Lincoln Laboratory

Lincoln Laboratory is a Department of Defense (DoD) federally funded research and development center 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 (AFB) 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 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.

Lincoln Laboratory's 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, homeland protection, maritime defense technologies, microelectronics, air traffic control, and intelligence, surveillance, and reconnaissance (ISR).

The Laboratory's deep expertise in sensors, information extraction (signal processing and embedded computing), and systems analysis is applied to all of these domains as well as to new areas such as biomedical systems, energy, and humanitarian assistance and disaster relief. The Laboratory focuses on prototyping new technologies and capabilities to meet DoD needs that cannot be met as effectively by existing government or contractor resources.

Increasingly, artificial intelligence (AI) techniques are being utilized to strengthen the capabilities of decision support systems and applications. Lincoln Laboratory has initiated work that is applying AI to a range of uses, such as distinguishing objects in imagery, guiding autonomous systems, and identifying networks of interest in social media. Two groups at the Laboratory have been reorganized to focus R&D on exploring AI solutions for national security needs: the AI Technology and Systems Group in the Cyber Security and Information Sciences Division and the AI Software Architectures and Algorithms Group in the ISR and Tactical Systems Division.

Lincoln Laboratory has unique facilities that enable R&D for a wide range of applications. The Microelectronics Laboratory is a US government trusted foundry and its most capable foundry. This 70,000-square-foot lab has the tool sets to fabricate semiconductor wafers with diameters up to 200 millimeters and perform 193-, 248-, and 365-nanometer optical projection lithography. The Autonomous Systems Development Facility, housed in a hangar on Hanscom AFB, allows researchers to test prototype ground, aerial, and undersea autonomous systems and boasts a motion-capture environment with the world's largest volume.

Lincoln Laboratory operates a fleet of seven aircraft at its full-service Flight Test Facility on Hanscom AFB. All of these aircraft, which range from a small single-engine plane to a Gulfstream jet, can be modified to accommodate the particular airborne systems the staff need to flight test (e.g., communication systems and airborne imagers). The Sensorimotor Technology Realization in Immersive Virtual Environments (STRIVE) Center in Billerica is an approximately 4,000-square-foot facility in which researchers can use a computer-assisted virtual reality dome to measure subjects' physiological responses to various environmental conditions or to assess prototype physiological monitors.

Strides in manufacturing fabrics embedded with light-emitting diodes and sensors are being made in the Defense Fabric Discovery Center. Researchers in that facility are working to develop advanced fabrics that can store energy, emit and detect light, monitor health, or enable communication. These fabrics could provide soldiers with lightweight, wearable capabilities. The Lincoln Laboratory Supercomputing Center recently installed a powerful new computer, increasing the center's ability to process tens of thousands of operations per second and enabling research that demands complex computations and simulations. Many other small specialized labs and facilities available to the Laboratory's staff range from labs for assessing air traffic control algorithms to one that is used to characterize biological materials.

Specific examples of this year's R&D activities are presented in the Technical Program Highlights section.

Lincoln Laboratory's fiscal year runs from October 1 to September 30. For FY2018 (October 1, 2017, to September 30, 2018), Lincoln Laboratory received approximately $1.027 billion in total funding to execute R&D on sponsored projects. While most of the research is sponsored by DoD, funding is 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 (NOAA). In addition, Lincoln Laboratory also 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 interaction between staff and line management. Sponsors' 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 coordinate and manage the technical and programmatic challenges of large-scale developments.

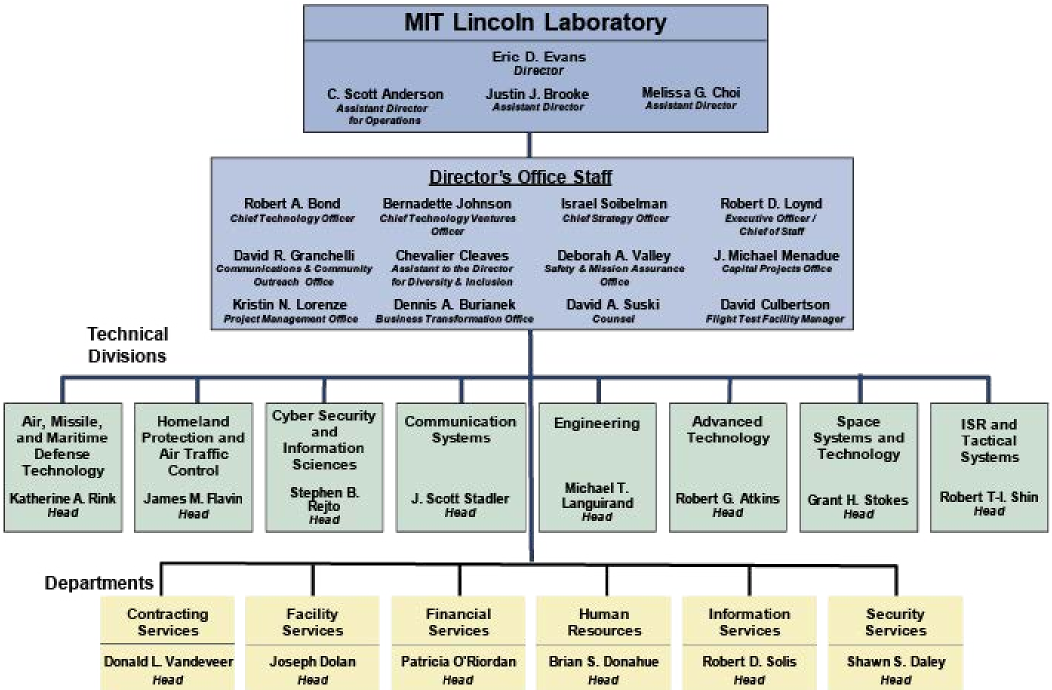

Figure 1. Lincoln Laboratory's organizational structure as of August 1, 2019.

Leadership Changes

Justin J. Brooke was appointed assistant director of Lincoln Laboratory. Prior to this appointment, he was head of the Laboratory's Air, Missile, and Maritime Defense Technology Division.

Melissa G. Choi was also appointed assistant director of Lincoln Laboratory. Prior to this, she was head of the Laboratory's Homeland Protection and Air Traffic Control Division.

Chevalier P. Cleaves was named assistant to the director for diversity and inclusion; before joining Lincoln Laboratory, he served as chief diversity officer for the US Air Force.

David Culbertson joined Lincoln Laboratory to become manager of the Flight Test Facility; he has spent more than 35 years in aviation and flight testing, including service in the US Navy as a pilot and flight instructor and experience in industry as a flight test pilot.

Robert D. Loynd joined the director's office staff as executive officer to the director and chief of staff; prior to assuming this position, he worked in administration at Tufts University and the University of Maryland University College.

Katherine A. Rink was promoted to head of the Air, Missile, and Maritime Defense Technology Division; she formerly served as the division's associate head.

James M. Flavin was promoted to head of the Homeland Protection and Air Traffic Control Division; he was formerly the division's associate head.

D. Marshall Brenizer was promoted to associate head of the Space Systems and Technology Division; he formerly served as the division's assistant head.

Marc N. Viera was promoted to associate head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division; he formerly served as the division's assistant head.

James Ward was promoted to associate head of the Communication Systems Division; he was formerly the division's assistant head.

Thomas G. Macdonald was appointed assistant head of the Communication Systems Division; he formerly served as a leader for various groups within the division.

Jesse A. Linnell, formerly a member of the technical staff in the Laboratory's Systems Engineering Group, was named an associate technology officer in the Technology Office, which is responsible for managing strategic technology investments and helping to grow technical relationships outside the Laboratory.

R. Louis Bellaire was appointed deputy of the Technology Ventures Office (TVO), which works to facilitate the rapid transfer of advanced technology into and out of Lincoln Laboratory for the benefit of national security.

Robert J. Boston, Derek W. Jones, and Scott J. Mancini were promoted to assistant heads in the Security Services Department (SSD).

Technical Program Highlights

Research and development at the Laboratory focus on national security problems across a broad range of mission areas: tactical and intelligence, surveillance, and reconnaissance 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 670 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 Transiting Exoplanet Survey Satellite (TESS) NASA Explorer Mission was launched on a SpaceX Falcon 9 rocket on April 18, 2018, from the Kennedy Space Center in Florida. Lincoln Laboratory, in partnership with MIT's Kavli Institute for Astrophysics and Space Research, provided the detector arrays, optical subsystem, system engineering, integration and testing, and program management for the science payload. After reaching its highly stable lunar-resonant orbit and completing its on-orbit commissioning, TESS is now collecting all-sky catalog data in search of planets orbiting large nearby stars.

The Micro-sized Microwave Atmospheric Satellite-2A (MicroMAS-2A) CubeSat was launched into low Earth orbit by the Indian Space Research Organisation's Polar Satellite Launch Vehicle on January 12, 2018. MicroMAS-2A successfully demonstrated an advanced compact microwave sounder and provided the first multiband radiometer measurements from a CubeSat payload. The MicroMAS-2B CubeSat, fitted with a duplicate microwave sounder payload, was successfully assembled, integrated, tested, and delivered in anticipation of a 2019 launch by Virgin Orbit.

SensorSat completed operational testing following its August 2017 launch and is now a contributing sensor in the US Space Surveillance Network. SensorSat is a small satellite built by Lincoln Laboratory for the Operationally Responsive Space Office to meet a US Strategic Command critical need in space situational awareness.

Figure 2. The Space Surveillance Telescope mount installation is under way in the newly completed enclosure in northwestern Australia.

All Space Surveillance Telescope (SST) components were shipped and are in storage at the Naval Communication Station Harold E. Holt in northwestern Australia. Assembly, integration, and testing of the telescope will continue throughout 2019 (Figure 2), with first light for SST-Australia expected in 2020.

A portfolio of activities continues to deliver critical space domain awareness information and tools to the National Space Defense Center in Colorado. The Laboratory is also leading an effort to extend and apply the Open Mission Systems architectural governance and the UCI (Universal Command and Control Interface) messaging standards to a prototype space domain system in support of space command and control.

The TROPICS mission was selected by NASA as part of the Earth Venture Instruments program and is now in implementation with planned launch readiness in late 2019. TROPICS will comprise a constellation of six CubeSats in three low-Earth orbital planes. Each CubeSat will host a compact cross-track scanning microwave spectrometer with 12 channels spanning 90 to 205 GHz to provide observations of 3D temperature, humidity, and cloud ice and precipitation structure at high temporal resolution. TROPICS data will be used to improve scientific understanding and forecasting of tropical cyclones. The system design is complete, a flight-qualification system has been built and tested, and flight hardware is undergoing assembly, integration, and testing.

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 employ intentional and unintentional countermeasures.

Figure 3. Several new signal processing techniques and airborne radar prototypes were tested with the Laboratory's unique airborne test assets, including the de Havilland Twin Otter, seen here with the development and test team.

The Laboratory developed and deployed a unique hardware-in-the-loop testing capability that uses state-of-the-art processing hardware and algorithms to support testing of many sensors and interference sources simultaneously in order to analyze combined effects.

In collaboration with MIT campus groups and the Woods Hole Oceanographic Institution, Lincoln Laboratory conducted experiments during the US Navy's 2018 Ice Exercise to investigate the effects of the rapidly changing Arctic on underwater acoustic propagation and noise.

An initial prototype of a small-form-factor advanced sensor suitable for an airborne test bed was demonstrated. This demonstration also provided risk-reduction information to enable an analysis of options and initial concept development for a space-based advanced sensor.

The Laboratory has employed sidecars (BMDS Analysis Enclaves, or BAEs) on numerous BMDS sensors, leveraging commercial hardware and advanced processing to prototype algorithms for tracking, discrimination, multisensor fusion, and kill assessment. This year the BAEs were used to explore advanced algorithms, including wind farm clutter-mitigation techniques tested at Aegis Ashore.

Laboratory staff traveled to the Atlantic Undersea Test and Evaluation Center (AUTEC) to test imaging capabilities against maritime targets, collecting full-spectrum imagery across the ocean surface to support development of improved optical propagation models. Laboratory staff also conducted extensive testing at AUTEC and at the Shipboard Electronics System Evaluation Facility to characterize periscope performance.

A prototype infrared search-and-track system that uses a novel optical multiplexing approach was tested in numerous field deployments in maritime environments to inform the design of a future naval sensor that could deliver persistent hemispherical surveillance capability.

Lincoln Laboratory is prototyping technology to address hypersonic defense needs. Key experiments and prototype capability focus areas include systems analysis, advanced sensing, hypersonic phenomenology, and interceptor technology. Recent testing at hypersonic facilities is providing new aerodynamic and aerothermal phenomenology insights informing defense needs. The wind tunnel experiments will be compared with existing flight test data to guide future hypersonic testing. Key findings are and will continue to be presented to advise DoD and Missile Defense Agency decisions about technology investments and future defense technology and system development.

Communication Systems

Figure 4. The HALO (High-altitude Attritable Link Offset) program successfully demonstrated the first balloon-based communications relay array. Ten low-cost balloon payloads used distributed adaptive array processing techniques to achieve over-the-horizon communications despite co-channel interference.

Lincoln Laboratory validated the performance of a new protected tactical military satellite (MILSATCOM) waveform in multiple demonstrations over both military and commercial satellites. These demonstrations included the first airborne test of the waveform.

The Laboratory completed development and flight testing of a prototype airborne communication system that extends beyond-line-of-sight communications to US Navy assets in a contested environment.

Techniques developed to coherently combine multiple optical apertures will enable high-performance, low-cost ground terminals for space-to-ground laser communication systems.

The Communication Systems and Engineering Divisions worked with industry to create a new modular, scalable, spaced-based laser communication terminal designed to support a broad range of user missions. Prototypes of the terminal will be flown on the International Space Station and NASA's Orion spacecraft.

An adaptive beamforming technique developed by the Laboratory has been incorporated into an airborne tactical radio. The algorithms significantly enhance the performance of legacy tactical data links in contested environments and are compatible with current and planned radios.

A quantum network test bed with a 40-kilometer span of deployed fiber has been established between the Laboratory and the MIT campus. This operational test bed, which features synchronized entanglement sources, has been used to demonstrate the feasibility of entanglement swap and will be used in the future to support R&D into scalable, multi-span quantum networks.

A free-space laser communications test and diagnostic terminal was deployed to a field site to support the 2019 launch of the NASA Laser Communications Relay Demonstration.

Lincoln Laboratory is developing narrow-beam optical communications for high-rate, day or night communication over short-range undersea links. A prototype of a blue-green laser communication terminal was integrated on two remotely operated undersea vehicles. In an experiment conducted in an outdoor pool, the prototype system demonstrated active beam pointing, acquisition, tracking, and communication at gigabit-per-second rates.

Cyber Security and Information Sciences

Figure 5. The Lincoln Research Network Operations Center enables researchers and network defenders to collaborate on cyber analytics and visualization tools.

Lincoln Laboratory created a set of architectural underpinnings for incorporating cyber security into small satellites. This work included an adaptation of a formally verified, Defense Advanced Research Projects Agency–derived microkernel called seL4, a small piece of software that provides only the most essential operating system functions.

Laboratory staff provided key systems analysis expertise to five major studies for the intelligence community on topics such as the future impact of artificial intelligence and advanced cyber threats.

Multiple software-based situational awareness capabilities were delivered to the US Transportation Command to help analysts understand threats to and improve their awareness of networks that the command depends on.

After technical analysis, researchers developed three proof-of-concept prototypes for the US Cyber Command Capabilities Development Group. This work will help the group define the architecture for a joint cyber operations platform for the Cyber Mission Forces.

The Laboratory performed research on the effective virtualization of embedded computer systems, a process known as rehosting, under the Rapid Rehosting of Embedded Systems (RAREM) project. RAREM will enable thorough vulnerability assessments to be performed on embedded computers in military systems, civilian transportation, and consumer devices.

A single-channel speech enhancement system based on deep neural networks improved the quality of speech signals recorded in the presence of real-world noise and reverberation. Delivered to DoD and the intelligence community, the system has received excellent reviews for its benefit to analysts.

A new petascale system is accelerating the transition of advanced technology to the nation's critical missions by empowering researchers with interactive supercomputing.

A new multigroup effort to design, implement, and operationally employ practical methodologies, tools, and subsystems will help ensure the security and resiliency of mission systems built by the Laboratory.

Laboratory researchers collected cyber and radio frequency (RF) measurements during a military exercise held in Japan in December 2017 for the III Marine Expeditionary Force. Sponsored by the Office of Naval Research, this effort aims to help the US Marine Corps integrate cyber and electronic warfare technology into tactical missions. Lincoln Laboratory established a new test bed facility in 2018 to support this research and development of cyber and electronic warfare technology.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Two airborne radar test beds have been built and are now collecting data and demonstrating prototype technologies. A single-channel X-band radar has collected data for deep-learning-based target-classification algorithms and for advanced synthetic aperture radar exploitation modes. Later this year, a six-channel Ku-band radar in the final stages of integration will be used for experiments supporting development of advanced radar algorithms.

Lincoln Laboratory researchers developed advanced machine learning techniques for computer vision and object recognition in commercial imagery. Normally, large amounts of manually labeled truth images are needed to train computer vision algorithms. The researchers demonstrated the use of active learning, a technique in which the computer tells the engineer what data would be most useful for algorithm training. This technique has achieved high performance in computer vision algorithms with dramatically reduced training data.

The Laboratory is developing new RF sensing architectures, such as multistatic sensing, to extend moving target indication and imaging performance in contested environments. This work includes demonstration of multifunction RF sensors and potential integration of these payloads on unmanned platforms.

Under development is an integrated big data analysis environment for supporting the development and acceleration of machine learning and graph analytics techniques that use databases of billions to trillions of entries. The Laboratory prototyped a unique graph processor that scales to address large graph problems posing computational challenges for high-performance commercial processors. This system performs key mathematical functions up to 100 times faster while consuming less power than commercial processors.

The Lincoln Laboratory–built Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), an advanced foliage-penetrating ladar, completed its 608th sortie. MACHETE has been deployed to countries in South America, producing image products that have contributed to tactical and strategic successes in the region. A planned update will improve the performance of the world's most capable ladar system.

The single-photon-sensitive Geiger-mode avalanche photodiode camera, seen in Figure 6, can operate with multiple detector array formats and has been engineered to support low-SWaP (size, weight, and power) applications. The camera incorporates field-programmable gate array technology that enables real-time processing and image formation. In addition, the camera forms the bases of multiple laser-radar system designs, allowing their integration onto SWaP-limited airborne and ground-based platforms.

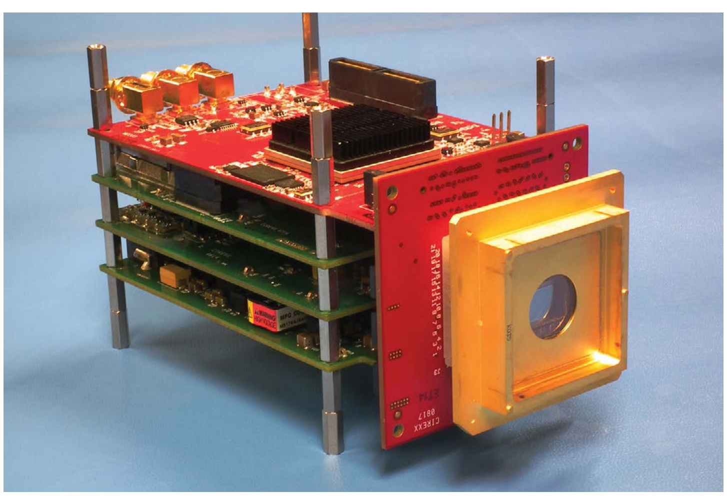

Figure 6. The single-photon-sensitive Geiger-mode avalanche photodiode camera is used in several laser-radar systems developed by Lincoln Laboratory.

Tactical Systems

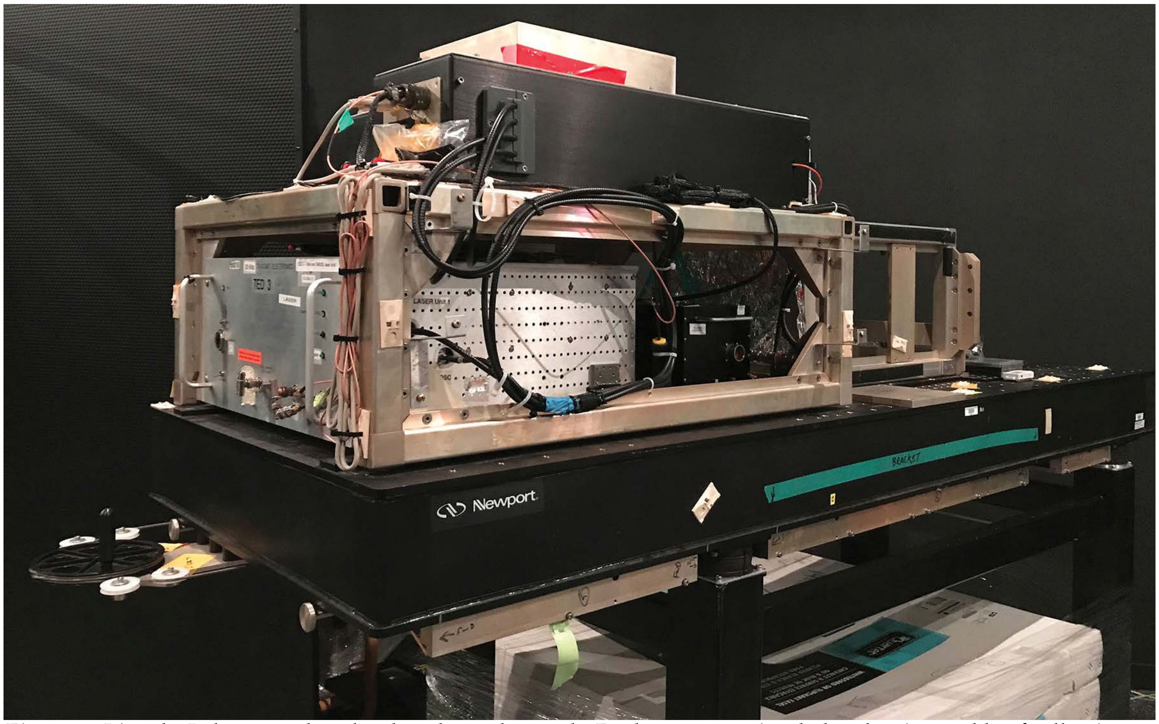

Figure 7. Lincoln Laboratory has developed an advanced 3D photon-counting ladar that is capable of collecting high-fidelity 3D imagery with 25-centimeter resolution at impressive area rates of 200 square kilometers per hour.

In multiple US Air Force and DoD field tests, Lincoln Laboratory demonstrated prototype software systems to show how software tools can aid decisions, reduce errors, and speed up operations.

Lincoln Laboratory researchers continue to conduct system analyses, laboratory testing, and flight-system data collections that inform assessments of the performance and limitations of Air Force aircraft against current and future foreign threats. These assessments—which include investigations of missile systems' performance, electronic attack and electronic protections, and RF and advanced infrared sensor kill chains—have been presented to DoD leaders to advise their decisions about technology investments and future system capabilities.

The Laboratory is prototyping advanced technologies and systems for signal intelligence missions. These efforts include significant upgrades to systems that were previously transitioned to the government and industry and are currently in operation. A new software-defined radio architecture was developed, prototyped, and fielded this year.

Novel micro air vehicles that Lincoln Laboratory is developing will enable a number of national security missions. Projects executed in close collaboration with the MIT Department of Aeronautics and Astronautics include the development of a transonic micro air vehicle called Firefly and the creation of a virtual reality training environment for air vehicles. In these and other efforts, the Laboratory serves a critical role as a bridge between the basic research in autonomous systems at universities and DoD's challenging mission demands.

The Laboratory continues to develop and analyze new concepts for air dominance and for intelligence, surveillance, and reconnaissance. Several advanced technologies that will enable new capabilities in these areas have been identified for the Air Force. Detailed modeling and systems analyses are being performed to determine the feasibility and performance of these technologies.

Lincoln Laboratory is developing a low-VHF (very high frequency) radar test bed to investigate the surveillance capabilities of phased array radars that use modern digital signal processing. This instrumented sensor is used for making measurements of the background RF environment and ground clutter and supports the development of algorithms for detecting and tracking airborne targets.

Advanced Technology

Under FAA and NOAA sponsorship, Lincoln Laboratory delivered the first full-scale dual-polarized Multifunction Phased Array Radar Advanced Technology Demonstrator to the National Weather Service forecast office in Norman, OK, for field testing and evaluation in July 2018. The prototype will be used to determine the viability of replacing the current network of mechanically scanning aircraft and weather surveillance radars in the National Airspace System with this novel, low-cost, electronically scanning phased array radar technology.

After successfully demonstrating in a laboratory environment the highest brightness electrically powered laser built to date, the Laboratory completed the design and build of a fully packaged fiber-combined high-energy system with low size, weight, and power usage. Currently in its test phase, this system will pave the way for application demonstrations on airborne military platforms.

Under a Department of Energy–sponsored program, compact slab-coupled optical waveguide amplifiers (SCOWAs) operating at a wavelength of 1.65 micrometers were developed and provided to a commercial partner, Bridger Photonics, for evaluation in a methane-gas remote-sensing ladar system. The ladar system was flown on aircraft to generate maps of methane emissions. These flight tests represent the first field demonstration of the Laboratory's SCOWA.

Four low-noise, high-sensitivity, wide-field-of-view cameras designed and built at the Laboratory were integrated into NASA's Transiting Exoplanet Survey Satellite that successfully launched in April 2018. Each camera uses 4-megapixel, deep-depletion charge-coupled devices that were fabricated in the Microelectronics Laboratory. In the next two years, TESS will survey space for Earth-like planets orbiting nearby stars.

Superconducting electronics is emerging as a leading candidate for beyond-CMOS (complementary metal-oxide semiconductor) technology for high-performance computing to address emerging DoD and commercial needs. The Intelligence Advanced Research Projects Activity's Cryogenic Computing Complexity program successfully demonstrated an 8-bit microprocessor.

Under the Defense Advanced Research Projects Agency's Reconfigurable Imaging program, a field-programmable imaging array (FPIA) integrated circuit was designed and submitted for fabrication in a 14-nanometer fin field-effect transistor process. An architectural innovation, the FPIA enables the creation of a software-programmable imager that is based on field-programmable gate array concepts; it allows sensor imaging operational modes to be defined after fabrication and supports multiple simultaneous applications. This flexibility leads to increased investment and capability in the integrated circuit because it can be reused by multiple systems.

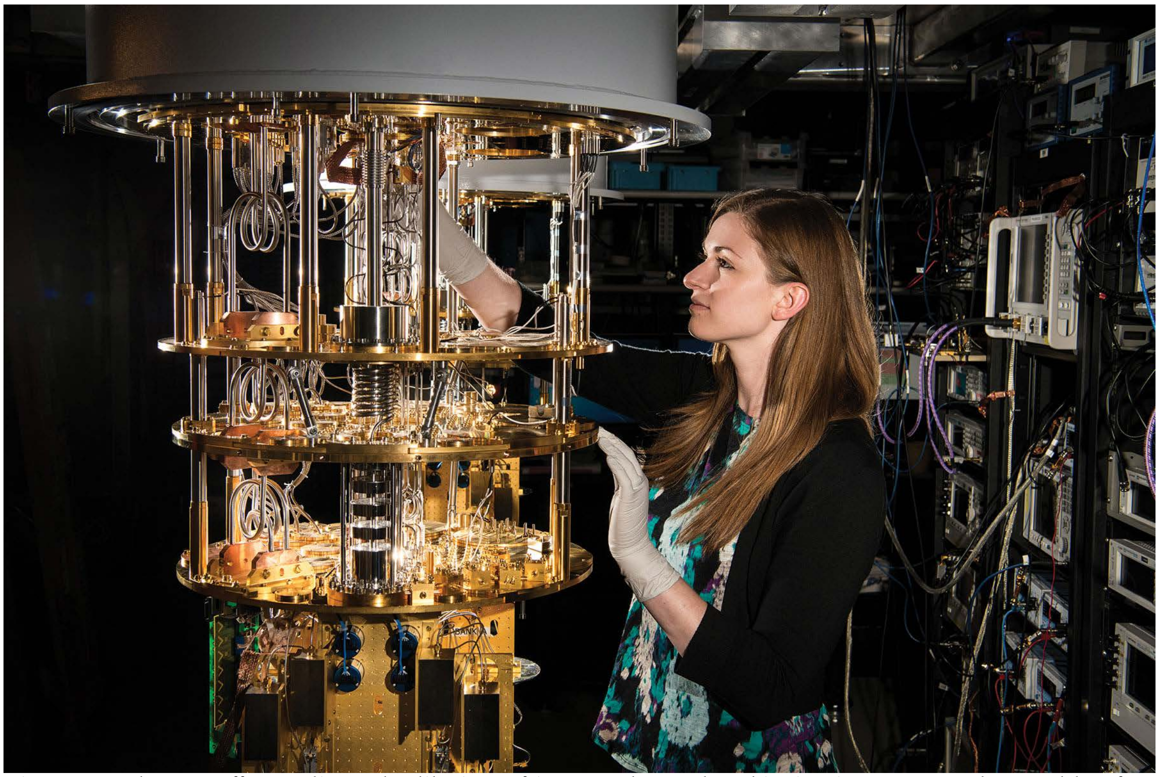

Figure 8. Bethany Huffman adjusts the dilution refrigerator that cools qubit circuits to twenty thousandths of a degree above absolute zero when operating. Lincoln Laboratory's 3D approach to fabricating qubits is enabling more flexible and complex circuitry needed to advance superconducting quantum computers.

Homeland Protection

A gap analysis was completed for a proposed US Army system that will provide actionable information to leaders of small units to maintain and improve warfighter performance and safety.

The Laboratory led a multinational phenomenology measurement campaign at Dugway Proving Ground, UT, to characterize emerging threat scenarios for warfighters.

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.

Under DHS Science and Technology Directorate sponsorship, Lincoln Laboratory continued to develop novel technology to protect critical infrastructure (e.g., mass transit rail systems) against explosive attacks. This work includes the development of prototype systems to detect concealed threats. These systems combine multiple technologies to provide a higher level of security in environments with high passenger traffic.

Figure 9. Engineers test a microwave imaging system in a Massachusetts Bay Transportation Authority training center. The system collects radar reflections off liquid, metal, or plastic objects concealed on pedestrians; algorithms process the imagery in real time to determine whether the objects are threat items.

Using synthetic biology, researchers advanced the Laboratory's work in cell-based sensors. A mammalian-cell metabolic pathway was re-engineered to produce luminescent reporter molecules as a means of simplifying the sensing of biomolecules in living systems.

A prototype automated neural-tracing pipeline is accelerating research into brain connectomics. The image processing pipeline uses machine learning and tracking algorithms to trace long-range neurons through dense fiber networks.

Tasked by the Defense Health Agency, the US Army Medical Research and Materiel Command, and the Defense Threat Reduction Agency, the Laboratory is developing ways to use physiological status biomarkers, acquired via wearable sensors, to improve soldiers' health and enhance their performance.

Lincoln Laboratory, in collaboration with the Home Base Program for Veteran and Family Care, Spaulding Rehabilitation Hospital, Massachusetts General Hospital, and Harvard Medical School, has designed and implemented a protocol for assessing sensorimotor and cognitive deficits resulting from mild traumatic brain injuries. This protocol uses the instrumentation and virtual reality technology in the STRIVE Center to promote sensitive and specific diagnoses of hidden, lingering impairments caused by these injuries.

Air Traffic Control

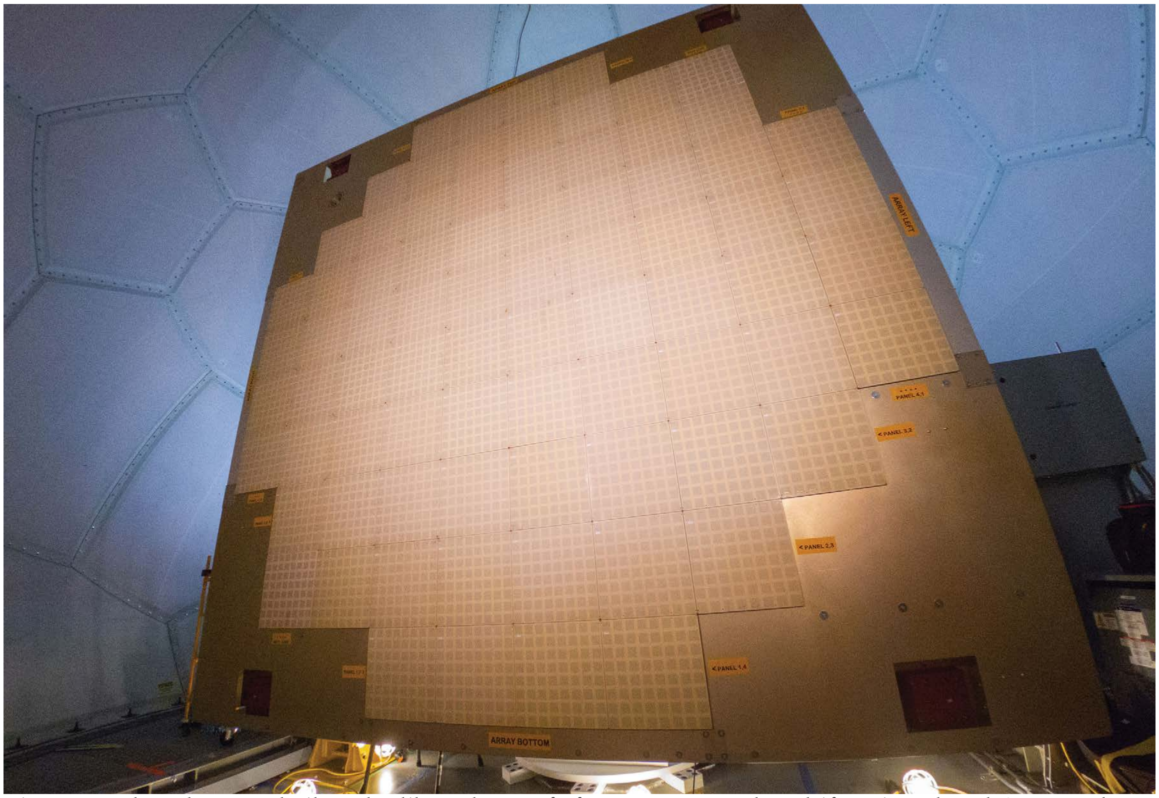

Figure 10. The Laboratory built and calibrated a proof-of-concept 76-panel Multifunction Phased Array Radar Advanced Technology Demonstrator (ATD). The ATD, shown in its radome, was deployed to the National Severe Storms Laboratory in Norman, OK.

A demonstration of the prototype Small Airport Surveillance Sensor achieved surface surveillance with an accuracy of 30 feet and airborne surveillance out to 20 nautical miles.

Lincoln Laboratory's Airborne Collision Avoidance System Xa (ACAS Xa) was adopted by the international community as the new manned aircraft collision avoidance standard. The Laboratory supported the execution of the second developmental flight test of ACAS Xu for unmanned aircraft and released an ACAS Xu system specification compliant with detect and avoid standards.

The Laboratory continued the transfer of technology from its reference implementation of the Next Generation Weather Processor (NWP) system to the FAA. The NWP consolidates multiple weather systems into a single platform to provide an integrated aviation weather display. Algorithms developed by the Laboratory enable enhanced hazardous weather detection and improved air traffic management decision support capabilities.

Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a radar-like view of convective weather that is beyond the coverage of land-based radars. Under the Air Force's Global Synthetic Weather Radar program, the Laboratory is extending OPC to provide global real-time weather products.

Activities are ongoing in air traffic management decision support for the FAA's Plan, Execute, Review, Train and Improve initiative; the improvement of Northeast Corridor operations; the transition to initial trajectory-based operations; and the efficient introduction of new entrants into US airspace.

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

To support research on and development of small unmanned aircraft systems (sUAS), the Laboratory has developed an internally funded sUAS test bed with a variety of platforms that allow staff to test new sensors and collision avoidance logic. Under Federal Aviation Administration sponsorship, the Laboratory is developing and testing collision avoidance technologies for sUAS that leverage ongoing research on manned aircraft and large UAS.

Engineering

Lincoln Laboratory expanded its energy resilience analysis efforts to 27 DoD installations and performed whole installation outage exercises at two DoD installations, including one of critical national importance. This work will continue as the Laboratory develops a framework for analysis and exercise that can be implemented widely within DoD.

The Laboratory performed power systems analyses showing that advanced controls could limit blackouts in regions, such as Puerto Rico, that are impacted by natural disasters.

A prototype of multiplexed imaging capabilities leveraging the Lincoln Laboratory–developed digital focal plane array began field testing for maritime applications.

The Laboratory continued to develop additively manufactured metal heat exchangers with complex internal flow geometries for laser systems. The heat exchangers enable performance gains, provide structural support, and reduce the size and weight of laser systems. In addition, they have enabled record-setting brightness of beam-combined fiber lasers.

Advanced semiconductor devices enable new capabilities for electronic systems, but their performance is limited by an inability to reject heat. The Laboratory demonstrated a technique that uses embedded microjets to cool these devices and initiated technology transfer activities to industry.

To make small, low-cost unmanned aerial vehicles, the Laboratory has explored electro-aerodynamic propulsion and fluid-mechanical-based approaches. Technology transfer activities in this area are under way.

Autonomous systems employ complex autonomy algorithms with nondeterministic and adaptive behaviors that challenge traditional verification and validation approaches. The Laboratory developed new algorithms that help improve the likelihood of mission success.

Lincoln Laboratory tested the SensorSat space vehicle on orbit and monitored the vehicle's performance. The Laboratory supported operational testing of the vehicle and its transition to operations and developed capabilities in data exploitation.

Figure 11. Lincoln Laboratory staff performed the final closeout and inspection of the SensorSat space vehicle during integration on the Minotaur rocket from which it was launched at Cape Canaveral, FL. SensorSat is now providing data for space situational awareness.

The Laboratory developed two prototype PACECR (Protected Aerial Contested-Environment Communications Relay) pods for the Navy Joint Aerial Layer Networking Maritime (JALN-M) program to demonstrate the utility of aerial layers for providing critical communications in contested areas. The Laboratory also developed communications and support systems that were individually qualified for the demanding airborne and thermal environment. The pods flew in 29 missions in support of the JALN-M program and successfully demonstrated all required capabilities.

Technology Transfer

Most of Lincoln Laboratory's R&D projects result in some form of technology transfer either nationally (to government agencies, the commercial sector, or academia) or globally. The mechanisms for these transfers 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, and presentations at conferences and workshops; collaborative research via Small Business Innovation Research/Small Business Technology Transfer projects (which are government-funded joint research partnerships with small businesses) and Cooperative Research and Development Agreements (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, Fiscal Year 2018

Transfer mechanism	Number
Articles in technical journals	87
Papers in published proceedings	110
Presentations at external conferences	418
Lincoln Laboratory–hosted conferences	16
Technology disclosures filed	83
US patents issued	65

Technology Ventures Office

In 2018, Lincoln Laboratory established the Technology Ventures Office to provide strategic coordination for technology transfer activities across the Laboratory enterprise and with MIT proper. As such, TVO works closely with the Contracting Services Department to expand Lincoln Laboratory's engagement with the commercial sector and with MIT's Technology Licensing Office to protect and manage intellectual property deriving from R&D at the Laboratory.

TVO's primary mission is to facilitate the rapid transfer of advanced technology into and out of Lincoln Laboratory for the benefit of national security. In its first full year of operation, the office initiated a number of new efforts, including:

- Developing guidelines for the Laboratory's transition of technologies in support of sponsored research programs
- Growing the Laboratory's intellectual property output by increasing the emphasis on timely filing of technology disclosures and simplifying the filing process
- Working with the Technology Licensing Office to increase the quality and quantity of licensing agreements
- Developing a network and database of agile, often nontraditional companies with advanced capabilities to help support our sponsored research
- Helping to create a more entrepreneurial workforce by working with the MIT I-Corps team to offer a customized entrepreneurship course at Lincoln Laboratory
- Exploring government-supported options for stronger engagement with early-stage companies and obtaining a funding award from the Defense Advanced Research Projects Agency for embedded entrepreneurial fellows at Lincoln Laboratory
- Expanding the amount of collaborative research the Laboratory conducts with nongovernment sponsors in order to provide regional and national economic benefits

Technical Workshops

Dissemination of information to the government, academia, and industry is a principal element of Lincoln Laboratory's technical mission, achieved through annual workshops and seminars that bring together members of the technical and defense communities.

These events foster a continuing dialogue that enhances technology development and provides direction for future research. The following workshops were held in the July 1, 2018, to June 30, 2019, time span:

- Advanced Prototype Engineering Technology Symposium
- Advanced Technology for National Security Workshop
- Air, Missile, and Maritime Defense Technology Workshop
- Air Vehicle Survivability Workshop
- Anti-access/Area Denial Systems and Technology Workshop
- Cyber Endeavor
- Cyber Technology for National Security Workshop
- Defense Technology Seminar
- Graph Exploitation Symposium
- Homeland Protection Workshop Series
- Human Language Technology and Applications
- Human-Machine Collaboration for National Security Workshop
- Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
- Lincoln Laboratory Communications Conference
- Software Engineering Symposium
- Space Control Conference

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

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, 2018, and June 30, 2019, Lincoln Laboratory staff published 110 papers in proceedings from conferences, 87 articles in technical journals, 11 self-published E-prints of technical articles, and nine major technical reports available through the Defense Technical Information Center.

In a partnership with The MIT Press, Lincoln Laboratory established a book series to present its fundamental research. Authored by Lincoln Laboratory experts, often with contributions from colleagues in academia and industry, the volumes in the MIT Lincoln

Laboratory Series are intended as resources for researchers, engineers, and university educators and students. In August 2018, The MIT Press published the seventh book in the series, Jay R. Sklar's *Modern HF Signal Detection and Direction Finding*. This college textbook is a comprehensive reference that supports the application of detection, direction-finding, and signal-estimation methods to high-frequency (HF) communication systems.

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, seven collaborations were funded through the Advanced Concepts Committee, ranging from explorations of high-extinction optical switches and self-healing materials to the development of coupled oscillator-based analog computing 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 front-line experiences of the officers who are assigned to technical programs within the Laboratory. In 2018–2019, 55 military officers worked in various technical groups under fellowships. In addition, in summer 2019, 61 cadets and midshipmen from the US military academies are participating in an internship program at the Laboratory.

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 2018–2019, the Laboratory offered Introduction to Radar Systems, Networking and Communications, and a one-day course, ISR Systems and Technology.

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. In 2018–2019, courses in cyber security, ballistic missile defense, and space technology were offered.

Lincoln Laboratory technical staff led activities offered during MIT's 2019 Independent Activities Period (IAP). During the semester intersession, Laboratory staff members developed and led the following non-credit offerings: Build a Small Radar System, Free-Space Optical Communication, Hands-on Holography, Introduction to Autosec, Mathematics of Big Data and Machine Learning, RACECAR: Rapid Autonomous

Complex-Environment Competing Ackermann-steering Robot, Software Radio, and Using Drones for Research: Data Processing and Legal Issues. The Build a Radar activity is also offered as a class in the MIT Short Programs.

2018 R&D 100 Awards

Ten Lincoln Laboratory innovations earned R&D 100 Awards in 2018. 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 Magazine* editors and outside experts to be the most significant new developments of the year.

Three of the award winners are new algorithms or software platforms that help experts make decisions and gain insight from data quickly.

- Lincoln Laboratory worked with the DHS Science and Technology Directorate to develop a modernized hurricane decision support platform. The resulting web-based HURREVAC-Extended (HVX) platform is helping emergency managers make timely, accurate evacuation decisions. The platform integrates advanced analytics, such as a storm surge explorer tool and evacuation zone–based impact assessments, simulations, timelines, and reports, onto a single user interface. Used experimentally during the Harvey, Irma, and Maria crises, HVX became fully operational in the 2018 hurricane season.
- In collaboration with the Office of Naval Research, Lincoln Laboratory developed the Collaborative Optimization via Apprenticeship Scheduling (COVAS) algorithm to perform real-time ship defense for the US Navy. The algorithm uses artificial intelligence techniques to first learn from naval officers as they demonstrate ship-defense tactics. From these demonstrations, COVAS reasons how to best allocate defenses and then provides real-time solutions for problems too large for a single human expert to manage. COVAS's architecture has been applied to other challenging resource-management issues such as hospital logistics and triaging.
- The FastID and TachysSTR algorithms are the fastest known methods for comparing DNA samples against large data sets of reference profiles. The algorithms encode single nucleotide polymorphisms (SNPs) and short tandem repeats (STRs) in a DNA sample to bits (for example, by assigning each major SNP allele a 0 value and a minor SNP allele a 1 value) and then use computer hardware instructions to compare the sample with reference profiles. While current techniques require large computing systems and can take hours, the FastID and TachysSTR algorithms can compare a sample profile against 20 million reference profiles in just over five seconds on a laptop.

Three new processes or techniques to advance technology or to protect it earned awards.

- Lincoln Laboratory developed a breakthrough process for fabricating superconducting electronics. Superconducting electronics rely on precisely engineered microscopic switches called Josephson junctions. The process set the world record for both the number and density of these junctions in superconducting digital circuits. The circuits produced through this process are faster and more energy efficient than semiconductor-based technologies.

- The multi-rate differential phase shift keying (DPSK) technique developed at Lincoln Laboratory enables efficient free-space laser communications over a wide range of data rates by using a single, easy-to-implement transmitter and receiver design. The multi-rate DPSK will be the optical communications technology base for NASA's Laser Communications Relay Demonstration, scheduled for launch later in 2019.
- The Laboratory invented a new technique called dynamic flow isolation (DFI) to improve network security. The technique uses software-defined networking to minimize unnecessary connectivity between assets on enterprise networks. This connectivity is what cyber attackers often rely on to expand a small foothold to a full-scale attack. DFI enables and enforces policies that allow only minimal network-level connectivity for operations, thwarting an attacker's attempts to move laterally.

Four devices or systems that are providing new or improved capabilities were recognized.

- An optical fiber device called a photonic lantern provides the ability to scale the power in, shape, and steer a laser beam in the presence of optical turbulence and disturbances. These capabilities can benefit a wide range of laser applications. For example, scaling a beam's power improves the productivity of laser manufacturing processes by delivering energy to the target with higher efficiency. Beam shaping improves the laser's transmission through scattering media (e.g., biological tissue) for applications in endoscopes and medical imaging.
- With funding from the DHS Science and Technology Directorate, Lincoln Laboratory developed a wide-area video surveillance system called the Immersive Imaging System. It provides very-high-resolution images and 360-degree coverage from a single vantage point, monitoring an area equivalent to that of seven football fields. Unlike other surveillance cameras that reduce their field of view when zooming in on a target, this imaging system provides operators a high-resolution zoomed image while maintaining a big-picture view.
- In collaboration with the US Army Communications-Electronics Research, Development, and Engineering Center and Wyle Labs, Lincoln Laboratory built the Intelligent Power Distribution device. This device forms the power distribution backbone of tactical microgrids and allows soldiers to interactively monitor power systems and coordinate energy resources and loads.
- Lincoln Laboratory and MIT's Laboratory for Information and Decisions Systems teamed up to create Peregrine: Network Navigation. This novel system enables navigation in places where GPS is unavailable, particularly indoors. The system is powered by cooperative algorithms and for the first time demonstrates scalable, highly accurate, and efficient localization networks based on small, low-cost, and easily deployable devices.

Notable 2018 Technology Transfer Activities

During the past year, Lincoln Laboratory transitioned several technologies to industry or to government sponsors, as described below.

Communication Systems

The design for a compact off-axis telescope was transitioned to industry in support of laser communication terminals being developed for NASA's Orion Crew Exploration Vehicle and the International Space Station.

Cyber Security and Information Sciences

Software developed in a project called the Scalable Cyber Analytic Processing Environment (SCAPE) was released as open source. The SCAPE software allows researchers to explore multisource cyber defense data sets.

As requested by the US Navy, the Laboratory transferred a security cyber module prototype to the Space and Naval Warfare Systems Command, Johns Hopkins University's Applied Physics Laboratory, and Thales Group, an aerospace company. The prototype will be used for securing communication of future ground unmanned systems such as explosive-ordnance disposal robots.

At the request of the US Air Force, the Laboratory transferred its high-assurance cryptographic and key management technology, called SHAMROCK, to GE Aviation in support of the Agile Resilient Embedded Systems program.

In support of the US Army's High Performance Computing Modernization Program, the Cyber Adversarial Scenario Modeling and Artificial Intelligence Decision Engine prototype is being transitioned to provide automated network segmentation in response to detected cyber threats.

Lincoln Laboratory transitioned 10 state-of-the-art open-source analytics and tools to the Defense Advanced Research Projects Agency's Memex Open Catalog:

- MIT Information Extraction Toolkit
- Lincoln Laboratory Text Classification tool
- Topic classifier
- Speech processing tool for speaker, language, and gender recognition
- VizLinc, a visual analytics platform
- TweetE, a tool for processing Twitter postings
- Lincoln Laboratory Author Classification tool
- String processing software
- Tool for efficient searching via an index of locality-sensitive hash tags
- GraphQuBE, a tool that enables graph query by example

Supercomputing

The BigDAWG polystore system, created in collaboration with MIT and other universities, was released as an open-source product. Polystore systems have spurred a new field of database research, and BigDAWG as a software package is currently being evaluated by a number of organizations.

The GraphBLAS open standard, created by a consortium led by the research team at the Lincoln Laboratory Supercomputing Center to solve large graph problems, was officially released to the community.

The Julia programming language, co-founded by the Lincoln Laboratory Supercomputing Center and used by millions of programmers worldwide, was successfully transitioned to a startup company.

Air Traffic Control

Today, air traffic controllers in Houston, Miami, San Juan, and New York, as well as at the National Air Traffic Control System Command Center near Washington, DC, are using radar-like images estimated by Lincoln Laboratory's Offshore Precipitation Capability to help plan safe, efficient routes through airspace over oceanic regions outside the coverage of land-based radar systems.

Air, Missile, and Maritime Defense Technology

Lincoln Laboratory prototyped and demonstrated automation algorithms and associated operator displays in support of wide-area passive acoustic undersea surveillance. The intellectual property was transitioned to PMS-485 and is undergoing further development to be inserted into the Integrated Undersea Surveillance System common software suite. The Laboratory is actively supporting the transition agent in assessing algorithm performance, developing concepts of operations, and adjusting displays and algorithms in response to operator feedback.

A 256 × 256–pixel digital focal plane array (DFPA) design was transitioned to the Missile Defense Agency's Aegis Ballistic Missile Defense Program Office and Raytheon Vision Systems. The DFPA technology, which is a hardware upgrade for the SM-3 IB Modernization program, delivers greater sensitivity and dynamic range.

Space Systems and Technology

The Transiting Exoplanet Survey Satellite NASA Explorer Mission completed the first year of its prime mission in July. Lincoln Laboratory, in partnership with MIT's Kavli Institute for Astrophysics and Space Research, developed the TESS instrument, which includes four wide-field cameras with deep depletion charge coupled devices for enhanced sensitivity to planetary transit events around cooler stars. Since its launch in April 2018, TESS has discovered 21 new planets and 850 more potential worlds that have yet to be confirmed, all residing within a few dozen light years of the sun and our own solar system. TESS data are made publicly available within a few months of observations. As of June 2019, scientists from around the world have referenced the TESS mission in 84 peer-reviewed papers in fields ranging from exoplanet characterization to stellar physics and solar system science.

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 makeup of the Lincoln Laboratory staff by academic degree and academic discipline is shown in Figure 12 (as of April 2019). The total number of Laboratory employees is 3,875, with 1,772 professional technical staff, 1,068 support staff (including technical support personnel), and 461 subcontractors.

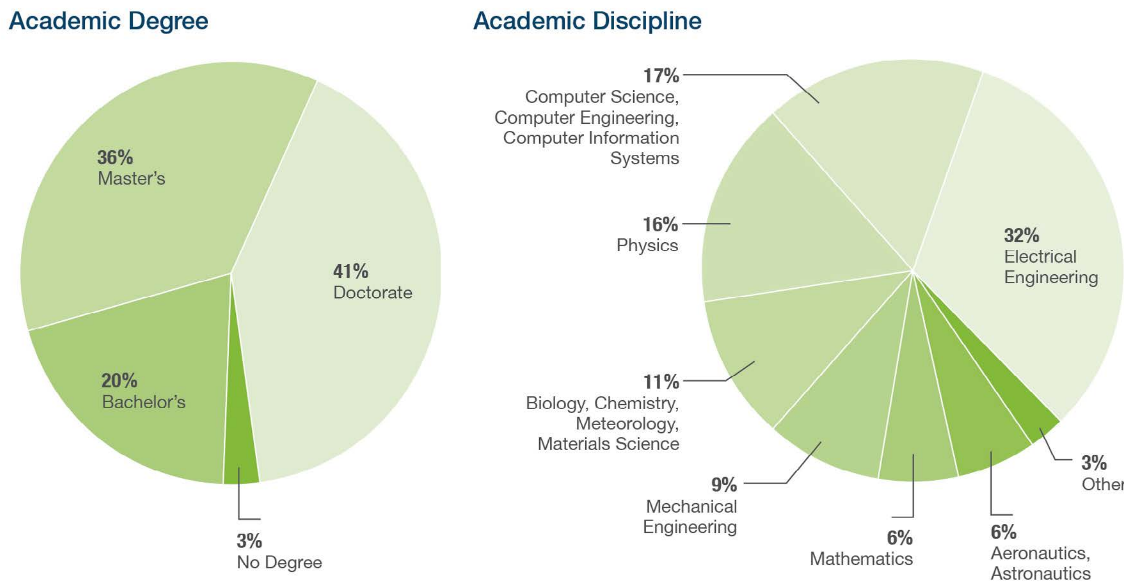

Figure 12. Composition of the Lincoln Laboratory professional technical staff by academic degree (left) and academic discipline (right).

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.

Christine A. Wang was elected to the National Academy of Engineering in recognition of her distinguished contributions to engineering in the field of epitaxial crystal growth of III-V compound semiconductors and design of organometallic vapor-phase epitaxy reactors.

The 2018 MIT Lincoln Laboratory Technical Excellence Awards were presented to James K. Kuchar for sustained leadership and technical contributions in the development, integration, and testing of air traffic control and other transportation-related systems, as well as for innovative work in collision avoidance and risk assessment, and to Michele A. Schuman for exceptional leadership and a wide range of contributions to the field of radio frequency satellite communications, including system design and analysis, algorithm development, and system integration and testing.

The 2018 MIT Lincoln Laboratory Early Career Technical Achievement Awards were presented to Danelle C. Shah for her contributions to research and development of data analytics, machine learning, and artificial intelligence techniques and to Thomas

Sebastian for his innovative new concepts in aerospace systems, including micro unmanned aerial vehicles, thermal management of lasers, and biodefense sensors.

The 2018 MIT Lincoln Laboratory Best Paper Award was presented to Mark S. Veillette, Eric P. Hassey, Christopher J. Mattioli, Haig Iskenderian, and Patrick M. Lamey for "Creating Synthetic Radar Imagery Using Convolutional Neural Networks," published in the *Journal of Atmospheric and Oceanic Technology*.

The 2018 MIT Lincoln Laboratory Best Invention Award was presented to Darrell O. Ricke, Tara L. Boettcher, Philip D. Fremont-Smith, Adam M. Michaleas, Martha S. Petrovick, Eric D. Schwoebel, and James G. Watkins for invention of the Advanced DNA Forensics System.

The 2019 MIT Lincoln Laboratory Administrative and Support Excellence Awards were presented to Marie L. Dow (administrative staff category) for dedication to improving visual communications across the Laboratory, Jason B. Williams (administrative staff category) for continually elevating the design of visual materials for Lincoln Laboratory staff and events, John F. Orthmann (support staff category) for his work as a machinist providing technical support to multiple projects of significance at the Laboratory, and Terri L. Welch (support staff category) for outstanding management of her group's administrative duties and for contributions to the Quantum Communications Workshops.

A 2019 MIT Excellence Award in the Advancing Inclusion and Global Perspectives category was presented to William H. Kindred for sustained efforts to improve diversity and promote inclusiveness at Lincoln Laboratory. In addition, an Excellence Award in the Outstanding Contributor category was presented to Christopher Budny for exceptional support of his group's development of technology that enhances crisis management capabilities.

Robert D. Solis, head of the Information Services Department, was chosen by the Boston CIO Leadership Association as the recipient of the 2019 Boston CIO of the Year ORBIE Award in the nonprofit category. ORBIE Awards recognize chief information officers who have shown outstanding leadership and whose technology initiatives have had a significant, lasting impact on their organizations.

William J. Blackwell was named a 2019 IEEE Fellow for his contributions to atmospheric remote sensing algorithms and instrumentation.

Gregory D. Berthiaume received a 2019 NASA Exceptional Public Service Medal. This NASA Agency Honor Award is presented to non-government individuals who demonstrate sustained outstanding contributions to a NASA project or program. Berthiaume was recognized for his leadership of Lincoln Laboratory's R&D for the TESS program.

James E. Evans was awarded the 2019 Aviation & Space Operations Weather Prize for lifetime achievement in aviation weather hazard detection, warning, and mitigation by the Friends and Partners in Aviation Weather group of the National Business Aviation Association.

Jessica Zhu and Casey Evans, military fellows at Lincoln Laboratory, were selected by the Aviation Week Network as two of its 2019 20 Twenties, an annual recognition of 20 engineers in their 20s identified by the network, in partnership with the American Institute of Aeronautics and Astronautics (AIAA), as making significant contributions to aerospace-related research and engineering.

Meredith K. Drennan, Anu K. Myne, Alexander M. Stolyarov, and Mark S. Veillette were named by the Armed Forces Communications and Electronics Association International to its 2019 40 Under 40 list, a recognition 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.

The American Institute of Aeronautics and Astronautics presented the 2019 AIAA Dr. John C. Ruth Digital Avionics Award to the design team for the Advanced Collision Avoidance System X (ACAS X): James K. Kuchar and Wesley Olson, Lincoln Laboratory technical staff members; Mykel J. Kochenderfer, Lincoln Laboratory consultant; Joshua Silbermann of the Applied Physics Laboratory; and Neal Suchy of the FAA. The team was recognized for applying machine learning technology, statistical risk assessment, and flight test campaigns to develop ACAS X.

David Culbertson, manager of the Laboratory's Flight Test Facility, was named a fellow of the Royal Aeronautical Society in recognition of his extensive experience and contributions to the profession of aeronautics.

In 2019, Cultivating Lincoln Achievement and Success Awards were presented to Daryl A. Easler (Leadership Award for Advancing Organizational Culture), Samantha Jones (Peer Award for Cultural Impact), and Hsiao-hua K. Burke (Emeritus Award for Advancing Organizational Culture).

Professional Development

Lincoln Laboratory's commitment to the professional development of its staff is seen in the diversity of opportunities presented through the Human Resources Department's educational program. The Human Resources Department coordinates programs in graduate education, technical education, professional leadership development, and computer/software training.

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. During the past year, 20 staff members were enrolled in the Lincoln Scholars 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, which 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. These courses, in areas such as computer networks, cryptography, and software engineering, can be taken independently or as part of a Boston University certificate or master's degree program.

The technical education program offers both short-term and semester-length courses taught by Lincoln Laboratory technical staff or by outside experts. The 2018–2019 schedule of 15 courses included offerings in applied statistical signal analysis, building a radar, electromagnetics and antenna technology, laser physics technology, light detection and imaging, machine learning through the Lincoln Laboratory Supercomputing Center, optical engineering, and modern graph analysis.

The professional and leadership development program again sponsored courses in leadership techniques, project management, preparing presentations, and scientific and technical writing. Computer training in common software applications (Word, PowerPoint, Excel, Illustrator, Photoshop, etc.), programming, and technical software (MATLAB, Simulink, VMware, etc.) is offered on-site throughout the year. A new offering this year was a tutorial on non-parametric Bayesian methods.

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 typically held twice a month and are chosen to reflect current and leading-edge trends in today's technology.

Highlights of the 2018–2019 seminar program include the following:

- "Imaging Black Holes with the Event Horizon Telescope," Vincent Fish, MIT Haystack Observatory
- "A Vision for Tactile Dexterity and Reactive Manipulation," Professor Alberto Rodriguez, MIT Department of Mechanical Engineering
- "AI Neuroscience: Can We Understand the Neural Networks We Train?" Jason Yosinski, Uber
- "Tools for Analyzing and Controlling Complex Biological Systems," Professor Ed Boyden, MIT Media Laboratory
- "Solar Geoengineering: Taking the Edge off Climate Change?" Professor Frank Keutscho, Harvard University
- "Looking for Planets Outside Our Solar System with Superconducting Photon Detectors," Professor Ben Mazin, University of California, Santa Barbara
- "Architectured Metamaterials: Harvesting Light, Tunable Sound Switches and Beyond," Professor Nicholas Fan, MIT Department of Mechanical Engineering
- "From Gene Editing to Automated Machine Learning: Using AI to Tune Complex Systems," Nicolo Fusi, Microsoft Research

Artificial Intelligence Seminar Series

Because of the emerging importance of artificial intelligence to applications across multiple fields relevant to the Laboratory's mission areas, Lincoln Laboratory instituted a series of seminars on facets of AI technology. In these seminars, speakers from the Laboratory, academia, and industry discuss strides being made in AI.

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 from September to June, major projects are highlighted. Every week, Laboratory employees can attend multiple division seminars in which staff present the latest results of ongoing programs. These seminars allow staff from across the Laboratory to learn about the work in which colleagues are engaged 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 leverages and 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 are contributing 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 (LLHLN), the Pan Asian Laboratory Staff Network (PALS), and the Lincoln Laboratory Veterans' Network.

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 has hired 18 GEM Fellows as interns for summer 2019.

The following highlighted events from July 2018 to June 2019 contributed to an inclusive environment.

Laboratory staff celebrated the end of Hispanic Heritage Month with a discussion led by a panel of Hispanic and Latino speakers. The panel, put together by LLHLN, consisted of four distinguished speakers who specialize in the fields of cyber defense, medicine and infectious diseases, artificial intelligence, and data analytics and big data visualization. The panel revolved around celebrating Hispanic and Latino contributions to science, technology, engineering, and mathematics (STEM). The panelists spoke about topics including creating a more diverse STEM workforce and addressing the STEM pipeline to maintain a competitive advantage in technology and innovation in the United States.

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

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

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

Lincoln Laboratory held its second Cultivating Lincoln Achievement and Success symposium with the theme of developing leadership at every professional level. The symposium, which lasted five days, hosted multiple Laboratory and external speakers and a workshop for staff to explore the meaning of leadership and receive training and advice on enhancing leadership skills.

On March 13, 2019, LEAN hosted the sixth annual Martin Luther King Jr. Luncheon. The event marked the conclusion of LEAN's month-long celebration of Black History Month, which featured technical presentations from staff members and seminars involving a variety of guest speakers. The luncheon's keynote speaker was Robbin Chapman, associate dean of diversity, inclusion, and belonging at the Harvard Kennedy School. The theme of the event, "Lead, Inspire, Excel: A Call to Service," was designed to call upon every person at the Laboratory to inspire the community to pursue excellence. To express this theme, LEAN invited Chapman to speak about King's legacy and leadership style, their impact upon her life, and strategies to make the Laboratory a more inclusive environment.

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.

Information Services Upgrades

Efficiencies were gained by implementing virtual smart cards for users to gain access to their operating systems and to the virtual provider network, streamlining the authentication process for employees. Internal web application log-in processes were also simplified through an enterprise-wide, single-sign-on architecture for internal web applications.

Managing documents became easier through file synchronization and data backup services. Employees are now synchronizing documents on their devices so that updates made to a document on their laptops, for example, are reflected on their mobile devices, tablets, and desktop computers. They are now also electing to have the data from their devices backed up either continuously or at times convenient to them.

Enhancements to mobile services enabled easier web-conferencing options for staff through FaceTime and iMessage, mobile device access through Touch ID, and mobile admission to the Laboratory's intranet via a secure browser. Further mobile efficiency enhancements included the use of voice-activated and voice-directed services such as Siri and voice-to-text dictation capabilities.

The Laboratory's Secret Internet Protocol Router Network (SIPRNet) infrastructure was re-architected to create centralized hubs from which staff can access the network, resulting in improved services and streamlined management capabilities. Dedicated SIPRNet locations facilitate specific program requirements.

The Laboratory's external website was redesigned with modern functionalities, a restructured architecture, and a new look and feel to attract potential new hires, research collaborators, business partners, and students and teachers seeking educational outreach programs.

Business Transformation Office

The Lincoln Laboratory Business Transformation Office (BTO) was established in 2018 to help address the challenges that result from the increasing complexity of modern business processes. The office's mission is to oversee a strategic effort to evaluate internal business processes and systems, improve operational efficiencies, provide cost-saving opportunities, and better enable the work of Laboratory personnel. Collaborating closely with representatives from across the Laboratory's divisions and departments, BTO is guiding the implementation of several key initiatives. For example:

- The Purchasing Card (P-Card) Improvement Project streamlines the end-to-end P-Card process to allow for quick purchasing, reduce administrative complexities, and improve the timeliness and transparency of all data involved in P-Card transactions.

- The Enterprise Resource Planning Modernization Project is a major effort to replace the Laboratory's business data systems that will soon become obsolete with a new master data architecture. This initiative builds on the Laboratory's transition to SAP HANA, a modern, in-memory, cloud-based application-development platform.

Ongoing Business Improvements

The Efficiency Improvement Team, established as an outcome of a widespread efficiency study in 2017, continuously evaluates the Laboratory's operational processes and recommends ways to improve efficiency. In 2018, the team created an efficiency improvement website through which the Laboratory community provides ideas on ways to improve processes and through which the team shares the status of projects. The team currently has more than 40 projects under way related to cost reductions, time savings, process improvements, and communication improvements.

The Laboratory completed a project to improve the quality of procurement tools to reduce staff time and avoid acquisition delays. In addition to streamlining P-Card processes, the Laboratory developed procurement training modules and co-located Contracting Services Department staff to assist business managers and technical staff members with major procurements and other agreements.

The Laboratory replaced an inefficient paper-based reporting process that burdened technical staff with 7,000 paper forms annually. The team developed a new electronic process (the Special Programs Reporting Tool) that improves the Security Services Department's ability to approve, track, and generate foreign travel and foreign contact reporting.

Training requirements were streamlined by creating computer-based training modules. For example, the Laboratory made counterintelligence awareness training available for end users to view online, reducing months-long delays in scheduling in-person training.

Facility Improvements

The Facility Services Department manages the operations and maintenance of approximately 2 million square feet of Laboratory and general-use facilities. Core services include operations and maintenance of all facilities, renovation and construction projects, and custodial, mail, food, hazardous materials, and parking services.

In fiscal year 2019, the department executed more than $30 million of project work. One of the most critical projects was the completion of a new laboratory in Building L. This laboratory space, which encompasses approximately 8,000 square feet and includes a class-10,000 clean room, provides vital capabilities for designing, fabricating, assembling, and testing integrated systems for a variety of sponsored research programs.

The department's most visible project was the construction of an 1,800-square-foot addition adjacent to the main auditorium. This addition provides much needed space for conference-related functions that were previously held in a rather narrow corridor-type space. A rooftop patio was also built to give conference attendees the option of an outdoor venue for gatherings.

The department also completed the second phase of a renovation of Annex VI to house the Defense Fabric Discovery Center, a state-of-the-art, end-to-end prototyping facility that enables functional fiber and fabric design, fiber device drawing, textile production, and integration of electrical devices within fabrics.

Security Services

The Security Services Department led the effort that earned Lincoln Laboratory its 13th consecutive "superior" security rating from the US Air Force. This rating was based on 31 government security-related audits conducted by various government agencies. The department also completed multiple sponsor inspections supporting special programs.

The department strengthened emergency preparedness by increasing training and education throughout the Laboratory. This training included seminars and exercises on active threat response, building evacuations, suspicious packages, force protection condition changes, emergency communications, and workplace violence.

A continuity of operations plan was completed for the Laboratory's service departments. A major cyber breach tabletop exercise conducted in fall 2018 involved senior Laboratory leadership. This exercise simulated a breach of the Laboratory's network and covered the required actions to be taken and the potential impacts of such a breach.

The department received outstanding feedback on its security education program from senior leaders of the Office of the Secretary of the Air Force, the Defense Counterintelligence and Security Agency, and the Defense Advanced Research Projects Agency.

The department organized, planned, and executed the annual FFRDC/UARC (federally funded research and development center/university-affiliated research center) Security Leadership Conference, during which security professionals exchanged information, discussed metrics, and shared best practices. SSD personnel provided security services for several high-profile, large-scale Laboratory-hosted conferences and sponsor-requested technical reviews, , accommodating more than 8,200 visitors this year.

The Laboratory's Secure Protocol Network was transitioned to the Risk Management Framework, reducing the number of information security plans from 19 to two and the approximate number of users from 1,200 to 400. In addition, the classified protected distribution system was upgraded to meet government regulations and to allow consolidation of the network from multiple locations into six main "centralized" operating hubs. This collaborative effort involved more than 50 team members from different divisions and departments. These two substantial security, usability, and compliance improvements have contributed significantly to the department's preparation for a future Command Cyber Readiness Inspection.

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, a hallmark of an MIT education, and leverages the expertise and enthusiasm of MIT faculty, students, and researchers and Lincoln Laboratory staff to broaden research and educational partnerships.

A key component of Beaver Works is the capstone project, which is typically associated with a two-semester design-and-build class that challenges students to develop an engineering solution to a real-world problem. In a unique project this year, students in the 2.013 Engineering Systems Design and 2.014 Engineering Systems Development undergraduate courses, offered by the Department of Mechanical Engineering in collaboration with Lincoln Laboratory, designed and built a marine platform that will carry a sensor for measuring the dynamics of the ionosphere, the ionized layer of the atmosphere that extends 50 to 600 miles above Earth's surface. The platform, which floats on the water's surface but carries the payload submerged underwater, was developed to address the lack of ionospheric data for regions above the ocean. The students have tested the platform in the Charles River, and plans are to have the system tested in actual ocean conditions off the Kwajalein Atoll in the Marshall Islands, where Lincoln Laboratory maintains field offices at the US Army's Reagan Test Site.

On May 24, 2019, Beaver Works hosted a ribbon cutting for a new facility housed in Building 31. Known as AeroAstro Beaver Works, the new 4,000-square-foot maker space will support capstone engineering projects in aeronautics and astronautics, including the development of autonomous air vehicles and small satellite designs.

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 2018–2019, 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.

Lincoln Laboratory collaborates with the Worcester Polytechnic Institute (WPI) on its Major Qualifying Project (MQP) program, which requires a student to complete an undergraduate project equivalent to a senior thesis. Students participating in the program spend nine weeks during the fall term working on their projects full time at Lincoln Laboratory. Their work at the Laboratory culminates in a thesis-like document detailing their research and a presentation before WPI faculty and the Laboratory community. In fall 2019, eight students will begin their MQP research at Lincoln Laboratory.

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 has hired 274 undergraduates and graduate students from 85 different colleges and universities to work as interns during summer 2019.

Throughout the year, cooperative education students from area colleges such as Northeastern University and Wentworth Institute work at the Laboratory. Between 40 and 95 cooperative education 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 program of STEM activities.

Science on Saturday, the Laboratory's first STEM program, drew approximately 1,500 K–12 students, parents, and teachers to science demonstrations given by technical staff members during AY2019. Offerings included presentations on computers, robotics, and using light for science. Student volunteers participated in several demonstrations.

Figure 13. On April 13, 2019, children drove robots around the Cambridge Public Library during the annual Cambridge Science Festival. The festival is designed to showcase science, technology, engineering, art, and math (STEAM) for the general public and highlight the impact of STEAM on our everyday lives. Participants in the 2018 Robotics Outreach at Lincoln Laboratory program built the robots and volunteered to teach the children how to use them.

The Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) summer program offers 24 high school students from across the country a two-week, project-based course on radar fundamentals. The program includes instructional sessions on the basics of radar systems and radar imaging, workshops for building radar systems that can perform range-Doppler imaging, and opportunities to demonstrate the performance of the radars built during the workshops. The 2019 LLRISE program will begin in July. A high school teacher from Monroe, LA, will participate in the program and assess the possibility of incorporating the workshop into her school's science curricula.

Beaver Works introduced the MIT Beaver Works Summer Institute (BWSI) in 2016. The 2016 summer STEM program taught 46 talented rising high school seniors how to program miniature racecars to autonomously navigate a complex racetrack. In 2017, BWSI added supplementary online lessons and new courses on autonomous air vehicles and cognitive assistants, and the program grew to 98 students. The 2018 program was expanded to eight courses, each with its own online prerequisite tutorial, and 198 students who hailed from 110 schools across the country. The 2019 program will host 240 high school students and include 10 course topics ranging from autonomous systems and assistive technologies to disaster recovery and prevention. In addition, BWSI will pilot an autonomous miniature racecar course for 25 middle school students.

During the past year, one high school graduate interned at the Laboratory and another interned at the Beaver Works Center as part of a program managed by the Boston-Lexington chapter of the Armed Forces Communications and Electronics Association International. Intern Derek Ng was mentored by Laboratory technical staff in the Human Health and Performance Systems Group, and Jared Boyer was mentored by Kerri Cahoy, associate professor of aeronautics and astronautics at MIT.

Other returning educational programs included Lincoln Laboratory Cipher, a weeklong course teaching high school students cryptography; CyberPatriot, a national high school cyber defense competition; and Robotics Outreach at Lincoln Laboratory, a program of robotics activities designed to prepare teams of K–12 students to compete in age-appropriate events sponsored by FIRST (For Inspiration and Recognition of Science and Technology).

Community Service

LLCO helps increase Laboratory employees' awareness of events sponsored by charitable organizations. In 2018, the Lincoln Laboratory Ride to End Alzheimer's bicycling team and the Laboratory's team in the Walk to End Alzheimer's together raised more than $55,000 for research into the disease. Laboratory participants in the American Heart Association's Heart Walk raised $6,000 in 2018. Laboratory staff also walked and cycled for the CancerCare walk and the Pan-Mass Challenge.

Support Our Troops, one of LLCO's first community giving programs, is an ongoing campaign to collect and mail food, toiletries, and books to US soldiers overseas. In 2018–2019, Lincoln Laboratory sent 80 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 also donated hundreds of items to Toys for Tots, the Cradles to Crayons drive for children's essentials, and a campaign to collect winter clothing for Puerto Ricans who relocated to the Boston area after losing their homes to Hurricane Maria.

Summary

Lincoln Laboratory's portfolio of technology R&D programs continues to grow and is strategically balanced with programs that engage in large-scale system development, rapid prototyping of new systems, and 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 professional development program support the Laboratory's ability 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. Also, many employees are engaged in activities, such as walks or volunteer programs, that support charitable causes.

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

Eric D. Evans
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