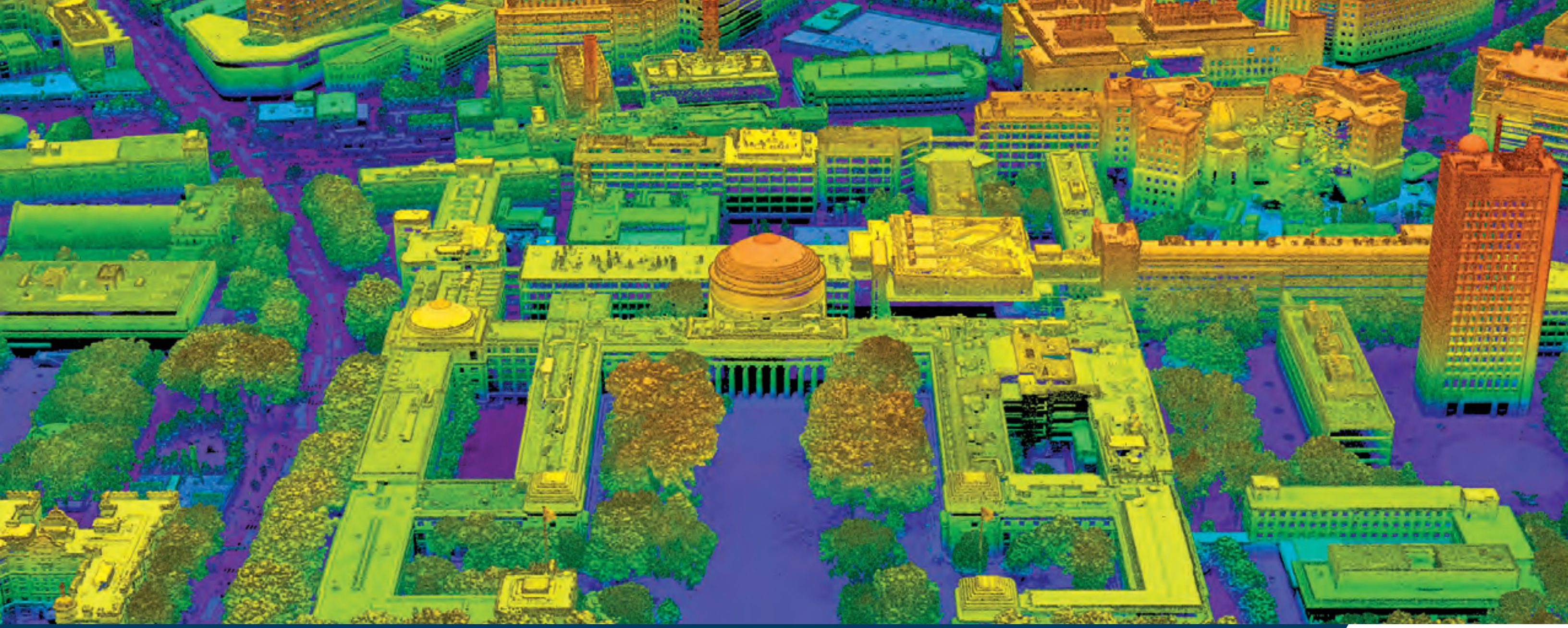
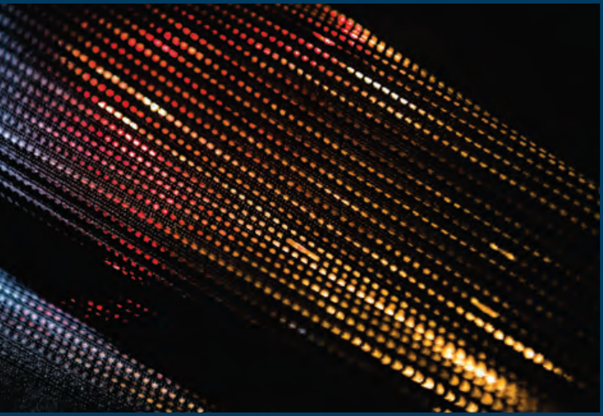
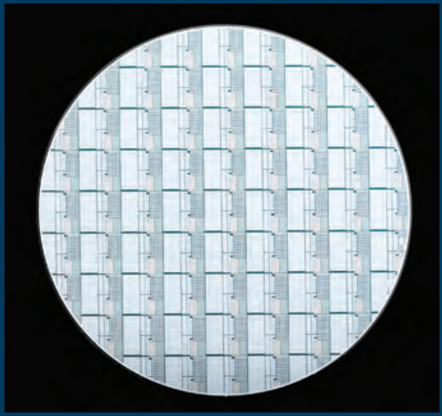
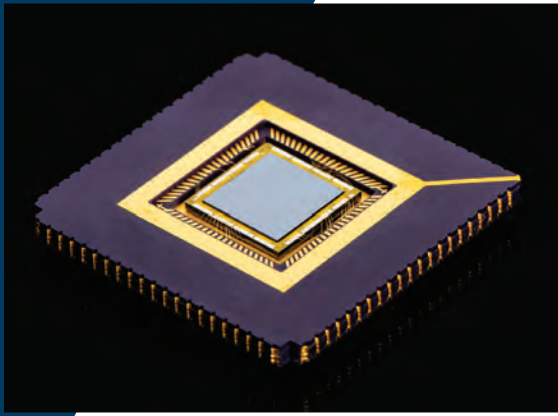




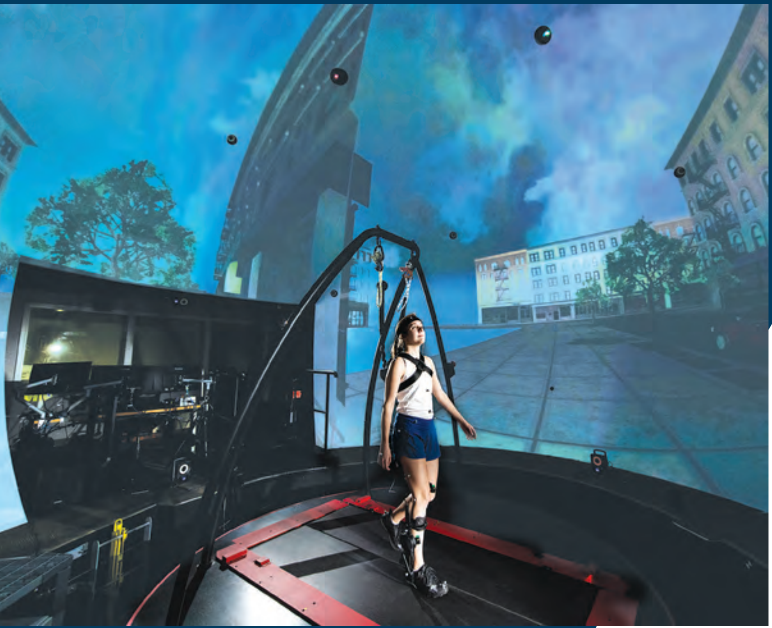




MIT LINCOLN LABORATORY

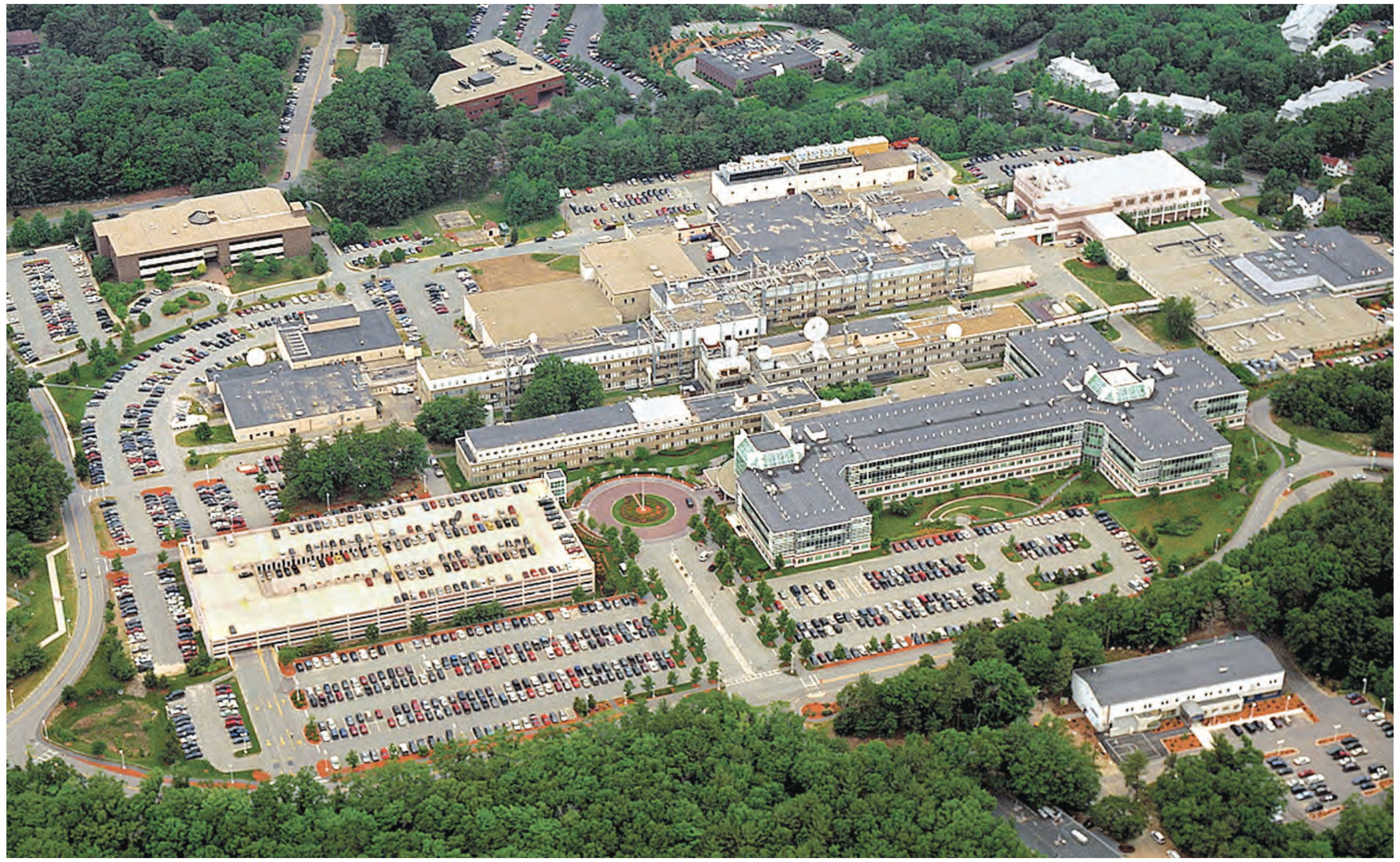
Technology in Support of National Security

2020
ANNUAL REPORT



Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts



MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2020

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 69 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

This year witnessed the impact of the COVID-19 pandemic on every aspect of our lives. Because Lincoln Laboratory was designated an essential service, we pulled together considerable resources to remain open and productive. We are proud of the effort and patience exhibited by every member of our community as we continued to develop advanced technology for national security. The significant undertaking of moving three quarters of our workforce to secure, remote operations; maintaining a safe physical environment for those who had to be on site; and sustaining administrative functions was made possible by the coordinated efforts of all technical divisions, service departments, and offices, and we greatly appreciate everyone involved.

Throughout the Laboratory, researchers looked for technologies and expertise that could be applied to counter the COVID-19 pandemic. Among these efforts were projects that explored methods for contact tracing, evaluated personal protective equipment, and predicted transmission spread. More about the research and development conducted to address aspects of the pandemic can be found in the feature article on pages 12 to 15.

We established a new division, Biotechnology and Human Systems, to address emerging threats to global and national security. The division is tapping the Laboratory's deep understanding of systems and architectures to develop advanced technologies designed to improve chemical and biological defense, human health and performance, and global resilience to climate change, conflict, and disasters. The new division consolidates work that was previously spread across several technical groups.

Our sponsored research and development continued to reach several milestones:

- We successfully integrated and tested the TROPICS Pathfinder CubeSat, which is equipped with an advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. The Pathfinder vehicle, built for the NASA Earth Venture Instrument's TROPICS constellation, is scheduled for launch in 2021.
- An integrated circuit with six billion transistors is bringing the flexibility of field-programmable gate arrays to digital focal plane imagers to transform Department of Defense imaging systems.
- We are applying artificial intelligence (AI) techniques to develop advanced sensors and algorithms that are aimed at ensuring robust performance of the Missile Defense System against ballistic, hypersonic, and other advanced missile threats.
- The Airborne Collision Avoidance System X (ACAS X) for manned aircraft was incorporated into international standards and is proceeding toward worldwide deployment.
- We transitioned the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), the most advanced U.S. airborne 3D foliage-penetrating lidar, to the U.S. Southern Command. MACHETE 2.0 achieves a five-fold increase in area coverage rate over its predecessor.
- Our instrumentation-grade terminals were used to make first contact with and calibrate the Department of Defense's Advanced Extremely High Frequency satellites AEHF-5 and -6.
- We developed methods that enable the ability to detect attempts to tamper with the security-critical components of a digital microelectronics circuit design.
- A prototype end-to-end system exploits AI techniques to detect hostile foreign narratives, classify accounts engaged in influence operations, and determine the most influential spreaders of disinformation.
- We developed lightweight composites, created with powders alloyed from metal and ceramic, to increase structural performance of 3D-printed components.

Throughout this annual report are descriptions of our diverse technical work, research collaborations, and involvement in communities. I encourage you to read more about the projects we completed during this challenging year. 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

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

Establishment of Biotechnology and Human Systems Division

Lincoln Laboratory established a division that will direct the Laboratory's unique expertise in system and architecture analysis, computer modeling, and system prototyping and field testing toward technology development that addresses current and evolving threats in the biotechnology area. To advance the nation's defenses against biological threats and its responses to health crises such as a pandemic, the division will expand upon its ongoing and growing work in the identification and early warning of pathogens, bioinformatics, molecular diagnostics, and synthetic biology. The division will also focus on R&D for improving human conditions on many fronts, such as therapeutics for diseases and disabilities, humanitarian assistance, rapid disaster response, and the impacts of climate change.

Edward C. Wack
Division Head, Biotechnology and Human Systems

Mr. Wack's career at Lincoln Laboratory has involved the development of a range of sensors, beginning with ones for weather satellites and moving into ones for biodefense. As Assistant Head of the Homeland Protection and Air Traffic Control Division, he helped develop the strategy for positioning the Laboratory at the forefront of the intersection of national security, life sciences, and engineering. He has also directed Steering Committee studies on combating global climate change and on pandemic preparedness and response.

Jeffrey S. Palmer
Assistant Division Head, Biotechnology and Human Systems

As the former Leader of the Human Health and Performance Systems Group at Lincoln Laboratory, Dr. Palmer had oversight of multiple research programs focused on health, human performance, objective neurocognitive analytics, and biosensing via wearable, ingestible, and implantable devices. He has extensive experience in biotechnology areas and has been instrumental on several COVID-19 response efforts with the National Institutes of Health and Mass General Brigham Center for COVID Innovation.

Christina M. Rudzinski
Assistant Division Head, Biotechnology and Human Systems

Dr. Rudzinski has contributed to many biological and chemical defense projects. Under her technical leadership, the Laboratory became nationally recognized for its subway threat phenomenology measurement expertise. As Leader of the Chemical and Biological Defense Systems Group, she expanded the Laboratory's traditional chemical and biological defense work into the counter-weapons of mass destruction (C-WMD) domain.

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

Dr. Viera is widely recognized as a national expert in integrated air defense systems and advanced capabilities, including infrared and radio frequency systems, electronic warfare, and ISR and tactical system architectures. He has contributed to many Air Force Red and Blue Team activities—integrating systems analysis, prototyping, instrumented field testing, and countermeasure assessment to develop capabilities and technology road maps. In his former roles as Assistant and Associate Division Head, he helped direct the Laboratory's research and development efforts in air vehicle survivability, system-of-system architectures, advanced airborne sensors, and intelligence and decision technologies.

Jennifer A. Watson
Assistant Division Head, Intelligence, Surveillance, and Reconnaissance and Tactical Systems

During her career at Lincoln Laboratory, Dr. Watson has contributed to several programs that advanced communications with undersea vehicles. She was involved in the design, fabrication, and test of antenna elements for a system to communicate with submarines at depth. She also worked on adaptive sonar beamforming for undersea surveillance systems and developed expertise in passive sonar processing. Prior to this appointment, she served as the Leader of the Airborne Radar Systems and Technology Group, in which she oversaw programs that developed advanced signal processing techniques.

Edwin F. David

Division Head, Engineering

In his more than 20 years at Lincoln Laboratory, Dr. David has conducted research and development on diverse sensors and systems. He led the development of advanced electronic attack architectures and prototypes for countering improvised explosive devices. As Leader of the Homeland Protection Systems Group, he directed efforts to develop system architectures, conduct technology assessments, and perform risk-reduction prototyping and demonstrations in support of missions such as maritime and land border surveillance, air defense and security, and airport security. During his recent tenure as Assistant Head of the Engineering Division, he oversaw the maturation of many technology initiatives, including programs in energy systems and autonomous systems.

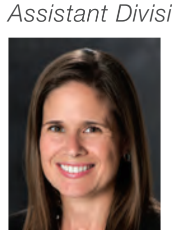
Keith B. Doyle

Assistant Division Head, Engineering

Dr. Doyle has made key contributions to major Lincoln Laboratory programs. For the Haystack Ultrawideband Satellite Imaging Radar upgrade, his analysis of the impact of diurnal thermal variations on RF antenna gain led to new control requirements for the system. His evaluation of expected jitter levels was instrumental in identifying the successful flight design for NASA's Lunar Laser Communication Demonstration. As Leader of the Structural and Thermal-Fluids Engineering Group, he oversaw technology advances in optomechanics, thermal management, aerodynamics, materials, and integrated modeling. In 2015, he received the SPIE Technology Achievement Award, and in 2018, he was presented with the Laboratory's Leadership Award for Advancing Organizational Culture, which recognized his efforts to create an inclusive workplace.

Kristin N. Lorenze

Assistant Division Head, Engineering



Ms. Lorenze formerly served as the Head of the Program Management Office, where she made advancements in Lincoln Laboratory's implementation of management and prototype development methodologies streamlined and tailored for an evolving R&D environment. Prior to her leadership in program management, she was an associate staff member in the Mechanical Engineering Group, focusing on electromechanical design engineering. During this time, she served as the Engineering Division's lead on the HSV-1 program. Currently, she is also a member of the Laboratory's Executive Diversity and Inclusion Council.

Heidi C. Perry

Assistant Division Head, Air, Missile, and Maritime Defense Technology

Having joined Lincoln Laboratory in 2018 as Principal Staff in the division, Ms. Perry led technology initiatives aligned to her division's strategic goals, serving as its Chief Innovation Officer and a liaison to both the Technology Office and the Technology Ventures Office. To her new role, she brings extensive experience in space systems, naval defense, biomedical systems, special operations, and energy systems. In her previous career at Draper Laboratory, she was responsible for technology development in guidance, navigation, and control systems; autonomous systems; communication systems; modeling and simulation; human-machine cognitive systems; and clinical decision support systems.

Christopher A. D. Roeser

Assistant Division Head, Homeland Protection and Air Traffic Control

Dr. Roeser has worked on a variety of systems analysis problems as part of the Laboratory's Air Force Red Team efforts. He is a nationally recognized expert in tactical infrared and RF sensors, electronic warfare, and integrated air defense. During his career at Lincoln Laboratory, he has made significant contributions to system-level assessments that have helped Department of Defense senior leaders understand foreign threats to U.S. aircraft. After serving in several group leadership positions, he transitioned to a senior staff position in the Advanced Technology Division, in which he applied a systems-level perspective to a broad range of R&D efforts and developed important new strategies for U.S. microelectronics, advanced fibers and fabrics, and artificial intelligence.

Jeffrey C. Gottschalk

Assistant Division Head, Cyber Security and Information Sciences

Mr. Gottschalk brings broad technical experience to his new role. His early work at Lincoln Laboratory was in RF technology. He went on to lead projects to develop new techniques and hardware for optical communications. After serving as an Intergovernmental Personnel Act assignee at the U.S. Air Force's Space and Missile Systems Center, he returned to the Laboratory in 2007 as an Assistant Leader of the Tactical Defense Systems Group, focusing on airborne countermeasures and test systems, and defining a cyber role for the Air Force Red Team. Since 2009, he has led groups in the Cyber Security and Information Sciences Division, helping to develop a broad cyber portfolio that has allowed the Laboratory to play a major role in architecting and delivering capabilities to the nation's Cyber Mission Forces.

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 R. Martinez

Dr. Martinez is recognized as a national leader in high-performance embedded computing; advanced signal processing; sensing technology for intelligence, surveillance, and reconnaissance (ISR) applications; and artificial intelligence (AI). His work in these areas has had significant impact on the development of systems for the U.S. Department of Defense and has contributed importantly to the research community.

During more than 30 years at Lincoln Laboratory, he led the development of unique high-performance embedded computing processors, the creation of the Laboratory's early road maps for decision support, the development of cybersecurity and cloud computing technology, and studies on the application of AI to national security challenges. He has served in several leadership capacities: Leader of the High Performance Embedded Computing Group, Head of the ISR Systems and Technology Division, president and chair at Mercury Federal Systems, and Principal Staff in the Communication Systems and Cyber Security Division. In 2013, he became the Associate Head of the Cyber Security and Information Sciences Division, where he spearheaded initiatives to advance research in AI.

Dr. Martinez is a Fellow of the IEEE, the coauthor of the seminal textbook *High Performance Embedded Computing Handbook*, and one of the originators of the High Performance Embedded Computing Workshop, now the IEEE High Performance Extreme Computing Conference.

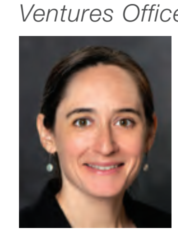
Daniel M. Marcus

Head, Mission Assurance Office

Mr. Marcus is focusing on ensuring that programs are supported by risk-informed decisions. He comes to Lincoln Laboratory from L3Harris, where he was the senior manager of mission assurance for the division specializing in high-precision optics and payloads for space. He was responsible for building the division's mission assurance organization, leading the deployment of procedures to assure the reliability, availability, and safety of systems.

Teresa A. Fazio

Ventures Officer, Technology Ventures Office



In this position, Dr. Fazio will contribute to the office's efforts to improve the process for transitioning technology to Lincoln Laboratory's government sponsors, to expand collaboration with small businesses and nontraditional companies, and to enhance intellectual property and licensing activities. Prior to joining the Laboratory, she served as an officer in the Marine Corps, worked in the technology transfer office of Columbia University, reviewed new technologies from U.S. universities and federal laboratories for a venture firm, and served on Johns Hopkins University Applied Physics Lab's Technology Commercialization Panel.

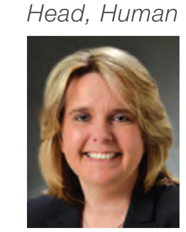
Alex W. Lupafya

Deputy Chief Diversity and Inclusion Officer

Mr. Lupafya joined the Diversity and Inclusion Office after working for 13 years at Staples, Inc., where he was responsible for building the organization's first ever Office of Diversity and Inclusion. He collaborated with the Staples leadership to implement a diversity and inclusion strategy for this global corporation of 16,000 employees in 26 countries. In addition, as Staples' head of charitable grants and its head of disaster response, he led multiple cross-organizational teams.

Kerry A. Harrison

Head, Human Resources Department



Ms. Harrison's experience in human resources spans areas that include employee compensation and benefits, wellness programs, professional development, and performance metrics. In 2001, she led the Laboratory's SAP HR/Payroll system implementation and its integration with MIT Campus. She has served on executive-level selection committees, task forces, and working groups. Currently, she represents the Laboratory on several internal and external advisory boards.

The ceremony marking the departure of N404PA from "active duty" as an airborne test bed drew roughly three dozen people who honored the aircraft's historical contributions to vital Lincoln Laboratory programs.

Lincoln Laboratory Bids Farewell to Its 707 Test Bed

On September 15, 2020, Robert Maynard piloted the last data collection flight of Lincoln Laboratory's flying test bed, a modified Boeing 707 aircraft. For 32 years, this aircraft, tail number N404PA, supported the Laboratory's development and testing of airborne systems. The 707 was being retired, and after flying 1,075 missions, the aircraft had one flight remaining—to Davis-Monthan Air Force Base, the boneyard for excess military and government aircraft.

On October 23, N404PA, was officially consigned to retirement at a ceremony held at the Laboratory's Flight Test Facility on Hanscom Air Force Base. At the event, Lincoln Laboratory's Director Eric Evans, its Assistant Director for Operations Scott Anderson, representatives from the U.S. Air Force, Federal Aviation Administration (FAA), and sponsor agencies came together to commemorate the retirement with staff who crewed N404PA or who worked on programs that relied on the aircraft's unique airborne capabilities.

Dennis Hamel, chief mechanic, accepts the Charles Taylor Master Mechanic Award for his many years of service to the aircraft maintenance industry.

In welcoming the guests, Evans acknowledged the contributions of the people who had employed N404PA to support the Laboratory's R&D: "The Laboratory teams who did prototyping and testing projects on this 707 aircraft have truly put some of the best new technology in the hands of the warfighter. We really appreciate what they all have done."

Retired Air Force colonel Niles Cocanour, who had been tasked in 2002 to build an Air Force team at the Flight Test Facility to demonstrate a multi-sensor command and control airborne test platform, gave a testimony to N404PA's value to R&D. Also acknowledging N404PA's importance to development programs was Colonel Jonathan Sorbet from the Air Force Nuclear Weapons Center. Col Sorbet oversaw the Family of Advanced Beyond-Line-of-Sight Terminals program, which was the tenant sponsor for N404PA since 2011. Also sharing remembrances of N404PA's uniqueness via a Zoom connection were Major General David Eichhorn (ret), who was the chief pilot on N404PA for 73 flights in the early 1990s, and Lieutenant General Chris Bogdan (ret), the chief Air Force pilot for the aircraft from 1996 to 1999.

During the event, David Culbertson, the manager of the Flight Test Facility, presented plaques honoring three current flight facility employees who have been involved with N404PA since, or nearly since, its arrival at Hanscom: Maynard, chief pilot; Dennis Hamel, chief mechanic; and Michael Kilkenny, engineering assistant. Hamel later accepted the Charles Taylor Master Mechanic Award from David Cardullo, the regional representative for the FAA; this FAA award recognizes an individual's 50 or more years of exceptional service to the aircraft maintenance industry.

David Kettner, the manager of the program for which the 707 was purchased in 1988, summarizes: "N404PA served her country as a flying electronics lab and served her well. For those of us that were involved as crew chiefs, flight crew members, and program staff, the association with the N404PA community gave us a shared and unique bond and great sense of pride and accomplishment—she will surely not be forgotten by those that touched her."

Dennis Hamel, chief mechanic, left, and Robert Maynard, chief pilot, right, are congratulated on their many years of service to N404PA by Scott Anderson, Assistant Director for Operations, Lincoln Laboratory.

> *"N404PA served her country as a flying electronics lab and served her well."*
>
> **David Kettner, the manager of the program for which the 707 was purchased in 1988**

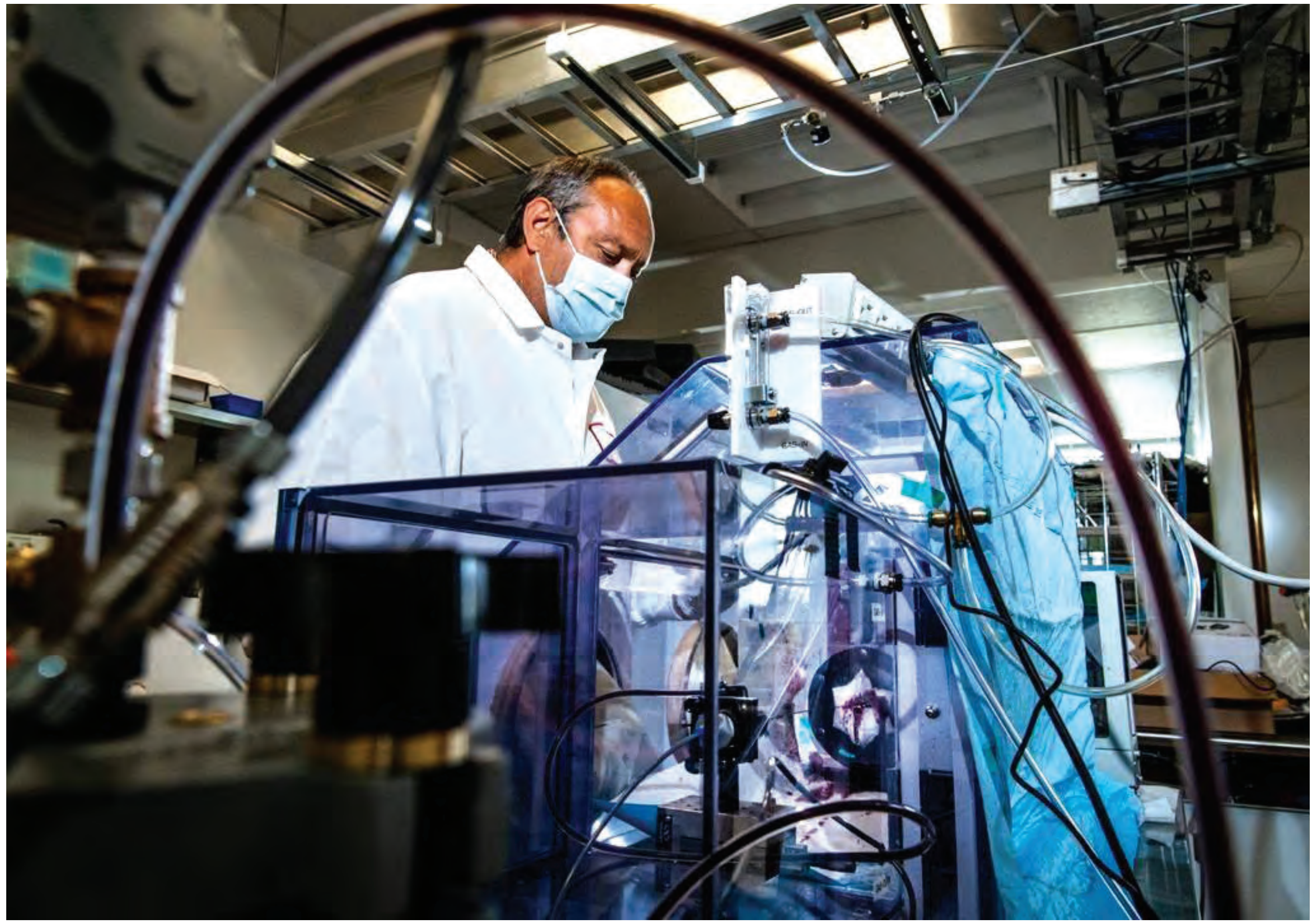
Director Eric Evans says goodbye to N404PA at the end of the retirement ceremony.

TECHNOLOGY INNOVATION 11

Lincoln Laboratory is exploring the use of various ions to perform quantum logic operations. This ion-trap chip holds a calcium ion and a strontium ion still as the qubits the ions house become entangled.

A Global Pandemic Demands Novel Technology

In 2020, the novel coronavirus disease, COVID-19, spread globally. As the outbreak surged in the United States in early spring, government sponsors sought Lincoln Laboratory's expertise in systems architecture and technology development to meet the unprecedented challenges of the pandemic. How to keep healthcare workers safe, how to monitor and inhibit the spread of infection, and how to predict the progression of the outbreak were among the most pressing questions. Below is a sampling of technologies that Lincoln Laboratory has brought to the national and global response to COVID-19.



Laboratory engineers rapidly built filtration and liquid-penetration test setups to gauge the effectiveness of foreign-sourced N95 masks.

Tracking Infections

Contact tracing is key to controlling the outbreak of an infectious disease. MIT Campus, Massachusetts General Hospital, and Lincoln Laboratory led the development of a framework called Private Automated Contact Tracing (PACT) that augments the manual tracing efforts of public health officials. The framework relies on short-range, anonymized Bluetooth signals emitted by and picked up by smartphones. People who test positive for COVID-19 can upload the signals their phone emitted in the past 14 days to a database, and other people can scan the database to see if any of those signals match the ones picked up by their phones. If there's a match, a notification will inform those who may have been exposed to the virus.

A PACT-like framework was integrated into Apple and Google's jointly created Exposure Notification System. The system has been enabled on millions of smartphones worldwide and has resulted in hundreds of thousands of exposure notifications. The system has been integrated into contract tracing efforts in several states, including Pennsylvania, California, Virginia, New York, and New Jersey, and in Washington D.C.

In the Autonomous Systems Development Facility, Laboratory researchers use robots to test the Private Automated Contact Tracing (PACT) mobile application and its ability to detect close, prolonged contact via Bluetooth with another PACT-enabled device. If a PACT user tests positive for COVID-19, that person can enable the app to alert other users of possible exposure, without revealing any personal information.

Closer to home, MIT leadership considered its own abilities to track infections and control outbreaks as students returned to campus in the fall. The MIT Quest for Intelligence and Lincoln Laboratory developed a situational awareness platform, called the MIT COVID-19 Response System, that models population densities in campus buildings, predicts the flow of people at entrance points, and identifies potential hotspots and infection risks. The system has helped MIT leaders make daily decisions regarding the health and status of the MIT community.

Surgical-grade N95 masks are inspected for seepage after being sprayed with synthetic blood.

Readying PPE

In early spring, the Laboratory conducted a study to estimate daily demand for personal protective equipment (PPE) for frontline workers in Massachusetts. The analysis was conducted for the Massachusetts Manufacturing Emergency Response Team (M-ERT) to guide local businesses' production of PPE.

To estimate totals, the team modeled the in-hospital demand that scales with the number of hospitalized COVID-19 patients, and the in- and out-of-hospital demand that must be sustained over the outbreak duration. They estimated a daily demand through November 2021 of approximately 300,000 N95 masks, two million glove pairs, one million surgical masks, and 100,000 surgical gowns. Carolyn Kirk, M-ERT executive director, hailed the Laboratory's analysis as providing a "vital public service."

The Laboratory also tested the quality of various foreign-sourced N95 respirator masks to help frontline workers avoid the use of faulty or fraudulent materials.

>> Continues on page 14

>> A Global Pandemic Demands Novel Technology, cont.

The tests, which measured filtration efficiency and liquid penetration, were conducted on hundreds of masks submitted by hospitals, first responders, and local governments, and the results were routinely published to the Massachusetts Department of Public Health's website.

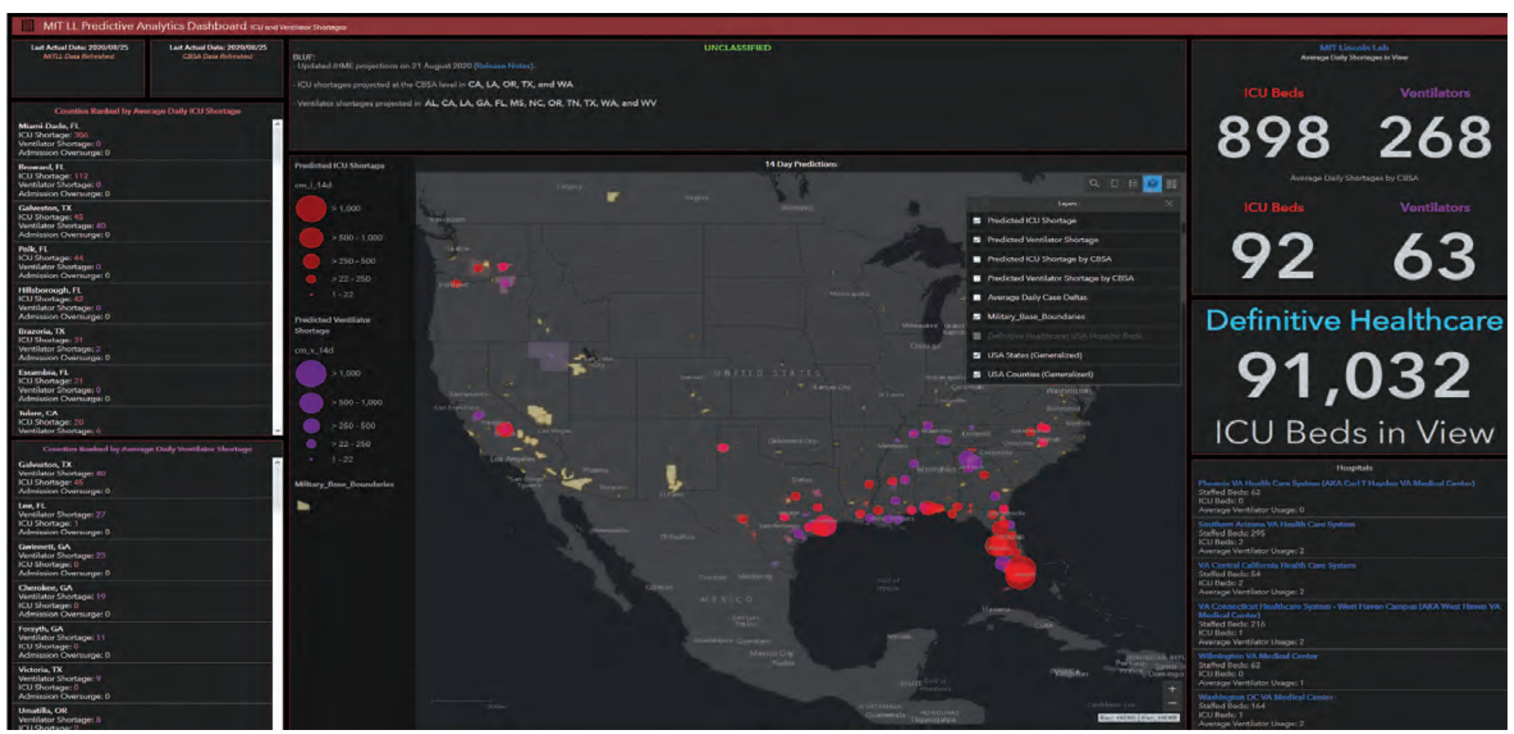
Predicting Outbreaks

As the federal response to the COVID-19 pandemic began to ramp up in early March, the U.S. Northern Command (USNORTHCOM) was deployed to provide medical staff to hospitals, construct healthcare facilities, and support logistics. However, the command soon found that they were deploying to locations that did not need their help. They reached out to the Laboratory requesting a capability to predict where an outbreak would occur and what resources would be needed there.

Within 24 hours, a team began building analytics showing outbreak predictors and healthcare capacity shortfalls in every county across the United States. These predictive analytics were delivered daily to the combatant commander, who used the data to reconfigure forces and proactively deploy them to locations in advance of regional outbreaks. The team also developed novel analytics to guide USNORTHCOM in the event of a multi-disaster environment, such as responding to hurricanes in a COVID-19-positive environment.

> *"Many of these efforts legitimately saved lives, identified areas of highest risk, and informed decisions at some of the highest levels of government."*
>
> **Jonathan Pitts, leader of the Humanitarian Assistance and Disaster Relief Systems Group**

Predicting and monitoring COVID-19 infections within the armed services has also been a national security priority. Today, wearable sensors can monitor service members' health to provide early warning of injury. In the era of the COVID-19 pandemic, wearable sensors are being investigated to determine if physiological status monitoring can provide early warning of SARS-CoV-2 exposure and COVID-19. A large number of ongoing studies funded by U.S. government agencies seek to quantify the use of wearables for an integrated early-warning capability. These studies are using a broad set of wearable devices, but share a common goal of developing artificial intelligence (AI) models for early warning of infection. These datasets represent an unprecedented collection of physiological data that can be used to answer many key questions beyond whether an individual is infected.



Analytics produced daily for USNORTHCOM show predicted ventilator and ICU bed shortages in the United States.

In collaboration with and under funding from the Defense Threat Reduction Agency, Biomedical Advanced Research and Development Authority, U.S. Army Medical Materiel Development Activity, and National Institutes of Health, Lincoln Laboratory has been building a platform to store and curate data and AI models from many of these ongoing studies. This platform is supporting the rapid development and validation of algorithms not just for providing early warning of COVID-19 infection, but also for detecting disease progression and recovery, and potentially for characterizing diseases and pathogens.

Mitigating Transmission

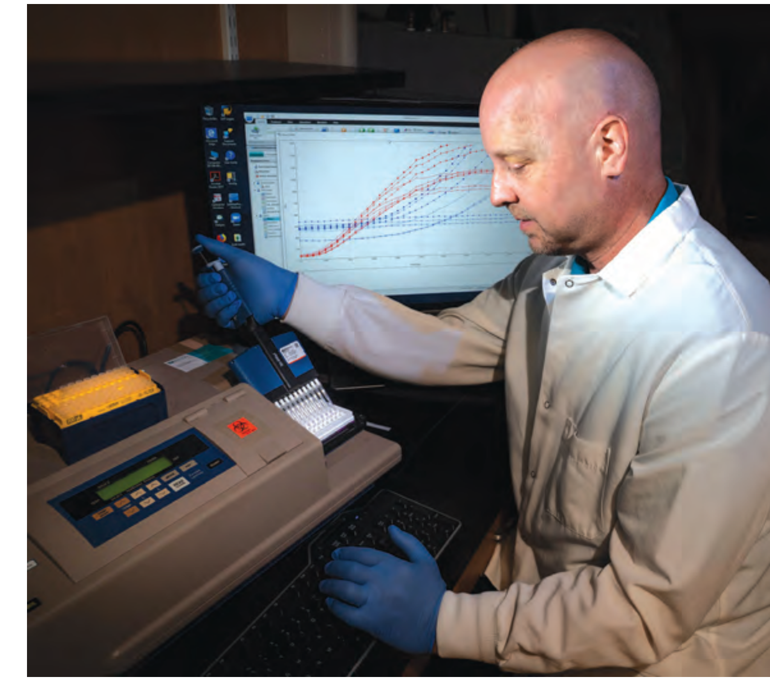
The aerosol hazards caused by COVID-19 respiratory therapies were identified as a key information gap in understanding virus transmission. To help quantify these hazards, the Laboratory collaborated with Tufts Medical Center to collect and analyze aerosol data. Air samples were collected during treatment of COVID-19 patients at Tufts Medical Center and analyzed for the presence of SARS-CoV-2 RNA at Tufts University. Aerosol measurements were initially collected from healthy participants undergoing these respiratory treatments to help guide sampling strategies. The team determined the spatial and size distribution of viral aerosols within a patient's room and characterized the infectivity of the aerosols. The research has helped clinicians evaluate risk during treatment and prioritize PPE usage.

The Laboratory is also working with the Department of Homeland Security Science and Technology Directorate to better understand virus transmission in public transit and to provide transit authorities with practical options for mitigating its spread. In a series of experiments, the researchers are disseminating safe viral simulants in various droplet sizes to mimic an infected passenger coughing or sneezing on buses and subway cars (occupied only by research staff). The particles are coated with DNA "barcodes" to allow the researchers to detect and track them in the air, on surfaces, and on clothing.

Through these experiments, the team is assessing the effectiveness of mitigation strategies, such as using different HVAC settings, opening windows and doors, and limiting occupancy levels. These tests are being conducted in partnership with New York City's Metropolitan Transportation Authority and are expected to be applicable to other transit systems.

Countering Disease

When a new pathogen emerges, identifying and validating medical countermeasures (MCMs)—drugs to treat a disease—can take months to years. In response to the COVID-19 outbreak, the Laboratory piloted a system under development with the Defense Threat Reduction Agency to speed MCM development, with a focus on restoring, sustaining,



A researcher uses a novel method, developed at the Laboratory, to rapidly screen drugs for their ability to inhibit the activity of SARS-CoV-2 enzymes necessary for viral replication.

and protecting warfighter health and performance. The goal of the program is to develop a systematic approach to rapidly identify, assess, and recommend MCMs to any new pathogen by focusing on screening MCM candidates that have already been FDA approved as treatments for other conditions.

Using the SARS-CoV-2 pathogen as a test case, the team prototyped a drug-candidate review pipeline and developed recommendations for actions to accelerate timelines. As part of this work, Laboratory researchers leveraged advanced DNA sequencing to generate large biological datasets. These datasets were used to develop a machine learning framework to answer biologically relevant questions about the pathogen and identify evidence to support inclusion or exclusion of candidate drugs for human studies. Candidate drugs were then analyzed to determine uncertainties, such as dosage, combinations with other drugs, or regulatory restrictions. In a related effort, the Laboratory applied a novel method for rapid, reproducible, and high-throughput screening of key molecular interactions to rapidly assess potential MCMs for efficacy in treating SARS-CoV-2 infections.

Because significant disease outbreaks are unpredictable, having an analysis infrastructure in place to rapidly identify MCMs is vital. The lessons learned from this project and the MCM identification system architectures will enable a more rapid and robust response to future pandemics while providing timely recommendations to address the current COVID-19 pandemic.

A Satellite's 44-Year Mission Ends

The longest continuously operating communications satellite in U.S. history, Lincoln Experimental Satellite–9 (LES-9), was decommissioned by MIT Lincoln Laboratory on 20 May 2020. The LES research team had monitored the satellite since its launch in 1976. The gradual reduction in available power coupled with the loss of the primary S-band telemetry data in early 2020 led to the decision to retire the satellite.

LES-9 and its jointly launched "sister" LES-8 were the last and most technically sophisticated of the systems developed under the LES program that ran from the early 1960s until the late 1970s. These satellites demonstrated the path forward for reliable communications among mobile users and for an expansion into very wideband RF SATCOM systems.

"The Lincoln Experimental Satellite program was a monumental technical achievement and created the architectural framework and technology foundation that has enabled the nation's military satellite communications systems," said David McElroy of Lincoln Laboratory's Communication Systems Division, who has been the principal researcher on many of the Laboratory's satellite communications (SATCOM) programs.

The Laboratory undertook the LES-8/9 program for the Department of Defense in response to national studies that had identified emerging Cold War–era threats that could jeopardize the connectivity of U.S. communication systems operating in remote areas.

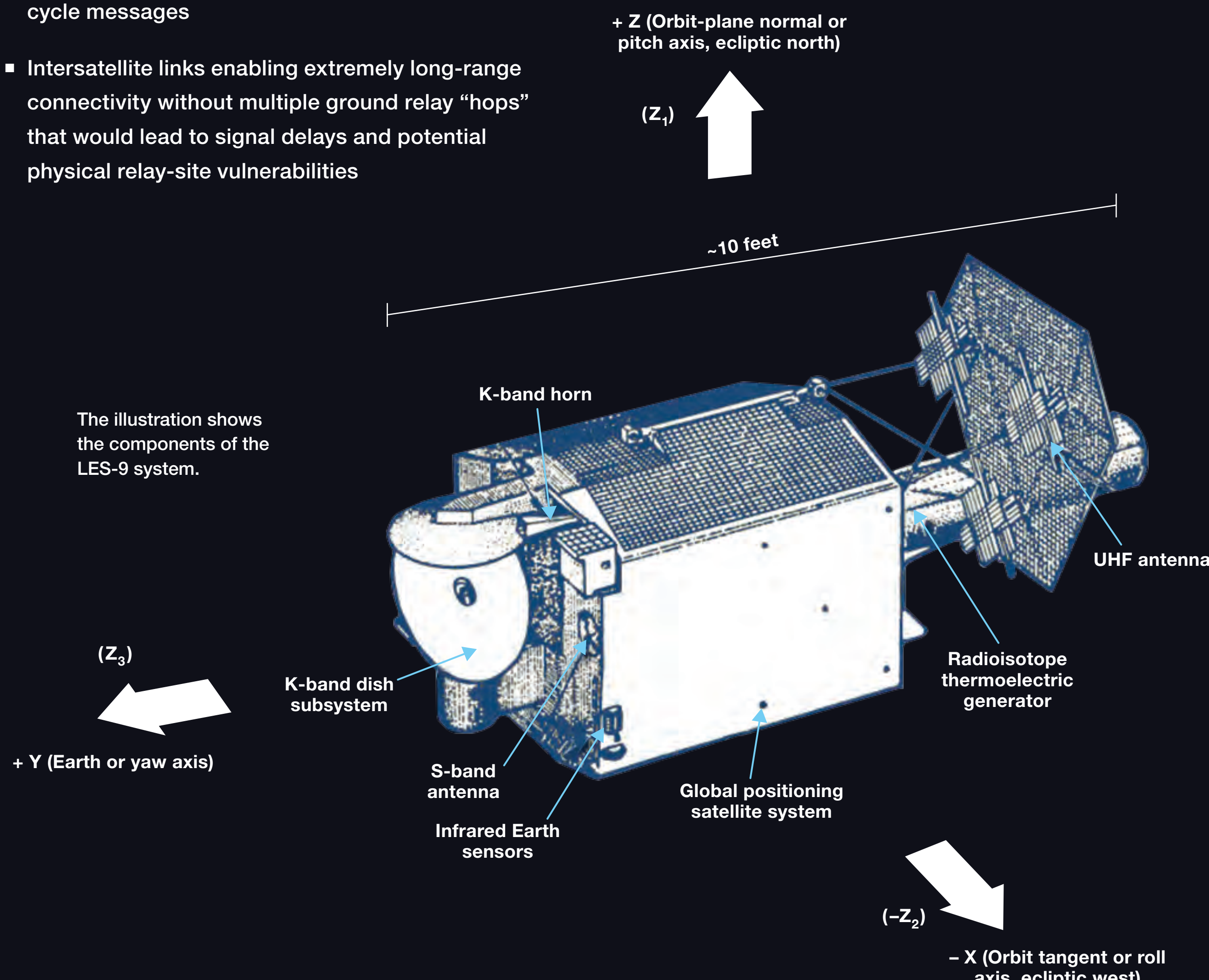
This image is an artist's depiction of Lincoln Experimental Satellite-9 in orbit.

The LES-8/9 vehicles along with their associated prototype terminals demonstrated the first use of several innovative concepts and technologies:

- Ka band for very wide bandwidths
- Extremely wideband, very fast, frequency-hopping, interference-mitigation spread-spectrum techniques
- Onboard digital processing and routing for the rejection of uplink interference and for effective use of satellite resources
- A new code-division multiple-access technique to allow a large number of asynchronous, bursty-traffic users to efficiently utilize bandwidth for low duty-cycle messages
- Intersatellite links enabling extremely long-range connectivity without multiple ground relay "hops" that would lead to signal delays and potential physical relay-site vulnerabilities
- Human-interface control panels that allowed staff to rapidly establish or change LES-8/9 communications configurations

In 2004, the functioning of LES-8's command system became intermittent and the satellite was decommissioned. LES-9 continued to provide reliable communications for uses such as email connectivity to stations on Antarctica.

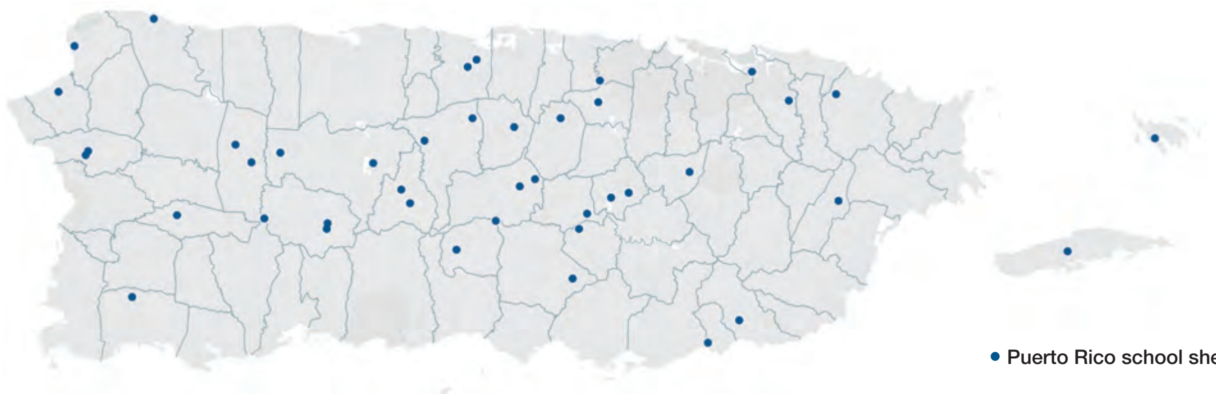
The decommissioning of LES-9 ended its record-setting employment, but the LES-8/9 development left a legacy of technological innovation.



The illustration shows the components of the LES-9 system.

A training session with local fire departments in Puerto Rico taught personnel how to set up the water system, including the onion tank pictured above. Below, the plumbing subsystem brings water from the tank to kitchen taps.

Above, water is pumped from a tank. At right, Laboratory researcher Brice MacLaren works with Red Cross and Water Mission staff to set up the system. Below, a map of Puerto Rico shows the 43 locations where the water system has been installed.



Cistern Systems Provide Clean Water Solution to Puerto Rico Shelters

Since Hurricane Maria's devastating toll on Puerto Rico in 2017, the American Red Cross has been collaborating with partners to improve water and power resiliency in state-run shelters on the island. Accessing clean water after Maria was a challenge for several reasons—water utilities shut off with power loss, ground water became contaminated, and road damage blocked aid from reaching isolated areas for weeks. To prevent water crises in the future, the American Red Cross called upon the Laboratory to identify or develop a resilient water system that could be deployed to shelters island-wide.

Laboratory researchers conducted a systems analysis to identify a solar-powered, low-cost, and low-maintenance system able to provide a sufficient quantity of emergency water. The team concluded that the best solution would be a temporary cistern, specifically a flexible, free-standing type called an onion tank, capable of holding 4,000 gallons of water. Two of these tanks would be stored at a shelter full time (folded up in storage) and brought out to be filled with utility water the day before a storm hits. Solar-powered pumps attached to the tanks would pressurize the water to deliver it to taps.

The team, including collaborators from the nonprofit Water Mission, visited nine shelters to investigate how the solution could be implemented at a range of sites and to gain feedback from shelter operators. While the original intent was for the tank to be tied into a facility's existing plumbing, doing so would require extensive plumbing modifications and could result in water losses from leaky pipes. The team instead designed a simple, isolated plumbing subsystem that would run water directly from the tank to kitchen taps and a public tap stand. The team also held training sessions to teach local fire departments how to set up the system.

As of 2020, the system has been deployed to 43 shelters across Puerto Rico. These shelters were identified by a Laboratory analysis as high-risk because of their geographical isolation and social vulnerability, which takes into account socioeconomic factors that may impact a community's ability to cope with a disaster. The system has also been integrated into the Puerto Rico Commonwealth Emergency Action Plan, ensuring that emergency staff are prepared to deploy the cisterns when a disaster is imminent.

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 Office of the Under Secretary of Defense for Research and Engineering and other government agencies. The Technology Office fosters collaborations with and supports university researchers, and aids in the transfer of next-generation technology to the Laboratory's mission areas. The 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)

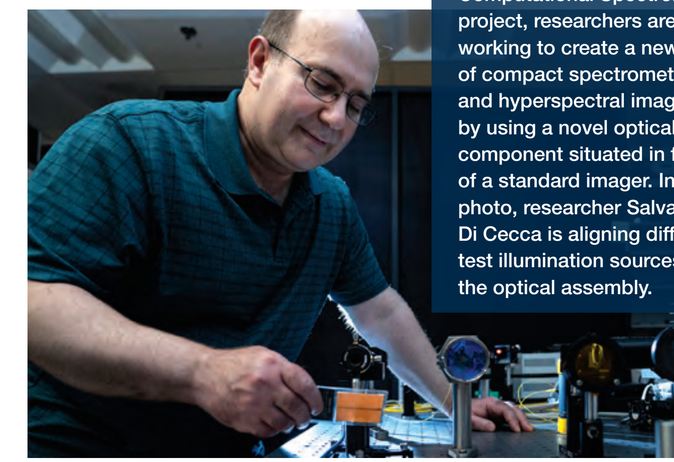
INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

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

Optical Systems Technology

Research into optical systems technology is central to enabling future mission capabilities in intelligence, surveillance, reconnaissance, and communications. The goal of this research is to fill critical technology gaps in emerging Department of Defense (DoD) threat areas. Projects emphasize research in ladar, high-energy lasers, imaging systems, optical communications, and novel optical components. In 2020, the Laboratory conducted several notable efforts in optical systems:

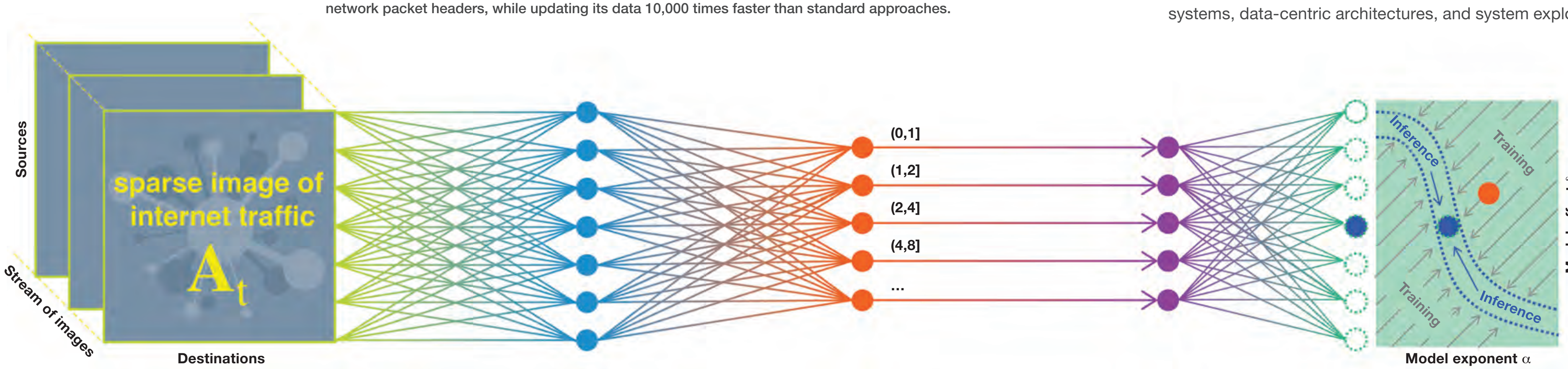
- Prototyped a spline-based freeform telescope using a patented non-uniform rational basis-spline (NURBS) system. The parallel-code implementation of the NURBS system gives it the computational power to handle designs of unprecedented complexity.
- Demonstrated the feasibility of long-range X-ray inspection using a test bed constructed from commercially available components.



In the Compact Solid Etalon Computational Spectrometer project, researchers are working to create a new class of compact spectrometers and hyperspectral imagers by using a novel optical component situated in front of a standard imager. In the photo, researcher Salvatore Di Cecca is aligning different test illumination sources onto the optical assembly.

- Prototyped a predictive adaptive optics technique to focus a laser operating on the ground onto a fast-moving object in orbit by pointing ahead of the object and compensating dynamically for atmospheric effects.

This figure illustrates a new approach to anomaly detection. Streams of internet traffic source-destination pairs are captured in sparse matrix snapshots, which are subsequently analyzed by machine learning algorithms to characterize normal and anomalous internet traffic patterns. Anomalous patterns (red dot) are identified by out-of-bounds model parameters (alpha and delta in the output) after the algorithm is trained on sample patterns. This system can analyze billions of network connections while using 3,000 times less storage than would be needed for standard network packet headers, while updating its data 10,000 times faster than standard approaches.



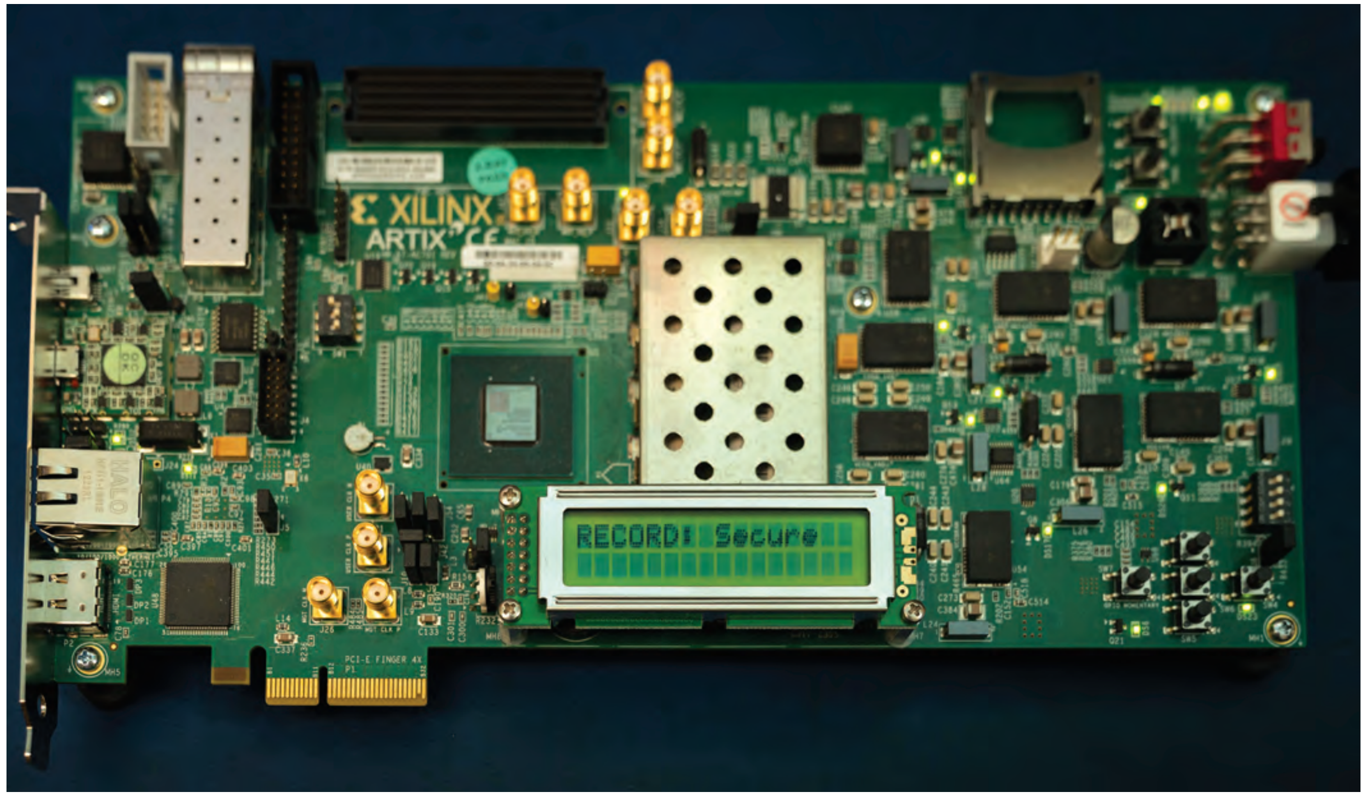
Cyber Security

All branches of the U.S. government, including the DoD, must continuously defend against diverse and persistent cyberattacks. Lincoln Laboratory conducts research and develops technology to secure, defend, operate, and ensure the resiliency of the nation's cyber systems. Starting with detailed understanding and analysis of cybersecurity issues, the Laboratory executes advanced security research across the full spectrum of the cyber problem space, from secure software and hardware architectures to innovative algorithm development and vulnerability characterization. In 2020, Lincoln Laboratory continued fundamental research in cybersecurity through the exploration and development of cybersecurity phenomenology, resilient systems, data-centric architectures, and system exploitation. Examples of this R&D are listed below:

- Applied machine learning and statistical techniques to characterize normal and anomalous behavior in global internet-scale traffic.
- Developed a novel technique to automatically discover and characterize buffer overflows, one of the oldest and most common types of computer bug. The technique used a new taint-based approach in which program variables are checked to determine if they can be modified by user input.
- Hosted the Artificial Intelligence (AI) for Cyber Security workshop at the 2019 Association for the Advancement of Artificial Intelligence Conference in New York City. This workshop's focus, and submitted papers, connected critical AI research to the cyber operational community.

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

Information, Computation, and Exploitation



Shown is a prototype of RECORD (Reconfigurable Edge Computing for Optimum Resource Distribution), a low-power self-reconfigurable processor that adapts its resources to minimize power consumption while securing the system during configuration and operation. RECORD is intended for deployment in environments where secure, long-endurance unattended computational capabilities are needed, such as remote monitoring systems.

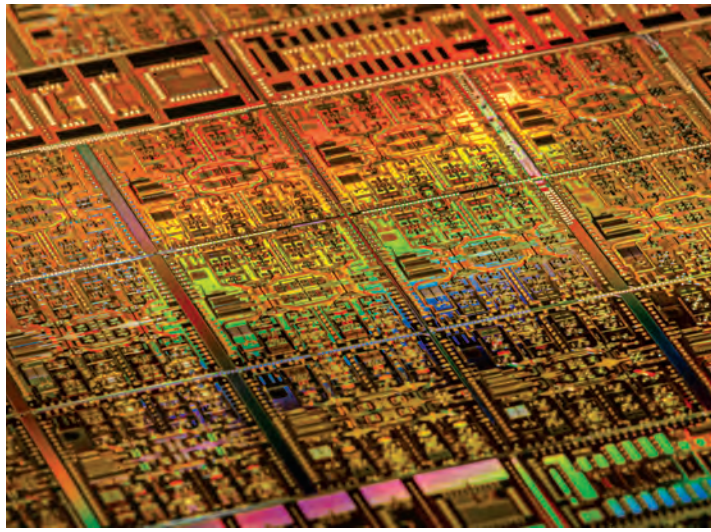
Research in the information, computation, and data exploitation (ICE) domains addresses challenges posed by the growth in both volume and variety of data used for national security and intelligence operations. The ICE research also seeks to apply emerging advances in AI technology to the Laboratory's established and emerging mission areas. Topics of current research are AI algorithms and workflows, novel applications, computing infrastructure, and approaches to advancing general-purpose AI engineering practices. Projects undertaken in 2020 included the following:

- Developed new techniques to highlight disinformation campaigns that are tactics of "gray-zone warfare." The work has been applied, most recently, to misinformation on COVID-19.
- Advanced reinforcement learning algorithms to enable the next generation of command and control that requires AI and humans to work together on the challenges posed by limited information, uncertainty, surprise, decentralized coordination, and imperfect control in dynamic and nonstationary environments with an adaptive adversary.
- Developed a new low-power, self-reconfigurable processor that dynamically adjusts power use, making it suitable for long-endurance and covert unattended deployment.
- Initiated prototypes on robust and resilient AI to align with DoD ethical AI objectives. Prototypes built include a deep learning algorithm with demonstrated robustness to adversarial attacks.

Radio Frequency Systems

Research and development in RF systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Emerging national security challenges include a rapidly expanding threat spectrum, the integration of sensors on platforms with constrained payloads, operations in strong clutter and interference environments, detection and tracking of difficult targets, and robustness against sophisticated electronic countermeasures. To address these mission requirements, research projects focus on next-generation phased arrays, wideband and compact systems, and advanced algorithms. The 2020 projects included some noteworthy accomplishments:

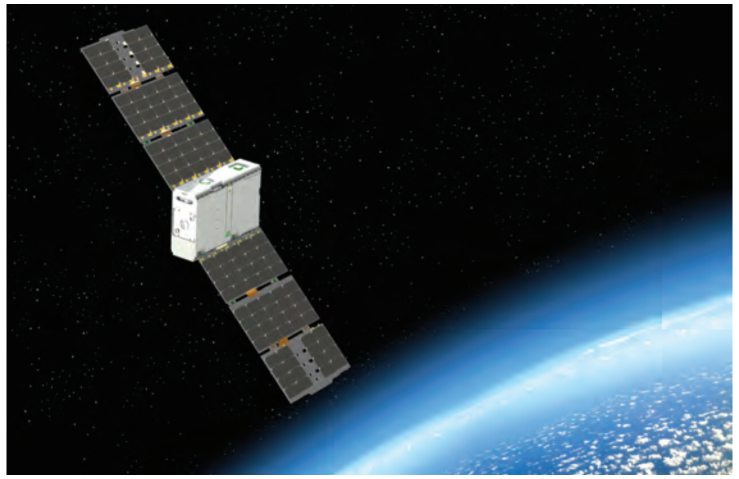
- Developed an eight-way test chip for a compact wideband (12 GHz) RF advanced spectral processor.
- Validated, using a scaled test bed, a communications jamming technique that allows blue forces to retrieve signals by applying a crypto-key while red forces remain jammed.
- Demonstrated improvements in synthetic aperture radar classification and remote sensing by employing a polarimetric interferometry image formation technique, with enhanced classification capabilities provided by a deep machine learning algorithm.



In 2020, the Airborne Radar Test Bed (ARTB) project successfully completed the design of components for an X- and Ku-band dual-polarized phased array panel, which will be the first of 10 panels combined to make an active electronically scanned array (AESA) composed of 2,560 active elements. The RF integrated circuit (RFIC), designed at the Laboratory, provides the core phase-control functionality necessary to enable the AESA beam steering capability. Shown in the photo is a wafer-level view of the RFIC that will be tested, diced, and assembled into the phased array panels.

Integrated Systems

Projects in the integrated systems category bring together scientists and engineers to 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. Several projects reached prototyping milestones in 2020:



The Agile MicroSat is being developed to demonstrate nanosatellite agility and autonomy to reliably maneuver and maintain low altitude. Satellite agility can be exploited to improve Earth remote sensing and space security missions. In 2020, significant progress was made on the subsystem engineering and bus design and procurement.

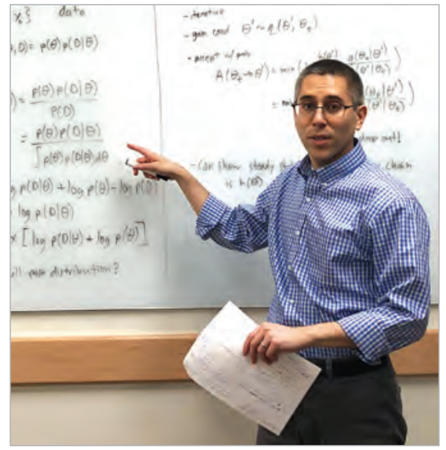
- Achieved sustained operation and beam extraction of an ion electrospray propulsion system for a wafer-scale satellite. This revolutionary spacecraft uses a stacked and bonded set of wafers (similar to the wafers used to manufacture integrated circuits) to provide full satellite functionality in a package that is 200 millimeters in diameter and 4 millimeters thick. The propulsion system allows the satellite to maneuver in space.
- Ground tested the world's first small-form-factor diamond quantum sensing 3D magnetometer, which may find application in GPS-denied navigation and directional magnetic sensing.
- Completed interim technology-mission analyses, including a trade study of an expendable undersea sensing platform and a technology performance requirements study of a lidar for littoral situational awareness.

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

Artificial Intelligence Initiatives

Artificial Intelligence Technology Group

In recognition of the strong potential for cross-cutting impact from advances in AI, a new group was formed in 2020—the Artificial Intelligence Technology Group. The group includes many of the Laboratory's top AI experts and reports directly to the Technology Office.



Michael Yee, a member of the AI Technology Group, shares his work on new methods for developing artificial intelligence programs. The AI Technology Group is bringing together a team of researchers from different backgrounds and perspectives to advance the state of the art in AI for national security.

Researchers in the new group are developing AI technologies to solve complex challenges facing the nation and the world. In close collaboration with the academic community, especially MIT, the group is working to define and advance the frontiers of applied AI. The group is also engaged in cultivating a leading AI workforce, both nationally and within the Laboratory, through classroom, online, and on-the-job training. The group has engaged in several notable early research projects:

- Rapid design and development of novel sensors, new materials, or medical countermeasures are critical to national security. The AI-Directed Experiment Design project is accelerating the design process by developing AI techniques for experimentation in complex and combinatorially large design spaces, in particular, for efficiently exploring properties inherent in biological molecular sequences and advanced material chemical structures.
- In collaboration with MIT, the group is working on developing cognitive AI assistants to provide support to aircrew in situations that require quick decision making under cognitive overload, especially when the crew are faced with dynamic unpredictable events. Work is underway to develop prototypes for an Air Force platform.
- The group is partnering with MIT to develop techniques to make AI more robust, explainable, and interpretable. A cross-functional team is building an AI toolbox that will have broad applicability to intelligence, surveillance, and reconnaissance (ISR), missile defense, and medical imaging; it will include tools for training AI to be robust to adversarial perturbations, common natural corruptions, and distribution shift.
- Training in AI for the DoD workforce has been identified as a critical need. Over the last year, the group has been involved in spearheading the development and delivery of AI courses to Air Force cadets, Air Force senior leaders and airmen, as well as the attendees of the Laboratory's annual Recent Advances in AI for National Security (RAAINS) Workshop.

The Mission-ready Reinforcement Learning (MeRLin) project developed an approach to training independent agents that enables them to coordinate and perform tasks to achieve mission goals. The ultimate objective of the MeRLin project is to demonstrate effective teaming between autonomous agents with humans of various skill levels for a variety of DoD missions. Pictured is Army GroundForce, a simulation environment for AI development in which agents can be trained to defend against incoming counter–rocket artillery mortar and unmanned aerial vehicle attacks.

Air Force–MIT Artificial Intelligence Accelerator

MIT and the U.S. Air. Force launched the AI Accelerator program to make fundamental advances toward improving Air Force operations while also addressing broader societal needs. Air Force personnel alongside MIT and Lincoln Laboratory scientists and engineers are drawing on interdisciplinary perspectives and disparate fields of AI to create new algorithms and solutions. Several ongoing projects, including the two described below, span a broad range of AI topics and applications.

The AI Accelerator is focusing on rapid deployment of artificial intelligence innovations for operations, disaster response, and medical readiness. The MIT–Air Force AI Accelerator kickoff with Air Force Vice Chief General Wilson was held in fall 2019 at the MIT Stata Center in Cambridge, Massachusetts.

- The FastAI project is addressing compute and data integration challenges. FastAI researchers are developing a new suite of compiler technologies, tools to simplify complex data integration tasks, and a revolutionary challenge problem to spur innovations in data management and datacenter analytics from academia, government, and small businesses.
- The Earth Intelligence Engine project will develop AI capabilities to advance weather and climate prediction in support of Air Force mission planning and long-term base planning needs. The team is working on establishing a data platform of curated earth systems data to facilitate collaboration and innovation from the larger AI community; designing weather and climate prediction algorithms that perform well even with sparse or missing data; and developing algorithms to generate "satellite imagery of the future" that visualizes the predicted impact of climate change.

RAAINS Workshop

The Laboratory hosted the inaugural RAAINS Workshop, which focused at a deeper technical level on recent state-of-the-art national security AI applications. The workshop engaged a diverse audience with excellent keynote speeches, presentations, interactive demonstrations, and three optional AI tutorial tracks.

At the RAAINS Workshop, David Martinez, Laboratory Fellow in the Cyber Security and Information Sciences Division, delivered a keynote presentation that covered a short history, present developments, and future outlook on AI for national security.

INVESTMENTS IN EMERGING TECHNOLOGY

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

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 year, an increased emphasis on human and team performance is being added to this portfolio to address DoD health and performance needs and gaps in commercial technologies. Existing Lincoln Laboratory infrastructure for device prototyping, supercomputing, biological experimentation, human performance testing, and electronic and optical measurement is critical to the success of this portfolio. In 2020, R&D in this domain achieved several milestones:

- Demonstrated genetic engineering of microbiome cells for sensing of gut molecules. Such sensing could be used in myriad DoD problems, for example, nutrition monitoring to disease sensing.
- Invented a new deep neural network method that estimates the uncertainty of an AI decision, allowing an "I don't know" answer, which is critical for augmenting high-impact medical diagnostic decisions.
- Prototyped and demonstrated a thought-activated speaker enhancement capability that can be used for intelligent hearing aids and other field-forward auditory attention problems.

Energy

Research in this area supports DoD energy needs, including remote power, advanced energy storage, in situ resource harvesting, and the sustainability and reliability of the national power grid. This year's work includes activities to address challenges such as advanced energy storage and novel platforms:

- Designed and built a customizable high-voltage battery architecture to extend the endurance of unmanned aerial vehicles by five to ten times the current duration.
- Analyzed and designed an unmanned underwater vehicle with a morphing hull that leverages neutrally buoyant fuels and fuel cells to extend endurance tenfold.
- Identified and prototyped intrinsically safe liquid fluorinated primary batteries with two to three times the energy density of traditional primary batteries.
- Prototyped and characterized a new form factor structural supercapacitor with high peak-power density.

A battery architecture and fabrication process was developed to enable a degree of customization not possible with current technology. In applications demanding a wide operating range over extreme conditions, this customization approach can in some cases improve performance by a factor of 10 or more.

TECHNOLOGY HIGHLIGHT

Interfacing with the Human Brain

Diffuse optical imaging methods noninvasively quantify activity in the brain by measuring near-infrared light that travels through the scalp and skull and interacts with brain tissue and red blood cells before traveling back. Properties of the measured light reveal aspects about brain metabolism, such as blood flow and oxygen utilization, which can be indicators of traumatic brain injuries.

While typical commercial systems make measurements from only a few locations and offer high temporal resolution (~5–10 hertz), they have poor spatial resolution (~2–3 centimeters) and a limited penetration depth (~1–1.5 centimeters beneath the scalp). Lincoln Laboratory's work on an optical imaging system improved the system's sensitivity to brain regions deeper than those imaged by commercial systems. The Laboratory researchers developed technologies that enable new measurement strategies, such as using longer wavelengths that scatter less when interacting with the brain and focusing on later-arriving photons that have traveled further into the brain. They are utilizing a neuroimaging technique known as functional near-infrared spectroscopy.

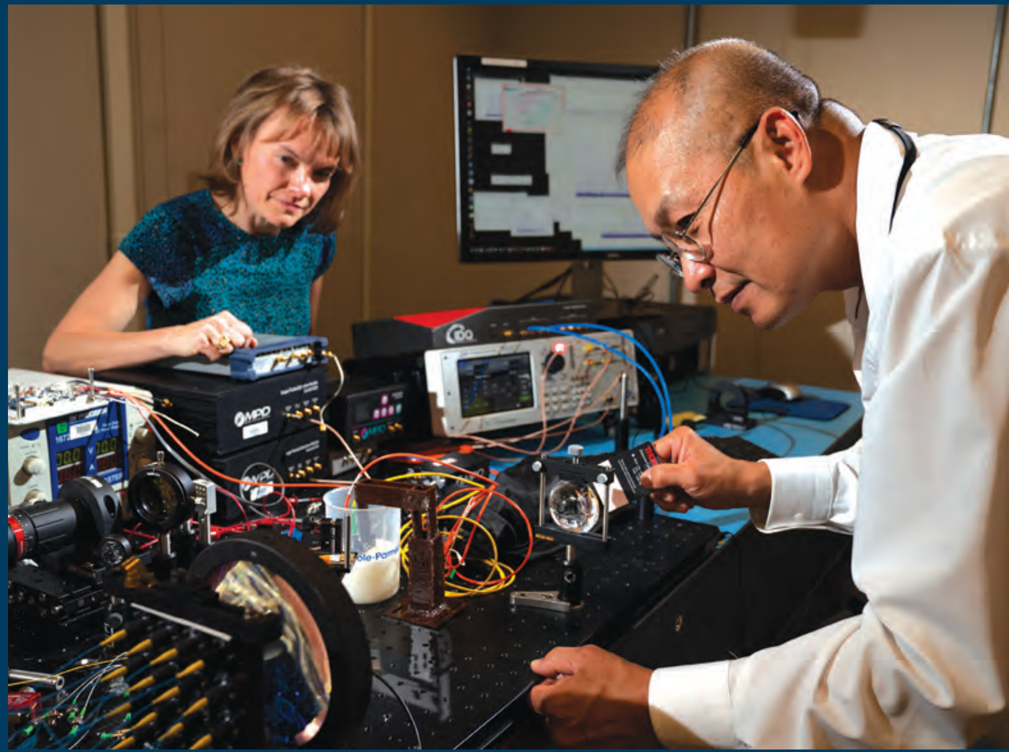
The Laboratory team and researchers at the Optics Division of the Martinos Center for Biomedical Imaging at Massachusetts General Hospital demonstrated that using a 1064-nanometer wavelength instead of the standard 750–850-nanometer wavelengths results in an approximately tenfold increase in delivered photons and enables interrogation of brain structures that are 25% deeper than those typically imaged. These advantages were demonstrated by

The vision of the Advanced Functional Near-Infrared Spectroscopy project is to create a wearable neuroimaging system that uses 128 laser sources and independent detectors to expand coverage and reach deep structures in the brain.

using photon-transport simulations implemented at the Lincoln Laboratory Supercomputing Center and validated with phantom measurements.

Human neuroimaging measurements require single-photon-sensitive detectors, such as the Laboratory-developed Geiger-mode avalanche photodiodes that have helped produce centimeter-scale relief maps of Boston, Haiti, and Afghanistan. However, neither these custom detectors nor commercial ones are sufficient to map activity deep within the human brain.

To overcome the limitations of existing detectors, the research team designed and fabricated a custom array, and is in the process of characterizing its performance. A follow-on grant by the National Institutes of Health BRAIN (Brain Research through Advancing Innovative Neurotechnologies®) Initiative is funding human-subject testing of the custom detector paired with novel laser sources, which were also conceptualized as part of this project. Ultimately, the goal is to demonstrate the first multichannel, portable system to advance neurocognitive monitoring for both military and commercial applications.



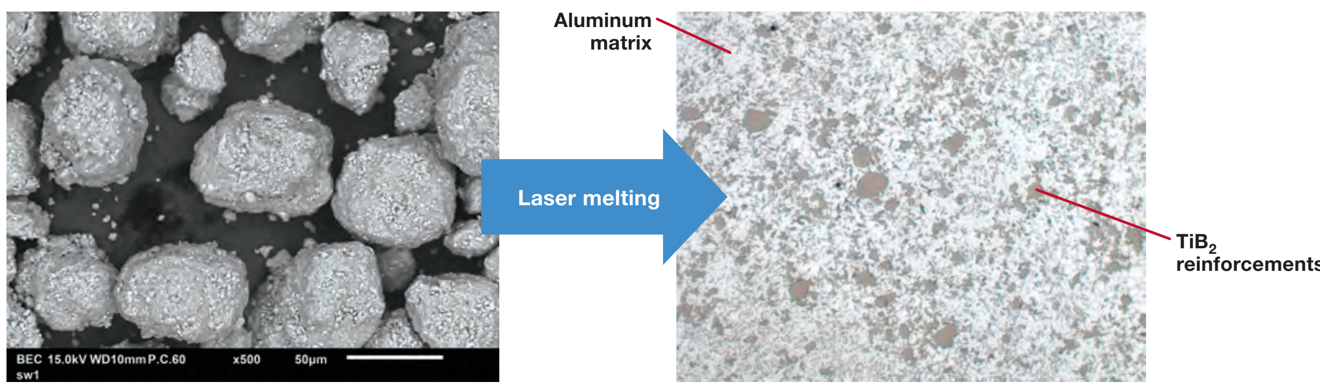
Cost-effectively expanding the brain coverage achieved by an optical imager requires moving to an array format. To develop custom, single-photon-sensitive detector arrays that overcome the limitations of commercially available systems, Megan Blackwell and Niyom Lue test the alignment of multiple beams on an array of avalanche photodiode detectors.

>> Investments in Emerging Technology, cont.

Advanced Materials and Processes

Research in advanced materials and processes seeks to invent materials and establish innovative processing capabilities to improve sensing, imaging, and manufacturing technologies for the nation. Efforts include the development of non-silicon electronic materials, advanced sensors, integrated microsystems, and advanced structures. In 2020, R&D in this area included several highlights:

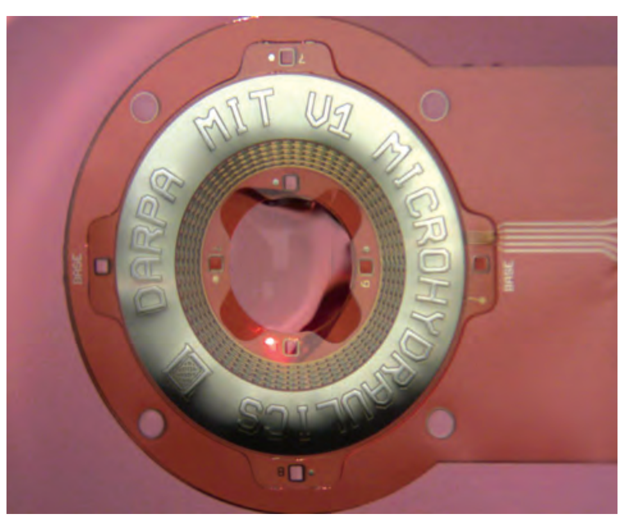
- Developed a new phase change metamaterial for ultra-fast shutters for lidar.
- Demonstrated enhanced nitrogen-vacancy center coherence times for diamond (30 times greater than commercial-grade diamond) used for quantum sensing applications. Long coherence time is a key determinant of sensor performance.
- Initiated a Materials-by-Design Initiative, which utilizes first-principles materials theory in tandem with materials synthesis, characterization, and mission analysis in a closed-loop process to facilitate the rapid development of new materials for vital national security goals.



The above pictures show the aluminum/titanium diboride (TiB_2) powder mixture before and after laser melting. The result is an aluminum composite with high ceramic content, which should result in superior specific stiffness. Stiffness is a key requirement for many mechanical subsystems, especially in cases such as optical payloads for satellites when vibrations and large environmental variability can challenge sensor 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, including RF technology, lasers, advanced computing, imagers, and microsystems applications. Projects realized significant accomplishments in 2020:



Pictured is a multilayer microhydraulic motor with an 8-millimeter diameter. This motor has more than 100 times the torque density of traditional inductive motors of similar diameters.

- Demonstrated world-record low contact resistance (0.45 ohms-millimeter) and DC power density (200 watts per millimeter) for diamond-based transistors. This class of transistor, once matured, promises to enable world-class power amplifier technology for future generations of radar and other devices.
- Demonstrated a world-class wideband (65-gigahertz) lithium-niobate integrated on nitrade (LION) modulator for a millimeter-wave photonic signal processor. The high bandwidth will allow the development of new, multifunction RF sensing and communication systems.
- Achieved high-energy X-ray sensitivity of ~60 kiloelectron volts with a germanium imager. This capability, once scaled, will support new applications in space science and other applications.
- Continued work on a computing technology that uses superconducting circuitry to perform machine learning with unprecedented power efficiency and throughput.

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 intelligent perception and decision-making algorithms, multi-agent systems that include the human-machine team, platform technology, and the challenges of verification and validation. In 2020, the Laboratory made novel accomplishments in autonomy:

- Prototyped an adaptive, human-aware AI teaming algorithm and benchmarked the performance of a human-machine team in a DoD-relevant scenario. Initial results show reduced human workload and improved performance.
- Developed and demonstrated risk-based counterfactual reinforcement learning algorithms that enable teams of expendable robots to execute cooperative tasks in hazardous environments. Performance was shown to surpass state-of-the-art multi-agent learning algorithms.
- Prototyped and transitioned to the Army a mission specification language for heterogeneous teaming applications.
- Designed and fabricated an 8-meter (25-foot) technology demonstrator ocean-going sparse aperture sonar array to demonstrate high-resolution mapping of the seabed from the ocean surface.

Researchers deployed the technology demonstrator of an undersea mapping sparse sonar array. This array (24 × 24 feet) is a surface-based, distributed multiple-input, multiple-output sparse aperture sonar designed to support deep ocean floor mapping with a resolution two orders of magnitude greater than what is currently achievable.

Engineering

The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of advanced prototype systems. In the engineering area, technological investments are made in new tools and processes with the potential to enable new applications and to provide cross-cutting prototyping capabilities with broad applicability to Laboratory mission areas. In 2020, several efforts complemented this diverse portfolio:

- Developed a capability based on neural networks that significantly reduces alignment times for complex optical systems. This capability was demonstrated with both refractive and reflective telescope hardware configurations.
- Developed a guidance, navigation, and control software suite to replace the low-cost controllers typically furnished with unmanned air vehicles. The suite provides attitude control, path guidance, and visual-inertial sensor fusion, and allows the incorporation of custom algorithms to support specialized missions.
- Implemented and integrated an open-source finite element analysis capability into the Laboratory's suite of structural, thermal, and optical analysis tools. This capability takes advantage of the Laboratory's supercomputer to provide more rapid and thorough multidisciplinary design optimization.

>> Investments in Emerging Technology, cont.

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

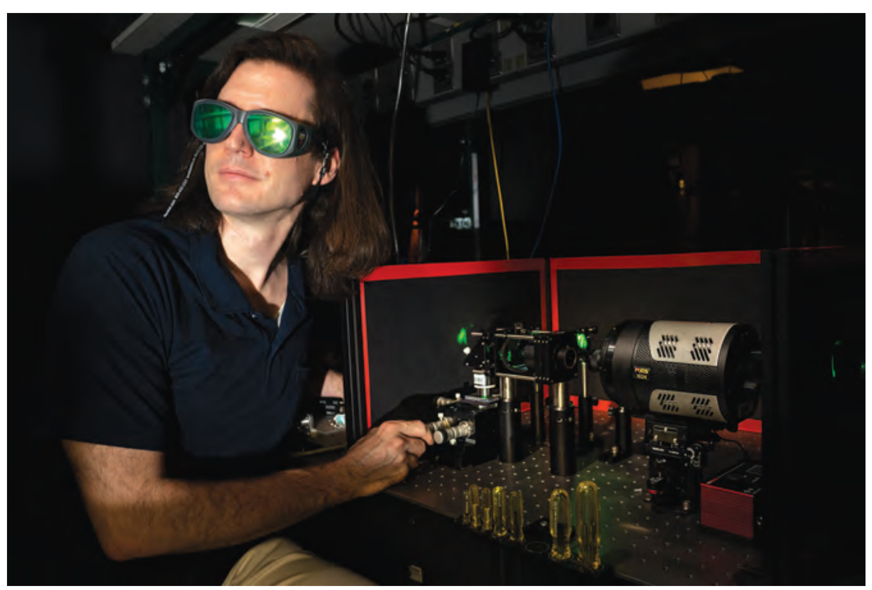
Investments in these areas emphasize foundational research and infrastructure development needed to produce advanced capabilities applicable to a diverse set of critical national security needs. Investments support solutions to national challenges in air and ground transportation, land border and maritime 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. Highlights from 2020 include the following projects:

- Continued the development of disease simulants and the quantification of pathogen-containing aerosol collections. This work enabled quick-turn collaborative efforts to determine COVID-19 hazards created during critical care procedures.
- Developed test beds to evaluate enhancements to the Federal Aviation Administration's automation systems, future concepts such as urban air mobility, and the use of unmanned aircraft to collect meteorological observations.
- Conducted phenomenology collection and analytics to inform a novel system for providing early warning of earthquakes.

Quantum Systems and Science

Quantum systems can enable significant advances in sensing, communication, and computing capabilities. The Technology Office is investing in the next generation of these technologies, beyond the nearer-term focus of commercial efforts. In 2020, significant progress was made on a number of projects:

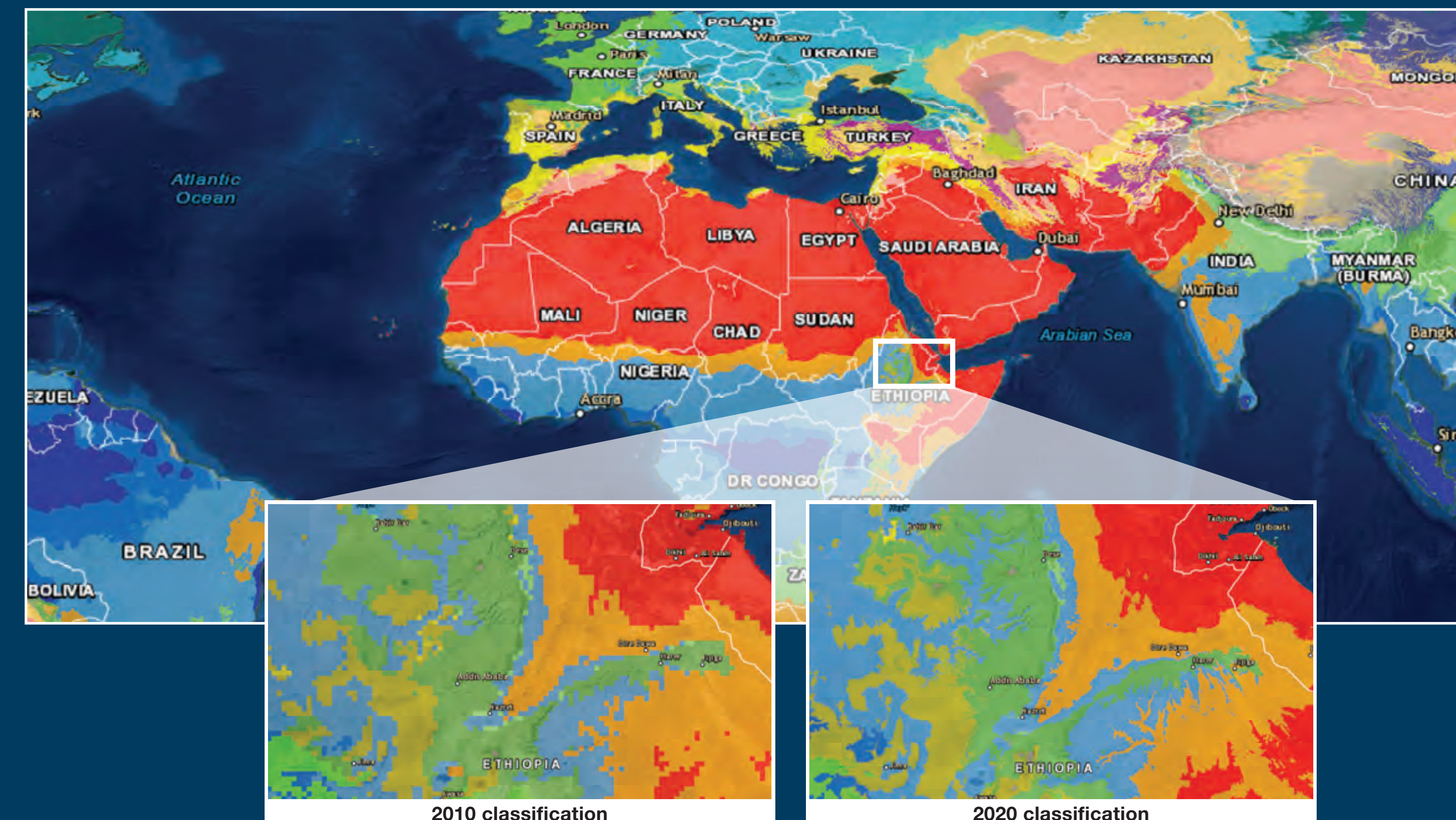
- Continued test bed demonstrations of free-space and fiber quantum networks. This year, the team implemented a quantum repeater to achieve coherence (i.e., storage) times required for space-to-ground quantum links. Lincoln Laboratory, MIT, and Harvard University are collaborating to demonstrate repeater operation over optical fiber that links all three locations.
- Developed analytics and simulations to explore quantum computing architectures based on measured experimental data. This research explores how metrics, such as number of qubits, gate fidelity, and connectivity, impact the optimal circuit designs for many target quantum algorithms.
- Prototyped and integrated componentry for a compact optical atomic clock, achieving stabilities comparable to atomic clocks that are orders of magnitude larger. This revolutionary clock is made possible by using an ultra-stable laser that probes quantum transitions in a trapped 88Sr+ ion.



Defect centers in diamond provide an attractive means of achieving a quantum repeater. Because the quantum memory function in diamond is realized via small crystal defects in which two adjacent carbon atoms are replaced by a silicon atom, a confocal microscope was developed to scan a diamond sample and locate and register quantum memory defect center candidates. Each memory center is carefully characterized to determine its coherence time prior to the fabrication of optical and RF interconnects required to interface the quantum repeater to fiber or free-space channels.

TECHNOLOGY HIGHLIGHT

Climate Initiative at Lincoln Laboratory: EarthPulse



As can be seen in the comparison of a section of Ethiopia above, the new models greatly increase the resolution of regional climate-zone models and reveal new details about the local ecosystems. These maps can detect unexpected micro-climate changes and provide alerts in real time.

The EarthPulse project was initiated to provide stakeholders with real-time alerting and reporting on the impact of climate change and its potential to cause abrupt transformations to ecosystems and their ability to render essential goods and services.

In 2020, the research team developed models to produce a high-resolution updated global climate-zone classification system. Using the latest temperature and precipitation measurements gathered from more than 130,000 weather stations globally, Lincoln Laboratory generated a 2019–2020 climate-zone model at 1-kilometer resolution. The most recent global climate zone classification that is free and publicly available was produced in 2010 at a resolution of 10 kilometers. In the new model, a global 30-meter-resolution digital elevation model was used to account for the effects of altitude and topography on climate.

These new models furnish superb detail to reveal micro-climates and the effects of altitude on climate. In addition to this high-resolution global climate–zone classification system, the EarthPulse project produced global models providing indices of human alteration, land cover and land use, biogeographical regions, seasonality and humidity provinces, night lights, population density, travel cost friction surfaces, and remoteness. All of these models were used together to predict the best locations on Earth to serve as "pulse points" for future persistent remote sensing.

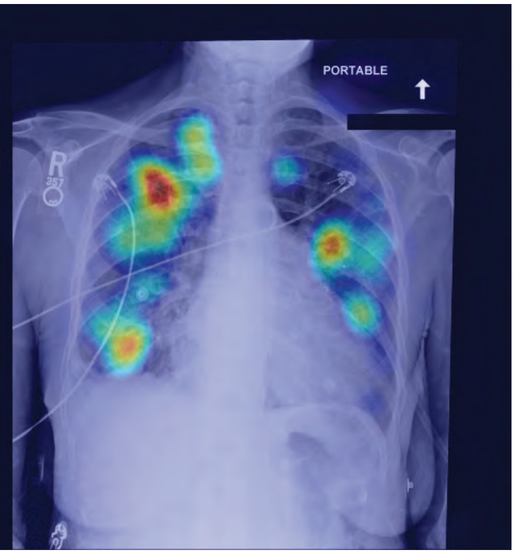
INVESTMENTS IN INNOVATIVE RESEARCH

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

Advanced Concepts Committee

The Advanced Concepts Committee (ACC) provides funding and technical and programmatic guidance for the development of basic and applied technology concepts that address important technical problems.

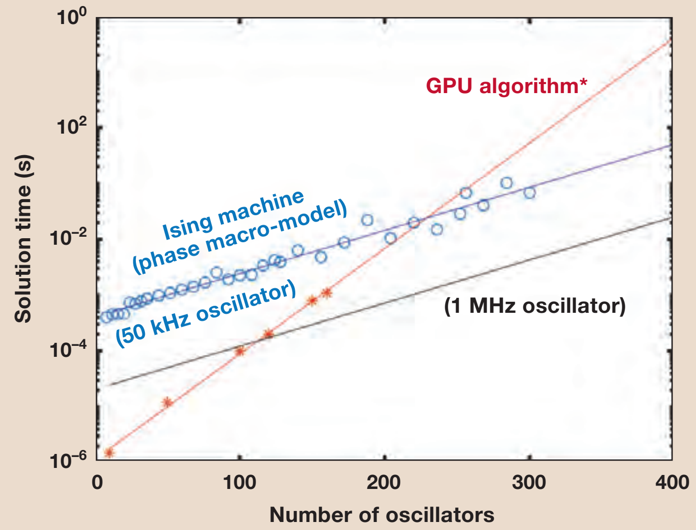
The ACC funds a breadth of highly innovative, high-risk research that, if successful, has the potential for significant impact on the Laboratory's mission areas.



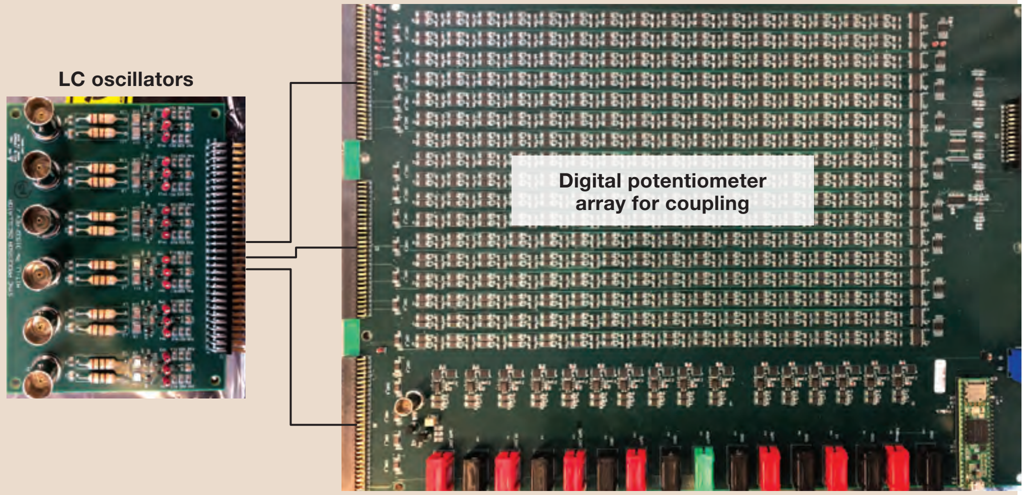
In 2020, the ACC invested in a collaboration between Lincoln Laboratory and the MIT Computer Science and AI Laboratory to develop deep learning methods for automatically assessing the severity of illnesses, such as pulmonary edema, on the basis of chest X-ray images. Specifically, self-supervised and contrastive learning approaches are used to provide better predictions from unlabeled data. Shown is a sample chest X-ray image in which the algorithm has highlighted the areas that are at high risk of pulmonary edema.

Seedlings

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



The Sync Processor, an analog computing system with coupled electronic oscillators, is capable of solving complex combinatorial optimization problems. This computational approach enables solutions to problems that are traditionally difficult to solve with standard computing architectures, and has the potential to provide orders of magnitude reductions in time to solution for large-scale implementations.



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

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 2020, the office hosted the Technology for Advanced Fibers, Fabrics, and Extruded Elements (TAFFEE) challenge. This challenge was hosted in conjunction with the Defense Fabric Discovery Center (DFDC), whose expertise was leveraged to mature the competing proposals and to assist in the proposal evaluations.

Lincoln Laboratory staff were asked to submit their ideas to an online crowdsourced tool known as the Ideation Engine. A downselected subset of the initial concepts was presented at an event during which the projects were "pitched" and teams were formed. The top ideas were then refined and shared with the Technology Office Advisory Group and the DFDC in a formal proposal presentation.

The winner of the TAFFEE challenge was the Wearable Triboelectric Generator. Under this concept, the static electricity generated by human motion is harvested to power electronics embedded in advanced fibers that can be woven into clothing.

Invited Speakers

The Technology Office hosts more than 20 seminars throughout the year to spark curiosity, creativity, and collaboration at the Laboratory. The speakers are renowned in their respective fields, and the seminars cover a broad range of topics and perspectives.

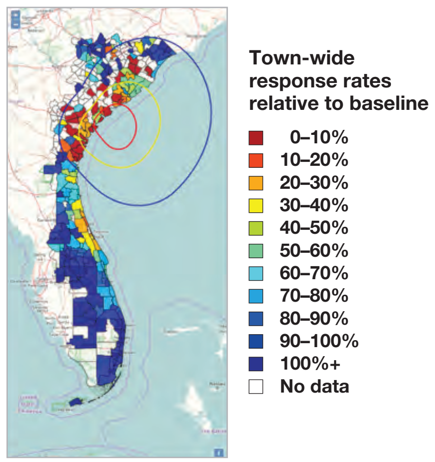
Jason Yosinski, the co-founder of Uber AI Labs, presents his seminar *AI Neuroscience: Can We Understand the Neural Networks We Train?*

R&D 100 Awards

R&D World magazine presented 2020 R&D 100 Awards to eight technologies developed by Lincoln Laboratory researchers, either solely or in partnership with other organizations. These awards recognize 100 groundbreaking technological innovations developed by research institutes and companies worldwide and introduced during the prior year. From hundreds of nominees, the winners are selected by an international judging panel composed of editors from *R&D World* and technical experts from academia, industry, and national laboratories.

Cyber Sensing for Power Outage Detection

A system that uses data on internet traffic to rapidly estimate and map the extent and location of power outages across geographic boundaries.



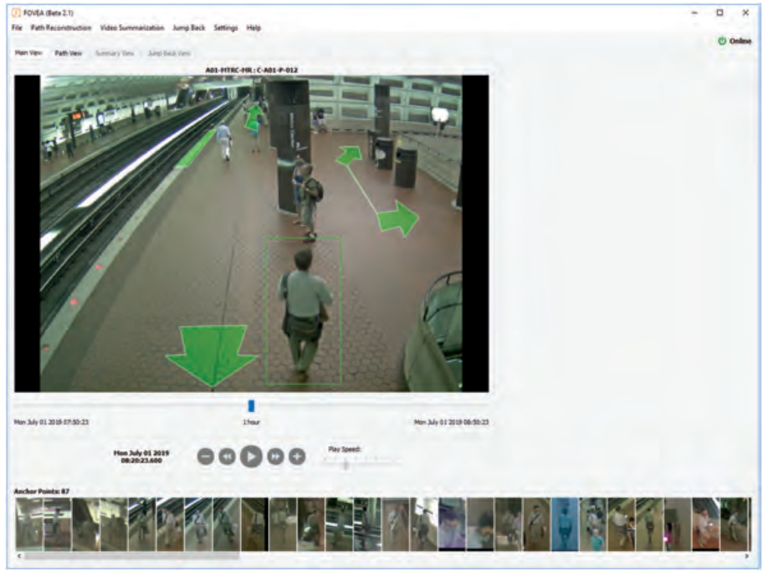
LINCOLN LABORATORY TEAM: Kendra Kratkiewicz, project lead; Joaquin Avellan, Christopher Budny, Stephanie Foster, and Adam Norige

Defensive Wire Routing for Untrusted Integrated Circuit Fabrication

Techniques that deter an outsourced foundry from maliciously tampering with or modifying the security-critical components of a digital circuit design.

LINCOLN LABORATORY TEAM: Timothy Trippel, project lead; Kevin Bush and Matthew Hicks

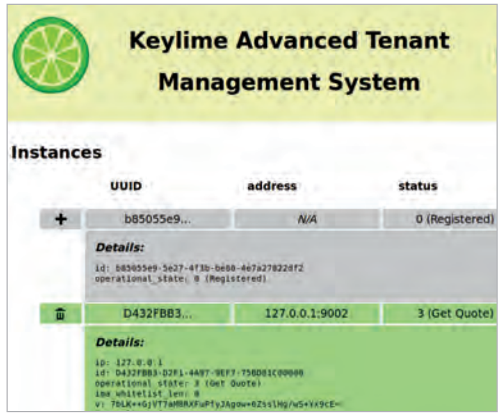
Forensic Video Exploitation and Analysis



A suite of tools that enables users to efficiently analyze video captured by existing large-scale closed-circuit television systems.

LINCOLN LABORATORY TEAM: Marianne DeAngelus and Jason Thornton, project leads; Jesslyn Alekseyev, Kimberlee Chang, Ronald Duarte, Zach Elko, Heather Griffin, Brett Levasseur, Taylor Sherer, and Marc Vaillant

Keylime



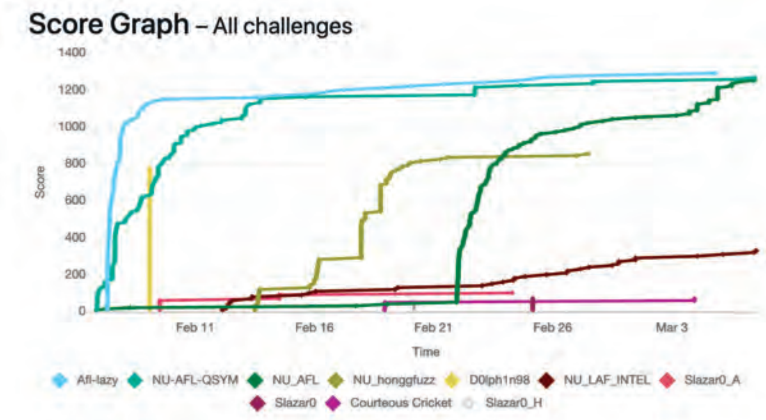
An open-source key bootstrapping and integrity management software architecture that is designed to increase the security and privacy of Edge, Cloud, and Internet of Things (IoT) devices.

LINCOLN LABORATORY TEAM: Charles Munson and Nabil Shear, project leads; Patrick Cable, Joseph Cooley, Michael Depot, Martine Kalke, Timothy Meunier, and Bryan Richard

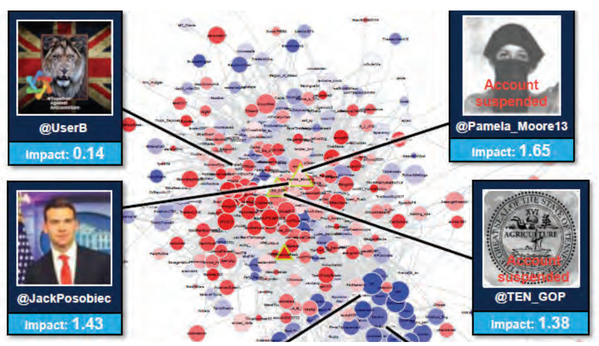
Large-scale Vulnerability Addition

A technique that injects numerous bugs into a program at known locations and constructs triggering inputs for each to create ground truth for evaluating bug-finding systems.

LINCOLN LABORATORY TEAM: Andrew Fasano and Timothy Leek, project leads; Patrick Hulin and Ryan Whelan. NEW YORK UNIVERSITY TEAM: Brendan Dolan-Gavitt, project lead, and Engin Kirda. NORTHEASTERN UNIVERSITY TEAM: Andrea Mambretti and Wil Robertson. U.S. ARMY: Frederick Ulrich



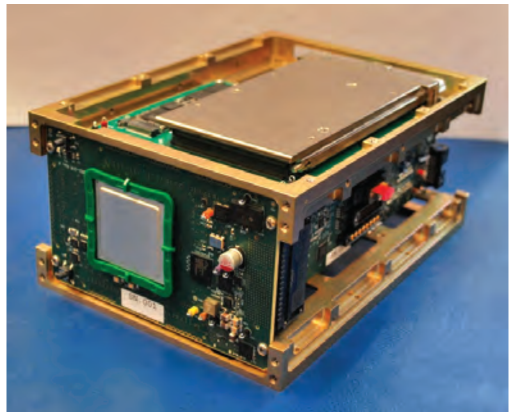
Reconnaissance of Influence Operations



A software system that automates the detection of disinformation narratives, networks, and influential actors to address the growing threat posed by adversaries using social media for political objectives.

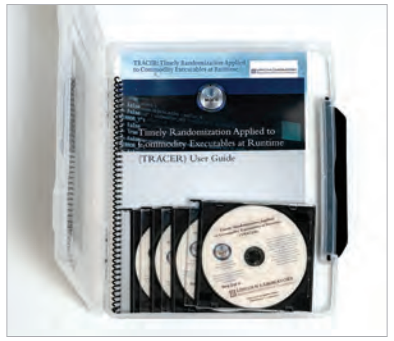
LINCOLN LABORATORY TEAM: Steven Smith, project lead; Edward Kao, Erika Mackin, Paul Metzger, and Joseph Zipkin. HARVARD UNIVERSITY: Donald Rubin

TeraByte InfraRed Delivery



An optical communications technology that enables error-free transmission of data from low Earth–orbiting satellites at a rate of 200 gigabits per second.

LINCOLN LABORATORY TEAM: Don Boroson, Curt Schieler, Bryan Robinson, and Jade Wang, project leads; Bryan Bilyeu, Joshua Brown, Robert Buchanan, Jamie Burnside, Jessica Chang, Steven Constantine, Ajay Garg, Farzana Khatri, Jacob La Rocca, Ryan Little, Robert Reeve, Kathleen Riesing, Ninoshka Singh, and Jeffrey St. Hilaire



Timely Randomization Applied to Commodity Executables at Runtime

A technique that protects Windows applications against cyber attacks by automatically and transparently re-randomizing the applications' sensitive internal data and layout every time an output is generated.

LINCOLN LABORATORY TEAM: Hamed Okhravi, project lead; David Bigelow, Kristin Dahl, Thomas Hobson, Jason Martin, and William Streilein

Technology Transfer

A core mission of Lincoln Laboratory is the development of advanced prototype technologies and their transfer to the government and industry. These transfers include the delivery of hardware, software, algorithms, designs, or other technical data to government sponsors; to the commercial sector; and to other not-for-profits, national laboratories, and universities for research purposes.

The Laboratory also publishes numerous technical reports and articles in peer-reviewed journals, and hosts and presents at technical conferences and workshops on a variety of topics germane to national security. Working with MIT's Technology Licensing Office, the Laboratory has developed a rich patent portfolio and works to broadly license dual-use technologies for the benefit of government sponsors and for the economic benefit of the United States.

FISCAL YEAR 2020 TECHNOLOGY TRANSFER BY THE NUMBERS

98 Articles in technical journals

83 Papers in published proceedings

65 Patents issued

12 Lincoln Laboratory–hosted conferences

148 Technology disclosures filed

8 R&D 100 Awards

THE TECHNOLOGY VENTURES OFFICE

The Technology Ventures Office (TVO) was established in 2018 to provide strategic coordination for technology transfer–related activities at the Laboratory.

Dr. Bernadette Johnson
Chief Technology Ventures Officer

Dr. R. Louis Bellaire
Deputy Technology Ventures Officer

Dr. Teresa Fazio
Technology Ventures Officer

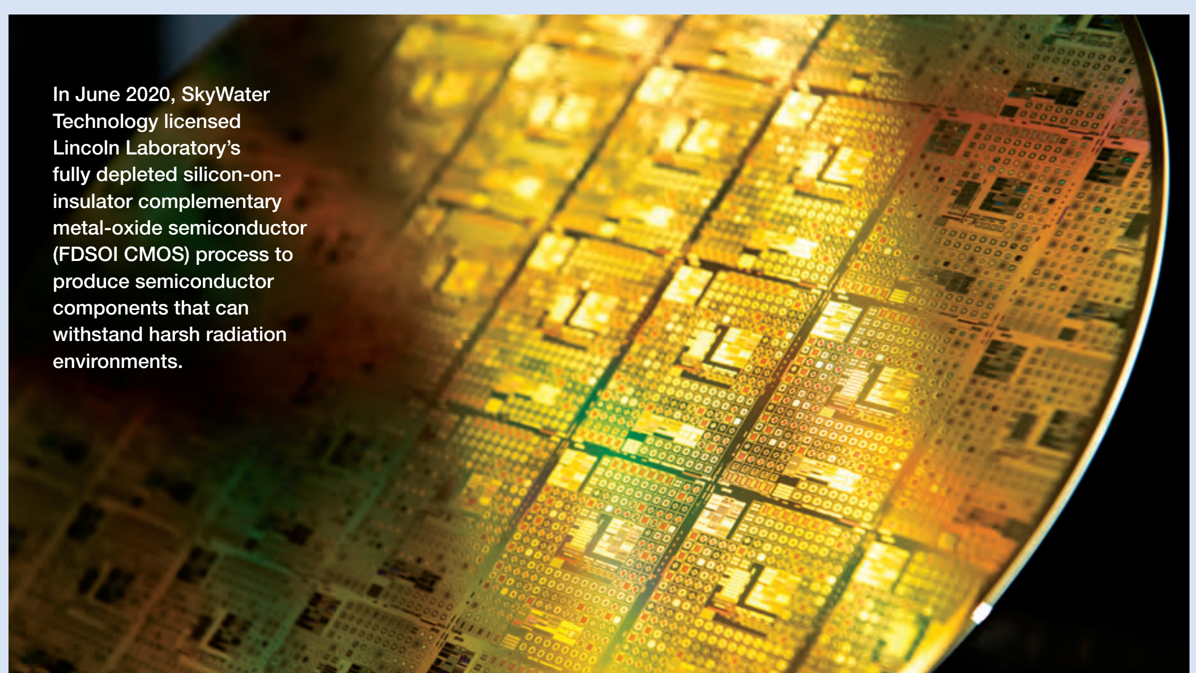
Jennifer A. Falciglia
Program Manager

The TVO's primary objective is to facilitate the rapid transfer of advanced technology capabilities into and out of the Laboratory for the benefit of its missions. The office focuses on three areas:

- Establishing guidelines, metrics, and analytics associated with sponsor-directed technology transition to industry and other partners
- Engaging with the commercial sector, especially small- to medium-sized companies and nontraditional defense contractors
- Developing an intellectual property strategy that promotes government access to Laboratory-developed technologies and that ensures (when applicable) commercial availability of these technologies for all

SPONSOR-DIRECTED TECHNOLOGY TRANSITION

Over the past two years, the TVO has continued to strengthen its sponsor-directed transition practices to ensure ready and cost-effective access to advanced technology. At the start of each new program, or as milestones evolve, all anticipated technology transfer actions (transitions of hardware, software, designs, etc.) are recorded so that the TVO can gain insight into important trends in mission areas, sponsoring agencies, transfer types, and transition partners. These data help the TVO develop a more complete assessment of the Laboratory's technology development's impact on national security.



In June 2020, SkyWater Technology licensed Lincoln Laboratory's fully depleted silicon-on-insulator complementary metal-oxide semiconductor (FDSOI CMOS) process to produce semiconductor components that can withstand harsh radiation environments.

The Laboratory and MIT's Office of Strategic Alliances and Technology Transfer created a single simplified transfer acknowledgment agreement. The "New Technology Transfer to Government Contractor Pursuant to Sponsor's Request" document allows the recipients to understand what intellectual property they are receiving and the conditions under which they may use it under their U.S. government contract. The document also includes an invitation to explore emergent commercial licensing opportunities with MIT's Technology Licensing Office. The agreement maintains the U.S. government's right to fully benefit from its R&D investments by promoting competition for government acquisition or procurement contract awards.

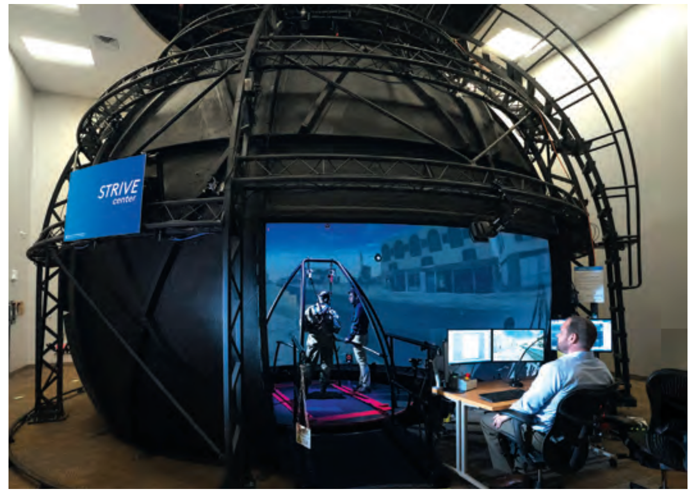
Government sponsors have expressed a desire to know more about how the Laboratory effectively transitions technology to meet national security needs. The transition from prototype development to availability at scale has many steps, and the sooner a transition plan is incorporated into development, the greater a technology's chances for success. The TVO has developed resources to facilitate conversations with sponsors, including a description of MIT's best practices and guidelines for actions that ensure a successful sponsor-directed technology transition.

>> Technology Transfer, cont.

Interacting with the Commercial Sector

Lincoln Laboratory engages with the commercial sector on several fronts to maximize the economic and societal impacts of research by transitioning prototype innovations into real-world products. In 2020, the Laboratory conducted collaborative R&D with 17 companies under Cooperative Research and Development Agreements (CRADAs), which are R&D partnerships funded by industry to advance dual-use or commercial technology development. CRADAs are an important mechanism by which the commercial sector and the public benefit from original investments by the U.S. government. The Laboratory also executed 24 Collaboration Agreements with not-for-profit institutions and an additional 27 sponsor-supported research collaborations with MIT departments. These collaborations advance the state of early-stage technology development for a variety of applications.

One important form of commercial engagement is the Laboratory's direct partnerships with small businesses to address specific government needs. In 2020, Lincoln Laboratory executed 10 Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) projects under sponsorship from government agencies such as the U.S Army, Navy, Air Force, and Department of Energy. The Laboratory has created a customized variant of the

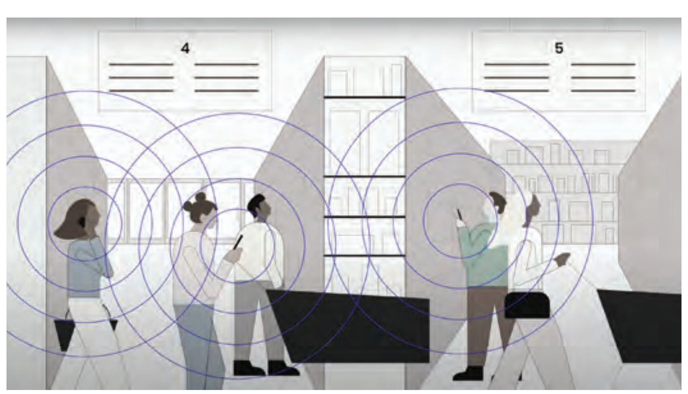


Through Cooperative Research and Development Agreements, partners can access the Laboratory's state-of-the-art facilities, including the Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center, pictured above.

Commercial Solutions Openings (CSOs), which are flexible technology development solicitations and contract awards that support small and nontraditional companies under R&D subcontracts. The CSOs allow the Laboratory to apply the best available commercial technology for rapidly and cost-effectively addressing pernicious challenges confronting the Laboratory's diverse sponsor base.

Intellectual Property Management

In 2020, approximately 15% of MIT's technology disclosures originated at Lincoln Laboratory, and close to half of them resulted in patent filings. About 20% of the Laboratory's technology disclosures represent copyright-protected software and non-software technical data, with an increasing demand for open-source distribution coming from our government sponsors. By open-sourcing key technology capabilities, Laboratory staff are sharing their technical priorities; building ecosystems; promoting emerging technology solutions and standards; and contributing to methods and practices through collaborative engagement with academic, government, and commercial partners.



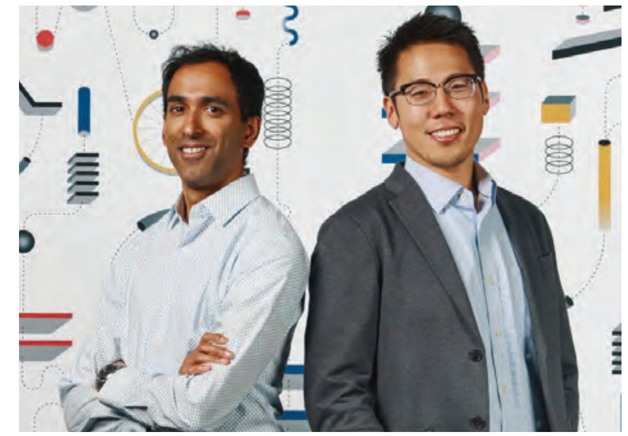
MIT collaborated with partners worldwide on the Private Automated Contact Tracing (PACT) project. They developed open-source software, datasets, and a crowdsourced algorithm with the aim of accurately identifying people at risk of infection from the novel coronavirus and advising public health authorities on how to limit the spread of COVID-19.

Over the past year, the TVO has worked to increase Laboratory transitions via open-sourcing in accordance with objectives and guidance from the Department of Defense. Activities have included partnering with peer organizations to learn and promulgate best practices, establishing criteria to flag candidate projects, streamlining practices for releasing new projects, and contributing to open-source communities. The Laboratory's open-sourcing initiatives progressed significantly in 2020, with more than twice as many new project offerings compared to 2019.

Keylime is an open-source key bootstrapping and integrity management software architecture that increases the security and privacy of cloud, Edge, and Internet of Things devices. Keylime is available for download, and the project continues to grow, with 18 contributors coming from outside of MIT.

Featured Spinout Companies

Sync Computing



In November 2019, two employees from Lincoln Laboratory (Suraj Bramhavar, left, and Jeffrey Chou) launched Sync Computing, a company commercializing a computational optimization processing unit that leverages the energy conservation properties of coupled electronic oscillators to solve combinatorial optimization problems. Sync Computing, based in Cambridge, Massachusetts, was funded by venture firms The Engine and Underscore VC.

Allthenticate

Chad Spenksy, a former Laboratory employee, launched Santa Barbara–based company Allthenticate in October 2019. Allthenticate's goal is to aggregate all user authentication mechanisms, both physical and digital, into a single smartphone application by using technology developed in the Laboratory's Cyber Security and Information Sciences Division and supported by a grant from the Lincoln Laboratory New Technologies Initiative. Allthenticate was selected as a TechCrunch Top Pick and as an alternate finalist to pitch at South by Southwest. It closed its seed funding round in August 2020.

Spotlight — Activate Fellowship Program

There is a growing recognition within the government and other circles that the private investment engine driving the U.S. economy has not focused on startups and small companies engaged in "tough tech"—the typically hardware-based, high-risk/high-payoff technology development that requires years of nurturing, expensive and/or specialized equipment, and a high degree of subject-matter expertise. To address this problem, Lincoln Laboratory, in partnership with Lawrence Berkeley National Laboratory, supported its first cohort of entrepreneurial research fellows in a multiyear program that incubates new companies focused on advanced electronic development. The Defense Advanced Research Projects Agency funds the fellows, and the fellowships are administered by the technology development nonprofit organization Activate.

Activate fellows will work at the Laboratory for two years to develop, among other capabilities, microelectronics fabrication techniques and sensor and chip architectures. Photo: Lawrence Berkeley National Laboratory

Looking Ahead

In the future, the TVO aims to add value to its sponsor-directed technology transfer by defining and gathering metrics that will allow Lincoln Laboratory to estimate the impact its transition activities are having on national security and U.S. economic competitiveness. The TVO is growing the Laboratory's intellectual property portfolio, including open-source software and non-software copyrightable works, and is developing a strategy that will promote rapid licensing, especially for dual-use technologies. The TVO also aims to expand educational efforts for the Laboratory community and Laboratory sponsors, and will continue to consult with peer organizations so that all parties can benefit from lessons learned.

>> Technology Transfer, cont.

U.S. Patents Granted to Lincoln Laboratory Inventors, 1 October 2019–30 September 2020

Method of Enhancing Fatigue Life of Grid Arrays
U.S. Patent 10,433,429; issued 1 October 2019

Method of and System for Optimizing NURBS Surfaces for an Imaging System
U.S. Patent 10,437,943; issued 8 October 2019

Systems and Methods for Dynamic Power Usage and Data Transfer Rate Management in a Sensor Network
U.S. Patent 10,440,450; issued 8 October 2019

System and Method for Non-contact Ultrasound
U.S. Patent 10,456,044; issued 29 October 2019

Methods and Apparatus for Liquid Crystal Photoalignment
U.S. Patent 10,459,293; issued 29 October 2019

Auxiliary Antenna Array for Wideband Sidelobe Cancellation
U.S. Patent 10,476,154; issued 12 November 2019

Systems and Methods for Automatic Customization of Content Filtering
U.S. Patent 10,482,146; issued 19 November 2019

Methods and Apparatus for Free-Space Undersea Communications
U.S. Patent 10,491,309; issued 26 November 2019

Methods and Apparatus for True High Dynamic Range (THDR) Time-Delay-and-Integrate (TDI) Imaging
U.S. Patent 10,491,839; issued 26 November 2019

Random Number Generator
U.S. Patent 10,496,376; issued 3 December 2019

Miniature Ultra-Wideband Multifunctional Antenna and Related Techniques
U.S. Patent 10,498,017; issued 3 December 2019

Apparatus and Methods for Photonic Integrated Resonant Accelerometer
U.S. Patent 10,502,757; issued 10 December 2019

Coincident Phase Centered Flared Notch Feed
U.S. Patent 10,505,281; issued 10 December 2019

Device Array Backframe with Integral Manifolding for High Performance Liquid Cooling
U.S. Patent 10,512,152; issued 17 December 2019

Rare Earth Spatial/Spectral Microparticle Barcodes for Labeling of Objects and Tissues
U.S. Patent 10,533,133; issued 14 January 2020

Integrated Coaxial Notch Antenna Feed
U.S. Patent 10,541,467; issued 21 January 2020

Power Amplifier Operation
U.S. Patent 10,541,658; issued 21 January 2020

Systems and Methods Evaluating Password Complexity and Strength
U.S. Patent 10,546,116; issued 28 January 2020

Using Correlation Structure of Speech Dynamics to Detect Neurophysiological Changes
U.S. Patent 10,561,361; issued 18 February 2020

Integrated Resonant Accelerometer Using Optical Strain Sensor
U.S. Patent 10,571,483; issued 25 February 2020

Methods and Apparatus for Phased Array Imaging
U.S. Patent 10,571,569; issued 25 February 2020

Dual-Mode Imaging Receiver
U.S. Patent 10,581,521; issued 3 March 2020

Cryogenic Electronic Packages and Assemblies
U.S. Patent 10,586,909; issued 10 March 2020

Secure Execution of Encrypted Software in an Integrated Circuit
U.S. Patent 10,592,433; issued 17 March 2020

Wave Damping Structures
U.S. Patent 10,597,839; issued 24 March 2020

Enhancement of Video-Rate Fluorescence Imagery Collected in the Second Near-Infrared Optical Window
U.S. Patent 10,598,914; issued 24 March 2020

System and Method for Non-contact Ultrasound with Enhanced Safety
U.S. Patent 10,602,931; issued 31 March 2020

Material Property Determination Using Photothermal Speckle Detection
U.S. Patent 10,605,662; issued 31 March 2020

Method and Apparatus for On-Chip Per-Pixel Pseudo-Random Time Coded Exposure
U.S. Patent 10,616,520; issued 7 April 2020

Systems and Methods for Dynamic Planning and Operation of Autonomous Systems Using Image Observation and Information Theory
U.S. Patent 10,618,673; issued 14 April 2020

Spin-Based Electrometry with Solid-State Defects
U.S. Patent 10,620,251; issued 14 April 2020

Imaging System for Immersive Surveillance (ISIS)
U.S. Patent 10,630,899; issued 21 April 2020

Apparatus, Systems, and Methods for Nonblocking Optical Switching
U.S. Patent 10,634,851; issued 28 April 2020

Cross-Talk Suppression in Geiger-Mode Avalanche Photodiodes
U.S. Patent 10,636,929; issued 30 April 2020

Methods and Apparatus for True High Dynamic Range (THDR) Time-Delay-and-Integrate (TDI) Imaging
U.S. Patent 10,638,064; issued 28 April 2020

Systems, Apparatus, and Methods Related to Modeling, Monitoring, and/or Managing Metabolism
U.S. Patent 10,638,956; issued 5 May 2020

Methods and Systems for Optical Beam Steering
U.S. Patent 10,649,306; issued 12 May 2020

Thermal Management of RF Devices Using Embedded Microjet Arrays
U.S. Patent 10,651,112; issued 12 May 2020

Plug-and-Play Reconfigurable Electric Power Microgrid
U.S. Patent 10,656,609; issued 19 May 2020

Superconducting Integrated Circuit
U.S. Patent 10,658,424; issued 19 May 2020

Surface Penetrating Radar and Battery Systems
U.S. Patent 10,663,579; issued 26 May 2020

Modular Microjet Cooling of Packaged Electronic Components
U.S. Patent 10,665,529; issued 26 May 2020

Compact Model Nonlinear Compensation of Bandlimited Receiver Systems
U.S. Patent 10,666,307; issued 26 May 2020

Spectrally Efficient Digital Logic
U.S. Patent 10,673,417; issued 2 June 2020

Network of Extremely High Burst Rate Optical Downlinks
U.S. Patent 10,680,712; issued 9 June 2020

Method and Apparatus for Smart Adaptive Dynamic Range Multiuser Detection Radio Receiver
U.S. Patent 10,686,513; issued 16 June 2020

Steering Techniques for Surgical Instruments
U.S. Patent 10,688,284; issued 23 June 2020

Methods and Apparatus for True High Dynamic Range Imaging
U.S. Patent 10,694,122; issued 23 June 2020

Stationary Magic Angle Spinning Enhanced Solid State Spin Sensor
U.S. Patent 10,705,163; issued 7 July 2020

Methods and Apparatus for Optically Detecting Magnetic Resonance
U.S. Patent 10,712,408; issued 14 July 2020

Paramagnetic Tree Coupling of Spin Qubits
U.S. Patent 10,719,775; issued 21 July 2020

Ground-Based System for Geolocation of Perpetrators of Aircraft Laser Strikes
U.S. Patent 10,718,613; issued 21 July 2020

Method and System for Localization of a Vehicle Using Surface Penetrating Radar
U.S. Patent 10,725,171; issued 28 July 2020

Control of Heating in Active Doped Optical Fiber
U.S. Patent 10,727,641; issued 28 July 2020

Data Security Using Inter-Zone Gate Circuits
U.S. Patent 10,728,231; issued 28 July 2020

Josephson Phase-Slip Qubits
U.S. Patent 10,735,003; issued 4 August 2020

Phosphor-Loaded Waveguide
U.S. Patent 10,740,493; issued 11 August 2020

Determining Surface Characteristics
U.S. Patent 10,746,867; issued 18 August 2020

Short Pulse Wavelength Tuning via Timed Soliton-Dispersive Wave Interaction
U.S. Patent 10,770,859; issued 8 September 2020

Methods for Enabling In-Field Selection of Near-Sensor Digital Imaging Functions
U.S. Patent 10,771,722; issued 8 September 2020

Dynamic Flow Isolation
U.S. Patent 10,778,722; issued 15 September 2020

Systems and Methods for Risk Rating Framework for Mobile Applications
U.S. Patent 10,783,254; issued 22 September 2020

International Patents Granted to Lincoln Laboratory Inventors, 1 October 2019–30 September 2020

Various Tools and Adaptations to Enable Endoscopic Spinal Surgery
Germany/European Patent Convention/France/United Kingdom Patent 3,200,704; issued 20 May 2020

Photothermal Speckle Imaging
Germany/European Patent Convention/United Kingdom Patent 3,338,075; issued 10 June 2020

Using Correlation Structure of Speech Dynamics to Detect Neurophysiological Changes
Germany/European Patent Convention/France Patent 3,057,493; issued 24 June 2020

Efficient Operations

Like many organizations, Lincoln Laboratory had to quickly adapt as COVID-19 impacted its ability to work and convene in traditional ways. A large fraction of the Laboratory's workforce was empowered to work remotely, an enormous change enabled by hard work across departments and divisions. At the same time, the Laboratory continued its efforts to simplify business processes, build new capabilities, and modernize technology so that all employees have the skills and tools needed to excel in the business of research.

From left to right, Scott Anderson, Assistant Director for Operations; Robert Solis, Chief Information Officer; Jeanne Ross, principal research scientist at the MIT Center for Information Systems Research; and Dennis Burianek, Business Transformation Office Head, gather following the Digital Enterprise Transformation showcase event in February 2020.

Modernizing operations

Lincoln Laboratory is modernizing the way it works as part of the Digital Enterprise Transformation (DET). The Business Transformation Office (BTO) continues to lead this multiyear initiative to achieve its five main objectives:

1. Simplify and improve core business processes
2. Utilize integrated technology solutions
3. Inform decisions with data-driven insights, and rely on metrics and key performance indicators to identify challenges and successes
4. Advance a culture of ownership, accountability, and deliberate continuous improvement
5. Enable new capabilities aligned with a digitally mature organization for the Laboratory's employees

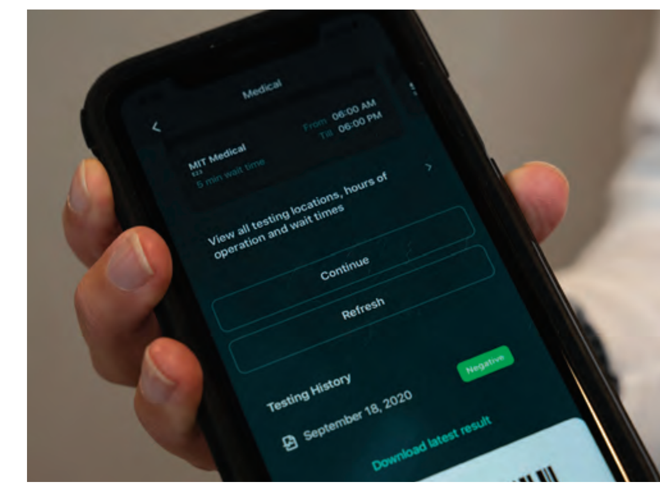
In 2020, the BTO partnered with department heads and project owners to make progress on several DET initiatives:

- SAP S/4 finance modernization. This initiative is providing the Laboratory with one trusted financial source and a scalable business platform that can grow with the Laboratory. The project will provide a simplified user experience, streamlined financial business processes, and improved accuracy and visibility of data.
- Business process management. This effort has identified nearly 300 core processes across the Laboratory and enabled process owners to identify stakeholders and customers and to document the steps, systems, and key data needed to execute processes.
- External workforce services. A new team was established that is dedicated to managing the lifecycle, from recruiting to offboarding, of contracted workers. The team is a liaison to vendors and provides partnership and support to hiring managers.
- Improved travel experience. The Laboratory launched Concur, a single system that integrates business travel booking and expense reporting.
- Organizational change management. This effort ensures that our leaders, teams, and community are informed about and able to support DET changes. The initiative will focus on consistent DET messaging, leadership engagement, and user training at all levels.
- MADOps challenge. An invitation was extended to the research community to submit proposals for projects that could use existing methodologies in machine learning, artificial intelligence, or data analytics to improve operations (MADOps) and be applied to a key Laboratory business area. More than ten proposals were received, of which five were funded.

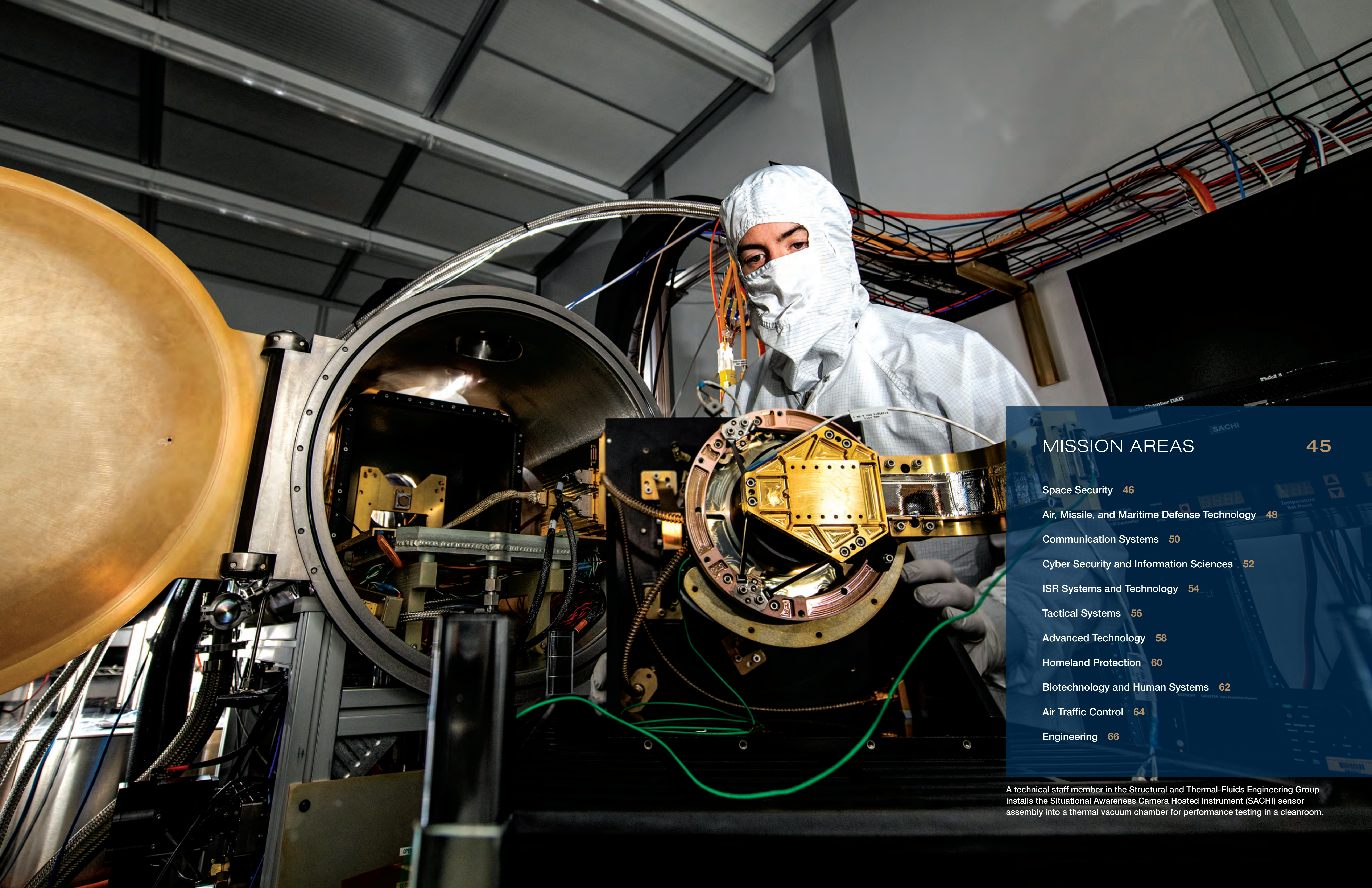
Adapting to a pandemic

Improvements to information technology services streamlined everyday processes, enhanced communication capabilities, and allowed the Laboratory to continue to function—and even thrive—during COVID-19 pandemic conditions. The Information Services Department (ISD) moved rapidly to provide capabilities required to facilitate remote work. Efforts were focused in the following critical areas:

- Amplified collaboration tools. Zoom for Government, Microsoft 365 Teams, the IX Workplace soft phone, and other applications that enabled communication between remote coworkers were implemented. Webinar training and support were provided for those learning to use these new technologies. To facilitate meetings in which some participants were at the facility while some were at home, ISD upgraded conference rooms with Owl technology, providing a more in-person meeting experience for all.
- Increased remote-support availability. Enhanced remote desk-side support capabilities ensured that all employees received technology support when needed. Two question-and-answer sessions—Training Tuesdays and Thursday Coffee Breaks—were also offered weekly to the community.
- Improved processes and workflows. Everyday procedures had to adjust for remote work, and ISD responded with numerous process enhancements. Efficiencies were gained in areas such as domestic and international travel-approval workflows, and secure, health-conscious methods to onboard new employees remotely. ISD modified computer-patching and data-backup schedules to avoid work hours and keep the Laboratory network and remote computers running at optimal speed. New computer-power and network-connection configurations ensured computers were available when patches and backups occurred.
- New health and safety applications. Novel leave-tracking systems were implemented within Human Resources technology to protect those whose health and work conditions were affected by COVID-19. ISD also collaborated with MIT to implement a health attestation application, which employees completed every day before they could access facilities. This application interfaced with MIT Medical and Security Services Department technology systems, working together to stop the spread of COVID-19 in the Laboratory community.
- Enhanced technology systems. The Laboratory's pre-pandemic infrastructure primarily focused on providing excellent onsite services. With the majority of the workforce now remote, ISD worked tirelessly to adapt these systems. The local network, virtual private network, and voice services were enhanced, and secure areas were updated with communication/video-teleconferencing capabilities. ISD also enacted endpoint protection enhancements, security operations modernization measures, and virtual desktop service expansions, further promoting the ease and security of remote work.



Employees complete a daily health attestation and can view COVID-19 test results via a mobile app.



MISSION AREAS 45

A technical staff member in the Structural and Thermal-Fluids Engineering Group installs the Situational Awareness Camera Hosted Instrument (SACHI) sensor assembly into a thermal vacuum chamber for performance testing in a cleanroom.

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 Space Surveillance Telescope, shown under the exquisitely dark skies of Northwestern Australia, achieved first light in February 2020 following relocation from New Mexico. The new location will allow improved surveillance of deep-space objects in the Asia-Pacific region.

Principal 2020 Accomplishments

- The Space Surveillance Telescope at the Naval Communication Station Harold E. Holt in Australia is undergoing final tuning and system acceptance testing before its transition to operations by the Royal Australian Air Force and maintenance by industry.
- The TROPICS Pathfinder CubeSat was successfully integrated and tested, and is scheduled to be launched in June 2021. The Pathfinder vehicle is the qualification development unit built for the NASA Earth Venture Instrument's TROPICS constellation. Launch and on-orbit demonstration of the vehicle will serve as a risk-reduction flight test ahead of the full TROPICS constellation launch scheduled for early 2022. TROPICS CubeSats are equipped with an advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms.
- The Situational Awareness Camera Hosted Instrument (SACHI) program is developing two identical hosted-payload space situational awareness (SSA) sensors. SACHI leverages ORS-5 (SensorSat) technologies to provide a rapid development and delivery sensor system that has significant onboard SSA data processing capabilities. After a successful Critical Design Review, researchers are procuring, fabricating, assembling, and testing the payload subsystems for planned delivery in 2022.
- A portfolio of activities is delivering critical space domain awareness information and tools to the National Space Defense Center in Colorado and the Combined Space Operations Center in California. The Laboratory is leading the modernization of networking, data architecture, and processing capabilities of legacy space surveillance sensors to improve the timeliness of missions. Prototypes of net-centric data libraries have enabled a universal data library that allows Space Force operators to leverage commercial space domain awareness data. An evaluation of the commercial data may lead to an increased capacity and diversity of sensors in the network.
- Systems and mission analyses continue to motivate new concepts leveraging advanced technologies at U.S. space organizations. In 2020, several prototypes were field-tested, and initial resilient architectures are planned for a 2023 delivery.

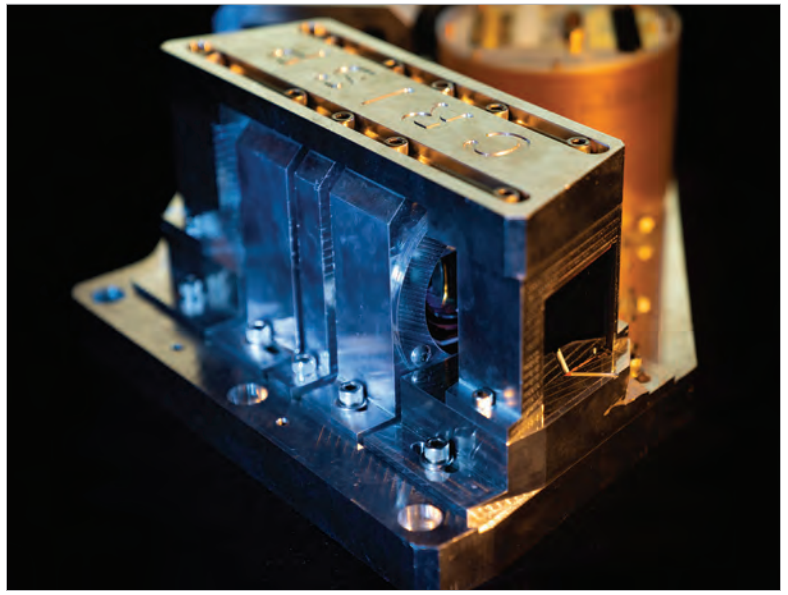
Future Outlook

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 grows. Improved space situational awareness, and responses on tactical timelines, will be the foundation for increasing the survivability of space systems. Space systems will need to be made fundamentally more resilient to potential adversary actions. The creation of the U.S. Space Force and the re-establishment of U.S. Space Command highlight the growing importance of the space domain.

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

Advancements for Hyperspectral Imaging

Space-based hyperspectral imagers have provided highly valuable data for earth resource usage and weather/climate monitoring. For NASA's Earth Science Technology Office, the Laboratory is developing two significant advancements for hyperspectral imagers. The Chrisp Compact VNIR/SWIR Imaging Spectrometer provides high performance in a very compact optical design combined with a novel lithographic grating. The Computational Reconfigurable Imaging Spectrometer (CRISP), at right, implements computational imaging techniques, providing increased performance and sensitivity in an uncooled, reconfigurable sensor. These advancements will enable proliferated small-satellite constellations to image larger areas with improved timeliness.



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

Heidi C. Perry
Asst. Division Head

Researchers deployed a technology demonstrator of an undersea mapping sparse sonar array. The array is a novel surface-based, distributed multi-input multi-output sparse aperture sonar to support deep ocean floor mapping with a resolution two orders of magnitude higher than is currently achievable.

Principal 2020 Accomplishments

- Lincoln Laboratory continued to develop advanced sensors and algorithms to ensure robust performance of the Missile Defense System (MDS) against ballistic, hypersonic, and other advanced missile threats that might employ intentional and unintentional countermeasures. Increasingly, the Laboratory is applying its expertise in artificial intelligence (AI) systems to enhance threat discrimination and is working to establish AI robustness as a key performance consideration.
- Sponsored by the Defense Advanced Research Projects Agency, the Laboratory developed hypersonic computational fluid mechanics algorithms to advance hypersonic vehicle modeling, design, and flight characteristics.
- The Laboratory tested and evaluated a prototype capability utilizing advanced signal processing techniques to enable distributed radar sensing for eventual use by forward-deployed forces.
- To inform future maritime infrared sensing, the Laboratory developed and deployed a reconfigurable infrared sensor test bed system featuring both analog and digital focal plane array cameras, as well as conventional and multiplexed imagers.
- Lincoln Laboratory was a central contributor to the Next-Generation Interceptor program initiation through its support to the GM Technical Direction Agent and is providing subject-matter expertise to the Air Force's Ground-Based Strategic Deterrent program.
- The Laboratory continues to lead the development of algorithms to provide real-time assessment of electronic warfare decoy performance and to discover the algorithms' operational effectiveness through the use of serious game environments.
- To enhance the performance of the submarine combat system, the Laboratory has been developing improved electronic warfare, sonar automation, and signal processing capabilities.
- Communications waveforms that simultaneously transmit and receive data while also being used as radar waveforms to detect and track moving objects achieved good communications and radar performance during a field test.

Future Outlook

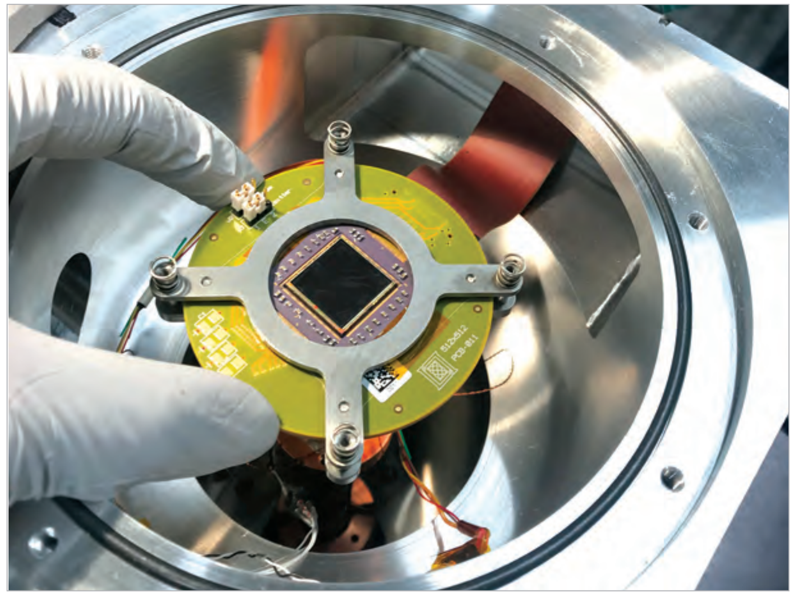
Hypersonic and advanced missile threats pose an emerging threat to the United States and its allies. Lincoln Laboratory is working with the Missile Defense Agency to define a defense architecture and develop advanced technologies to counter these threats.

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

To deter aggression in regional conflicts, forward-deployed forces may benefit from long-range, cross-domain webs, enabled by new sensing and engagement paradigms. The Laboratory is defining architectures and developing sensors.

Advanced Digital Focal Plane Array

Lincoln Laboratory conducted successful testing and witnessed "first light" of a two-color, 512 × 512 pixel, 32-bit digital focal plane array (DFPA) for the Missile Defense Agency Sea-Based Weapon Systems (MDA/SW/AB) program. The DFPA was hybridized to two detector materials—mercury cadmium telluride and strained-layer superlattice—to support both long-wave and mid-wave infrared operation. Dual 16-bit registers can be independently controlled or used in conjunction to provide a 32-bit register with a 15 trillion electron well for unprecedented dynamic range. The Laboratory's DFPA technology was successfully transferred to industry through MDA/SW/AB for use in next-generation missile defense seekers.



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. Gary F. Hatke, Principal Staff
Mr. Joseph J. Scozzafava, Principal Staff

Photonic integrated circuit (PIC) optical matched filters achieved excellent filter extinction (>45 dB) and highly Gaussian lineshape. Coupled with advanced digital signal processing, PIC technology will dramatically reduce the size, weight, power, and cost of future lasercom terminals.

Principal 2020 Accomplishments

- Lincoln Laboratory decommissioned the Lincoln Experimental Satellite-9 on 20 May 2020. Launched in 1976, LES-9 was the longest continuously operating communications satellite in U.S. history. For more on LES-9 innovations, see pages 16-17.
- The Laboratory's instrumentation-grade terminals were used to make first contact with and calibrate Advanced Extremely High Frequency satellites AEHF-5 and -6.
- Lincoln Laboratory completed prototyping modems for the Protected Tactical Service Field Demonstration. The waveform was tested over the Wideband Global System and with international partners over the Skynet satellite.
- Flight demonstrations were conducted for a new content-aware data distribution architecture. The approach enables dynamic mission execution across disparate networks by distributing tailored data to subscribers over the best available paths. The prototype implementation operates over military tactical radios as well as commercial wireless and satellite networks.
- A prototype of an advanced signal processing applique and new apertures will add resiliency to a legacy tactical data link.
- The Laboratory characterized the ability of Bluetooth Low Energy signaling to determine the proximity of cell phones. This characterization will be instrumental in helping public health professionals develop effective cell phone applications for automated contact tracing for the COVID-19 pandemic.
- A prototype high-frequency communications digital phased array was expanded to include dual signal polarizations and adaptive beamforming. The array was demonstrated with beyond-line-of-sight voice traffic during military tactical training exercises.
- In a collaboration with MIT, techniques were developed for a novel RF spectrum analyzer that leverages machine learning algorithms to decompose a congested spectral band into its component signals and classify them individually.

Future Outlook

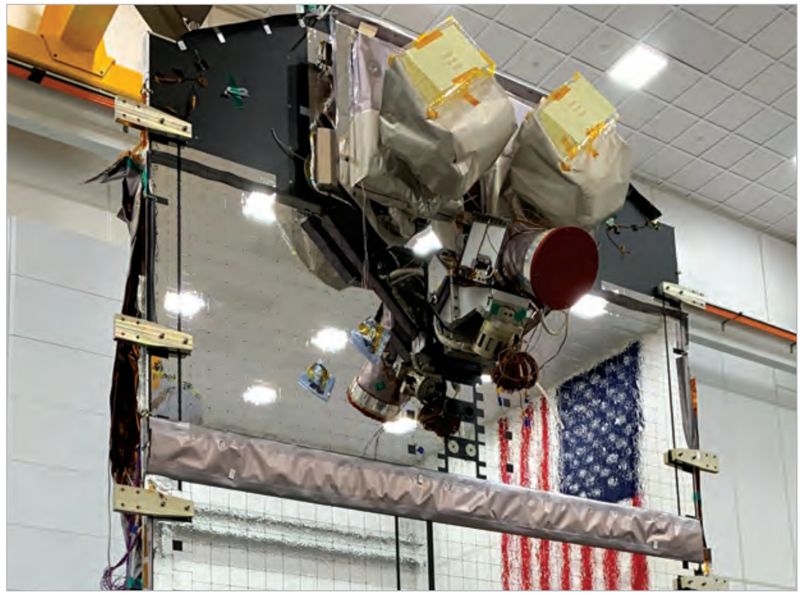
New architectures and prototypes will be developed to increase the resiliency of the next generation of UHF-band communication satellites.

Digital signal processing techniques will be designed for emerging multifunction systems spanning communications, radar, sensing, and electronic warfare.

The Laboratory will perform a quantum network architecture study and develop a plan for a demonstration satellite. In parallel, development will begin on a space-qualified quantum modem incorporating a high-rate spectrally pure entanglement source, a quantum state analyzer with high-efficiency single-photon processing, and a precision synchronization system.

Laser Communications (Lasercom) Terminal

Lincoln Laboratory transferred a lasercom terminal design to NASA Goddard Space Flight Center for the Laser Communications Relay Demonstration mission (LCRD). The NASA-built payload, which contains Lincoln Laboratory software and firmware, has been integrated, right, onto the U.S. Space Force's Space Test Program Satellite 6 for launch in 2021. A companion terminal being developed by the Laboratory will be flown on the International Space Station to relay high-rate data through LCRD to NASA ground stations via RF and optical links.



Cyber Security and Information Sciences

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

Leadership

Mr. Stephen B. Rejto
Division Head

Dr. Marc A. Zissman
Assoc. Division Head

Mr. Jeffrey C. Gottschalk
Asst. Division Head

Dr. Jeremy Kepner
Laboratory Fellow

Mr. David R. Martinez
Laboratory Fellow

The ROGUESAINT project is developing a next-generation cyber system and associated capabilities for the Federal Bureau of Investigation. The research requires a multidisciplinary approach of strategy development, low-level systems exploitation, and prototype development.

Principal 2020 Accomplishments

- The Lincoln Laboratory Supercomputing Center (LLSC) deployed the most powerful artificial intelligence (AI) supercomputer at any university in the world. The new system enables rapid prototyping, scaling, and application of AI systems across Department of Defense (DoD) missions.
- The Laboratory developed technology to improve the design integrity of microelectronic chips against supply-chain cyberattacks. The technology enhances the detectability of attempts to tamper with the security-critical components of a digital circuit design.
- The Laboratory demonstrated initial operation of its secure operating system Magnetite. Magnetite is implemented in a memory-safe language called Rust and leverages a formally verified microkernel called seL4. The system is designed to provide fine-grained resource isolation, recovery mechanisms, and cyber resilience for embedded platforms.
- The Applied Resilience for Mission Systems initiative is guiding the cyber resilience of DoD missions. The Laboratory published guidance that advises programs to adopt modern development, security, and operations practices; integrate commercial and open-source components; and leverage automated observability and infrastructure tools.
- A state-of-the-art speech enhancement system that employs the latest in machine learning advancements was transitioned to the U.S. government.
- The Laboratory developed a methodology to make adversarial activity a critical component of AI software testing. This methodology has been applied to evaluate and mitigate threats to decision support systems.
- Working with cyber operators from multiple combatant commands, the Laboratory identified a common workflow architecture for cyber situational awareness and developed technology-implementation strategies. A prototype capability is being assessed as part of the Joint Cyber Warfare Architecture.

Future Outlook

The Laboratory will create an integrated hardware-software computer stack in which performance and security are both treated as priorities and will apply this technology to improve cyber resiliency of next-generation mission systems.

The LLSC is developing the next-generation platform for rapid prototyping of world-class AI research.

The Cyber System Assessments Group will continue to assess systems critical to the nation by discovering and exploiting vulnerabilities. This work will help improve the U.S. national cybersecurity posture of critical systems.

The Laboratory will develop technology solutions to provide full-spectrum cyber operations and analysis capabilities through AI-enabled technology, system analysis, experimentation, and prototype development.

ARES

Throughout the five-year Agile and Resilient Embedded Systems (ARES) program, the Laboratory played a central role in developing and demonstrating cyber-secure and resilient unmanned systems. In addition to providing critical technology such as the Lincoln Open Cryptographic Key Management library, the team pioneered a cyber-focused systems-engineering methodology to synthesize mission needs, threats, and constraints into testable cybersecurity requirements. At right, a researcher prepares for a demonstration at the Avon Park Air Force Range, where cyber-protected and baseline unmanned aircraft systems were cyberattacked in flight.

ISR Systems and Technology

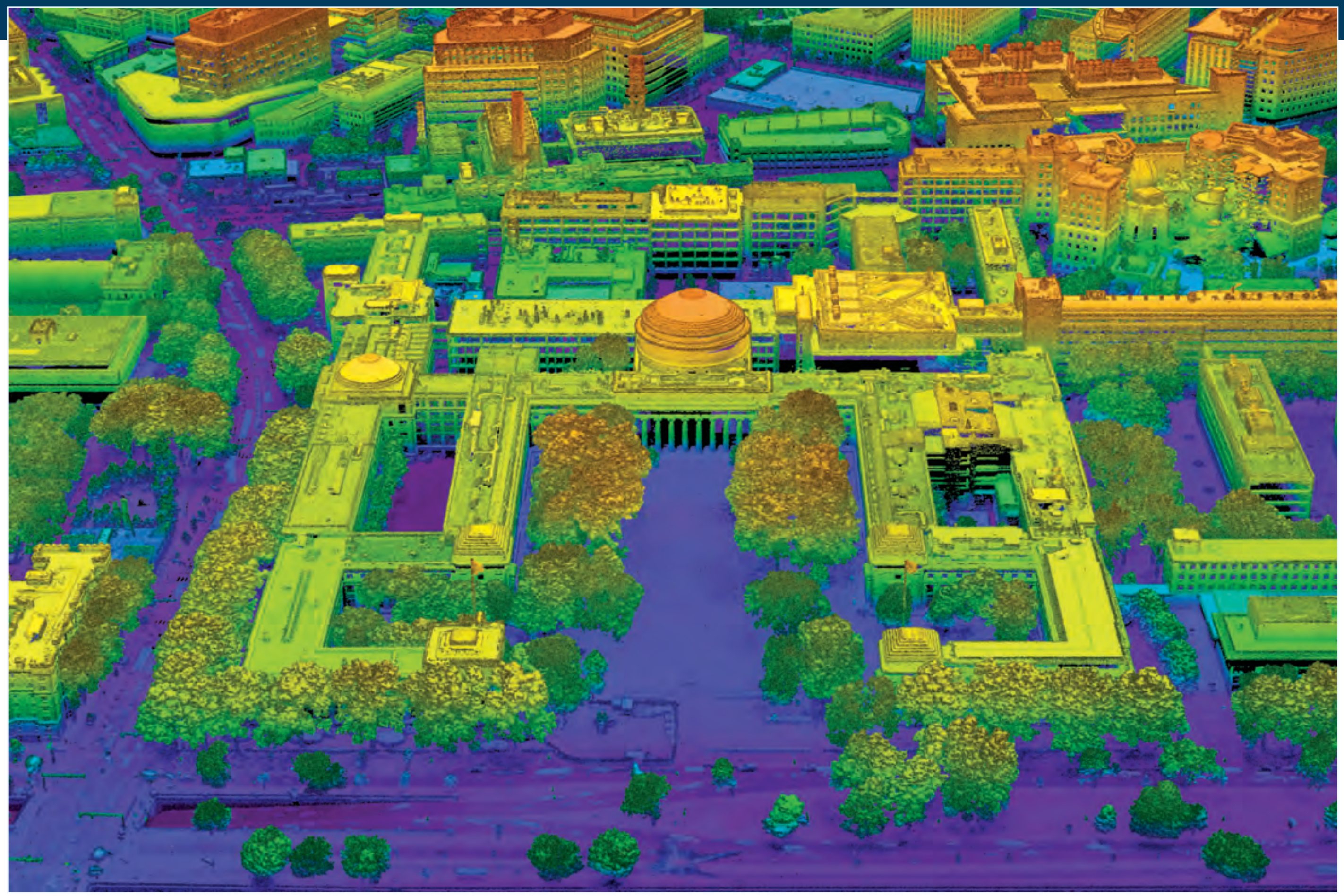
Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

Leadership

Dr. Marc N. Viera
Division Head

Dr. Richard M. Heinrichs
Asst. Division Head

Dr. Jennifer A. Watson
Asst. Division Head



The above three-dimensional image of MIT Killian Court was taken with the upgraded MACHETE 2.0 lidar system.

Principal 2020 Accomplishments

- Lincoln Laboratory transitioned the most advanced U.S. airborne 3D foliage-penetrating lidar to the U.S. Southern Command. The Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) 2.0 lidar system, which achieves a five-fold increase in area coverage rate over MACHETE 1.0, has already provided significant value to the counterterrorism and counter-narcotics intelligence communities.
- The Laboratory has developed advanced artificial intelligence algorithms that can automatically identify trails, riverbeds, and other communication lines that can be indicators of human activity in highly foliated scenes.
- The Laboratory is prototyping a distributed maritime reconnaissance system for use in contested environments. Sponsored by the Office of Naval Research, the system completed four flight experiments with operational P-3C and P-8A maritime patrol aircraft.
- Leveraging its integrated research environment for developing large-scale, graph-analysis technology, the Laboratory created a novel formulation of the subgraph matching kernel targeting advanced high-performance accelerators for important Department of Defense and commercial applications.
- Researchers at Lincoln Laboratory have analyzed the use of quantum-based vector magnetic field sensors for the detection of Earth's magnetic field. Through correlation of the measured field with a previously collected database, the researchers can discern the absolute location of the sensor.
- In collaboration with researchers at the Jet Propulsion Laboratory, Lincoln Laboratory designed a proof-of-concept real-time low-size, -weight, and -power ladar mapping system to support a future Europa Lander.
- Laboratory researchers 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.

Future Outlook

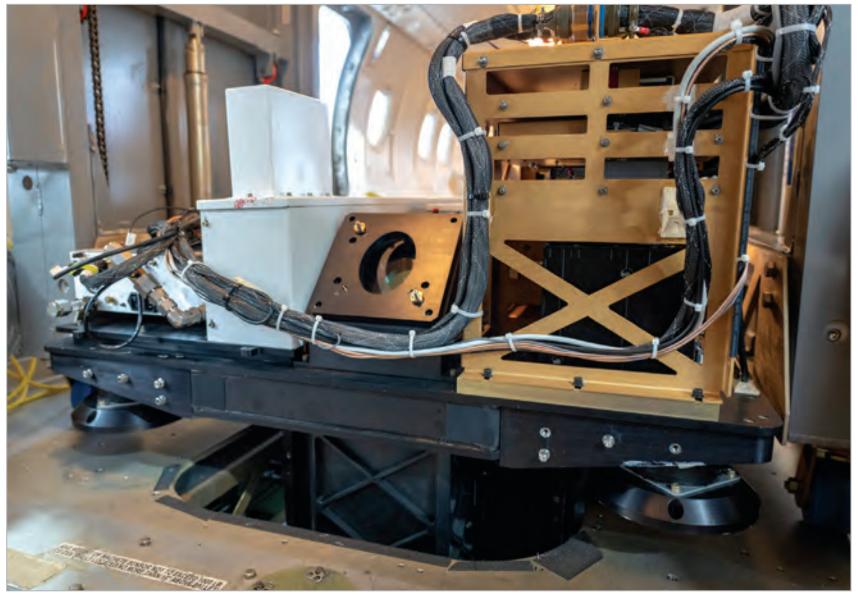
Artificial intelligence technology—adapted to the national security domain's constraints on data, computation, and algorithms—will revolutionize the scale and speed of ISR operations.

The Laboratory will continue to work closely with partners on MIT campus on foundational research that will enable large teams of unmanned vehicles to collaborate effectively in challenging and unstructured environments.

The Laboratory will demonstrate a secure reconfigurable processor architecture for low-power Department of Defense edge computing applications. This system, which is based on field-programmable gate array technology, will perform machine-learning-enhanced sensor signal processing and allocate available compute resources on the basis of a hierarchical energy-minimization approach.

MACHETE Integration

The MACHETE 2.0 sensor head, at right installed in the aircraft, includes the laser, transmit and receive optical systems, dual single-photon-sensitive Geiger-mode avalanche photodiode cameras, and inertial measurement unit. The optical bench sits on isolators and looks through the belly of the aircraft. Under the optical bench are a fast-steering mirror and gimbal that allow the system to rapidly scan large areas on the ground. Not shown are the electronics and computers used to control and operate the sensor and process the 3D data in near real time.



Tactical Systems

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

Leadership

Dr. Marc N. Viera
Division Head

Dr. Richard M. Heinrichs
Asst. Division Head

Dr. Jennifer A. Watson
Asst. Division Head

Dr. Josh G. Erling
Group Leader

Dr. Janet T. Hallett
Group Leader

The Airborne Seeker Test Bed is a customized aircraft used in flight testing radio-frequency and infrared sensors. To carry these sensors, the aircraft is modified with wing pylons, a nose radome, forward chin-pods, and computer and instrumentation racks in the interior.

Principal 2020 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.
- Prototyping of advanced technologies for airborne signals intelligence continues. Two major systems were successfully field tested. One represented a significant technical upgrade to an existing capability, and the second demonstrated a new capability for operators. Both systems and the relevant designs were transitioned to an industry partner for production and fielding.
- Software researchers continued to refine a software and cyber security architecture to support logistics systems for advanced U.S. fighter platforms, incorporating modern software design patterns and leveraging commercial best practices.
- State-of-the-art transfer-learning techniques enabled machine characterization of U.S. Army tactical communications data, pointing the way for tactical operations accelerated by artificial intelligence.
- In a series of joint U.S. Air Force–Army exercises, the Laboratory demonstrated how open software architectures and machine-to-machine interoperability will enable next-generation joint all-domain command and control.
- 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.
- The Lincoln Laboratory Army Blue Team continues to provide the Army Rapid Capabilities and Critical Technologies Office with targeted analysis and rapid prototyping across a wide variety of Army missions.

Future Outlook

Lincoln Laboratory will continue to support the U.S. 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.

Open architectures, artificial intelligence, and security-conscious agile software development methodology will enable heterogeneous families of tactical systems to accomplish new classes of missions.

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

Integrated Ka-band Radar Instrumentation System

The podded Integrated Ka-band Radar Instrumentation System (IKARIS), seen at right, is carried by a Gulfstream G-II airborne test asset. The IKARIS, which has been flown since November 2018, continues to make measurements of tactical aircraft to enable a better understanding of the propagation, scattering, and clutter phenomena at Ka-band. Over the next decade, valuable flight test data acquired by the IKARIS will inform the development activities of various Department of Defense programs.

Advanced Technology

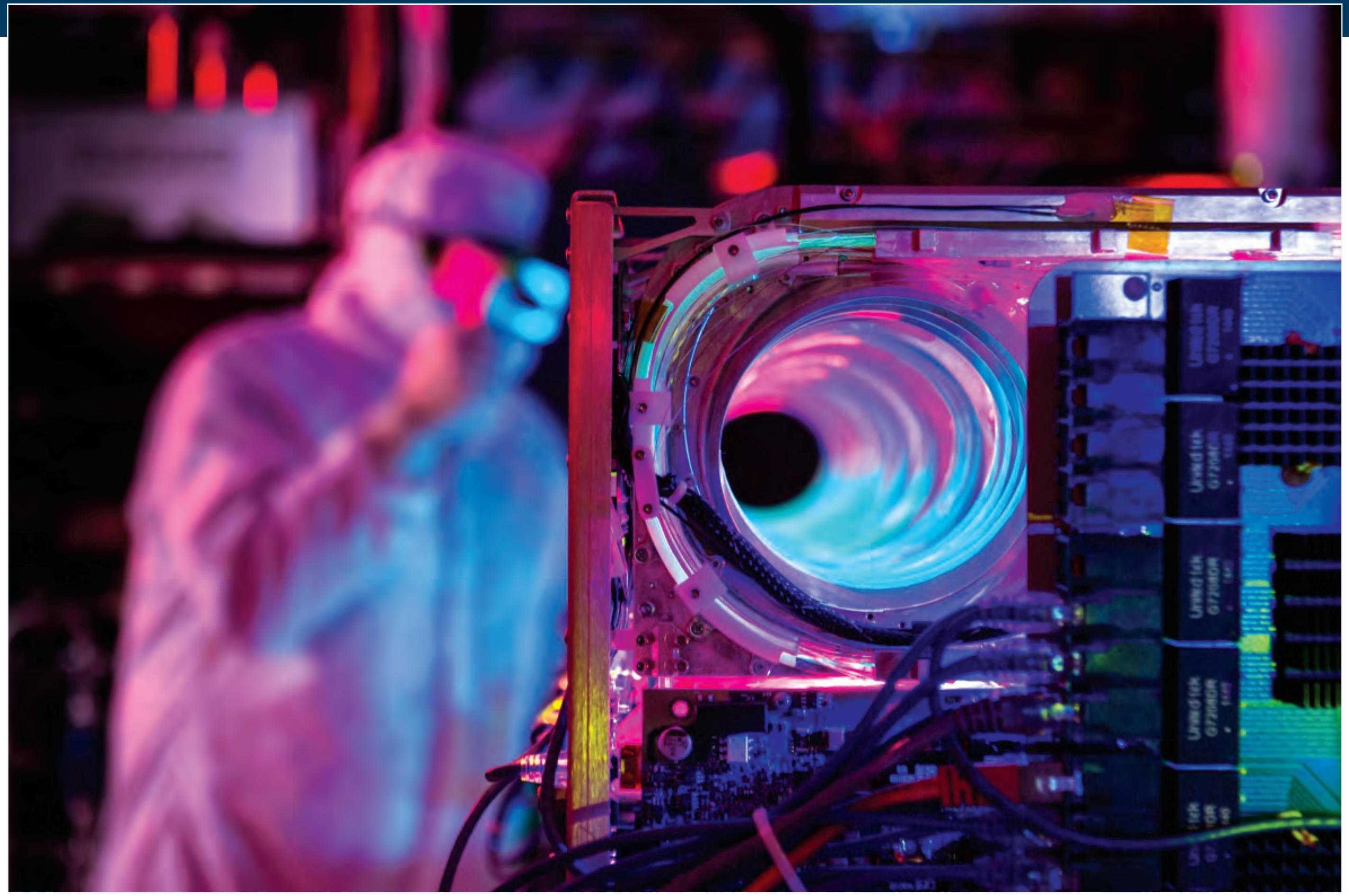
Leveraging solid-state electronic and electro-optical technologies, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

Leadership

Dr. Robert G. Atkins
Division Head

Dr. Craig L. Keast
Assoc. Division Head

Dr. Mark A. Gouker
Asst. Division Head



The Laboratory demonstrated a 46-kilowatt coherently combined high-energy laser system with the highest brightness per unit mass in the world. This demonstration of a packaged high-power optical phased array paves the way for testing on size-, weight-, and power-constrained platforms.

Principal 2020 Accomplishments

- Researchers working on ReImagine, a program to create reconfigurable imaging systems, completed the design of a second-generation integrated circuit. This technology brings the flexibility of field-programmable gate arrays, or FPGAs, to digital focal plane imagers that are transforming Department of Defense imaging systems. The circuit has six billion transistors.

- The Laboratory has begun work to add functionality to textile fibers, giving new capability to fabrics and other systems that the fibers compose. One of these activities is focused on integrating electronics into these textile fibers. In particular, power and communication buses are integrated into the fiber and can individually communicate with functional nodes on the fiber. The goal is to create one-dimensional systems with lengths on the order of a kilometer to perform sensing and communication functions.

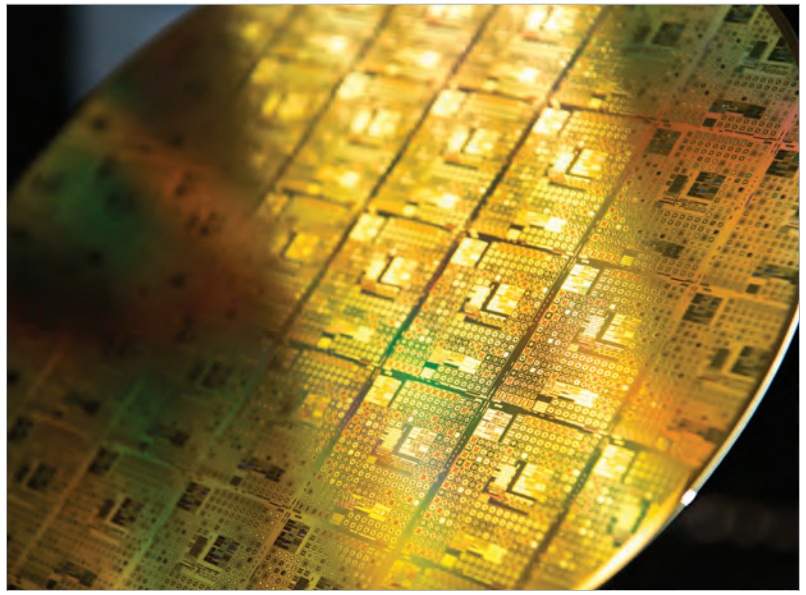
- The use of gallium-nitride (GaN) power transistors is revolutionizing radio-frequency communication and radar systems. Ongoing work is focused on fabricating GaN transistors on a silicon substrate to both reduce cost and provide a pathway to integrate complex logic and control circuitry with the power transistors. Recent measured results of an X-band transmit/receive front-end monolithic microwave integrated circuit showed performance comparable to the more expensive GaN-on-SiC (silicon carbide) process.

- The Laboratory completed the construction and qualification of its Photon-Counting Camera (PCC), which will be integral to enabling a laser communication link to the spacecraft being launched to the Psyche asteroid in 2022. The PCC is part of the Jet Propulsion Laboratory's Deep Space Optical Communications (DSOC) program. The goal of the DSOC program is to demonstrate both ground and space technologies for future bidirectional laser communication systems to deep-space missions.

- A respirator test facility provided efficacy data for more than 100 foreign-sourced N95 filtration masks. Data provided to the Commonwealth of Massachusetts guided the distribution of these respirators to frontline workers during the COVID-19 pandemic.

Radiation-Hardened CMOS

Lincoln Laboratory has advanced fully depleted silicon-on-insulator complementary metal-oxide-semiconductor (CMOS) processes over the past 20 years. One variant of the transistor technology, at right, has been optimized to work in extreme-radiation environments. This variant, the 90-nanometer CMOS node process, was transitioned to the semiconductor foundry SkyWater Technology and will be used to support U.S. government requirements for strategic radiation-hardened microelectronics. A less hardened version of this technology will be created for SkyWater Technology to support commercial technologies that must perform in environments where radiation is present.



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.

A team will undertake "materials by design," an approach that relies on computing properties of potential materials rather than synthesizing materials from known components and provides for more rapid discovery of new materials.

Work continues on components for several NASA programs, including a lidar for the Europa Lander concept and detectors for the Lynx X-ray Observatory concept.

Work is growing in developing multimaterial microsystems built with integrated-circuit fabrication tools to lower costs through economies of scale.

Homeland Protection

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

Leadership

Mr. James M. Flavin
Division Head

Dr. James K. Kuchar
Asst. Division Head

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

A radar system integrated on an unmanned ground vehicle can detect disaster survivors trapped under rubble. The radar extracts a breathing rate and wirelessly transmits the data and the location to rescue teams. Future work will focus on unmanned air vehicle integration.

Principal 2020 Accomplishments

- A prototyping facility was established for the U.S. Air Forces in Europe command that leverages the Laboratory's expertise in regional air defense and supports the Department of Defense (DoD) priority of base defense worldwide.
- A long-range radar and artificial intelligence (AI) algorithms were deployed for recognizing and tracking vessels that may be illegally transporting material across border waterways.
- A modern cloud-based data architecture was defined to support rapid integration and demonstration of new sensing and response technologies for North American Aerospace Defense Command and U.S. Northern Command homeland air defense objectives.
- The Laboratory provided characterization, technology assessments, and prototypes to counter small–unmanned aerial system (sUAS) threats to the homeland and military bases.
- A novel layered sensing architecture is being developed to fuse data from multiple sensors to recognize the transport of concealed threats in mass transit and other public settings.
- The Laboratory supported the development and integration of a counter-sUAS system for the Pentagon Force Protection Agency through operational evaluations, in-depth data analysis, and technology recommendations.
- A novel activated aluminum solid fuel was developed by the Laboratory and is being used to explore new operational concepts for U.S. infantry.
- Energy resilience readiness exercises performed for the DoD identified interdependent infrastructure important to critical missions. The assessment technology and systems approach were transitioned to the private sector.
- An end-to-end system was prototyped to detect hostile foreign narratives, classify accounts engaged in influence operations, and determine the most influential spreaders.
- Assessments were performed on gap-filling sensors being considered to mitigate the spectrum impact of windfarms located near joint-use air surveillance systems.

Future Outlook

Protecting critical infrastructure will require novel sensors and decision support architectures leveraging the Laboratory's advances in low size, weight, and power sensing and AI techniques.

Advances in AI technology will be adapted to resolve the national security enterprise's constraints on data, computation, and algorithms to revolutionize the scale and speed of Department of Homeland Security and law enforcement operations.

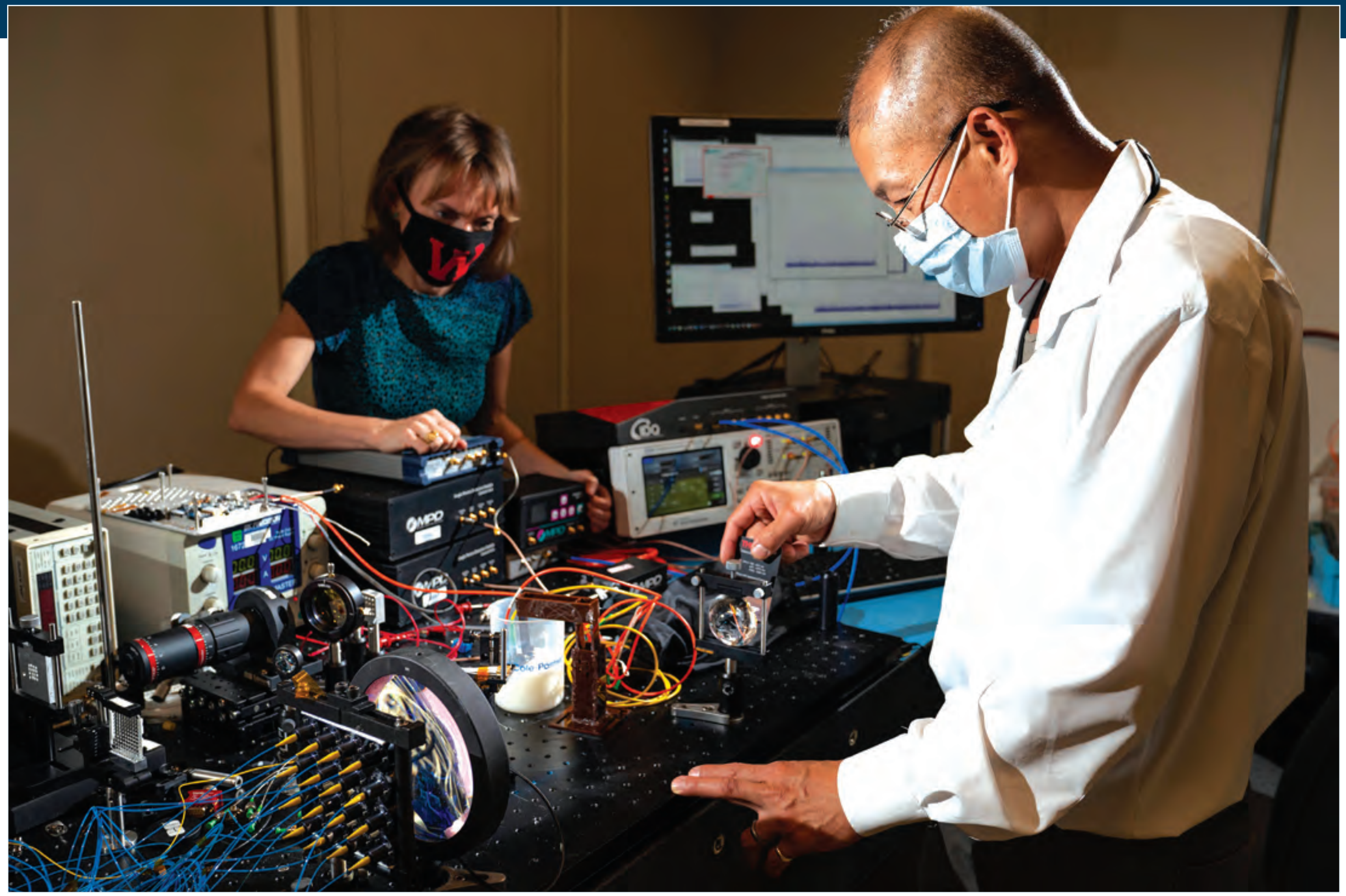
Open architectures for leveraging data, applying AI techniques, and providing secure cyber environments in the cloud will enable advanced command-and-control systems for homeland air defense and multidomain missions.

Co-Polarimetric Radar

Lincoln Laboratory developed a co-polarimetric radar prototype for maritime surface surveillance. The radar, the antenna for which is shown in the image at right, uses dual polarization to improve the detection of slow-moving vessels in sea clutter at high sea states. Laboratory researchers have developed algorithms that demonstrate the ability to use vertical and horizontal RF waveforms in combination with adaptive Doppler processing to help disambiguate between radar returns from the sea surface and those from human-made objects.

Biotechnology and Human Systems

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



Staff are developing a near-infrared spectroscopy system that leverages unique Laboratory Geiger-mode avalanche photodiodes to improve measurements of brain activity. This project is a collaboration with Massachusetts General Hospital and is funded by the National Institutes of Health.

Principal 2020 Accomplishments

- Lincoln Laboratory performed rapid analyses to help the medical, public health, and other communities respond to the COVID-19 outbreak. These activities included modeling the outbreak and the potential demand for personal protective equipment.
- The Laboratory worked with MIT campus, the public health community, and industry to develop the Private Automated Contact Tracing mobile app architecture and served as a technical advisor to state and federal personnel.
- Recent advances in 3D plume reconstruction are enabling better estimates of chemical and biological threat hazards and sensor performance needs.
- A holistic analytical framework to assess medical countermeasures for priority biothreats was developed to inform strategic investments for the Department of Defense.
- A novel blood-brain barrier in vitro culture device, designed to be compatible with high-throughput assays, successfully emulated physiological conditions.
- The Laboratory led a data collection event in Boston, Massachusetts, to evaluate chemical and biological sensors and obtain measurements of background chemical levels in urban environments.
- At the Department of Homeland Security Transportation Security Laboratory, Lincoln Laboratory staff demonstrated methods to enhance explosive trace–detection systems by inducing minor chemical changes in the explosives presented to the instrument.
- The Laboratory fully transitioned the web-based HURREVAC system to the Federal Emergency Management Agency as the official hurricane evacuation platform utilized by the United States and around the world.
- A suite of artificial intelligence algorithms was developed to automate a process for using remote-sensing data to assess damages resulting from disasters.

Leadership

Mr. Edward C. Wack
Division Head

Dr. Jeffrey S. Palmer
Asst. Division Head

Dr. Christina M. Rudzinski
Asst. Division Head

Future Outlook

The Laboratory's strengths in systems analysis, modeling, and prototyping will continue evolving to address the prevention of future pandemics.

Improving humanitarian assistance and disaster response activities will motivate work on advanced architectures, sensors, and analytics.

The Laboratory will develop advanced technologies and system architectures for chemical and biological defense to protect deployed forces and civilians.

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

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

Chemical and Biological Defense Test Bed

The Laboratory has been working closely with the Department of Homeland Security Science and Technology Directorate and the New York Metropolitan Transportation Authority to build and test chemical and biological detection systems. An important element of this work is understanding how particles move within transit systems. As SARS-CoV-2 emerged, the Laboratory quickly developed and deployed a safe aerosol dispersion device to understand how the virus spreads inside transit vehicles as well as evaluated mitigation strategies that would enhance occupant protection. These results are helping to guide transit authority decision making for both the current pandemic and future events.

Air Traffic Control

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

Leadership


Mr. James M. Flavin
Division Head


Dr. James K. Kuchar
Asst. Division Head


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


Dr. Marilyn M. Wolfson
Laboratory Fellow


Dr. Wesley A. Olson
Group Leader


Dr. Tom G. Reynolds
Group Leader


The Laboratory's Ground-Based Sense and Avoid system, operational at 12 military installations, provides maneuvering guidance to unmanned aircraft system operators to help them avoid nearby aircraft.

Principal 2020 Accomplishments

- Lincoln Laboratory completed demonstrations of the Small Airport Surveillance Sensor and initiated technology transfer with the Federal Aviation Administration (FAA) and industry partners.
- The Airborne Collision Avoidance System X (ACAS X) for manned aircraft was incorporated into international standards and is proceeding toward worldwide deployment. Development continues for ACAS X variants for unmanned aircraft systems and rotorcraft.
- The Laboratory completed an upgrade and technology transfer of the Ground-Based Sense-and-Avoid System to six U.S. Army and six Air Force sites.
- The Laboratory supported the acquisition of FAA Next Generation Weather systems, including rapid update weather radar mosaics and storm prediction technology, through contractor build and test cycles.
- The Offshore Precipitation Capability (OPC), developed for the FAA to depict storms beyond the range of land-based weather radars, is being evaluated at several Air Route Traffic Control Centers. A related program, under Air Force sponsorship, is extending the technology to provide global coverage.
- The Airport Capacity Evaluation and Prediction Tool was deployed to Toronto to assist NAV CANADA with air traffic management. The MIT Integrated Risk Analysis Tool was released to the FAA to help develop decision support to assist with the safe and efficient integration of commercial space operations.
- The Laboratory continues to develop methodologies for cyber threat identification and mitigation for air traffic control and aircraft systems. These methods include artificial intelligence (AI) techniques for detecting malicious activities on FAA networks.
- Using machine learning and AI-based methods, the Laboratory continues to develop data management and analytical tools to support mission planning and predictive maintenance for the U.S. Transportation Command.

Portable Airborne Derived Weather Observation System (PADWOS)

The PADWOS prototype shown here, developed under internal funding at the Laboratory, selectively interrogates aircraft transponders within approximately 100 nautical miles to extract information to compute the wind speed and direction at the aircraft's location. With these data, a wind model that is significantly more accurate and complete compared to those made by other techniques can be developed. Timely wind information, such as that provided by PADWOS, could enable higher-capacity traffic management procedures during dynamically changing environmental conditions.

Future Outlook

The Laboratory will continue to enhance the development of Next Generation Air Transportation System concepts, including trajectory-based operations, collision avoidance, and weather impact mitigation. Cybersecurity efforts will address the identification and mitigation of potential vulnerabilities in aviation systems. Innovation in improved weather capabilities will focus on sensing technology and algorithms for managing airspace capacity. Logistics and supply chain efforts will leverage artificial intelligence to forecast demand and allocate resources more efficiently and effectively.

The Laboratory will continue to develop standards, safety evaluation methods, threat avoidance algorithms, and real-time prototypes for unmanned aircraft systems, commercial space operations, and advanced air mobility.

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, communications, and autonomy

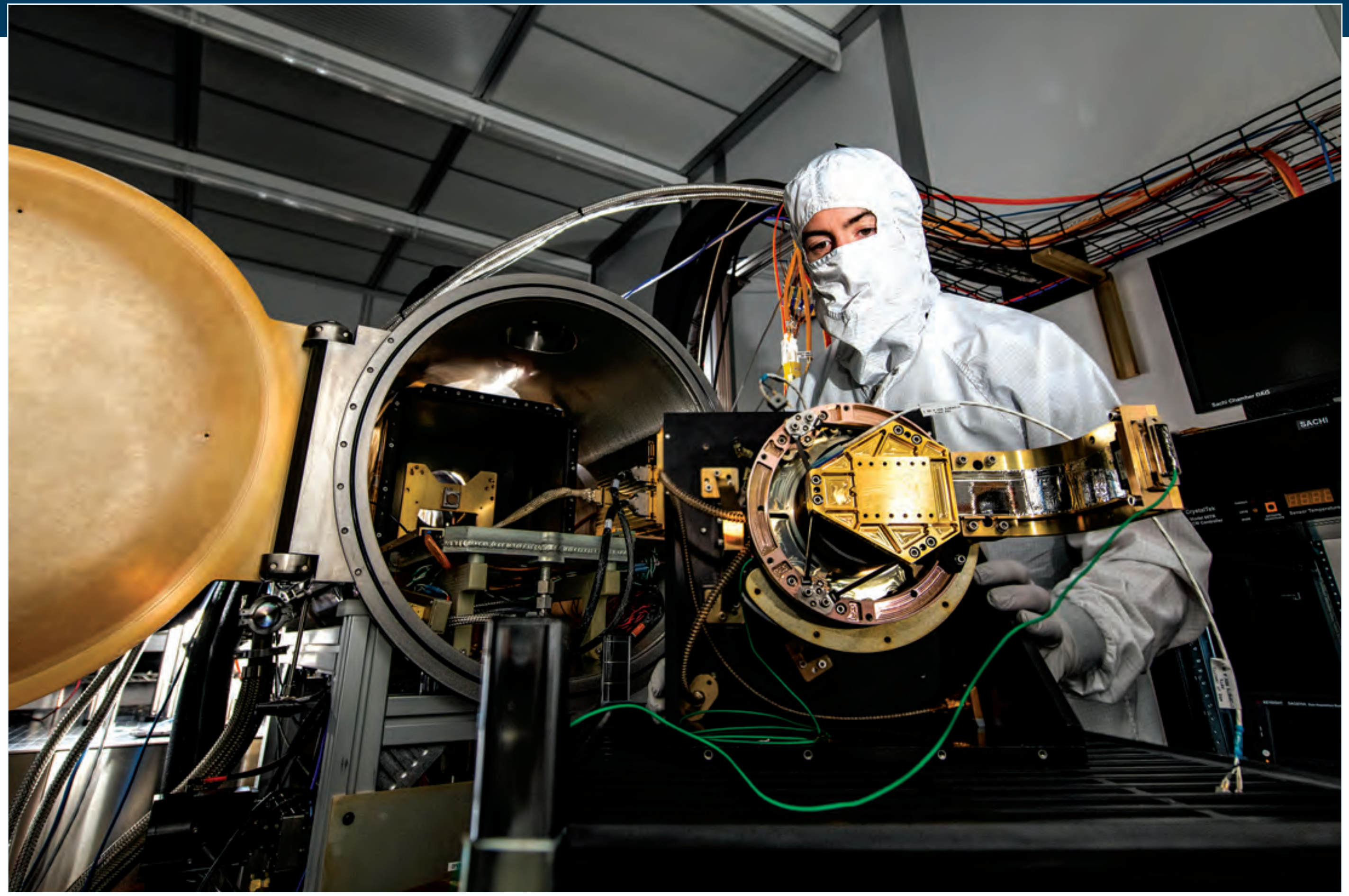
Leadership

Dr. Ted David
Division Head

Dr. Keith B. Doyle
Asst. Division Head

Vicky M. Gauthier
Asst. Division Head

Kristin N. Lorenze
Asst. Division Head



The sensor assembly for the Situational Awareness Camera Hosted Instrument is being placed in a thermal-vacuum chamber by a technical staff member in the Structural and Thermal-Fluids Engineering Group to replicate the environmental conditions of space where the instrument must operate.

Principal 2020 Accomplishments

- Lincoln Laboratory continued its digital engineering transformation and increased the use of state-of-the-art model-based systems engineering; advanced simulation tools that run on the Laboratory's supercomputing resources; and complex, model-driven fabrication. The Laboratory is successfully supporting pilot programs on the new digital engineering platform, which provides a common space for all hardware development activities.
- The development of autonomous vehicles was enhanced by the creation of an open data architecture that provides shared access to terabytes of sensor data. The architecture better enables the development of data-driven autonomy capabilities.
- The Laboratory is helping organizations identify capability gaps and solutions for warehouse modernization and automation. An automated ground vehicle test bed was developed to collect sensor data that helped define requirements for automated ground vehicles. The data will be used to evaluate navigation algorithms for autonomous operations at warehouses.
- Using a new activated aluminum energy source, the Laboratory is helping solve the logistical challenges of the Marine Corps' new operational concepts for austere environments. Aluminum-fueled prototypes are producing gas for lifting stratospheric balloons, filling high-pressure tanks for unmanned aerial vehicles, and reducing the battery burden for infantry.
- The Laboratory is developing lightweight composites for 3D printing that will increase structural performance. Powders alloyed from metal and ceramic were designed and manufactured for printing by laser consolidation. These powders were printed at virtually full density with higher specific stiffness than existing printable materials.
- Utilizing advanced manufacturing techniques, the Laboratory fabricated complex microfluidic channels inside millimeter-scale polymer fibers that enabled the integration and testing of miniature, lightweight recuperative heat exchangers and Joule-Thomson expanders for low-size, -weight, and -power cryogenic applications.

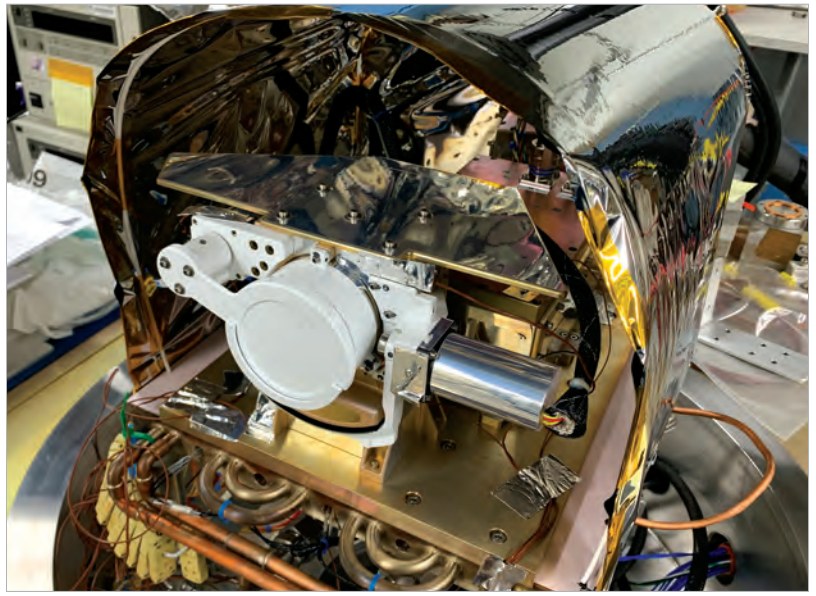
Future Outlook

The Laboratory will adopt augmented and mixed-reality technologies to enhance remote collaboration and to reduce the timeline and cost of prototype development. Augmented reality will superimpose full-scale digital prototypes in real-world settings for comprehensive, broad-based technical reviews. Later in the development, mixed reality will enhance communication of the digital engineering data to technicians and engineers during prototype fabrication, assembly, and testing.

When it opens in 2025, the Engineering Prototyping Facility will provide a modern building as a much-needed replacement for the aging facilities currently occupied by the Engineering Division. The division is working with architecture firms that will design the building and manage equipment moves. Construction is expected to start in 2022.

Local Area Space Surveillance Observations (LASSO)

The Local Area Space Surveillance Observations (LASSO) is a passive optical imaging space payload built by Lincoln Laboratory and delivered to the U.S. Space Force to conduct experiments on the International Space Station for a mission duration of approximately one year. The LASSO sensor consists of a camera, occulter, and a command-and-control processor unit. The primary objective of the LASSO program is to conduct on-orbit testing of a sensor designed for observing space objects with the sun in the camera field of view.



LABORATORY INVOLVEMENT

Students listen to a presentation in the Build a Small Radar course offered during MIT's Independent Activities Period in January 2020.

Research and Educational Collaborations

MIT INDEPENDENT ACTIVITIES PERIOD

Each January in the four weeks between academic semesters, MIT runs the Independent Activities Period, which is a program of for-credit classes for registered MIT students and non-credit activities open to all members of the MIT community. These IAP classes may span the full four weeks or a limited number of days, and range from academic classes to hands-on engineering projects to artistic pursuits.

IAP Highlight: Build a Small Radar

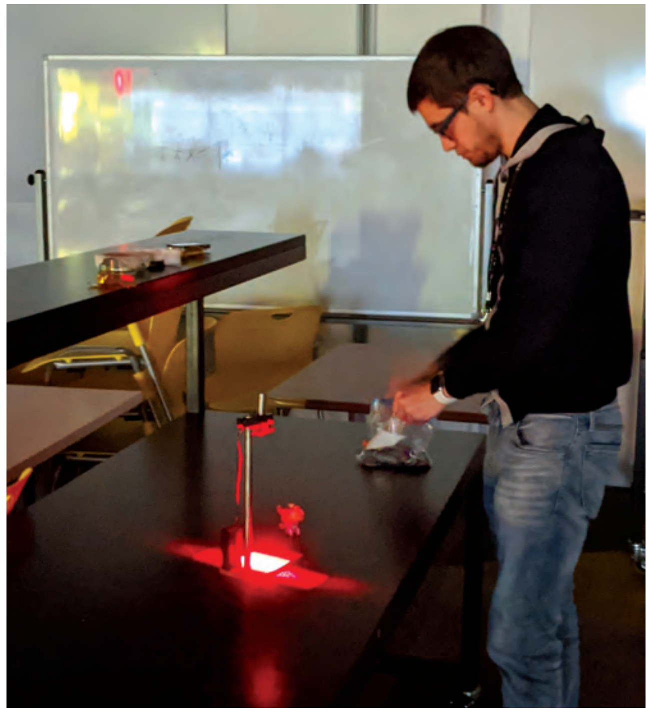
In its 10th year, the Build a Small Radar IAP course still attracted its maximum enrollment of 30 participants. The 2020 class is seen here with their instructors and the "coffee can" small radar systems they built and tested. The 2020 IAP was led by Kenneth Kolodziej with the assistance of Patrick Bell, Elizabeth Kowalski, John Meklenburg, and Bradley Perry.

Lincoln Laboratory technical staff led the following activities offered during MIT's Independent Activity Period (IAP):

- Build a Small Radar—In a hands-on workshop, participants created laptop-based radar systems capable of forming range, Doppler, and synthetic aperture images.
- Free-Space Laser Communication—Students applied principles of lasers and optical components, communication link design, and analog and digital modulation to build their own free-space laser communication system.
- Hands-on Holography—Participants learned the physics behind holographic images and produced both computer-generated and traditional optical holograms.
- Mission-driven Technology Transfer: Perspectives from MIT Lincoln Laboratory—The Laboratory's Chief Technology Ventures Officer led a discussion on the dynamics of transitioning technology developed for specific missions.
- Practical High Performance Computing: Scaling Beyond Your Laptop—With access to the MIT Supercloud, participants explored ways to utilize the high performance computing environment.
- Software-Defined Radio—After an introduction to the fundamentals of software radios, students undertook projects—for example, FM radio receivers and digital video transmission—that demonstrated the flexibility of software radios.

IAP Highlight: Hands-on Holography

The 17 enrollees in this activity sought the answer to "What is holography?" A simple dictionary definition says holography is a photographic method of making 3D images of an object by recording the interference pattern created by a split laser beam striking the object. Most people imagine a hologram as a translucent picture of objects or people. But holography is more than a visual art. It encompasses a variety of measurement and recording techniques at the intersection of wave-propagated interference and diffraction. Its uses range from detecting stresses in materials to generating medical imagery in 3D and color. This course demystifies holography by covering fundamental theory coupled with hands-on laboratory sessions in which students create their own computer-generated holograms and a take-home traditional optical hologram.



Zach Darling, one of the course instructors along with Gregory Balonek, Robert Freking, and Emma Landsiedel, is preparing the lab setup for students to make a reflection hologram.

MACHINE LEARNING TO DETECT AND CLASSIFY NETWORK ATTACKS

In their interactions with cybersecurity analysts, researchers in the Lincoln Laboratory Supercomputing Center and MIT Department of Electrical Engineering and Computer Science identified a need for automated tools that detect and classify threats to computer networks. Such tools would give analysts the information needed to respond appropriately to cyber threats.

The researchers developed a machine learning–based approach to detecting and classifying attacks in raw network traffic. Their approach was based on the hypothesis that different types of network attacks cause distinguishable changes in the entropy, or randomness, of features associated with network flows. For example, in a distributed denial-of-service attack, attackers cause disruptions by bombarding networks with traffic from multiple compromised systems. An observer to this attack would see a significant increase in the entropy of IP address sources. To develop their tool, the team downloaded a massive open-source collection of continually updated raw network data. The team then bucketed the data into 10-second time windows, extracting measures of entropy within various features, such as IP addresses, in the data.

The extracted entropy results were fed into a deep neural network, providing training data for the algorithm to detect entropy and use it to classify a network attack. The team found that their system could detect and identify attacks that affected as little as 5% of the total traffic flow within a network. With this successful initial demonstration, the team is continuing to build out their system for transition to cyber analysts. This work is supported by the MIT-Air Force AI Innovation Accelerator, a program to make fundamental advances in artificial intelligence that could improve Air Force operations while also addressing broader societal needs.

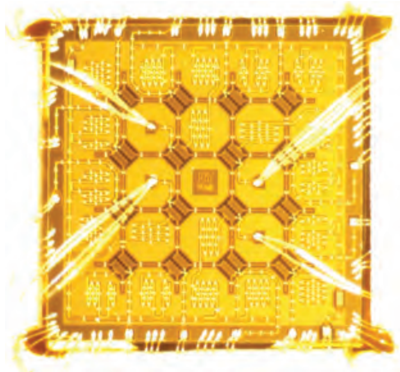
>> Research and Educational Collaborations, cont.

QUANTUM SYSTEMS ACCELERATOR

Lincoln Laboratory is a partner institute on a new Quantum Information Science Research Center announced in 2020. This research center, called the Quantum Systems Accelerator (QSA), is one of five centers stood up by the Department of Energy in support of the National Quantum Initiative Act, passed in 2018 to accelerate the development of quantum science and information technology applications.

The QSA is led by Lawrence Berkeley National Laboratory and incorporates a collaborative research team spanning multiple disciplines and institutions. Research will aim to push quantum computers "beyond-NISQ," the acronym referring to today's generation of noisy intermediate-scale quantum systems. The long-term goal is to develop a universal quantum computer, one that can perform computational tasks that would be practically impossible for traditional supercomputers to solve. To achieve that goal, researchers face enormous challenges in creating and controlling the perfect conditions for large numbers of quantum bits (qubits) to interact and store information long enough to perform calculations.

In their partnership with the QSA, the Laboratory and research partners at the MIT Research Laboratory of Electronics are focusing their efforts on co-designing fundamental engineering approaches to controlling qubits, with the goal of enabling larger programmable quantum systems built from neutral atoms, trapped ions, and superconducting qubits. Advancing all three hardware approaches to quantum computation within a coordinated effort will enable a deeper understanding of the fundamental engineering constraints to achieving large-scale systems.



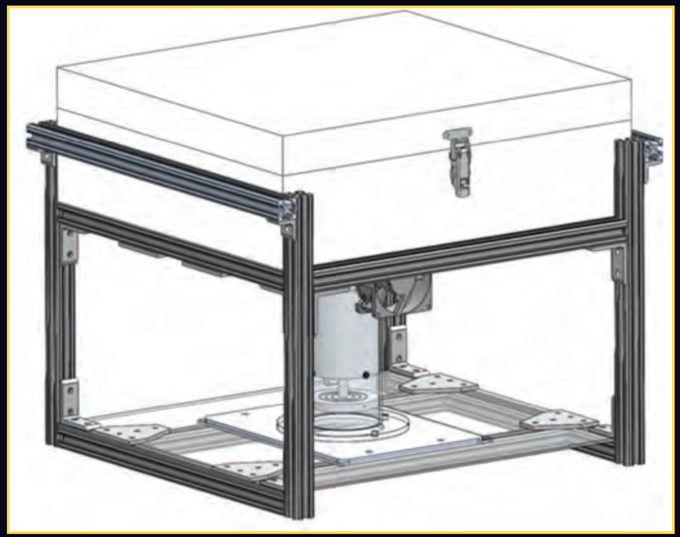
The 16-qubit superconducting quantum chip pictured here was designed, fabricated, and tested by researchers at Lincoln Laboratory and the MIT Research Laboratory of Electronics.

BEAVER WORKS CAPSTONES

Two unique capstone projects were undertaken by undergraduate students in the Engineering Systems Design and the Engineering Systems Development courses offered by the MIT Department of Mechanical Engineering in conjunction with Beaver Works. One team designed a variable-temperature cryo-cooler, and a second team developed a fast underwater glider.

Variable-Temperature Cryo-Cooler

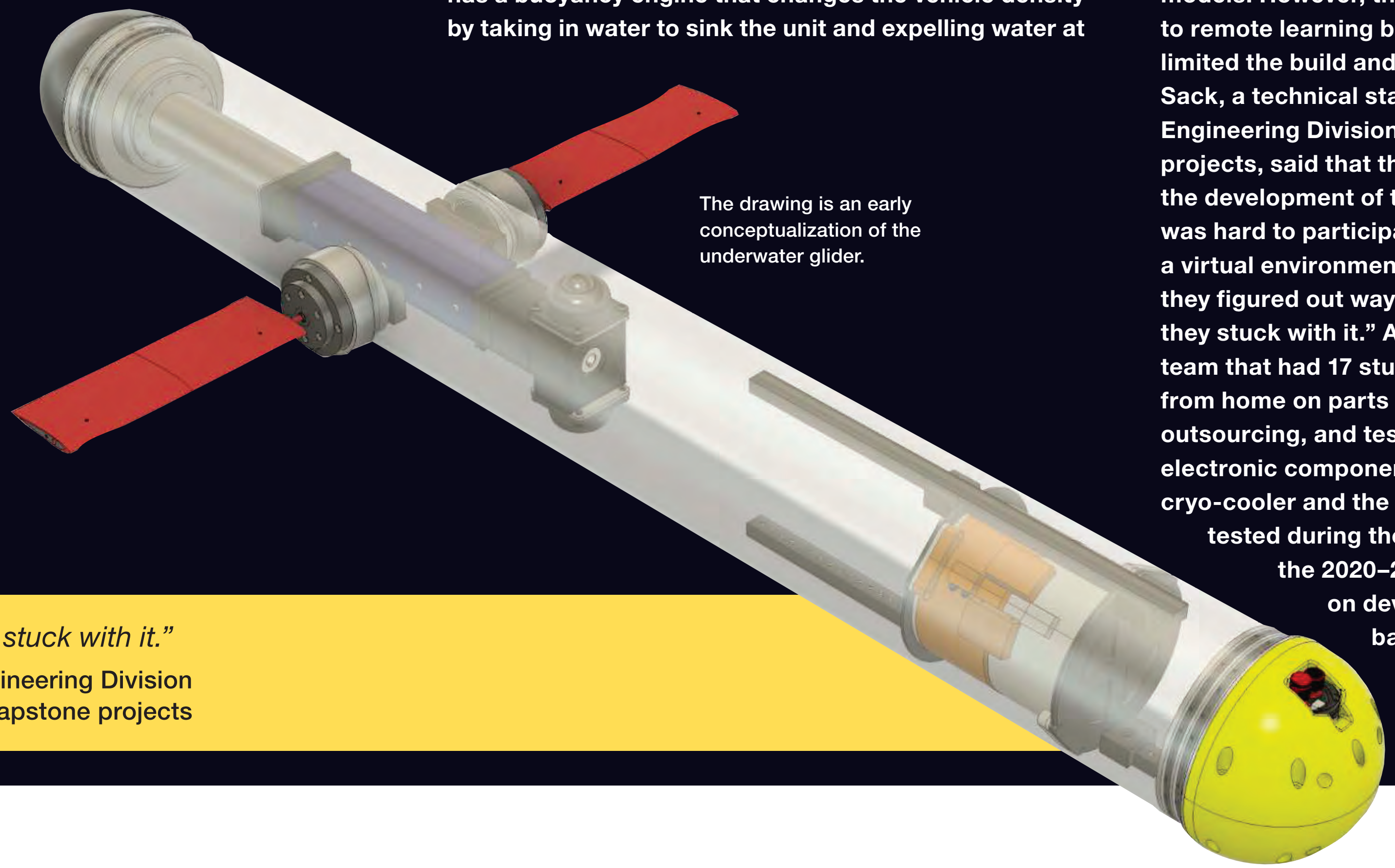
The cryo-cooler addresses a need that medical facilities in remote locations face: how to keep biological samples collected onsite cold enough to preserve until they can be delivered for analysis in a fully equipped biolab. Samples such as DNA or RNA must be stored at anywhere from –20 to –60 degrees Celsius to preserve their structure, and stem cells require storage at –150 degrees Celsius. For hospitals or clinics that are not outfitted, staffed, or funded to perform the sample analysis, a cost-effective cryo-cooler could be an interim storage environment.



The illustration shows the basic design for the variable-temperature cryo-cooler.

Underwater Glider

The team that designed the underwater glider was exploring a cost-effective method to collect water samples from beneath the sea's surface. Many unmanned undersea vehicles run on battery-powered engines that have to be recharged about every three days. These vehicles are high cost, both in money to build and operate and in time to collect sufficient, fresh data. The capstone team envisioned a swarm of inexpensive vertical gliders to quickly and autonomously survey areas of interest through repeated dives over one to two days. Each glider has a buoyancy engine that changes the vehicle density by taking in water to sink the unit and expelling water at the bottom of a dive to allow it to rise back to the surface. The gliders could be sent out to collect samples after an oil spill or to search for a shipwreck or downed airplane. If during a sample collection, the glider discovers interesting specimens, a more advanced underwater system could be dispatched to investigate.



The drawing is an early conceptualization of the underwater glider.

Challenges to the 2020 Course

Typically, in the second course of the design-build sequence, teams construct and test proof-of-concept models. However, the Institute's abrupt move in March to remote learning because of the COVID-19 pandemic limited the build and test portions of the projects. Jean Sack, a technical staff member in Lincoln Laboratory's Engineering Division and an instructor for the capstone projects, said that the students continued to work on the development of the two technologies even though it was hard to participate in a hardware-building class via a virtual environment. "It is a tribute to the students that they figured out ways to continue their work, and that they stuck with it." As an example, she cited the glider team that had 17 students in five time zones working from home on parts of the project, such as designing, outsourcing, and testing printed circuit boards and electronic components. While the prototypes of the cryo-cooler and the glider were not assembled and field tested during the past academic year, students in the 2020–2021 course are currently working on developing a long-endurance system based on the glider team's design and concept.

> *"It is a tribute to the students that they figured out ways to continue their work, and that they stuck with it."*
>
> Jean Sack, a technical staff member in Lincoln Laboratory's Engineering Division and an instructor for the capstone projects

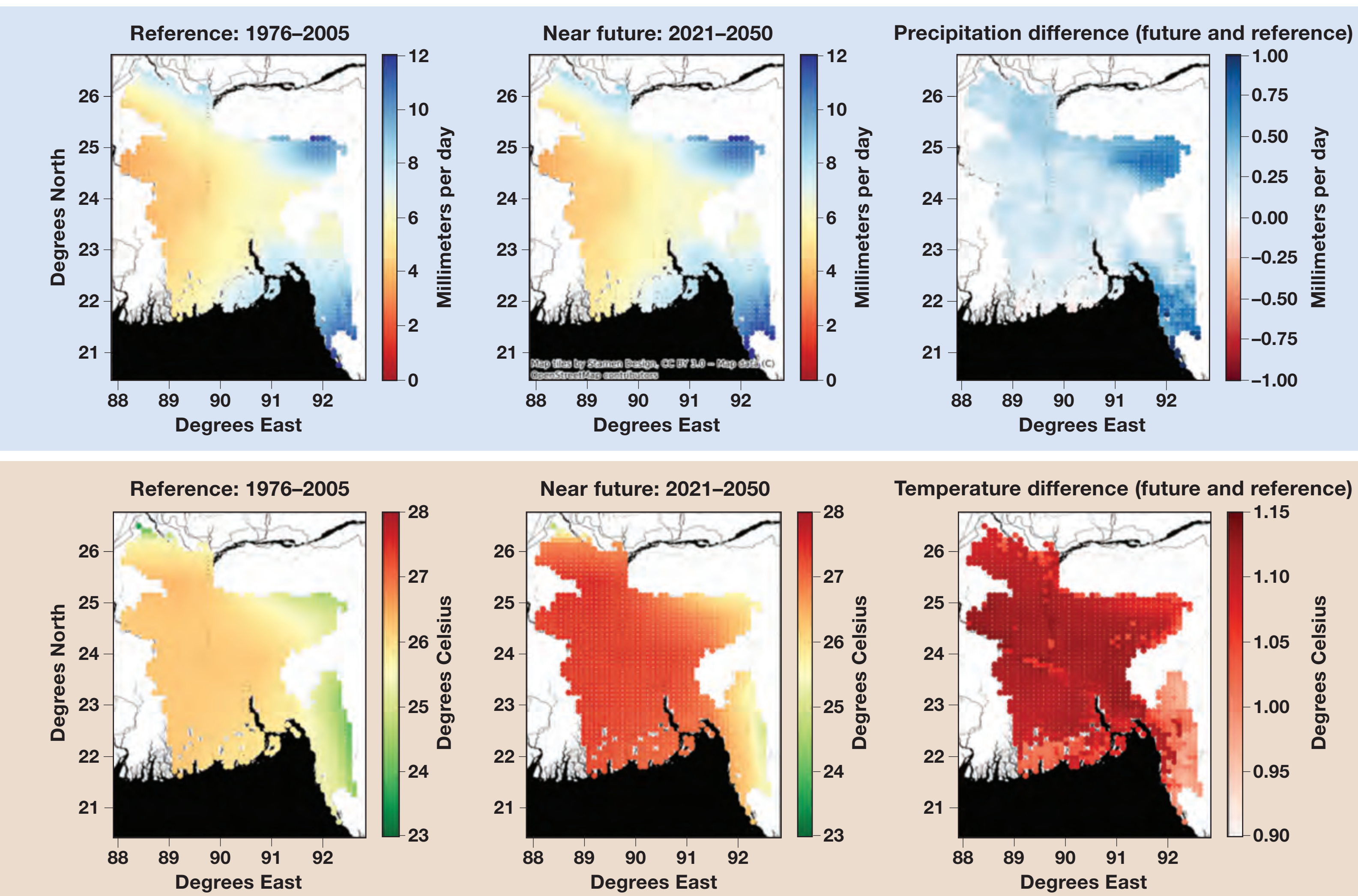
>> Research and Educational Collaborations, cont.

CLIMATE RESILIENCE EARLY WARNING SYSTEM NETWORK

Climate change is a national and global security concern and is already impacting vulnerable nations. One such nation is Bangladesh, which is facing intensified storms, salinity intrusion, severe flooding, and extreme heat waves. As these impacts intensify, affected populations must be aware of future climate dangers to form proactive plans to survive and thrive.

To empower communities to make these plans, Lincoln Laboratory has teamed up with MIT and BRAC, a Bangladesh-based global development organization, to develop the Climate Resilience Early Warning System Network (CREWSNET). CREWSNET combines models to predict the effects of climate change at the scale of ten kilometers with decision support tools and innovative resilience services to help communities develop resilience strategies. The team envisions Bangladeshi communities using the tool to understand specific impacts to their homes, health, and livelihoods. For example, a user could input a livelihood such as farming and see projected rainfall and wet-bulb temperatures and the sustainability of those conditions for crops or even human life. Decision support tools could then help people identify options for adaption or relocation. Understanding the future at the community level is vital for governments and organizations to take steps now to alleviate suffering and reduce displacement later.

In 2020, the team submitted CREWSNET to the MIT Climate Grand Challenges initiative, a research effort addressing the most difficult climate change problems. While CREWSNET is planned for initial adoption in Bangladesh, it has the potential to be adapted for global use.



Bangladesh climate modeling results are shown for the spatial distribution of precipitation and wet-bulb temperature for the business-as-usual trajectory for greenhouse gas emissions. Average annual precipitation—past, projected (2021–2050), and difference—show rainfall increases in the next three decades are most significant in the eastern cities of Sylhet, Chittagong, and Cox's Bazar. Average wet-bulb temperature for summer—past, projected (2021–2050), and difference—show the wet-bulb temperature is expected to exceed the U.S. National Weather Service danger threshold of 27 degrees Celsius primarily in the interior region, implying that dangerous heat stress will become normal in most low-lying plains of Bangladesh in the next few decades.

MILITARY FELLOWS PROGRAM

Every year, the Military Fellows Program offers military officers pursuing graduate degrees or advanced education the unique opportunity to engage in R&D at the Laboratory. Fellows are directly involved in developing capabilities important to national security, and in turn, Laboratory staff benefit from the officers' unique insights. Since the program's start in 2010, more than 310 fellows have worked alongside Laboratory staff mentors. In fall 2020, the Laboratory welcomed 26 military officers from the U.S. Army, Navy, and Air Force.

Above, U.S. Army Second Lieutenant Charlson Ro, a student in the MIT Sloan School of Management, analyzed technology development timelines for the Air Traffic Control Systems Group. At left, U.S. Air Force Second Lieutenant Albert Thieu developed error mitigation procedures for the Agile Micro Satellite project in the Applied Space Systems Group.

Because of the COVID-19 pandemic, the program's 2020 cohort conducted their work remotely. "Most of the challenges to the Military Fellows Program this year fell on the Lincoln Laboratory supporting staff, who once again rose to the occasion by joining the fellows in a remote way and providing them with the tools and equipment they needed to function effectively," said Robert Loynd, Lincoln Laboratory Executive Officer and Chief of Staff.

Despite the program's modified work model, the fellows acquired valuable skills and experiences that they would not have been able to attain elsewhere. "I liked being able to get my hands on actual data because the data we get for homework and class assignments are already clean, which is unrealistic. Going through data processing with my group was a highly useful exercise as a result," said U.S. Army Second Lieutenant Charlson Ro, who worked on a part production scheduling project in the Laboratory's Air Traffic Control Systems Group. Ro hopes to transition to the Army's Functional Area 49, Operations Research/Systems Analysis, and said his time at the Laboratory would help him gain practical experience in using analytical tools vital to his job.

U.S. Air Force Second Lieutenant Albert Thieu, an aerospace engineering student at MIT, contributed to the Agile Micro Satellite project, which aims to demonstrate a CubeSat's ability to change orbit. Successful demonstration of this capability would be a big step toward preventing satellite collisions and detection by adversaries, ultimately improving the survivability of satellites. Thieu not only was excited to work on a groundbreaking project, but also believed the Military Fellows Program would benefit his future as an Air Force pilot and the military service as a whole. "For the service, it provides more avenues for technical and organizational innovation at the lowest levels. For myself, I think it will provide me with the skills to contribute in Air Force and general scientific research both during and after my piloting assignments," he said.

>> 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.

Because of the COVID-19 pandemic, the following on-site workshops were canceled in the spring: Advanced Technology for National Security Workshop; Defense Technology Seminar; Space Control Conference; Air Vehicle Survivability Workshop; Lincoln Laboratory Communications Workshop; and Air, Missile, and Maritime Defense Technology Workshop. The summer and fall workshops that were not canceled were held in a virtual format.

2020 Schedule of Lincoln Laboratory Workshops

FEBRUARY

- **8** Artificial Intelligence (AI) for Cyber Security Workshop

JUNE

- **9–11** Next-Generation Identification and Awareness Workshop

AUGUST

- **29** Robustness of AI Systems Against Adversarial Attacks

SEPTEMBER

- **8** Human–AI Interaction Workshop
- **22–24** Human-Machine Collaboration for National Security Workshop

OCTOBER

- **6–7** Advanced Prototype Engineering Technology Symposium
- **14** Anti-Access/Area-Denial Systems and Technology Workshop
- **28** Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

NOVEMBER

- **3–4** Homeland Protection Workshop Series
- **16** Human-Machine Collaboration for National Security Workshop
- **17–20** Recent Advances in Artificial Intelligence for National Security

DECEMBER

- **1–2** Counter-Human Trafficking Technology Workshop
- **4** Defense Technology Seminar for Military Fellows (One Day)

2020 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.

22–24 September
IEEE High Performance Extreme Computing Conference

18–19 November
IEEE International Workshop on Wearable Sensors and Devices, AI and Wearables Market

Next-Generation Identification and Awareness Workshop

To support the mission of the Army's Next-Generation Identification and Awareness (NGIA) Office, the Laboratory established a technology development core team composed of staff from five different divisions to act as science advisor and support NGIA and special operations forces with system architecture analyses, long-term technology development, hackathons, innovation exercises, and annual workshops. The June workshop brought technology developers together, showed them the common mission problems, and got people working on collaborative solutions, combining special expertise across different organizations. The workshop included focus sessions, briefings, and opportunities for industry representatives to meet with the government employees. Because of the success of the virtual event, the team plans to host the workshop biannually, with one in person and the other virtual—tentatively planned for January and the summer of 2021.

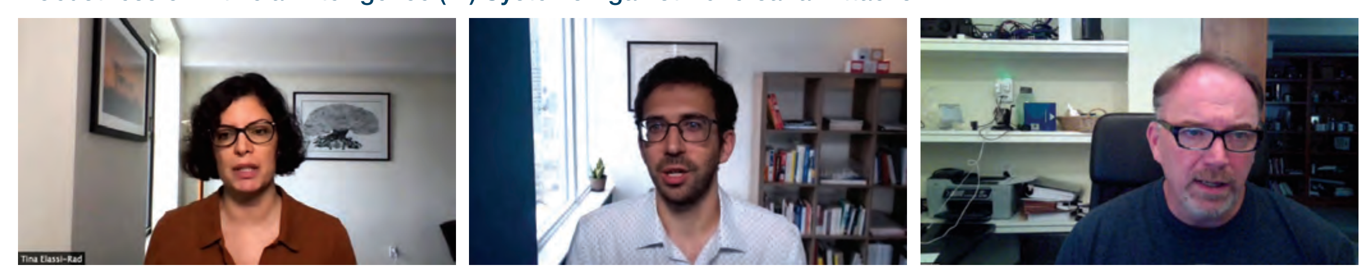
Counter-Insider Threat Social and Behavioral Science Research Summit

Lincoln Laboratory staff were selected to present a talk during the first annual Department of Defense Counter-Insider Threat Social and Behavioral Science Research Summit in September. The summit was a 30-day virtual education, awareness, and training event contributing to National Insider Threat Awareness Month. To support the theme of resilience and recovery, Daniel Hannon, Jeffrey Palmer, Hayley Reynolds, and William Streilein presented "Noninvasive Biomarkers of Mental State for Organizational Resilience and Recovery."

Artificial Intelligence for Cyber Security Workshop

The Laboratory hosted the Artificial Intelligence for Cyber Security (AICS) workshop on 8 February. The workshop focused on applying AI to problems in cybersecurity. "We hold the AICS workshop to establish the Laboratory's leadership role in human-machine teaming research," said Dr. Dennis Ross, Assistant Leader, Cyber Operations and Analysis Technology Group, and one of the organizers of the workshop. "Our intent is to inspire the academic AI community to tackle the hard problems in human-machine teaming and to lay the groundwork for research advances."

Robustness of Artificial Intelligence (AI) Systems Against Adversarial Attacks



Keynote speakers for the inaugural RAISA3 Workshop included, left to right, Professor Tina Eliassi-Rad of Northeastern University, Professor Nicolas Papernot of the University of Toronto, and Professor Patrick McDaniel of Pennsylvania State University. Each keynote focused on different aspects of ways to mitigate attacks on end-to-end AI systems.

On 29 August, Laboratory staff hosted the Robustness of AI Systems Against Adversarial Attacks (RAISA3) Workshop. The workshop included three keynote addresses and two paper presentations from Laboratory staff. "While most research efforts today are focused only on the algorithm," said William Streilein, co-chair of the workshop, "our approach is to explore the impacts of adversarial AI on the full system, including input, data conditioning, the algorithm, human-machine teaming, and mission application."

Diversity and Inclusion

A diverse workforce and an inclusive culture are more than just goals; they're vital to Lincoln Laboratory's technology mission. The Laboratory's culture must reflect the diversity of the nation it serves, and solving the nation's hardest problems takes the combined talents and unique views of many, sharing an environment where individuals are empowered to be their best. The Laboratory thrives when employees' views, experiences, and knowledge combine to drive innovation, and the ability to rapidly develop technology is made possible by a work environment in which employees are embraced for what they can do and for who they are. Diversity and inclusion are the Laboratory community members' responsibility to each other and to the nation they serve.

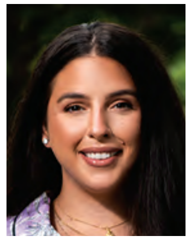
THE DIVERSITY AND INCLUSION OFFICE

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

LEADERSHIP

Chevy Cleaves
Chief Diversity and Inclusion Officer

Alex Lupafya
Deputy Chief Diversity and Inclusion Officer



Samantha Jones
Assistant Program Manager

The D&I Office offers many resources and events for the Laboratory community, including seminars that cover a variety of topics such as racial bias in healthcare, leadership development offsites where staff can learn how to lead effectively and inclusively, study groups, Laboratory-wide educational and cultural initiatives, and more.

Employee Resource Groups

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

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

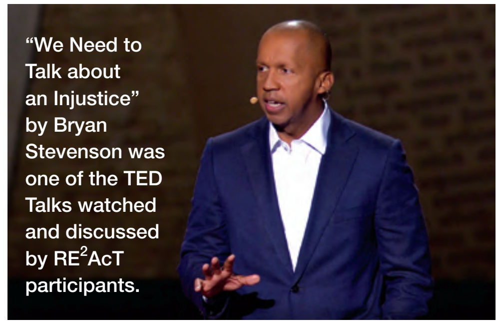
>> Diversity and Inclusion, cont.

Research. Educate. Empathize. Act. Transform (RE^{2}AcT) Initiative

2020 was a year of much unrest and cultural reckoning about ongoing racial injustices in the nation. In July, the D&I Office developed and launched an initiative to help members and leaders of the Lincoln Laboratory community develop the foundation necessary to strategically respond to the challenge of systemic racism while building a more diverse and inclusive organization. The RE^{2}AcT (Research. Educate. Empathize. Act. Transform) initiative was developed to help create the conditions for sustainable organizational success and to provide a safe space where staff could openly discuss their thoughts and reactions on the multitude of topics covered throughout the program. The goals of RE^{2}AcT are to

- Develop relational equity
- Create psychological safety
- Increase familiarity with new concepts and vocabulary
- Practice centering/recentering on the African American experience
- Foster greater cultural fluency
- Identify challenging areas that require increased focus
- Cultivate strategic resilience

During the year, a variety of virtual events and resources were offered to the entire Laboratory community through the



"We Need to Talk about an Injustice" by Bryan Stevenson was one of the TED Talks watched and discussed by RE^{2}AcT participants.

RE^{2}AcT program, including TED Talk and documentary screenings; online articles; and live panel discussions and seminars featuring prominent professors, activists, and writers. Topics ranged from the U.S. prison-industrial complex to biases and racism. These events were typically followed by discussion sessions during which participants were encouraged to express their thoughts about the subject material in a safe and open environment.

"This series has been very well received and continues to inspire empathetic discussions across a range of topics that have been acknowledged as being largely unfamiliar to our nonminority populations," said Chevy Cleaves, Chief Diversity and Inclusion Officer. "RE^{2}AcT has played a critical role in helping us advance toward our goal of building a more diverse Laboratory that is led inclusively and free of systemic racism."

2020 RE^{2}Act Events

"13th"
Documentary; Directed by Ava DuVernay

"The Removal of Confederate Monuments"
Speech; Mitch Landrieu

"What This Cruel War Was Over"
The Atlantic article; Ta-Nehisi Coates

"Race: The Power of an Illusion"
PBS documentary series

"From Privilege to Progress"
Live virtual panel discussion; Melissa DePino and Michelle Saahene

"How to Overcome our Biases? Walk Boldly Toward Them"
TED Talk; Verna Myers

"The Trauma of Systemic Racism Is Killing Black Women"
TED Talk; T. Morgan Dixon and Vanessa Garrison

"Color Blind or Color Brave?"
TED Talk; Mellody Hobson

"Racism has a Cost for Everyone"
TED Talk; Heather C. McGhee

"The Angry Eye"
Documentary; Directed by Susan A. Golenbock

"How to Deconstruct Racism, One Headline at a Time"
TED Talk; Baratunde Thurston

"The Danger of a Single Story"
TED Talk; Chimamanda Ngozi Adichie

"True Justice"
HBO documentary

"We Need to Talk about an Injustice"
TED Talk; Bryan Stevenson

"Creating Conscious Belonging"
Seminar; Howard Ross

"Overcoming Obstacles to Belonging: Addressing Identity Anxiety and Stereotype Threat"
Seminar; Rachel Godsil

"Picture a Scientist"
Live virtual panel discussion; Dr. Raychelle Burks and Dr. Jane Willenbring

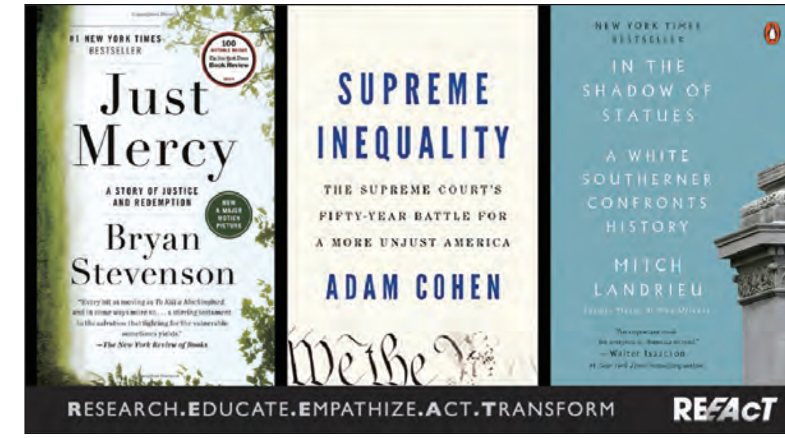
"Systemic Racism: The Role of Tech Leaders in Charting the Way Forward"
Seminar; Benjamin Reese

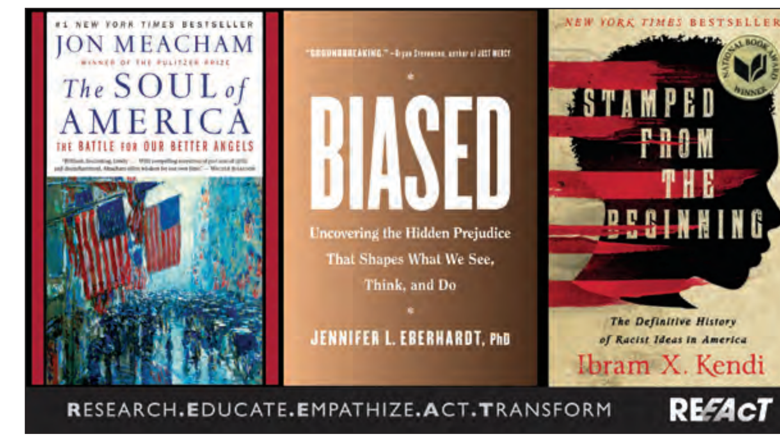
RE^{2}AcT Study Groups

In fall 2020, the D&I Office launched the RE^{2}AcT study groups. Laboratory employees who sign up for the study groups read and discuss books about social issues in America. The discussions are held in small groups of approximately 15 people, and facilitators moderate the conversations. In the fall and winter 2020 sessions, a total of 278 participants and 42 facilitators took part in the study groups. The goals of the study groups are to extend conversations kickstarted during the main RE^{2}AcT events; to create an inclusive and safe atmosphere for small-group learning and discussion; and to identify topics/areas for further research, learning, and development. A new set of books is offered each quarter, and the study groups are planned to continue through September 2021.

The books selected for these sessions cover a wide range of topics, including racial and socioeconomical biases in the American criminal justice system and education system. The first book featured in the series, *The New Jim Crow* by Michelle Alexander, discusses how mass incarceration in the United States has created a modern system of oppression similar to the Jim Crow laws of the 19th and 20th centuries that enforced racial segregation.

Kristan Tuttle, a participant in one of the *The New Jim Crow* study groups, said about her experience, "[The study group] has given me strength and confidence to talk to people outside of this group, like my family and friends, about incarceration and race to help make them aware of the new Jim Crow."





2020–2021 RE^{2}AcT Study Group Books

The New Jim Crow
by Michelle Alexander

The Price of Admission
by Daniel Golden

Everyday Bias
by Howard Ross

Just Mercy
by Bryan Stevenson

Supreme Inequality
by Adam Cohen

In the Shadow of Statues
by Mitch Landrieu

The Soul of America
by Jon Meacham

Biased
by Jennifer Eberhardt

Stamped from the Beginning
by Ibram Kendi

The Negro's Civil War
by James McPherson

Whistling Vivaldi
by Claude Steele

How to be an Antiracist
by Ibram Kendi

>> *Diversity and Inclusion, cont.*

Cultivating Leadership, Achievement, and Success (CLAS) Symposium

Deborah Lee James, former Secretary of the U.S. Air Force, delivered the keynote speech for the 2020 CLAS symposium.

On July 14, 2020, the Laboratory's ERGs hosted the third annual Cultivating Leadership, Achievement, and Success (CLAS) career development symposium. The theme of the event was innovation through inclusive leadership. The virtual sessions focused on helping attendees develop the skills necessary for the work-from-home environment, such as how to improve listening skills in an increasingly virtual work environment and how to become an emotionally intelligent leader.

Chevy Cleaves, Chief Diversity and Inclusion Officer at Lincoln Laboratory, opened the event with a discussion about diversity and inclusion in leadership. The keynote presentation was then given by Deborah Lee James, former Secretary of the U.S. Air Force and a member of the Laboratory's advisory board. In her talk, James shared a story of how a personal failure led her down a path that she ultimately found more fulfilling. She also discussed actions that helped her to navigate her career in the male-dominated fields of politics, business, and the armed services.

Following the keynote speech, Leslie Weiner Alger—the founder, CEO, and Executive Coach at Creative Edge Leadership and a former Lincoln Laboratory group leader—led a workshop about emotional intelligence and the importance of empathy in leadership and teamwork. Ken Estabrook, Manager of Training and Education at Lincoln Laboratory, gave a presentation on adapting listening skills to virtual interactions. The symposium ended with an awards ceremony and a speech on leadership presented by Lincoln Laboratory Director Evans.

"I would love for CLAS to help guide the entire Laboratory into a new era of diversity, inclusion, and overall awareness," said Bonita Burke, co-chair of the CLAS committee.

"By training and building the emotional intelligence skills we wish to see in leaders, we are training folks to be even better leaders as they move throughout their careers. It is good for programs, it is great for the Laboratory, and it is great for staff."

Attendees of the Cultivating Leadership, Achievement, and Success (CLAS) Symposium and CLAS committee members are shown with Leslie Weiner Alger, top left. Alger is the founder, CEO, and Executive Coach at Creative Edge Leadership and a former Lincoln Laboratory group leader.

Our Voices, Our Vote! A Century of Women Leading Change

As part of the Our Voices, Our Vote! initiative, the Communications and Community Outreach Office and Technical Communications developed and hung throughout the Laboratory banners that featured the stories of various women who work at the Laboratory.

In 2020, the United States marked a milestone in women's struggles for equality—the 100th anniversary of the adoption of the 19th Constitutional Amendment that guarantees women the right to vote in all state and federal elections. To celebrate the centennial of this historic moment, the Laboratory hosted a series of events throughout August, the month in which the amendment was adopted, as part of an initiative called "Our Voices, Our Vote! A Century of Women Leading Change (OVOV)." The events recognized the achievements of women at the Laboratory and encouraged the Laboratory community to reflect on the advances and setbacks along the path toward achieving gender equality.

The project came into being through the collaboration of departments, offices, and ERGs from all across the Laboratory, including the Diversity and Inclusion Office, the Communications and Community Outreach Office, Technical Communications, LLWN, LLOPEN, Knowledge Services, and the Information Services Department.

The month's events kicked off with a panel discussion about women in leadership at the Laboratory. The six panelists talked about how changes to the Laboratory culture and leadership have impacted their careers and those of other women over the years. A second panel discussed how identity is multifaceted and how different people may need different kinds of support from allies.

Teams from across the Laboratory took part in a trivia competition about women at the Laboratory; in STEM; and throughout history, sports, music, and movies. The final event was a screening of the documentary *Pioneers in Skirts* and a live panel discussion with the director and the producer of the film, Lea-Ann Berst and Ashley Maria. The documentary explores gender biases and the sexist load that wears women down, hurts their potential, and makes them question their dreams.

Also as part of OVOV, a set of banners was displayed throughout the Laboratory to spotlight some of the talented women who contribute to the Laboratory's mission to develop innovative technology for national security.

"Our hope with this initiative is that people will understand that women have come a long way, but that this fight is far from over," said Samantha Jones, who helped organize the event. "August 18, 1920, will forever be a monumental moment in the history of women's rights, but there is still much work to be done."

>> Diversity and Inclusion, cont.

Highlights: Staying Connected Through D&I

While the COVID-19 pandemic drove the majority of Laboratory staff to work remotely during 2020, the D&I Office and the ERGs inspired inclusion and belonging by hosting virtual events throughout the year. These events were an important way for employees to connect and maintain a sense of community while continuing impactful discussions and learning.

As part of Black History Month, LEAN hosted the seventh annual Martin Luther King Jr. Luncheon in February 2020. The theme of the event, “Fostering Strong, Moral, and Courageous Leadership,” was inspired by Dr. King’s “Give Us the Ballot” speech in which he urged the U.S. government to ensure voting rights for African Americans.

NASA Astronaut Stephanie Wilson delivered the keynote speech. She commemorated Katherine Johnson, an African American NASA mathematician whose calculations were critical to NASA’s first and subsequent crewed spaceflights, and talked about her own work at NASA where she flew three missions on Space Shuttle Discovery. Wilson challenged attendees to constantly think about how they can be inclusive as leaders and as team members. “It’s the people that surround us and give us encouragement who help us to achieve our dreams,” she said.

> *“It’s the people that surround us and give us encouragement who help us to achieve our dreams.”*
>
> Stephanie Wilson, NASA Astronaut

Kofi Williams from the Laboratory’s Facility Services Department ended the luncheon by teaching attendees a simplified version of Azonto, a dance from Ghana. “To see Laboratory leadership right at the front [of the room] dancing to Azonto—it was very encouraging to know that leadership is embracing diversity and cultural awareness,” Williams said. “We hope to promote more cultural awareness because we are all one people and we all have a goal to make the world a better place.”

In May 2020, PALS hosted three virtual events to celebrate Asian Pacific American Heritage Month (APAHM) and to bring employees together to discuss the historical and current experiences of those with Asian and Pacific Island heritage who are living in the United States.

Pan-Asian Laboratory Staff’s Asian Pacific American Heritage Month celebration included a virtual screening and discussion of the PBS documentary *Asian Americans*.

The first event was a mingle meeting for staff to celebrate the start of APAHM and to interact with each other in an open conversation. Dr. Madhavi Seetamraju, an assistant group leader at Lincoln Laboratory, participated in a Fireside Chat—a series of conversations with senior Laboratory staff to gain perspective on their career journeys. Seetamraju said that the informal nature of the chats helped participants feel open to sharing their thoughts. The last event was a discussion of PBS’s *Asian Americans* documentary series.

In addition, PALS held a series of discussions in the summer centered around Asian American allyship standing in solidarity with and supporting the sanctity of Black lives. PALS made available a list of resources for actions that the Laboratory community can take to combat racism.

Following APAHM is LGBTQ+ Pride Month in June, which commemorates the Stonewall riots in New York City that served as the catalyst for the gay rights movement in the United States.

LLOPEN collaborated with other Laboratory ERGs and the D&I Office to create joint efforts starting in June 2020. These events promoted the idea of solidarity and acceptance across a wide range of differences. LLOPEN and LLWN co-hosted a viewing of Susan Cain’s TED Talk “The Power of Introverts,” which discusses why introverts should be encouraged and celebrated in a society where extroverts are highly valued.

In conjunction with NEN, LLOPEN hosted a virtual spoken-word poetry open mic event inviting participants to perform their favorite published and/or original works of poetry, particularly those with a social justice focus. LLOPEN also worked with the Director’s Office and the Facility Services Department to secure approval for an all-gender restroom.

Hispanic Heritage Month (HHM), observed from September to October at the Laboratory and across the country, honors the contributions of Hispanic and Latinx Americans while celebrating heritage that is rooted in Latin American countries. Throughout the month, HLN hosted events that encouraged Laboratory members to celebrate, learn from, and identify with the Hispanic/Latinx community.

“Our vision when planning this year’s HHM events was to create events that highlight prominent Hispanic figures in STEM while simultaneously celebrating our diverse cultures through music, games, and social events,” said Jarilyn Hernandez-Jiminez, a co-chair of HLN.

Three keynote speakers were invited to discuss their important scientific work and contributions. Ricardo Baeza-Yates, Director of Graduate Data Science Programs at Northeastern University, spoke about bias on the web. Maria De-Arteaga, an assistant professor at McCombs School of Business at the University of Texas at Austin, explained how societal biases encoded in data may be compounded by machine learning models and offered solutions to this issue. Natalia Villanueva Rosales, an associate professor at the University of Texas at El Paso, discussed how her work aims to improve the efficiency and effectiveness of the discovery, integration, and trust of scientific resources.

Members of the Lincoln Laboratory Out and Proud Employee Network committee gathered for a photo in early 2020.

Awards and Recognition

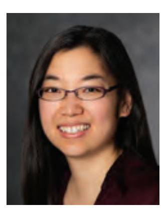
2019 Lincoln Laboratory Technical Excellence Awards

Dr. William J. Blackwell, for his wide-ranging, innovative contributions to the science and practice of environmental monitoring through the development of both flight hardware for making important atmospheric sounding measurements and novel methods for using neural networks to extract relevant information from the measured data.

H. David Goldfein, for his outstanding contributions to the analysis and development of innovative RF systems; his deep understanding of hardware and signal processing for signals intelligence, communications, and radar technology has had significant impact on national security missions.

2019 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Brian G. Saar, for his development of innovative concepts in active infrared technology and systems for spectroscopy, chemical defense, sensing, and countermeasures. His concepts explored the use of quantum lasers and infrared scattering.



Dr. Emily Shen, for her outstanding technical contributions and leadership in the area of advanced cryptography, particularly in the design, development, and application of secure multi-party computation (MPC) technology. She is highly involved with the academic MPC community.

2019 MIT Lincoln Laboratory Best Paper Award

Dr. Arthur Lue, **Jessica D. Ruprecht**, **Jacob D. Varey**, **Dr. Herbert E. M. Viggh**, and **Dr. Mark G. Czerwinski**, for "Discovering the Smallest Observed Near-Earth Objects with the Space Surveillance Telescope," published in *Icarus*, Volume 325, June 2019.

2019 MIT Lincoln Laboratory Best Invention Awards

Robert W. Haupt and **Dr. Charles M. Wynn**, for the invention of Noncontact Laser Ultrasound for Medical Imaging and Elastography.

Dr. Hamed Okhravi, for the invention of Timely Randomization Applied to Commodity Executables at Runtime.

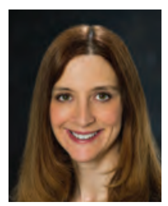
2019 Eugene G. Fubini Award

William P. Delaney, for more than 30 years of significant contributions as an adviser to the Department of Defense. The Fubini Award is the highest award given by the Secretary of Defense to a civilian who has had advisory roles in national-level defense studies and task forces.

Defense Science Board Chair

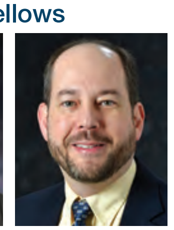
Dr. Eric D. Evans was named the chair of the Defense Science Board, a committee that is composed of technology experts and that advises the Department on Defense on technical innovations of relevance to national security.

Air Force Service Awards



Dr. Melissa G. Choi received the Exceptional Public Service Award for her participation and vice chairmanship on the Air Force Scientific Advisory Board (AFSAB). **Dr. David J. Ebel** received the Commander's Public Service Award for his contributions to AFSAB studies.

2020 IEEE Fellows



Dr. Richard P. Lippmann, far left, for contributions to neural networks and assessment of computer security systems. **Dr. Daniel J. Rabideau**, left, for contributions to radar architectures and technologies.

AIAA Associate Fellows

Dr. Robert T-I. Shin, left, and **Dr. Grant H. Stokes**, middle, were selected to the 2020 class of Associate Fellows of the American Institute of Aeronautics and Astronautics for their important and exceptional contributions to the arts, sciences, or technology of aeronautics or astronautics. The 2021 class of Associate Fellows included **Dr. Nathan J. Falkiewicz**, right.

2020 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative category: **Marilyn J. Lewis**, far left, for applying

her expertise in cataloging satellite orbital elements to lead the analyst team at the Lincoln Space Surveillance Complex; **James B. Lockler**, left, for developing and implementing the Laboratory's security education program.

Support category: **Laurie A. Briere**, far left, for supporting the

operations of the Advanced Technology Division and leading the administrative management of the 2019 Advanced Technology for National Security conference; **Robin J. Lucente**, left, for managing the administrative tasks involved in maintaining the security and operation of a closed facility used by multiple divisions.

2020 IEEE Power & Energy Society Outstanding Power Engineering Educator Award

Dr. Marija Ilic, for contributions to mentorship and education on modeling and control in power engineering.

2020 Associate Fellow of the Society of Experimental Test Pilots

Todd R. Lardy, a pilot at the Lincoln Laboratory Flight Test Facility, was elevated to Associate Fellow of this international organization in recognition of his many years of experimental flight testing.

2020 Above and Beyond Awards

Dr. Bonita J. Burke and **Julie A. Arloro-Mehta**, cochairs of the Lincoln Laboratory Women's Network, were recognized with honorable mentions in the Individual Leadership category of the Above and Beyond Awards given annually by the Diversity Best Practices national organization.

2020 HIRE Vets Award

Lincoln Laboratory was one of the organizations recognized by the Department of Labor with a 2020 Honoring Investments in Recruiting and Employing American Military Veterans (HIRE Vets) Gold Medallion for "exemplary efforts in recruiting, employing, and retaining our nation's veterans."

Dwight D. Eisenhower Award for Excellence

At left, Scott Anderson, Assistant Director for Operations at Lincoln Laboratory, accepts the 2020 Dwight D. Eisenhower Award from Jovita Carranza, Administrator of the U.S. Small Business Administration.

The U.S. Small Business Administration presented MIT Lincoln Laboratory with the 2020 Dwight D. Eisenhower Award for Excellence in the Research and Development category. This annual award recognizes a large federal government prime contractor that excels in partnering with small business subcontractors and suppliers.

Lincoln Laboratory awards approximately $500 million annually to subcontractors for parts and services, with 40 to 50% of that amount going to small businesses for R&D services, component parts for prototypes, and R&D service subcontractors. The Laboratory's Small Business Office is dedicated to fostering interactions with the small business community, networking with small businesses and hosting information sessions at which staff learn about businesses' services and products. The office also presents a Small Business Subcontractor of the Year Award to honor a company that has provided exceptional service to a Laboratory program. In addition, the Technology Ventures Office is establishing partnerships with small businesses that are developing innovative technologies that may complement the Laboratory's R&D.

>> Awards and Recognition, cont.

2020 Aviation Week's 20 Twenties Honoree

M. Kate Byrd was selected by Aviation Week Network as one 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.

2020 Stratus Award for Cloud Computing

The **TRACER** (Timely Randomization Applied to Commodity Executables at Runtime) technology developed by a team from the Cyber Security and Information Sciences Division received this award from the Business Intelligence Group in recognition of its innovative approach to secure cloud computing.

2020 FLC Northeast Regional Award for Excellence in Technology Transfer

The Federal Laboratory Consortium for Technology Transfer (FLC) selected Lincoln Laboratory as the Northeast region's winner of its award for outstanding achievement in technology transfer. The award recognized the Laboratory's work with Sync Computing to commercialize a computing system designed to solve combinatorial optimization problems.

2019 All-Inclusive Award

Dr. Bonita J. Burke was honored with an All Inclusive Award given by Color Magazine to an organization and individuals that have shown outstanding achievement in the advancement of diversity and inclusion in the workplace. Dr. Burke, assistant leader of the Counter-WMD Systems Group and co-chair of the Lincoln Laboratory Women's Network, received the Employee Resource Group Leader Recognition Award.

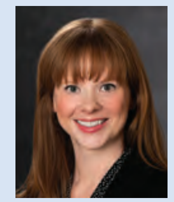
2019 Invented Here! Award

The Boston Patent Law Association presented one of its Invented Here! Awards to the patent for the Wave Damping Structures (U.S. Patent 10,151,074). **Robert W. Haupt**, **Dr. Mordechai Rothschild**, **Dr. Vladimir Liberman**, **Charles G. Doll**, and **Dr. Shaun R. Berry** are the inventors of this technology designed to mitigate the effects of earthquakes. The Invented Here! program celebrates innovators, their inventions, and the stories behind their innovations.

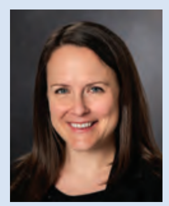
2020 MIT Excellence Awards

Advancing Inclusion and Global Perspectives:

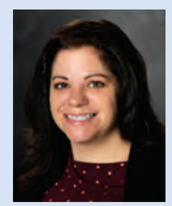
Julie A. Arloro-Mehta, far left, and **Dr. Bonita J. Burke**, left, (as a team); **Mischa M. Shattuck**, below

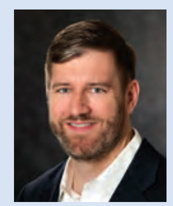


Bringing Out the Best:
Stephanie J. Foster



Outstanding Contributor:
Lisa C. Kelley Jeffrey W. McLamb





2019 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 14th consecutive Superior rating for the Laboratory.

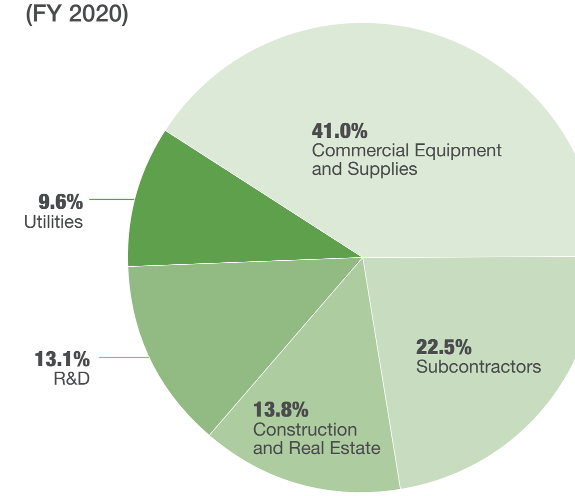
2020 Young AFCEA 40 Under 40 Awards

Dr. Raoul O. Ouedraogo, right, and **Dr. Michael P. Owen**, far right, 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.

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 2020, the Laboratory issued subcontracts with a value of $470.1 million to businesses in all 50 states, Washington, D.C., and Puerto Rico. The Laboratory purchased nearly $240 million in goods and services from New England companies, with $190.1 million in contracts awarded to Massachusetts businesses. The ripple effect of these purchases on the New England regional economy is estimated as $170 million, which includes business-to-business purchases along the supply chain and the wages and consumer spending of industry employees, for a total impact of $410 million. The Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

Contracted services*
(FY 2020)



**Estimates from $470.1M, total FY20 spend*
– Includes orders to MIT – $8.96M
– Figures are net awards less reductions

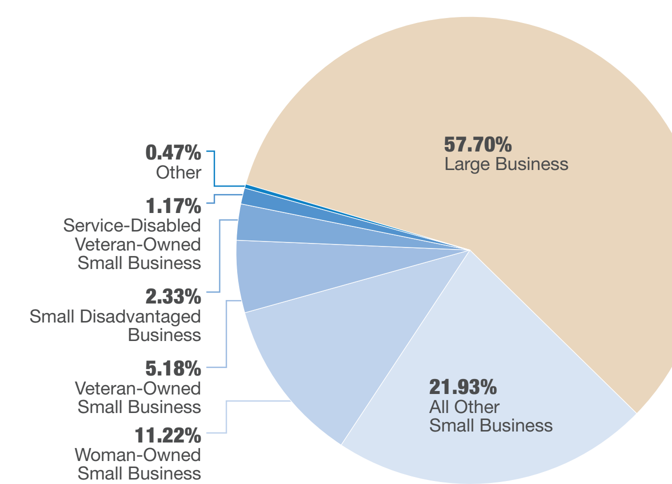
STATE	$ MILLION
Massachusetts*	190.1
Texas	44.7
New Hampshire	38.6
Maryland	29.3
California	23.4
Georgia	17.5
New Jersey	17.2
All Other	109.3
Total*	470.1

**Includes orders to MIT – $8.96M*

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 2020, more than 42% 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 2020)*



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

42.30%
Total for all small business

EDUCATIONAL AND COMMUNITY OUTREACH 91

Laboratory volunteers gather at the end of the G.I.R.L. Programming and Circuits Workshop at MIT's Beaver Works Center.

Educational Outreach

G.I.R.L. CYBER SAFETY WORKSHOP

At the workshop, girls were introduced to an activity that demonstrates how cybersecurity work can help keep sensitive data secure when communicating through the internet.

At the G.I.R.L. Cyber Safety Workshop in February, 26 middle school girls from Greater Boston met at Beaver Works to learn about internet security. Girls learned about social engineering, encryption and code breaking, network packet capture, and IP addresses. The course organizers and instructors—including nearly 20 Laboratory staff members—walked the girls through the fundamental technologies behind the internet, such as encrypted messages and network traffic, and taught them how to protect themselves online.

The Girls' Innovation Research Lab (G.I.R.L.) is an outreach organization sponsored by the Laboratory and dedicated to inspiring, empowering, and supporting underrepresented middle school girls through hands-on workshops and demonstrations.

As the event kicked off, the girls participated in a group demonstration about how messages travel through a network of computers and routers. Then, they tackled an escape-room experience with four activities that each emphasized a different topic they had learned about earlier in the day. Some of the activities included searching packets for usernames and passwords and learning how hackers break into unsecured networks to retrieve personal information. The students also learned how to decipher codes in Morse, binary, ASCII, and Caesar Cipher, a simple and well-known encryption system.

Jarilyn Hernandez-Jimenez, a volunteer for this workshop, said, "I chose to participate in the cybersecurity workshop because in the near future I hope to see continuous growth in activities that expose girls and women to STEM fields."

SCIENCE ON SATURDAY

On 31 October, Lincoln Laboratory's Science on Saturday series resumed in a virtual format. The event, Our Amazing Atmosphere and Its Gases, introduced the audience to the different gases that make up Earth's atmosphere and the roles they play. Through the Zoom interface, participants got a close-up view of dry ice creating a dense fog and liquid nitrogen freezing common household items and plants. As part of the presentation, Jude Kelley explained how invisible atmospheric gases protect the Earth from meteors, shield people from ultraviolet radiation, and regulate the outside temperature. He also demonstrated how cryogenically cooled superconductors make magnets levitate mid-air!

December's Science on Saturday event, Curious about COVID, was divided into two parts. In part one, Alan Hsu talked about an epidemiologist's job, explained popular terms used in discussing coronavirus (like pandemic, quarantine, herd immunity, and flatten the curve), and offered an online game to test participants' knowledge of coronavirus terms. In part two of the event, Lawrence Candell explained how Laboratory scientists quickly built a prototype to perform wide-area digital imaging of a crowd to scan for fevers, and how this prototype is used at the Lincoln Laboratory entrance instead of taking everyone's temperature individually.

Jude Kelley shows children tuning in via Zoom what liquid nitrogen looks like and how it functions in Earth's atmosphere and ecosystem.

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

In July 2020, Lincoln Laboratory ran its ninth Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), a two-week program for high school students entering their senior year, but this was the first year the program was offered in a virtual format. The program included instructional sessions on the basics of radar systems and imaging; workshops to build small radar systems that can perform range-Doppler imaging; and hands-on activities using the radars built in the workshops.

Because this course was held during the COVID-19 pandemic, students received online lectures and were mailed supplies and parts for a build-your-own radar. In previous years, students worked in teams of three to collectively build a Doppler radar, but this year each student was able to build a personal radar.

This year, 35 students participated in LLRISE virtually. Here, six of the students prepare to give their final presentations at the end of the workshop.

"This is probably the coolest thing I've done any summer."

LLRISE student

>> Educational Outreach, cont.

BEAVER WORKS SUMMER INSTITUTE

Because of the COVID-19 emergency, this year's Beaver Works Summer Institute (BWSI) carried on in a virtual format, offering seven classes to 178 students from 26 states across the country and Canada.

Each student in the RACECAR course received a RACECAR Model Nano (shown at left) in the mail.

The classes presented this year were Autonomous RACECAR, Autonomous Cognitive Assistant, Data Science for Health and Medicine, Build a CubeSat, Embedded Security and Hardware Hacking, Remote Sensing, and a new course called Serious Game Design and Development with AI. The program also offered its first-ever independent project, called pi-PACT. For this project, 176 students chose an aspect of a contact tracing application to evaluate, such as collection and characterization of data, in addition to developing algorithms to enable proximity detection between individuals.

Despite BWSI going virtual, hands-on learning remained a key component of the program. A miniature version of the robotic car, called the RACECAR Model Nano, was designed and built with the same sensors and computing capabilities as the original car, and was sent to all 21 students in the course.

Two student interns supporting the RACECAR program, Matthew Calligaro and Emi Suzuki, created a virtual environment to serve as an alternative in case of hardware difficulties or inadequate experiment space. The virtual environment mimics the hardware so that students could run their code simultaneously within the environment as well as with the physical cars.

The push to bring the program online has opened up new avenues for making the course materials available to as many people as possible. Joel Grimm, a manager for Beaver Works, said, "We now have a wealth of recordings that we can use to expand our online prerequisite courses, create asynchronous courses for learners, and expand the number of learners who can use the BWSI projects."

BEAVER WORKS SUMMER INSTITUTE: SERIOUS GAMES IN KWAJALEIN ATOLL

Students from the Kwajalein BWSI 2020 program pose for a photo with instructors from Lincoln Laboratory's Kwajalein Field Site.

In July, the Beaver Works Summer Institute launched a new class for high school students on Kwajalein Atoll. The course, Serious Game Development with Artificial Intelligence (AI), taught students how to address real-world problems by using game design and artificial intelligence. Sarah Willis, lead instructor for the program, explained that there was "a unique opportunity to take advantage of our isolation [and COVID-19-induced travel ban] this summer to engage the island students with a rigorous STEM program."

Fourteen students enrolled in the program, which included in-person classes and virtual meetings with Laboratory staff. At the end of the course, the students presented their work at a live poster session.

"On Kwajalein, BWSI provided students with an opportunity to make academic advances and explore potential career fields," said Willis. The instructors plan to offer a BWSI course on Kwajalein again in summer 2021.

COMPUTER SCIENCE WORKSHOP IN ALABAMA

Students worked in teams to build their own robot during a STEM workshop at East Lawrence High School, Alabama.

Located about 40 miles from the Laboratory's field site in Huntsville, the East Lawrence High School in northern Alabama is an underserved school with limited STEM educational resources. In December 2019, 11 Laboratory staff provided an all-day STEM workshop at East Lawrence for students interested in computer science. "The goals of the STEM workshop were to increase student interest in STEM-related career fields; increase pride, communication, and critical thinking skills," said Keith Henderlong, organizer of the workshop.

After an interactive trivia game to tell the students about the many STEM-related career opportunities available in their local area, students engaged in a conceptual activity called "Making a Peanut Butter and Jelly Sandwich" to understand the importance of specifically and logically identifying steps with detail when coding.

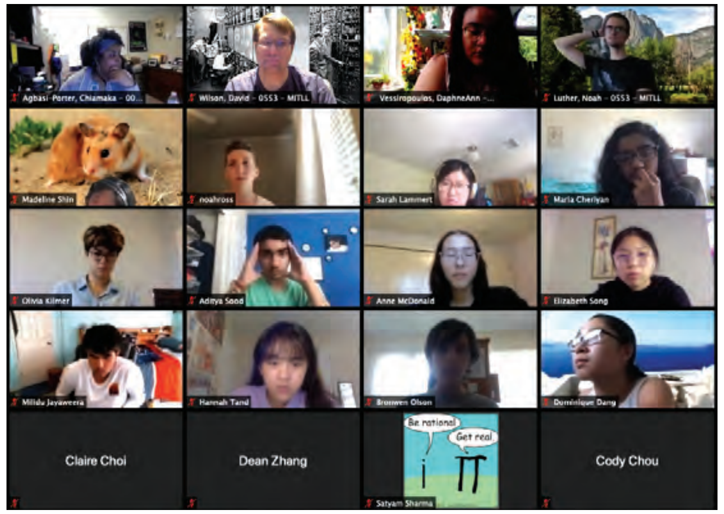
With robotics building kits consisting of snap-together parts, digital servo motors, an infrared sensor, a programmable LED light, and a control box, students programmed their robots through either the Blockly coding platform or by creating custom actions with the Press, Record, Play functions. Staff volunteers presented tips for building the robots, along with specific challenges for the students to work on. "It's exciting offering STEM instruction to students who have not been exposed to advanced technologies," said Henderlong. "It's our hope that we have encouraged students to pursue their interest in the engineering and science fields."

GIRLS WHO CAN

In the fall, Laboratory volunteers in a collaboration with MITRE and Harvey Mudd College offered three virtual workshops to encourage high school girls to try engineering. On Saturdays from October through December, 66 junior girls learned how to build a CubeSat, how to program a mini autonomous racecar, or how to hack code while learning about embedded security. These workshops were offered by the Beaver Works Summer Institute to provide crash courses just for girls. Lead instructors included Rebecca Arenson from Lincoln Laboratory, Gabriel Pascualy from MITRE, and Alina Saratova from Harvey Mudd College. Plans are underway to offer these courses next spring to underrepresented students from Boston and Cambridge, Massachusetts.

LINCOLN LABORATORY CIPHER

Lincoln Laboratory Cipher is a summer workshop that provides an introduction to theoretical cryptography. The 2020 program held in August was a weeklong enrichment class for 30 high school students from across the country who were interested in advanced mathematics or cybersecurity. Students were introduced to theoretical cryptography while learning how to build a secure encryption scheme and digital signature. Typically, the workshop curriculum includes hands-on demonstrations and interactive and small-group activities that reinforce basic lessons of classical and modern cryptography; however, in 2020, LLCipher was held in a virtual setting.



Thirty high school students from across the country participated in LLCipher this year and learned course material from Laboratory technical staff.

>> *Educational Outreach, cont.*

KWAJALEIN OUTREACH

Astronomy Nights

To foster the love of astronomy on the island, Sarah Willis has hosted a variety of Astronomy Nights on Kwajalein. This past year, she led the community in viewing the partial solar eclipse at Emon Beach and has held several "Ask an Astronomer" sessions with middle school and high school students.

Coral Reef Nursery

Thomas Sebastian, members of the local dive community, and Kwajalein High School students led by science teacher Matt Gerber are experimenting with coral reef rehabilitation. The centerpiece of the current effort is a nursery they constructed, from which fragments of coral are secured and/or suspended using various methods to encourage new growth. Fragments that demonstrate regrowth will be transplanted back to the reef. Data loggers are also being constructed (with support from Lincoln Laboratory volunteers) to record information necessary to understand ideal coral reef growth conditions.

School Lecture Series and Outreach

Laboratory staff also contribute their time and expertise to champion education via different school projects, such as scientific seminars and the Ebeye robotics club. Spencer Johnson leads the High School Lecture Series, coordinating volunteers to give STEM presentations to high school students. These lectures often pair with the students' current curriculum to provide an in-depth understanding of the real-world use of the scientific concept.

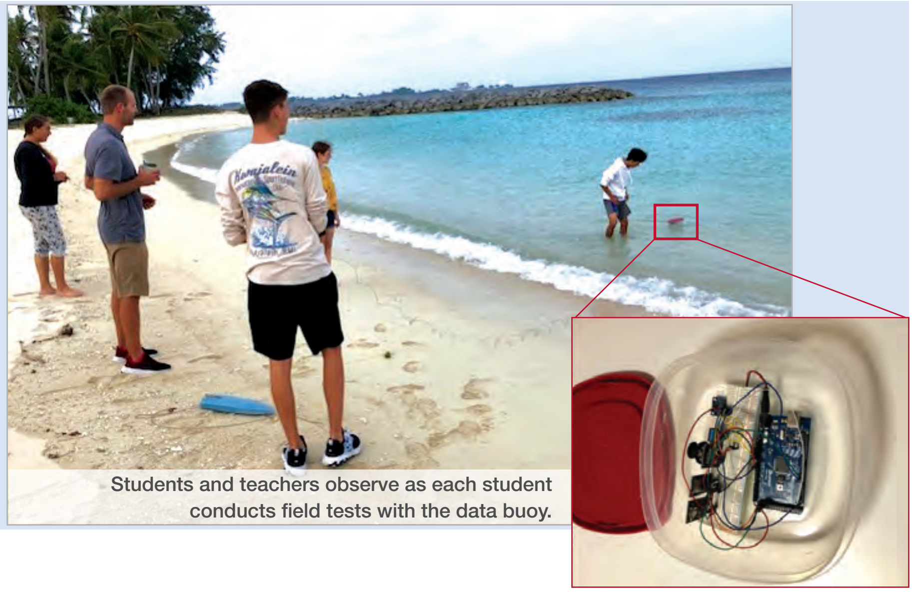
3D Printing Biocomposites

Thomas Sebastian explains the process and capabilities of 3D printing to a captivated audience of elementary school students on Kwajalein Atoll.

Thomas Sebastian is working with 5th and 6th grade students on a materials science project to develop a cheap method of turning raw coconut husks into a biocomposite material resembling particle board. He is helping young scientists determine the properties and characteristics of coconut husks, and then use the material to make a small model boat. He plans to adapt the process so that the material can be created using a 3D printer.

Oceanic Engineering Outreach

Andrew Mack partnered with Kwajalein High School teachers to focus on marine biology and engineering activities by having students create and build a data-logging buoy to use for a variety of experiments. Example projects include using a motion-sensing camera to conduct marine life detection; monitoring ocean water for alkalinity, temperature, and salinity; measuring tides and waves; and tracking weather patterns, including precipitation, wind speed, and air properties.

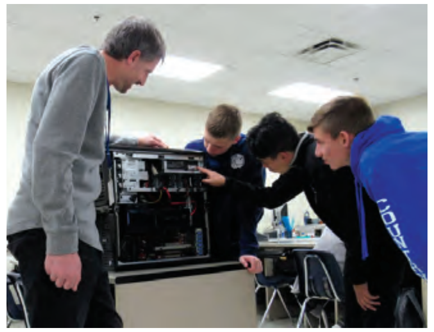


Students and teachers observe as each student conducts field tests with the data buoy.

Community Giving

COMPUTER DONATION

Laboratory staff from the Experimental Test Site (ETS) at the White Sands Missile Range donated outdated surplus equipment, including computers and monitors, to the nearby Socorro High School in Socorro, New Mexico. Students in the Socorro schools are now using these donations to augment class instruction. Older computers are being disassembled and used in electronics classes. "Many small schools have limited budgets for computer hardware and computer-related classes," said ETS site manager Gregory Spitz. "Some students have never seen the inside of a computer. The experience can be enlightening for them and sometimes it is enough to create a spark."



Gregory Spitz, site manager at the Experimental Test Site, looks on as students at Socorro High School, New Mexico, identify parts of a donated computer.

WINTER CLOTHING DRIVE

To help those most vulnerable members of our community, Christopher Gibbons started a winter apparel and accessories drive in October. Warm Hands, Warm Hearts is an easy and affordable way to provide comfort and dignity to Boston's homeless during challenging times and weather. The donations were distributed through Friends of Boston's Homeless.

GIVING PROGRAMS AT KWAJALEIN FIELD SITE

Telehealth Support for Ebeye

One of the many ways COVID-19 has affected the Marshall Islands is access to healthcare. Travel restrictions caused by COVID-19 have inhibited medical missions and training opportunities. A team led by Thomas Sebastian believes that providing telemedicine and remote training may improve healthcare access for the Marshall Islands. The team thinks that cellular devices paired with tablets could enable secure and reliable medical consultation with specialists outside the Islands. The team plans to use this project as a pathfinder effort linking MIT Medical with Ebeye Hospital to provide remote support and explore distribution of capability to other islands.

Seamstress Training

In August, the Laboratory donated sewing equipment to Ebeye Island in the Kwajalein Atoll to make face masks to help with COVID-19 prevention. Thomas Sebastian, coordinator of this project, said, "We wanted to invest in the people of the Marshall Islands." Sebastian spoke to local seamstresses and developed a solution to increase efficiency in sewing masks. He 3D-printed sewing machine jigs to hold fabric pleats in place and donated large boxes containing rotary cutters, fabric-cutting boards, elastic straps, and enough bolts of fabric suitable for making 4,000 masks.

Ebeye residents joined a training session to learn how to sew face masks. The session was part of a larger program to give vocational training opportunities to women while also promoting health. Photo: Jessica Dambruch

WALK TO END ALZHEIMER'S

Terri Welch, center, takes a break with her family while participating in the virtual Walk to End Alzheimer's. The Welch family chose to walk at Horn Pond in Woburn, Massachusetts.

Lincoln Laboratory has participated in the Walk to End Alzheimer's for 12 years, but this year marked the first time the event was held virtually. On 27 September, the 15 members of the Alzheimer's walking team walked locally and then convened online to raise $19,836. Like the Walk to End Alzheimer's, this year's Ride to End Alzheimer's was virtual. In place of the official ride, team members did individual bike rides in a location of their choice. The nine-member Lincoln Laboratory team raised $18,056, exceeding its goal of $15,000.

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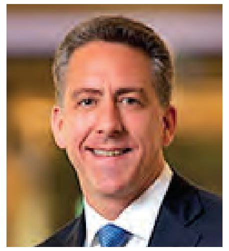

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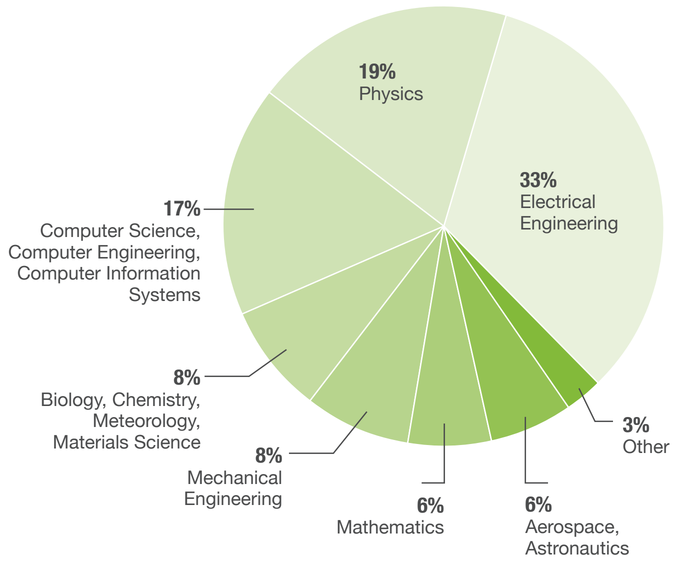
Staff and Laboratory Programs

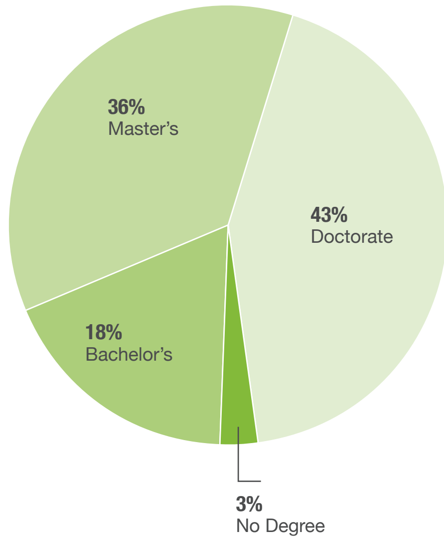
1776	Professional Technical Staff
1261	Support Personnel
532	Technical Support
489	Subcontractors
4058	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline



Academic Degree



Breakdown of Laboratory Program Funding

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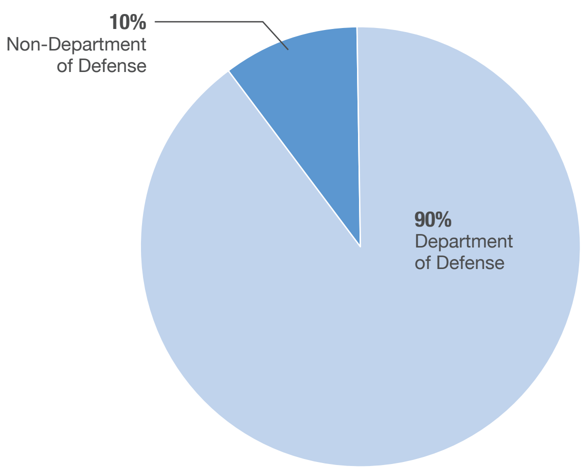
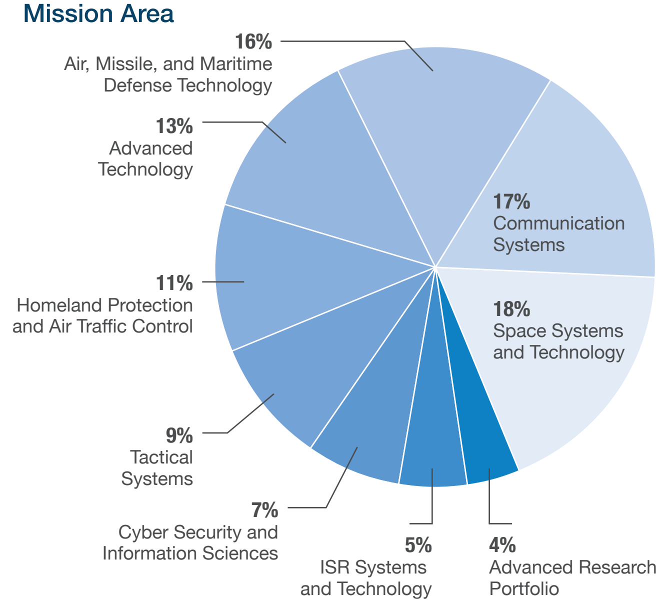


Mission Area



LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
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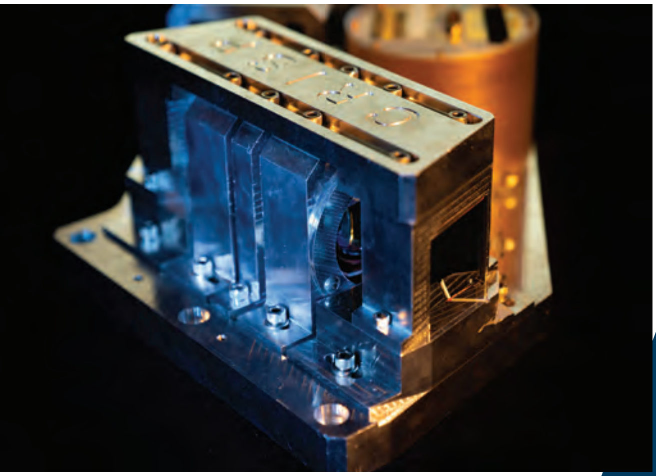

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY