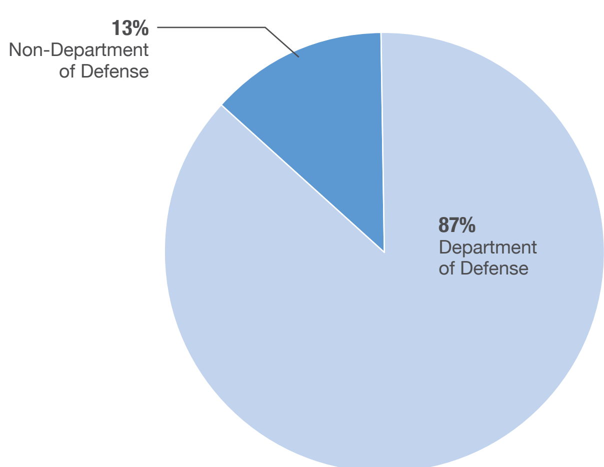
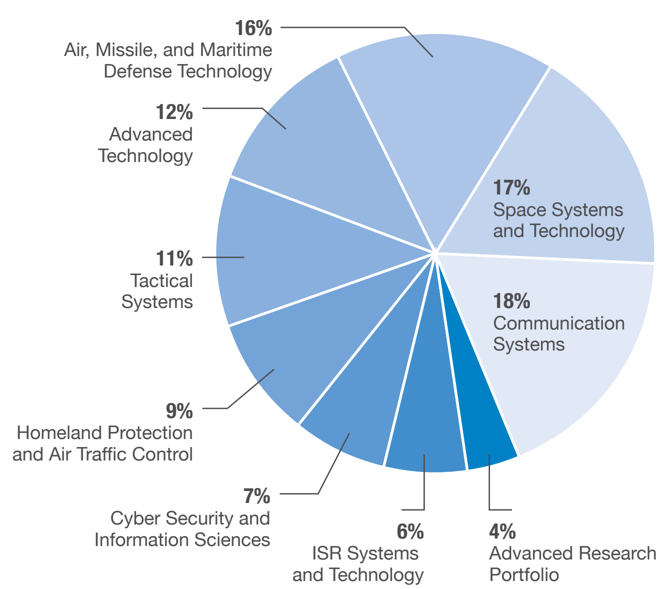


Mission Area



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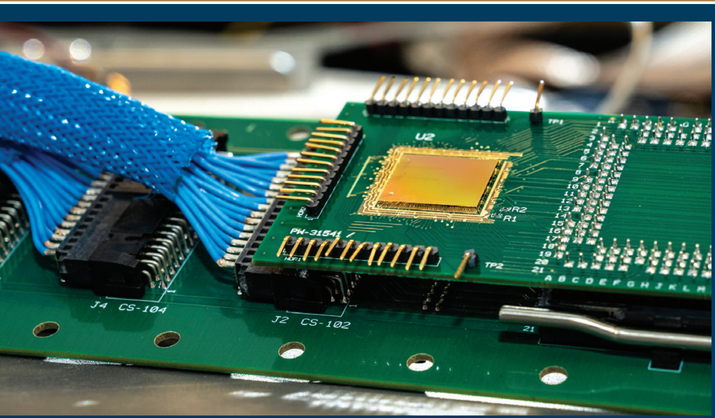

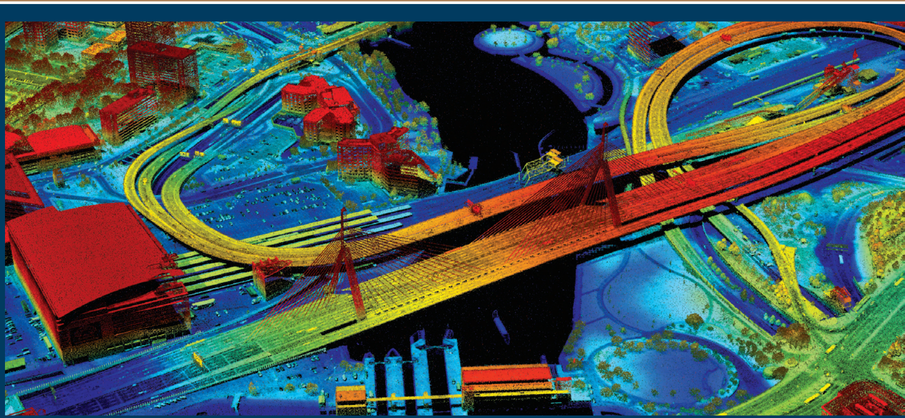

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY