Lincoln Laboratory

Lincoln Laboratory is a Department of Defense (DoD) federally funded research and development center (FFRDC) operated by MIT. Under a prime contract with the Department of the Air Force, Lincoln Laboratory conducts research and development on behalf of the military services, the Office of the Secretary of Defense, the intelligence community, and other government agencies.

The laboratory's main facilities are in Lexington, MA, partly on Hanscom Air Force Base property. The laboratory operates radar facilities in Westford, MA, and a virtual reality environment in Billerica, MA. Space at an office park two miles from the main laboratory site provides additional offices for both technical and administrative work. As the scientific advisor to the US Army's Reagan Test Site at the Kwajalein Atoll in the Marshall Islands, the laboratory has work and residential facilities for about 20 staff who serve in rotational assignments at Kwajalein. In addition, to facilitate both interactions with government sponsors and in-field testing and evaluation of systems, Lincoln Laboratory has field offices in several locations around the United States, including Huntsville, AL; Fort Meade, MD; and Colorado Springs, CO.

Our mission is to develop technology in support of national security. Research and development (R&D) conducted at the laboratory covers a broad range of domains, including space security, air and missile defense technology, cyber security, communication systems, bioengineering, maritime defense technologies, microelectronics, air traffic control, and intelligence, surveillance, and reconnaissance (ISR). Specific examples of this year's R&D are presented in the section outlining technical program highlights.

Artificial intelligence (AI) technology continues to advance within areas that span the laboratory's division-level missions, and much new fundamental technology is under development. Because of the breadth of many of the AI programs under way, our growing collaboration with the academic community, and the importance of AI technology for a wide range of national needs, the laboratory established the new Artificial Intelligence Technology Group. Much of the group's work will be conducted in collaboration with ongoing research on the MIT campus and will include the part-time involvement of MIT faculty, research staff, and students. The group will significantly improve the laboratory's ability to develop fundamental AI technology.

The COVID-19 pandemic had major implications for everyone in the MIT community, including Lincoln Laboratory. A Lincoln Laboratory COVID-19 task force was assembled in March 2020 following the state-of-emergency declaration in Massachusetts. By late March, the laboratory had gone through a major transition enabling a large fraction of the community to work remotely. A small percentage of employees continued to work on site for classified projects, hardware development, and other important needs. Strict social distancing guidelines and cleaning and sanitization steps were implemented for those employees to enhance health protection and safety. Throughout the pandemic, all personnel received a daily memo from the Director's Office summarizing any workplace changes, updates to state orders, and wellness resources. In addition, a comprehensive internal website and workplace guide were produced to keep the community informed about COVID-19 policies and impacts.

The laboratory pursued research and development to support the public health and medical communities' responses to the COVID-19 outbreak. These activities included modeling disease progression and the resulting demand for personal protective equipment. A rapidly developed respirator test facility provided efficacy data for more than 100 foreign-sourced N95 filtration masks. Data provided to the Commonwealth of Massachusetts helped guide the distribution of these respirators to frontline workers.

The laboratory also worked with the 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 partners. Other research focused on vocal biomarkers for early detection of COVID-19. In North Macedonia, the laboratory's Next-Generation Incident Command System helped emergency institutes coordinate pandemic response actions and communicate with the public. Several programs related to COVID-19 are still under way, leveraging artificial intelligence for rapid drug discovery, automated contact tracing, and improved analysis of medical system needs.

In fiscal year 2019 (October 1, 2018, to September 30, 2019), Lincoln Laboratory received approximately $1.109 billion in total funding to execute R&D on sponsored projects. While most of the research was sponsored by the DoD, funding was also received from the Department of Homeland Security (DHS), the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and the National Oceanographic and Atmospheric Administration. In addition, Lincoln Laboratory carries out noncompetitive research with industry under approved cooperative research and development agreements and other collaborative activities with academic institutions.

Organization

Lincoln Laboratory's three-tiered organizational structure—Director's Office, divisions and groups, and departments—encourages interactions between staff and line management. Sponsor interest in conducting research and development of more complex, integrated systems has raised the level of collaboration between divisions. Service departments provide critical administrative and infrastructure support. The Safety and Mission Assurance Office and the Program Management Office enable cross-divisional research teams to manage the technical and programmatic challenges of large-scale developments.

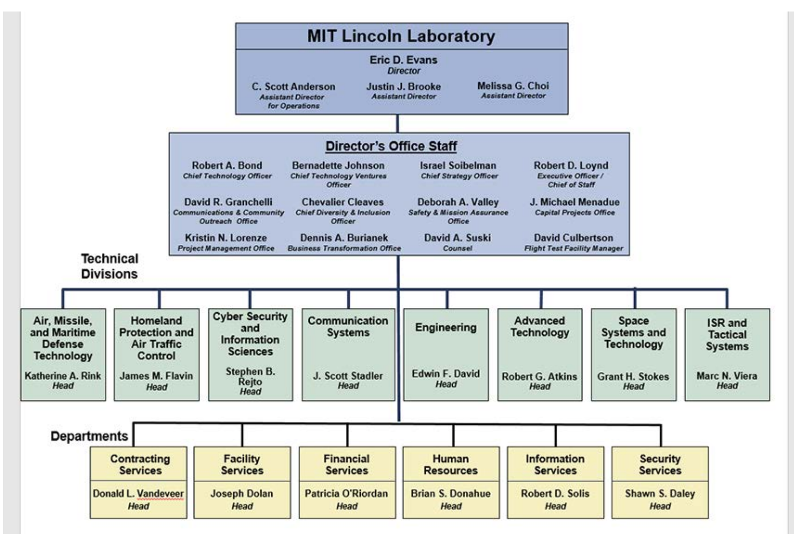


Figure 1. Lincoln Laboratory's organizational structure.

Leadership Changes

Marc D. Bernstein was selected to serve as the first US Air Force acquisition chief scientist. In this Intergovernmental Personnel Act assignment role, Bernstein will support the assistant secretary of the Air Force for acquisition, technology, and logistics and the US Air Force acquisition chief architect.

Israel Soibelman was appointed as chief strategy officer. He will foster strategic relationships and develop strategic plans and initiatives with government, academic, and industry partners. This appointment follows his five years as assistant to the director for strategic initiatives.

Marc N. Viera was promoted to head of the ISR and Tactical Systems Division; he formerly served as the division's associate head.

James K. Kuchar was promoted to assistant head of the Homeland Protection and Air Traffic Control Division; he formerly served as the leader of various groups within this division.

Jeffrey C. Gottschalk was appointed assistant head of the Cyber Security and Information Sciences Division; he formerly served in leadership positions for various groups within this division.

Jennifer A. Watson was appointed assistant head of the ISR and Tactical Systems Division; she formerly served in leadership positions for the Airborne Radar Systems and Techniques Group within this division.

Heidi C. Perry was appointed assistant head of the Air, Missile, and Maritime Defense Technology Division; she formerly led a number of technology initiatives aligned to the division's strategic goals.

Technical Program Highlights

Research and development at the laboratory focuses on national security problems across a broad range of mission areas: tactical and ISR systems; air, missile, and maritime defense; space security and space systems; chemical and biological defense; homeland defense; communications; cyber security and information sciences; and advanced electronics technology. In addition, the laboratory undertakes work in related nondefense areas such as air traffic control, weather sensing, and environmental monitoring. A principal activity of the laboratory's technical mission is prototyping, which involves the development of components and systems for experiments, engineering measurements, and tests under field operating conditions.

This year, Lincoln Laboratory worked on 760 programs ranging from large-scale hardware projects to small seedling initiatives. Notable highlights for each mission area are listed below.

Space Systems and Technology

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

Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS), a NASA Earth Venture Instrument program, is a constellation of CubeSats equipped with advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. Six TROPICS CubeSats have completed assembly, integration, and testing and are in storage awaiting launch manifest.

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

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

Figure 2. The TROPICS CubeSat is shown with its solar array deployed. All six of the CubeSats have successfully completed space vehicle environmental testing.

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

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

Air, Missile, and Maritime Defense Technology

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

Figure 3. Over-the-horizon radar (OTHR) can potentially support long-range surveillance of the polar region but is hindered by interference induced by the Aurora Borealis. To study the performance of clutter mitigation algorithms, the laboratory designed, developed, and deployed a full-scale OTHR to North Dakota.

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

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

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

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

The laboratory delivered recommendations to the Navy community about the development of advanced electronic warfare technologies and shipboard systems to counter advanced threats against the fleet.

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

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

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

Communication Systems

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

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

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

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

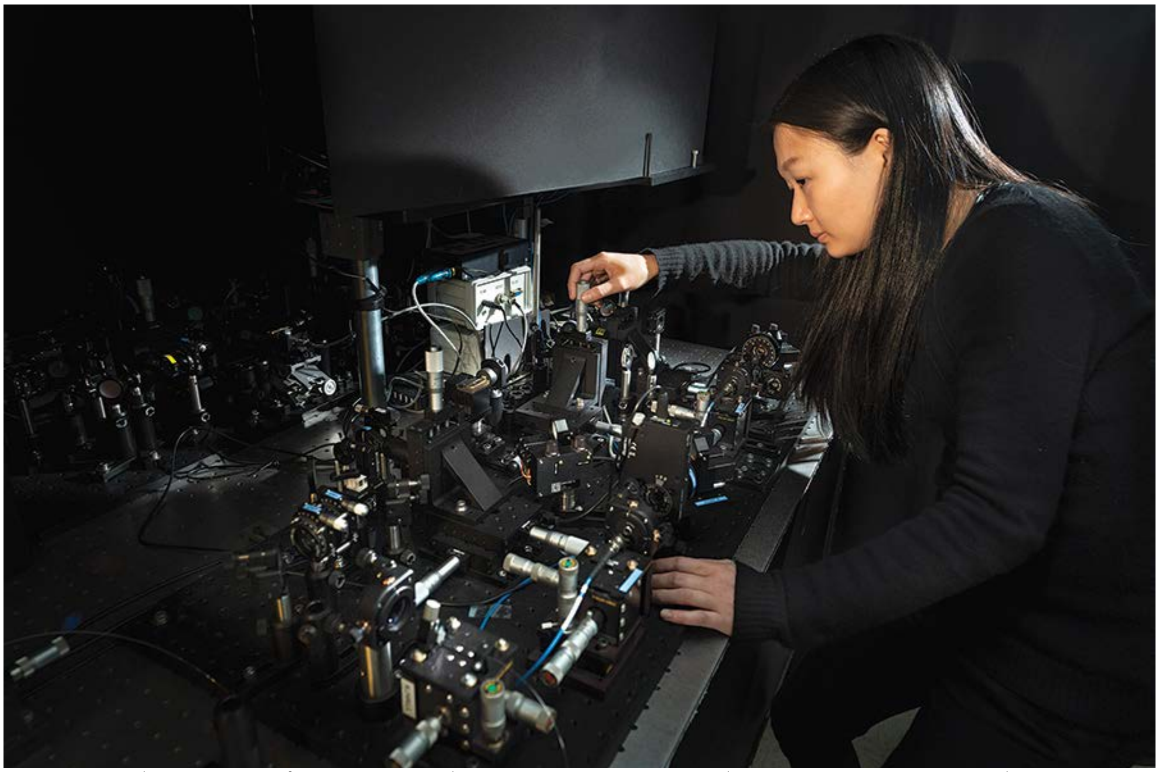


Figure 4. Catherine Lee performs an entanglement swap measurement by using two spontaneous down-conversion sources that generate entangled photon pairs at gigahertz rates. High-rate entanglement distribution is required to enable distributed quantum sensing, timing, and computing applications.

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

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

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

Cyber Security and Information Sciences

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

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

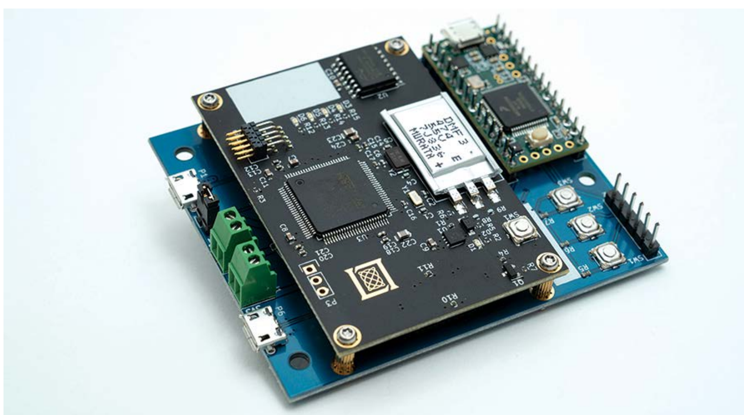


Figure 5. Under the DoD Joint Communications Architecture for Unmanned Systems program, the laboratory developed an architecture and hardware security module prototypes, such as the one pictured, for securing communication with small unmanned systems.

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

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

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

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

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

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Lincoln Laboratory developed deep-learning algorithms that achieved breakthrough performance in detecting objects within radar imagery, thereby augmenting a national capability to exploit sensor data from this critical modality.

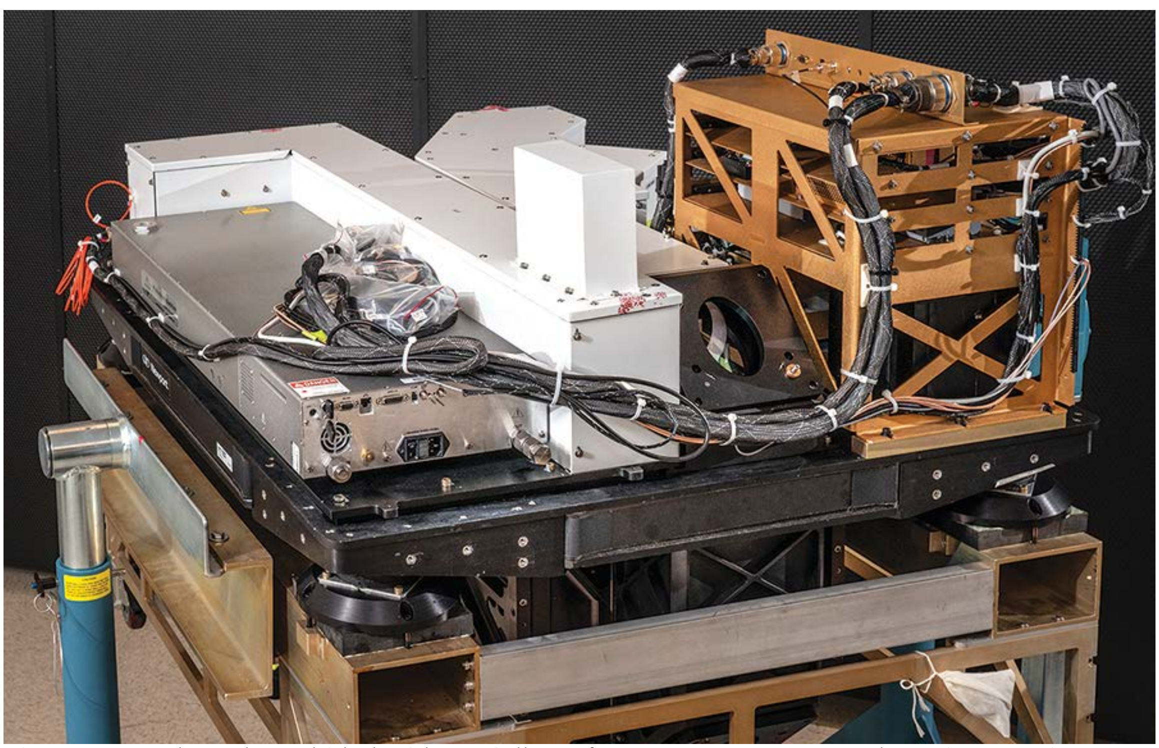


Figure 6. Upgrades to the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) ladar imaging system enhance the system's resolution capability and increase its area coverage rate sixfold.

Researchers continue to develop the Transparency by Design artificial intelligence system, which not only has achieved state-of-the-art performance in interpreting images on the basis of a plain text query but is also capable of describing the logic behind its decisions.

A successful counter–unmanned aircraft system field campaign employed novel sensing technology that promises game-changing capability for wide-area day and night detection in challenging clutter environments.

The laboratory is finishing the development and integration of a next-generation airborne sensing capability that is scheduled to be deployed in the US Southern Command's area of responsibility in 2019.

Lincoln Laboratory demonstrated a novel distributed multiple-input multiple-output (MIMO) radar system that integrates a third-party active electronically scanned array with the laboratory's open-architecture Airborne Radar Test Bed to image maritime targets.

Collaborating with researchers on the MIT campus and at Massachusetts General Hospital, Lincoln Laboratory technical staff developed a novel noncontact laser ultrasound technology that may be a low-cost and portable solution for medical imaging of bone injuries in the field.

Lincoln Laboratory developed an integrated ecosystem for exploring very large-scale, graph-based data analytics. This ecosystem comprises an advanced processor optimized for the acceleration of sparse mathematical computations and a software architecture structured for ease of use. The prototype system has been used to explore important national security problems such as foreign influence operations.

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

Tactical Systems

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

The laboratory's open-architecture technology was employed to enable a joint Army–Air Force sensor-to-shooter interoperability demonstration. This technology creates new opportunities for machine-to-machine artificial intelligence to dramatically increase operational capabilities in multidomain environments.

Software researchers developed an initial resilience infrastructure with which they demonstrated concepts for data access and synchronization to support logistics systems for advanced US fighter platforms.

Figure 7. The Airborne Seeker Testbed team poses in front of the Gulf Stream II aircraft. The plane is modified to carry a variety of instrumented sensors to assess the performance and limitations of Air Force aircraft.

The continued development of advanced, small autonomous systems included successful closed-loop flight tests to demonstrate vision-based navigation algorithms applicable to GPS-denied environments.

In multiple US Air Force and DoD field tests, Lincoln Laboratory continued to demonstrate prototype software systems to aid decisions, reduce errors, and speed up operations.

Lincoln Laboratory formed a new Army Blue Team to provide the Army Rapid Capabilities and Critical Technologies Office with targeted analyses and rapid prototyping across a wide variety of Army missions.

In its R&D work on a novel radar concept for Army vehicle protection, Lincoln Laboratory is conducting phenomenology measurements at multiple test ranges. Researchers evaluated the potential for the radar to integrate a communication capability that could enable the high-bandwidth, short-range communications required for the Army's future unmanned ground vehicles.

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

Advanced Technology

Lincoln Laboratory's work to develop microhydraulic actuators has increased with funding from the Defense Advanced Research Projects Agency (DARPA). This technology mimics the actuation of human muscle by applying an electric field to electrodes that force water droplets inside the actuator in one direction, causing motion. The laboratory produced linear and rotary actuators exceeding the efficiency and power density of human muscle.

Figure 8. The Multifunction Phased Array Radar (MPAR) Advanced Technology Demonstrator is undergoing tests in Norman, OK, at the National Weather Radar Testbed. MPAR is a candidate for a new nationwide system that will combine the separate sensors used for tracking aircraft and weather events.

The laboratory demonstrated an ultrastable laser suitable for use in deployed systems. Traditional approaches to stabilizing a laser have relied on the use of bulky cavities housed in a controlled vacuum environment, but these cavities do not function under the vibrations and temperature variations present in fielded systems. Using a new technique based on stimulated Brillouin scattering, the laboratory produced a laser with a 20-hertz linewidth that functions in an unshielded environment. The laser's first use will be as a key component in a deployable optical atomic clock that is under development.

Germanium-based charge-coupled-device (CCD) imagers passed a significant milestone with the demonstration of a 128-by-128-pixel array. This technology has sensitivity and noise performance equivalent to that of state-of-the-art silicon-based CCDs while greatly extending the imager's spectral range, from the soft X-ray to the near infrared. Future work will focus on producing megapixel-class imagers.

On paper, diamond is the ultimate material for high-power electronic applications. Its high thermal conductivity and high breakdown voltage should produce transistors with 10 times higher power handling than state-of-the-art gallium nitride transistors. The laboratory has begun to develop this potential and has demonstrated a transistor with world-record power density.

Significant progress was made toward deployable quantum sensors with the field testing of a breadboard magnetometer. The sensor is based on nitrogen-vacancy quantum defect centers in diamond, which have the potential for higher sensitivity and greater long-term stability measurements than commonly used fluxgate magnetometers.

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

Homeland Protection

Under the sponsorship of the DHS Science and Technology Directorate, Lincoln Laboratory developed technologies for detecting concealed threats at future Screening at Speed checkpoints; the technologies are designed for secure high-throughput passenger and bag screening in airports.

A land-based surveillance system for northern border land and waterway security was developed for Customs and Border Protection and has been transitioned to industry for future deployment and sustainment.

The laboratory established a prototype system, an integration facility, and test sites to enable the development of technologies to counter unmanned aerial systems in urban environments.

The laboratory continued to expand its work applying artificial intelligence and machine learning to solve critical biomedical challenges, including improved detection of injuries with ultrasound and AI-enabled semiautonomous trauma treatment tools for field-forward care.

Key milestones were achieved in the laboratory's development of advanced DNA forensics methods, algorithms, and systems and in the transitioning of these developments to the Federal Bureau of Investigation (FBI) for assessment.

In collaboration with academic, industry, and DoD partners, the laboratory expanded its focus on assessing, restoring, and enhancing human performance by developing innovative exoskeleton prototypes. This R&D leverages the unique combination of sensors and virtual reality technologies available at the Sensorimotor Technology Realization in Immersive Virtual Environments Center.

Advanced capabilities were successfully transitioned to the FBI Laboratory and Terrorist Explosive Devices Analytical Center, including capabilities for enabling improved attribution of improvised explosive threats from terrorist networks.

Laboratory staff tested a particle measurement system in the Czech Republic during outdoor hazard assessment and characterization trials.

Figure 9. Laboratory staff tested a prototype system at Boston Logan Airport; the system allows law enforcement to rapidly locate individuals who are using handheld lasers near airports to disrupt the vision of pilots in flight.

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

Air Traffic Control

Lincoln Laboratory completed another successful demonstration of the Small Airport Surveillance Sensor at Bedford Airport and initiated technology transfer with the FAA.

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

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

Figure 10. Researchers evaluate aviation weather system technology. Advances in radar signal processing and weather algorithms provide nationwide 0- to 8-hour forecasts to aid in routing air traffic around thunderstorms.

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

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

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

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

Lincoln Laboratory initiated ACAS X under internal funding in 2008 to improve flight safety and reduce nuisance collision alerts. The FAA has funded ACAS X development since 2009. The laboratory has served as the logic development lead on the FAA design team to produce a family of collision avoidance systems for manned aircraft (ACAS Xa), large unmanned aircraft (ACAS Xu), and small unmanned aircraft (ACAS sXu).

Engineering

Lincoln Laboratory is making a significant investment in model-based engineering as part of a digital transformation initiative to enable more efficient prototype system development. The first phase established a common database for information and fully digitized processes for design and fabrication using a product life cycle management tool.

The laboratory developed a chamber to perform semiautomatic testing on full 200-millimeter wafers at temperatures below 5 Kelvin with magnetic flux density nulling less than 1 μTesla. The chamber supports research at the Microelectronics Laboratory on superconducting integrated circuits, which are a promising solution to ever-increasing high-performance computing demands.

Figure 11. The Time-Resolved Observation of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) constellation of 3U CubeSats will provide rapid revisit passive microwave sounding in the 90- to 200-gigahertz frequency range for improved characterization and prediction of tropical storms.

Flight system subassembly designs were completed for laser communication terminals that will fly on the International Space Station and the Orion space vehicle. Critical design reviews were held, and the designs were released for fabrication.

TROPICS, the first CubeSat-enabled NASA science mission, was developed to provide tropical storm characterization for weather prediction. The laboratory led the design, building, integration, and testing of six space vehicles for TROPICS.

A groundbreaking optical design capability that allows freeform optical surfaces to be incorporated and optimized in optical system designs was developed. This capability helped improve the performance of conventional systems and enabled missions previously unachievable with conventional optical systems.

The laboratory assisted the DoD in testing the energy resilience of three Army and two Air Force installations by developing an energy resilience and readiness exercise framework to safely disconnect the installations from commercial electrical power systems. The DoD tested backup capabilities, interdependent missions, and infrastructure for up to 12 hours. Mission owners identified interdependencies between missions and other tenants, identified misconfigured backup systems, and tested a force deployment during an outage.

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

Technology Transfer

Most of Lincoln Laboratory's R&D projects result in some form of technology transfer to government agencies, the commercial sector, or academia. The mechanisms for this transfer include delivery of hardware, software, algorithms, or advanced architecture concepts to government sponsors or their designated partners; dissemination of concepts via Lincoln Laboratory technical reports, publications in professional journals, or presentations at conferences and workshops; collaborative research via small business innovation research (SBIR)/small business technology transfer (STTR) projects (which are government-funded joint research partnerships with small businesses); cooperative research and development agreements (CRADAs), which are R&D partnerships funded by industry to advance dual-use or commercial technologies; and patent filing, copyright protection, and licensing activities.

Technology Transfer by the Numbers

Transfer Mechanism	Transfers in FY2019
Articles in technical journals	92
Papers in published proceedings	116
R&D 100 Awards	10
Lincoln Laboratory–hosted conferences	12
Technology disclosures	83
US patents	72

Technology Ventures Office

In 2018, Lincoln Laboratory established the Technology Ventures Office (TVO) to provide strategic coordination for technology transfer activities across the laboratory. TVO's primary objective is to facilitate the rapid transfer of advanced technology into and out of Lincoln Laboratory for the benefit of national security. This office, working with others across the laboratory and MIT, focuses on three areas:

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

In 2019, Lincoln Laboratory conducted collaborative research and development with 15 companies under CRADAs, had 46 collaborative agreements in place with not-for-profit institutions, and engaged in an additional 26 sponsor-supported collaborative research efforts with MIT campus departments. These types of agreements are an established means of transferring technology developed in federal laboratories to the commercial sector. Lincoln Laboratory also executed 16 SBIR/STTR–supported projects under sponsorship from multiple government agencies.

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

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

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

Technical Workshops

Dissemination of information to the government, academia, and industry is a principal activity of Lincoln Laboratory's technical mission. One way this aim is achieved is through annual workshops and seminars that bring together members of technical and defense communities. These multiday events foster a continuing dialogue that enhances technology development and provides direction for future research. The following workshops were held over the past year:

- Advanced Prototype Engineering Technology Symposium
- Anti-access/Area Denial Systems and Technology Workshop
- Cyber Technology for National Security Workshop
- Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
- Recent Advances in Artificial Intelligence for National Security

In addition, Lincoln Laboratory is a technical partner for the Institute of Electrical and Electronics Engineers (IEEE) High Performance Extreme Computing Conference, the IEEE International Symposium on Technologies for Homeland Security, and the Air Traffic Control Workshop.

To reduce the coronavirus health risks from laboratory events with large attendee numbers, many planned spring and summer conferences and workshops were canceled or postponed.

Publications

Technology transfer is also achieved through the diverse venues in which Lincoln Laboratory researchers publish. Technical staff members publish articles in journals, both peer reviewed and general, and present at national technical conferences such as the IEEE Radar Conference and the International Conference on Acoustics, Speech, and Signal Processing. Between July 1, 2019, and June 30, 2020, Lincoln Laboratory staff published 110 papers in proceedings from conferences, 38 articles in technical journals, 19 self-published e-prints of technical articles, and five major technical reports available through the Defense Technical Information Center.

Research Collaborations

Technical staff at Lincoln Laboratory collaborate on projects with faculty and scientists at universities throughout the country; most collaborations are with researchers from MIT. The Advanced Concepts Committee provides short-duration grants to MIT faculty and Lincoln Laboratory staff for focused research in basic and applied science and in technology areas of potential interest to the laboratory. These grants are awarded on a rolling basis throughout the year. In 2019, nine collaborations were funded through the Advanced Concepts Committee, including efforts ranging from explorations of smart photovoltaic micro-grids for disadvantaged communities and self-healing materials to development of artificial intelligence techniques to facilitate decision making among doctors and medics working at military field installations and a miniature high-vacuum pump suitable for eventual use in a portable mass spectrometer.

Military Fellows Program

Lincoln Laboratory awards fellowships to support the educational pursuits of active-duty military officers who are fulfilling requirements for the US military's senior service schools or the Army's Training with Industry program or who are working toward advanced degrees. This program helps the laboratory establish cooperative relationships with military officers and allows researchers to gain constructive insight from the frontline experiences of the officers who are assigned to technical programs within the laboratory. In 2019–2020, 55 military officers worked in various technical groups under fellowships.

Courses for External Audiences

Lincoln Laboratory hosts a number of multiday courses for user communities with which the laboratory interacts. These courses for invited military officers and DoD civilians enhance understanding of current research and the systems developed at the laboratory. In 2019–2020, the laboratory offered Introduction to Radar Systems. The annual Networking and Communications and ISR Systems and Technology course offerings were canceled because of the coronavirus pandemic.

In addition, through a program with the Naval War College in Newport, RI, technical staff present courses for naval officers; each term, courses are selected to address the college's needs. The courses scheduled in 2019–2020 were in the areas of cyber security, ballistic missile defense, and space technology.

Lincoln Laboratory technical staff led activities offered during MIT's 2020 Independent Activities Period. During the semester intersession, Lincoln Laboratory staff members developed and led six non-credit offerings: Build a Small Radar System, Build a Laser Communication Terminal, Hands-on Holography, Software-Defined Radio, Practical High Performance Computing, and Mission-Driven Technology Transfer. Mathematics of Big Data and Machine Learning is offered as MIT Open Courseware, and RACECAR: Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot is offered in an Open EdX format as well.

2019 R&D 100 Awards

Ten Lincoln Laboratory innovations earned R&D 100 Awards in 2019. The winning technologies were developed either solely by laboratory researchers or collaboratively with scientists from partner organizations. Presented annually since 1962, the R&D 100 Awards recognize the 100 technology products judged by a panel of *R&D World* magazine editors and outside experts to be the most significant new developments of the year. The following 10 inventions bring to 58 the number of R&D 100 Awards presented to Lincoln Laboratory since 2010.

New Capabilities for Communications

- The Aperture Level Simultaneous Transmit and Receive Phased Array represents the first-ever demonstration of a phased array antenna system with sufficient isolation to enable practical multi-beam full-duplex communication. This technology allows multiple devices to share a single wireless channel while maintaining high data rates over long ranges. The problem of self-interference caused by transmitting and receiving on the same frequency is solved with a combination of adaptive digital beamforming to reduce coupling between transmit and receive antenna beams and adaptive digital cancellation to further remove residual noise. In this manner, the system effectively mitigates self-interference, which is particularly challenging for phased array systems because of the close proximity of the multiple antennas in the array.
- The Dual-Mode Imaging Receiver integrates the previously disparate functions of high-frame-rate photon-counting imaging and single-photon-sensitive communications into a single optical receiver, enabling the user to simultaneously have a wide-field-of-view image of the source of the transmission and receive data from one or more sources. This low-power, compact system requires only a single receive aperture to support multiple concurrent optical communication links from spatially separated users within the field of view,

thereby reducing or eliminating the need for precision beam pointing. The receiver is enabled by a custom chip that provides automatic, concurrent, on-chip detection, tracking, and demodulation of the multiple communication signals.

- With the Targeted Acoustic Laser Communication system, Lincoln Laboratory researchers beamed an audio signal directly to a person across the room; the intended recipient does not need a receiver, and the message is received only by that recipient. The key to this audio delivery resides in laser photoacoustics, a technique in which a laser tuned to interact with water vapor in the air creates sounds near a listener's ear loud enough to be picked up by human hearing. The system localizes the signal in both range and angle, providing an extra layer of security, and represents the first time such a technique can be used safely around humans.

Devices to Advance Biomedical Research

- The small, low-cost ArtGut (for artificial gut) device is the first in vitro platform to enable high-resolution, physiologically relevant gut microbiome studies. ArtGut emulates the physiochemical microenvironment of the human gut by mimicking the precise oxygen gradients and mucus substrates necessary to grow and maintain the gut's polymicrobial communities, and as such it provides a solution to the lack of adequate testing models for studying the human gut microbiome.
- The Mobility and Biomechanics Insert for Load Evaluation (MoBILE) is a biomechanics laboratory built into a shoe insert and small ankle package. The insert and ankle package contain a variety of high-end sensors that measure a user's weight and lower leg movements. MoBILE informs users when their gait significantly changes, when their biomechanics measurements are above acceptable thresholds, and when they are at risk for lower leg injury. MoBILE helps users track the amount of weight they are carrying over time, select the best placement for carrying heavy equipment, and determine optimal rest cycles and training routines.

Tools for Improving Decision Making

- The Gas Mapping LiDAR™ sensitively images methane gas plumes, identifies the source locations of gas leaks, and quantifies leak rates so that the owners and operators of oil and natural gas infrastructure can determine and prioritize repairs before even visiting the site. Designed and built by Bridger Photonics and enabled by Lincoln Laboratory's high-power slab-coupled optical waveguide amplifier technology, the Gas Mapping LiDAR provides aerial photography and 3D lidar data overlaid with sensitive gas-concentration maps in user-friendly formats so that oil and gas operators can make quantitative cost-benefit analyses and efficiently schedule leak repairs.
- The Rapid Convective Growth Detector software system enables national-scale detection of hazardous storm growth at a rate 10 times faster than comparable ground-based weather systems. The system uses tilt-by-tilt radar processing, storm tracking and motion-compensated trending analysis, and mosaicking to generate specific hazard-avoidance regions updated every 25 seconds. Data from

this system are generated fast enough to support short-term tactical warnings to the cockpit, enabling pilots to avoid rapidly growing storms that may not yet be visible to weather radar on board the aircraft.

- The Visibility Estimation through Image Analytics (VEIA) software system, developed by the laboratory in partnership with the FAA, provides air traffic managers and pilots an inexpensive, yet effective, way to automatically extract data about meteorological visibility from cameras. Using edge detection that is sensitive to changes in the visual scene, the system's algorithm compares the overall edge strength of the current image with edges of an image of a clear day to estimate visibility in miles. With the proliferation of web-based camera imagery for monitoring conditions near airports and other remote locations, VEIA can significantly expand the quantity of visibility observations available to the aviation community, especially in areas that are not covered by traditional sensor systems and where low visibility can have dire consequences.

Technology for Enhancing Efficiency

- The Tactical Microgrid Standard (TMS) Open Architecture provides an interoperability standard for highly modular, resilient, scalable, and mission-specific microgrid solutions. This architecture offers a user-friendly family of interoperable devices useful for both military and commercial microgrid applications. The TMS architecture was developed by a DoD-led consortium of government, industry, and academic partners, with Lincoln Laboratory in a lead role. This consortium was tasked with solving challenges faced by military personnel at remote bases, where reliable power is a critical foundation for successful operations.
- Lightweight Deployable Array Panels for Space reduce the cost of launching space-based communications and remote sensing systems by minimizing the panels' weight and size, which translates to lower rocket fuel costs and the capacity to deploy more systems per launch. After a system equipped with the laboratory's panels reaches its designated altitude, the antenna panels deploy to create the desired radiating aperture size. The panels use a patented weight-reduction technique for stacked patch antenna arrays and an innovative packing system. This design minimizes weight and maximizes stowed volume efficiency without substantially affecting RF performance.

Notable Technology Transfer Activities

During the past year, we transitioned several technologies to industry or to government sponsors.

Emergency Response System

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

Signal Processing Algorithms

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

Subsystems for Laser Communications

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

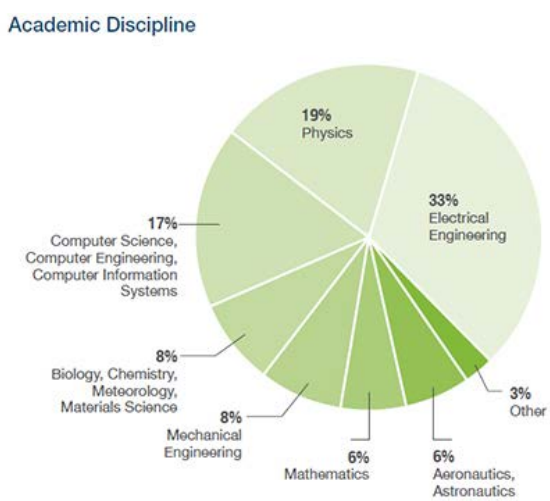
Rapid Agent Aerosol Detector

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

Staff

Key to maintaining technical excellence at Lincoln Laboratory is its staff of highly talented scientists and engineers. The laboratory recruits at colleges and universities nationwide. Seventy percent of the laboratory's new professional technical staff are hired directly from the nation's leading technical universities.

The total number of Laboratory employees is 4,056, with 1,820 professional technical staff, 1,726 support staff (including technical support personnel), and 510 subcontractors.



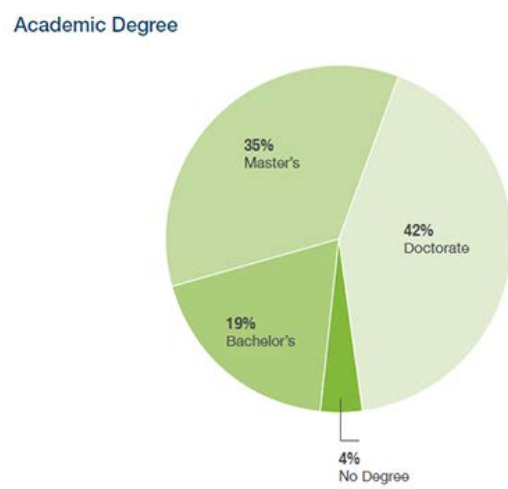


Figure 12. Composition of professional technical staff at Lincoln Laboratory by academic discipline and academic degree.

Awards and Recognition

During the past year, several Lincoln Laboratory staff members were recognized for achievements in their fields and for their commitment to professional activities, as follows.

Raoul Ouedraogo and Michael Owen were named by the Armed Forces Communications and Electronics Association to its annual 40 Under 40 list of individuals under the age of 40 who have shown exceptional leadership and made significant, innovative contributions to STEM (science, technology, engineering, and mathematics) fields.

Richard P. Lippmann was named an IEEE Fellow for contributions to neural networks and assessment of computer security systems.

Daniel J. Rabideau was named an IEEE Fellow for contributions to radar architectures and technologies.

Robert T-I. Shin and Grant H. Stokes were elevated to the rank of associate fellow of the American Institute of Aeronautics and Astronautics for important and exceptional contributions to the arts, sciences, or technology of aeronautics or astronautics.

Kate Byrd was named one of the Aviation Week Network's 20 Twenties for 2020, recognizing her as a young leader in engineering and aerospace.

Richard Shay was part of a team that received the 2020 Allen Newell Award for Research Excellence for their pioneering contribution to the science of evaluating password strength and for embodying this science in online tools.

Laura Ross received the National Defense Industrial Association (NDIA) Professor Robert E. Ball Young Professional Award for Combat Survivability. This award is given annually by NDIA to a person 35 years old or younger who has made technical, analytic, or tactical contributions to survivability.

Bryan Ward and Ryan Burrow were selected as first-prize winners in AFCEA's 2020 Cyber Edge Writing Contest. Their article, "Software Security for Real-Time and Embedded Applications," was published in *SIGNAL* magazine's June 2020 issue.

A research team composed of staff from Lincoln Laboratory, MIT's Koch Institute for Integrative Cancer Research, and Massachusetts General Hospital received an award from *STAT*—a publication focusing on health, medicine, and life sciences—that recognizes the best innovations in science and medicine each year. The group's work involved the use of fluorescent nanotubes to help detect small ovarian tumors.

Bonita Burke and Julie Arloro-Mehta received an honorable mention in the Individual Leadership category for 2020 Above & Beyond Diversity Best Practices. Burke also won the 2019 All-Inclusive Award from *Color* magazine for her work promoting diversity in her community.

William P. Delaney received the 2019 Eugene G. Fubini Award for more than 30 years of significant contributions as an adviser to the DoD. 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.

Lisa Kelley and Jeffrey McLamb received the MIT Excellence Award in the Outstanding Contributor category; Mischa Shattuck received the MIT Excellence Award in the Advancing Inclusion and Global Perspectives category; and Stephanie Foster received the MIT Excellence Award in the Bringing out the Best category.

Laurie Briere and Robin Lucente received 2020 MIT Lincoln Laboratory Support Excellence Awards, and Marilyn Lewis and James Lockler received 2020 MIT Lincoln Laboratory Administrative Excellence Awards.

Lincoln Laboratory Cultivating Leadership, Achievement, and Success Career Development Symposium Awards were presented to Michelle Lloyd for employee resource group excellence, to Michael Burke for advancing organizational culture, to Cassian Corey for championing equity, and to David Maurer and Michael Vai for outstanding mentorship. Raoul Ouedraogo received the peer award for culture. The strength in unity award was given to the LLOPEN committee as well as to the team that coordinated the laboratory's presence at the 2019 Massachusetts Conference for Women.

MIT Lincoln Laboratory Technical Excellence Awards were presented to William J. Blackwell for his innovative contributions to the science and practice of environmental monitoring through the development of both flight hardware and novel methods to extract relevant information and to H. David Goldfein for his outstanding contributions to the analysis and development of innovative RF systems and his significant impact on national security missions.

MIT Lincoln Laboratory Early Career Technical Achievement Awards were presented to Brian G. Saar for his development of innovative concepts in active infrared technology and systems for spectroscopy, chemical defense, sensing, and countermeasures and to 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 technology.

The 2019 MIT Lincoln Laboratory Best Paper Award was presented to Arthur Lue, Jessica D. Ruprecht, Jacob D. Varey, Herbert E. M. Viggh, and Mark G. Czerwinski for "Discovering the Smallest Observed Near-Earth Objects with the Space Surveillance Telescope," published in June 2019 in *Icarus*.

MIT Lincoln Laboratory Best Invention Awards were presented to Robert W. Haupt and Charles M. Wynn for the invention of Noncontact Laser Ultrasound for Medical Imaging and Elastography and to Hamed Okhravi for the invention of Timely Randomization Applied to Commodity Executables at Runtime.

The 2019 National Fire Control Symposium Outstanding Paper second-place award was presented to Joseph A. Munoz for "Information Denial for Missiles"; Munoz was honored in the Early Career Award category.

American Security Today, a publisher of government and general security news, presented a 2019 ASTORS Homeland Security Award in the Best Video Analytics Solutions category to the DHS Science and Technology Directorate's Office of Mission and Capability Support for the development, with Lincoln Laboratory, of the Forensic Video Exploitation and Analysis Tool Suite.

In November, the Missile Defense Agency (MDA) presented the MDA Special Access Programs Team Award for Test and Assessment to the Countermeasures Mitigation Team, which included five laboratory staff.

Professional Development

Lincoln Laboratory's commitment to the professional development of its staff is seen in the diversity of opportunities presented by the Human Resources Department's educational program.

For highly qualified candidates, Lincoln Laboratory offers the opportunity to apply to the Lincoln Scholars program, which supports the full-time pursuit of advanced degrees. The candidates accepted into the program perform their thesis research work at the laboratory while serving as contributing members of the staff. From July 1, 2019, to June 30, 2020, 12 staff members were enrolled in the Lincoln Scholars program. Almost 200 staff members have pursued full-time technical graduate work through the program.

The Part-Time Graduate Studies program enables staff members to continue to work at the laboratory while earning master's degrees in fields that are relevant to laboratory mission areas or business needs. Staff members can take courses toward their degrees through universities' part-time programs that may include classes offered online and/or outside traditional work hours. Lincoln Laboratory staff are also eligible to take courses in computer science offered at Hanscom Air Force Base by Boston University (BU). These courses, which have included computer networking, cryptography, and software engineering offerings, can be taken independently or as part of a BU certificate or master's program. From July 1, 2019, to June 30, 2020, 16 people participated in these programs.

The technical education program offers both short-term and semester-length courses taught by Lincoln Laboratory technical staff or by outside experts. In the 2019 fall semester, nine courses were offered on amateur radio, electromagnetics, estimation/association, fundamentals of flight dynamics, laser physics, space control, human factors engineering, spacecraft design, and undersea systems.

The professional and leadership development program again sponsored courses in non-parametric Bayesian methods, leadership techniques, project management, preparing presentations, and scientific and technical writing. Computer training in common Office and Adobe software applications, programming, and technical software is offered on site throughout the year.

Technology Office Seminars

The Technology Office directs a program of seminars presented at the laboratory by both in-house speakers and researchers from universities and industry. The seminars are chosen to reflect current and leading-edge trends in today's technology. The speakers are renowned in their respective fields. All seminars are meant to spark curiosity, creativity, and collaboration.

Highlights of the 2019–2020 program included the following seminars:

- "Active Learning in Risky Environments: Exploring Deep Sea Volcanoes and Ocean Worlds," Professor Brian Williams, CSAIL
- "Image-to-image Translation," Jan Kautz, NVIDIA
- "Elections Security," Professor Ron Rivest, MIT Institute Professor
- "Swarms of Small, Flying Robots," Vijay Kumar, University of Pennsylvania
- "Mars Cube One," Andrew Klesh, Jet Propulsion Laboratory
- "Solar Climate Intervention," Kelly Wanser, SilverLining

Staff and Division Seminars

Throughout the year, technical staff members present talks on work that is ongoing in the laboratory's divisions. In biweekly staff seminars sponsored by the Director's Office, major projects are highlighted. Every week, laboratory employees can attend multiple seminars in which staff present the latest results of current programs. These seminars allow staff from across the laboratory to learn about the work colleagues are engaged in and, in particular, acquaint new staff with the breadth of R&D the laboratory conducts.

Diversity and Inclusion

The laboratory continues to foster an inclusive workplace that supports the talents and perspectives of its staff. Recruitment at a broader range of universities, programs in mentoring, employee resource groups, and flexible work options contribute to the hiring and retaining of a more diverse workforce.

Nine employee resource groups promote an inclusive workplace by increasing awareness of various cultures, communities, and identities: Lincoln Employees with Disabilities, the Lincoln Employees' African American Network (LEAN), the Out Professional Employee Network, the Lincoln Laboratory New Employee Network, Recent College Graduates, the Lincoln Laboratory Women's Network, the Lincoln Laboratory Hispanic and Latino Network, the Pan Asian Laboratory Staff Network (PALS), and the Lincoln Laboratory Veterans' Network (LLVETS).

Lincoln Laboratory is an active member of the National GEM Consortium, which, through partnerships with universities and industries, provides support to students from underrepresented groups who are seeking advanced degrees in science or engineering. The cornerstone of this effort is the internship program, which connects graduate students with employment opportunities at organizations engaged in technology development. Lincoln Laboratory usually hires approximately 15 to 18 GEM Fellows as interns; however, in the spring of 2020, GEM internships were canceled to decrease coronavirus risks.

The following highlighted events from July 2019 to June 2020 contributed to an inclusive environment.

In October 2019, the Lincoln Laboratory Hispanic/Latino Network invited Natalia Guerrero to deliver a keynote address for Hispanic Heritage Month. Guerrero is a researcher at the MIT Kavli Institute for Astrophysics and Space Research and is also the MIT communications lead for NASA's Transiting Exoplanet Survey Satellite (TESS). The presentation focused on Guerrero's personal story growing up Hispanic American and TESS's recent achievements. Guerrero's experiences and advocacy of accessible science education resonated with laboratory staff members who grew up as first-generation American college students.

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

The Pan Asian Laboratory Staff Network employee resource group held its annual signature event, the Lunar New Year Celebration, in January. The PALS celebration showcased a variety of Asian cultures. Highlights of the event were performances by MIT Bhangra, an Indian folk dance troupe, and an interactive lion dance performance by the New England Chinese Cultural Studio. Opportunities to learn Chinese calligraphy and paper cutting were also offered.

The seventh annual Martin Luther King Jr. Luncheon was hosted by LEAN in March to celebrate the impact that the life and legacy of Dr. King have had on increasing diversity and inclusion within the technical domain. Astronaut Stephanie Wilson was the speaker for this year's luncheon, which had the theme "Fostering Strong, Moral, and Courageous Leadership."

Several of Lincoln Laboratory's annual diversity and inclusion events in the spring and early summer were canceled because the majority of the workforce was working remotely from home during the coronavirus pandemic. However, the LLVETS annual Memorial Day Recognition Event was hosted virtually, allowing veterans from both the laboratory and remote locations to participate. Rear Admiral William Kelly, 42nd superintendent of the US Coast Guard Academy, delivered a keynote that highlighted the significance of Memorial Day, the importance of diversity and inclusion in any organization, and the relationship between Lincoln Laboratory and the Coast Guard Academy.

The Diversity and Inclusion Office also offers opportunities for staff to participate in mentoring and leadership programs that focus on mentorship of multicultural communities. The curriculum for both programs builds competence in self-leadership, relationship skills, and organizational skills.

In response to civil unrest related to systemic and structural racism, the Diversity and Inclusion Office created an initiative called RE2AcT (Research. Educate. Empathize. Act. Transform) to help Lincoln Laboratory create conditions for sustainable success. The office is planning to host weekly content throughout the coming months to generate a common level of understanding about systemic racism.

In advance of the 100th anniversary of the adoption of the 19th Amendment, the Diversity and Inclusion Office formed a committee to plan a campaign celebrating the contributions of women. The campaign's goal is to raise awareness of women's successes and the continuing struggles they face in society, particularly the workplace.

Efficient Operations

The growing complexity of today's business operations and rapid evolutions in technology are changing traditional ways of working. Over the past year, Lincoln Laboratory continued to assess and adapt business operations to improve processes and empower employees to work efficiently and effectively.

Continual Efficiency Improvements

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

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

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

- The laboratory launched a major modernization to update SAP business data systems and provide upgraded tools and a new master data architecture.
- Human Resources implemented a new onboarding program that starts new hires on the same weekday, streamlines the background investigation and badging process, takes new hires through tours and orientations, and assigns each new hire a guide to further help the person acclimate to the laboratory's culture.
- The Financial Services Department launched the SAP Concur tool, which allows staff to digitally plan their travel, make reservations, and submit expenses.

- Knowledge Services established a centrally managed process that requires all departments and divisions to write, review, and share procedures in the same way. As part of this process, all procedure owners now review their procedures annually.
- The Director's Office raised group leaders' approval limit from $10,000 to $50,000 for the acquisition of products and services.
- The Security Services Department developed computer-based training that users can access at their desktops and that is tracked in the laboratory's Learning Portal. The department also replaced its inefficient paper-based process, improving the department's ability to electronically approve, track, and generate foreign travel and foreign contacts reporting.
- The Contracting Services Department rolled out a new function called External Workforce Services that streamlines the hiring and supervision of subcontractors at the laboratory, making it easier for hiring managers to bring in the help they need. Improvements included streamlining purchasing-card validation processes, developing procurement quick cards and training modules, co-locating contracting staff to assist division business managers with major procurements, and simplifying administrative procedures.

Enhancements to Information Services

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

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

Community Outreach

Educational Outreach for University Students

Beaver Works

Beaver Works, a joint venture between Lincoln Laboratory and the MIT School of Engineering, facilitates project-based learning and leverages the expertise of MIT faculty, students, and Lincoln Laboratory staff to broaden research and educational partnerships.

A key component of Beaver Works is the capstone project, which is associated with a two-semester design-and-build class that challenges students to develop an engineering solution to a real-world problem. This year, students in the MIT undergraduate courses 2.013 Engineering Systems Design and 2.014 Engineering Systems Development, offered by the Department of Mechanical Engineering in collaboration with Lincoln Laboratory, created proactive, integrated decisionsupport tools and services that empower frontline communities to prepare for climate impacts and minimize losses. For example, the Climate Resilience Early Warning System Network (CREWSNET), which will start in western Bangladesh but is scalable to other frontline nations across the globe, will combine leading-edge climate forecasting and socioeconomic analysis with innovative resilience services to empower people to make informed decisions about adaptation and relocation to minimize loss of life and property.

University Student Programs

Lincoln Laboratory offers a variety of research and internship opportunities to university students. Candidates in MIT's 6-A Master of Engineering Thesis Program can spend two summers as paid laboratory interns, participating in projects related to their fields. Then the students work as research assistants while developing their theses under the supervision of both Lincoln Laboratory engineers and MIT faculty. In 2019–2020, 11 students chose to do their thesis research at Lincoln Laboratory. The laboratory also typically employs about a dozen other research assistants from across MIT's engineering departments.

Each summer, the laboratory hires undergraduate and graduate students from top universities as interns in technical groups. In addition to participating in technical projects, the students attend in-house demonstrations and seminars and give final presentations on their work to the laboratory community. The laboratory hired 63 undergraduates and graduate students to work as interns in summer 2020.

Throughout the year, cooperative-education (co-op) students from area colleges such as Northeastern University and the Wentworth Institute of Technology work at the laboratory. Around 40 co-op students from area schools are employed in technical divisions and service departments at the laboratory each year.

Educational Outreach for K–12 Students

Recognizing the importance of preparing young people for careers in STEM, Lincoln Laboratory Community Outreach (LLCO) administers a significant program of STEM activities.

In December, laboratory staff provided an all-day computer science workshop for students at East Lawrence High School in Alabama, an underserved school 40 miles from the laboratory's field site in Huntsville. The goals of the workshop were to increase student interest in STEM-related career fields; increase pride, communication, and critical thinking skills; and help students learn coping skills by introducing them into an environment where failure and challenges can be overcome by innovation and determination. The students were given a JIMU Robot Builderbot Kit, shown tips for building the robots, and given specific challenges to work on in the future.

(LL-Fig13_Outreach_Alabama STEM)

Figure 13. Students enjoy working together in teams to build their own robot during a STEM workshop at East Lawrence High School in Alabama.

Laboratory staff extended a new outreach opportunity, the G.I.R.L. Cyber Safety Workshop, for young women to learn about career fields related to science and engineering. In February, 26 middle school girls learned about Internet security, social engineering, encryption and code breaking, network packet capture, and Internet Protocol (IP) addresses. They had to search packets for usernames and passwords while learning how hackers use these skills to break into unsecured networks to retrieve personal information; in addition, they were required to decipher codes in Morse, binary, ASCII, and Caesar Cipher, a simple and well-known encryption system.

This year's Beaver Works Summer Institute was held in a virtual format, with seven classes offered to 178 students from 26 states and Canada. This fifth year of the program—a four-week hands-on STEM learning experience for high school seniors—concluded with a showcase of student projects and a virtual grand prix. The classes included 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. This course was also offered at Lincoln Laboratory's satellite location on Kwajalein Atoll, where 14 students enrolled.

Our two-week radar workshop, Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), now in its ninth year, challenges high school seniors to build their own small radar systems as they tackle college-level lectures in physics, electromagnetics, signal processing, antennas, and circuitry. This year, in a virtual format workshop, 35 students were sent a pre-assembled radar to limit the complexity of debugging radars. The students conducted hands-on experiments that exhibited radar fundamentals and presented their final projects to family, friends, and laboratory staff while demonstrating their new knowledge about radar.

Thirty high school students from across the country attended the virtual 2020 Lincoln Laboratory Cipher (LLCipher) workshop. The weeklong workshop offered students an introduction to theoretical cryptography while teaching them how to build a secure encryption scheme and digital signature. Typically, the workshop curriculum includes hands-on demonstrations and interactive, small-group activities that reinforce basic lessons of classical and modern cryptography; however, this year LLCipher had to accommodate a virtual setting.

Community Service

LLCO helps increase laboratory employees' awareness of events sponsored by charitable organizations. Support Our Troops, one of LLCO's first community giving programs, is an ongoing campaign to collect and mail food, toiletries, and books to soldiers overseas. In 2019–2020, Lincoln Laboratory sent 160 care packages to troops. Participants in the Star-Spangled 5K Walk raised $2,600 to provide training for assistive dogs that work with wounded veterans.

Laboratory employees donate funds annually to the American Heart Association, Ride to End Alzheimer's, CancerCare, Toys for Tots, Boston Children's Hospital, the Jimmy Fund, Bedford Veterans Hospital, the Lowell Humane Society, the Pan-Mass Challenge, Coats for Kids, and the American Foundation for Suicide Prevention. Some dedicated laboratory staff have created their own charitable events such as Race 2 the Summit, a half-marathon to Wachusett Mountain to benefit the Dana-Farber Cancer Institute, and Grab a Chemo Activity Bag (C.A.B.), which collects items and creates bags full of activities and creature comforts to cheer cancer patients while they undergo chemotherapy.

Our field sites work to help charities in their local areas by providing trees, engaging in island cleanup, and helping to fund school lunch programs.

Summary

Lincoln Laboratory's portfolio of technology R&D programs continues to grow and is strategically balanced with programs that conduct large-scale system development, that perform rapid prototyping of new systems, and that involve innovative, often multidisciplinary, research projects. Mission areas across the laboratory are pursuing answers to new challenges created by today's reliance on big data, cyber security, satellites, and artificial intelligence.

The laboratory continues to transition its technologies to its government sponsors, to industry, and to the research community to help ensure that the US military has access to leading-edge systems and that US industries remain international leaders in defense technology.

Ongoing improvements to administration and infrastructure and a strong program in professional development are enabling the laboratory to achieve technical excellence in its work.

Community involvement is strong at the laboratory. Educational outreach programs are encouraging young people to consider careers as scientists and engineers. Many employees are engaged in walks or volunteer programs that support charitable causes.

In conclusion, Lincoln Laboratory is well prepared to achieve continued success in its mission of "technology in support of national security."

Eric D. Evans
Director