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. Lincoln Laboratory's mission is to develop technology in support of national security. The majority of the research and development carried out at the Laboratory is in the areas of sensors, integrated sensing, information extraction (signal processing and embedded computing), decision support, and communications, all supported by a broad research base in advanced electronics. Projects focus on developing and prototyping new technologies and capabilities to meet DoD needs that cannot be met as effectively by existing government or contractor resources.

Lincoln Laboratory maintains its relevancy by continually leveraging its capabilities to meet new challenges presented by the evolving needs of the nation and its military forces. Over the past year, the Laboratory has been growing programs to develop innovative solutions to the nation's energy demands and improve the security and resiliency of the nation's energy infrastructure; to develop acoustic and nonacoustic sensors, autonomous vehicles, and communication systems for undersea uses; and to research and then develop advanced technologies that can enhance disaster response operations. Cyber security, critical to protecting the hugely expanding volume and variety of digital data, continues to be an important focus for the Laboratory. Demand for both tactical systems and intelligence, surveillance, and reconnaissance (ISR) systems remains strong. The Laboratory is applying its competencies in sensors, advanced electronics, and microfluidics to advance novel biomedical technologies and systems to enhance soldier fitness and resilience to injury. To address the importance of ensuring the reliability and mission success of the nation's space assets, researchers in the Space Systems and Technology Division have been prototyping advanced sensors and systems.

For the fiscal year July 1, 2015, to June 30, 2016, Lincoln Laboratory received approximately $955.9 million in total funding that supported the efforts of approximately 1,850 professional technical staff and 1,600 technical and administrative support personnel; outside procurement exceeded $522.5 million. While most of the research is sponsored by the DoD, funding is also received from the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Department of Homeland Security (DHS), 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.

Laboratory Operations

Lincoln Laboratory operations are marked by the following fundamental attributes: high-caliber staff, streamlined organizational structure, high-quality infrastructure, well-defined strategic focus, and strong alignment with the MIT campus.

Organization

Lincoln Laboratory's success has been built on the core values of technical excellence and integrity, which are exemplified by the Laboratory's exceptional staff. The three-tiered organizational structure—director's office, divisions and departments, and groups—encourages interaction between staff and line management (Figure 1). Sponsors' interest in conducting research and development of more complex, integrated systems has raised the level of collaboration between divisions. In addition, service departments, as providers of critical administrative and infrastructure support, and the Safety and Mission Assurance and Program Support Office, as a primary advisor, enable cross-divisional research teams to coordinate and manage the technical and programmatic challenges of large-scale developments.

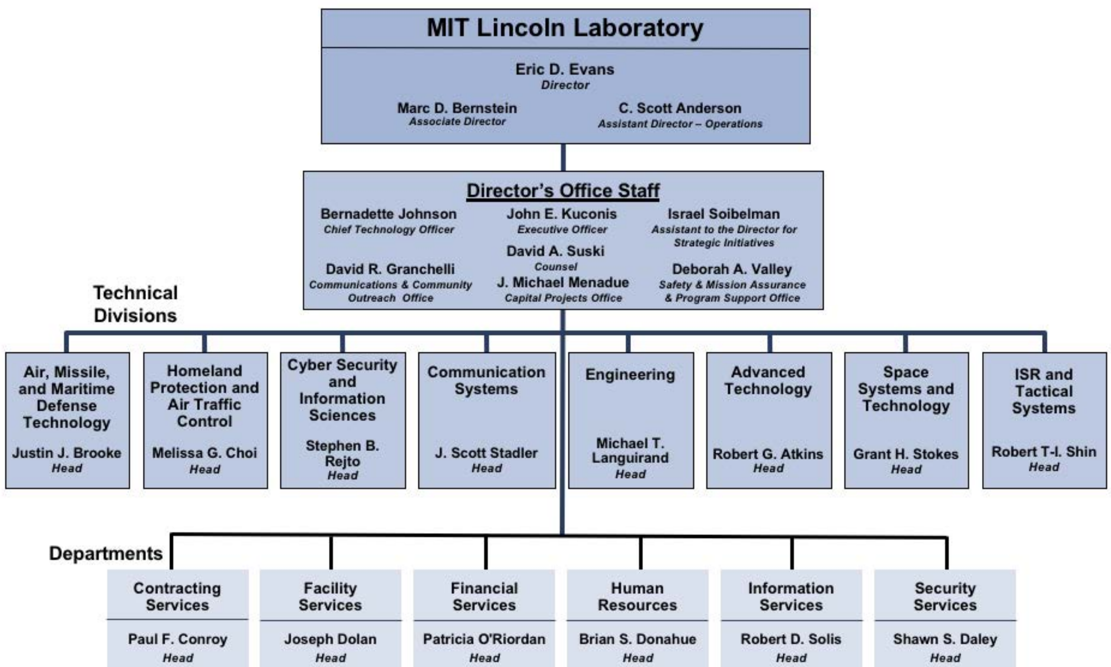

Figure 1. Lincoln Laboratory's organizational structure as of July 1, 2016.

Leadership Changes

Advanced Technology Division

Mark A. Gouker was named the assistant head of the Advanced Technology Division. Prior to this appointment, he served as the leader of the division's Quantum Information and Integrated Nanosystems Group.

Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division

Marc N. Viera was appointed assistant head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division. Formerly, he was the leader of the division's Advanced Capabilities and Systems Group.

Information Services Department

Robert D. Solis was named chief information officer (CIO) and head of the Information Services Department. He comes to Lincoln Laboratory from the University of Massachusetts System, where he served as vice president and CIO, with responsibility for information services for the system's four campuses and medical school.

Staff

Key to maintaining excellence at Lincoln Laboratory is its technical 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 degree and academic discipline is shown in Figure 2. The total number of Laboratory employees is 3,988, with 1,863 professional technical staff, 1,613 support staff (including technical support personnel), and 512 subcontractors.

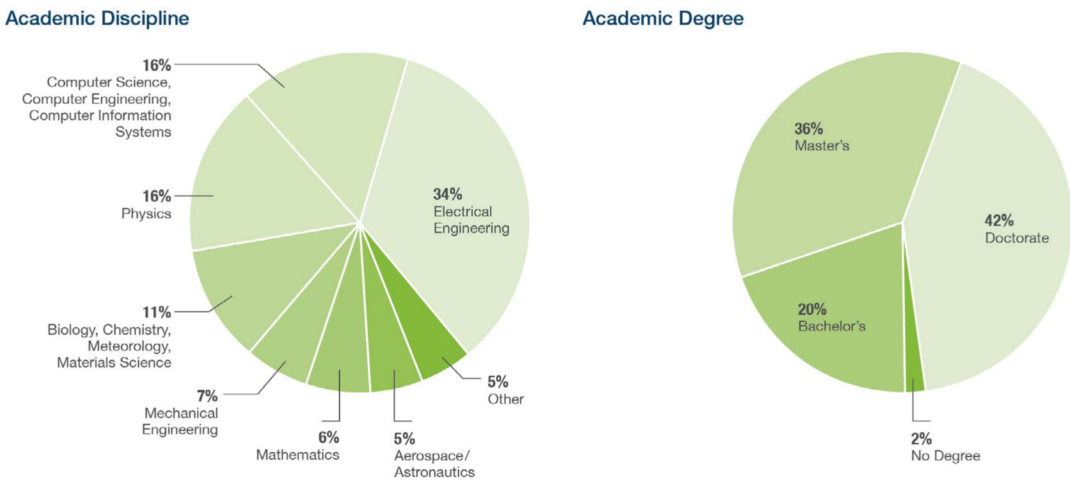

Figure 2. Composition of the Lincoln Laboratory professional technical staff by academic discipline (left) and academic degree (right).

Recognition

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

- Grant H. Stokes was elected to the National Academy of Engineering for "innovations in systems for space situational awareness and the discovery of near-Earth asteroids." Election to the National Academy of Engineering is among the highest professional honors accorded to an engineer.
- Dimitris G. Manolakis was named a fellow of the Institute of Electrical and Electronics Engineers (IEEE) for "contributions to signal processing education, algorithms for adaptive filtering, and hyperspectral imaging."
- Jillian M. James and Sophia Yaboukov were selected by Aviation Week Network as two of its 20 Twenties, an annual recognition of 20 engineers in their 20s whom the network, in partnership with the American Institute of Aeronautics

and Astronautics, has identified as having already made significant contributions to research and innovation in engineering, math, and science.

- 2015 MIT Lincoln Laboratory Technical Excellence Awards were presented to Daniel A. O'Connor, for his outstanding technical contributions to the field of ballistic missile defense (BMD), creativity in developing and demonstrating techniques for BMD, and leadership in initiating a major national effort in discrimination technology, and Joseph J. Scozzafava, for his leadership and creativity in developing laser communications technology, significant contributions to solving critical mechanical issues on major space payload and radar developments, and innovative work on mechanical rotary interface and electro-optical devices.
- 2015 MIT Lincoln Laboratory Early Career Technical Achievement Awards were presented to Bow-Nan Cheng, for his work in the development, understanding, and standardization of radio-to-router interface technology as a means of separating radio and router functionality and allowing greater interoperability among systems, and Francesca D. D'Arcangelo, for her systems analyses and architecture development in the areas of counter–unmanned aircraft systems, chemical and biological threat detection, air security, border monitoring, and maritime security.
- Timothy. M. Yarnall, David J. Geisler, Mark L. Stevens, Curt M. Schieler, Bryan S. Robinson, and Scott A. Hamilton won a 2015 MIT Lincoln Laboratory Best Paper Award for "Multi-aperture Digital Coherent Combining for Next-Generation Optical Communication Receivers." The paper was delivered at the IEEE International Conference on Space Optical Systems in October 2015.
- Danielle A. Braje and colleagues from MIT—Hannah A. Clevenson, Matthew E. Trusheim, Carson A. Teale, Tim Schröder, and Professor Dirk R. Englund—were presented with a 2015 MIT Lincoln Laboratory Best Paper Award for "Broadband Magnetometry and Temperature Sensing with a Light-Trapping Diamond Waveguide," which appeared in *Nature Physics Letters* in April 2015.
- Yaron Rachlin, Tina Shih, R. Hamilton Shepard, and Vinay N. Shah received a 2015 MIT Lincoln Laboratory Best Invention Award for the development of their "Rapid and Precise Optically Multiplexed Imaging" device, for which a technology disclosure was filed in March 2015 and a provisional patent application in May 2015.
- Donna E. Dickerson and Amy S. Grossman won 2016 MIT Lincoln Laboratory Administrative Excellence Awards, and Anne Marie Cappucci and Jon C. Barron received 2016 MIT Lincoln Laboratory Support Excellence Awards.
- 2016 MIT Excellence Awards were presented to the Lincoln Employees' African American Network (LEAN) Committee (Raoul O. Ouedraogo, David C. Freeman, Bakari N. Hassan, Crystal A. Jackson, Shakti K. Davis, Jason B. Williams, Brandon K. Matthews, and John O. Nwagbaraocha) in the Advancing Inclusion and Global Perspectives category; Dale A. Eastwood and Tamara H. Yu in the Bringing Out the Best category; R. Hamilton Shepard in the Innovative Solutions category; C. Chamee Cross, Dorothy S. Ryan, and Joshua W. Manore in

the Outstanding Contributor category; and Matthew Hubbell in the Sustaining MIT category.

- The Optical Multiple-Access Innovation Team, composed of scientists from NASA and Drs. Don M. Boroson and Bryan S. Robinson from Lincoln Laboratory, was recognized with a 2016 Robert H. Goddard Award for Exceptional Achievement in Engineering for its contributions to the development of an architecture for the Space Mobile Network, a NASA effort to provide users with a space-based communications and navigation experience that is closer to that of terrestrial mobile network users.
- The Solar Dynamics Observatory Team, which included David M. Weitz from Lincoln Laboratory, received a 2016 Robert H. Goddard Award for Exceptional Achievement in Science for "operating the Solar Dynamics Observatory, enabling the scientific results, mesmerizing the public, and reaching full mission success." This NASA observatory is a satellite on a five-year mission to collect data on the Sun and its atmosphere.

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, 24 staff members were enrolled in the Lincoln Scholars program.

The part-time graduate studies program helps staff members pursue master's degrees in fields that are relevant to Laboratory mission areas or business needs while continuing to work at the Laboratory full time. Staff members earn their degrees through universities' part-time programs, which may include online courses and/or classes offered outside traditional work hours. During the past year, 16 staff members were working on degrees under this program.

Lincoln Laboratory staff members are eligible to take courses in computer science offered on-site at Hanscom Air Force Base by Boston University (BU). These courses, which have included computer networking, cryptography, and software engineering offerings, can be taken independently or as part of a certificate or master's degree program through BU. Since 2012, 130 staff members have taken courses through BU's Master of Science in Computer Science program.

The technical education program offers both short-term and semester-length courses taught by Lincoln Laboratory technical staff or by outside experts. The 2015–2016 schedule included the following courses: Theory and Application of Estimation and Association, Text Mining and Analytics, Mathematics of Big Data, Big Data: Infrastructure and Applications, Introduction to Spacecraft Design and Engineering, Principles of Electro-optics, Human Factors Engineering, Information Theory: Gaussian Channels, Undersea Systems and Technology, Statistical Learning and Signal Processing: Part I, Optical Communications, Software Engineering, and Microelectronics Fabrication.

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.

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 such as the New Employee Network, and flexible work options are contributing to the hiring and retaining of a more diverse workforce.

In 2015, the Pan Asian Laboratory Staff Network became the eighth employee resource group established at the Laboratory. These groups (Lincoln Employees with Disabilities, LEAN, the Out Professional Employee Network, the Lincoln Laboratory New Employee Network, the Lincoln Laboratory Women's Network, the Lincoln Laboratory Hispanic and Latino Network, and the Lincoln Laboratory Veterans' Network) promote professional development activities, encourage volunteering at educational and charitable outreach programs, and provide support to all members of the Laboratory community.

On February 23, 2016, to commemorate Black History Month, LEAN hosted the Martin Luther King Jr. Luncheon at the Minuteman Commons Community Center on Hanscom Air Force Base. The keynote speaker was Aprille Ericsson, program manager for small business innovative research and small business technology transfer research at the NASA Goddard Space Flight Center, and the focus of her talk was "Converging on the Dream."

In June, the Lincoln Laboratory Office of Diversity and Inclusion hosted a seminar on the effects of unconscious bias on human behavior and ways to counter such biases in the workplace. The interactive session, "Mind Bugs: The Ordinary Origins of Bias," was presented by Carlee Beth Hawkins, an assistant professor of psychology at the University of Illinois, Springfield, and a researcher with Project Implicit, a nonprofit organization studying the role of implicit social cognition in human interactions.

Lincoln Laboratory is a member of the National Graduate Education for Minorities (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. In summer 2016, Lincoln Laboratory hired 20 GEM Fellows as interns. In addition, over the past two years, the Laboratory has hired four GEM Fellows as technical staff members. In August 2015, Eric Evans, director of Lincoln Laboratory and president of GEM, welcomed board members, representatives from the consortium's partners, and GEM students to the annual GEM board meeting and conference, which was held in Boston for the first time.

Technical Program Highlights

Research and development at the Laboratory focus on national security problems in diverse areas: tactical and intelligence, surveillance, and reconnaissance systems; air, missile, and maritime defense; space situational awareness 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 the development of components and systems for experiments, engineering measurements, and tests under field operating conditions.

During fiscal year 2015, Lincoln Laboratory worked on approximately 680 sponsored programs ranging from large-scale hardware projects to small seedling initiatives. Notable highlights for each mission area are listed below.

Advanced Technology

Microelectronics/Microsystems

Lincoln Laboratory completed the first wafer-scale demonstration of heterogeneous integration of electronic and photonic components. Utilizing 90-nm complementary metal-oxide semiconductor (CMOS) electronics and silicon photonic wafers, the Laboratory exploited its high-density, three-dimensional (3D) wafer-scale integration technology to create circuits that convert electrical signals into optical signals that can be routed off a chip to other components.

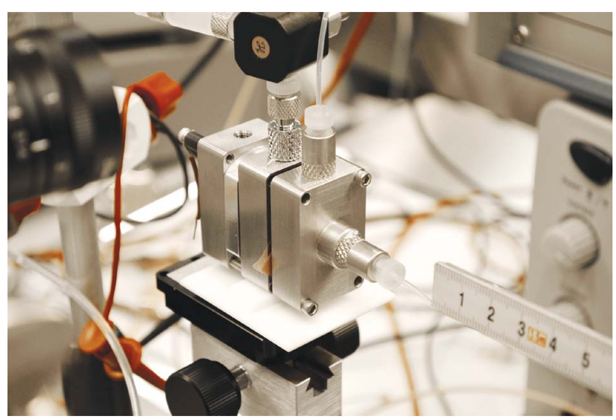

Figure 3. A prototype of a microhydraulic actuator uses electrowetting inside an array of microcapillaries to convert electrical power into hydraulic power.

The Microelectronics Laboratory has fabricated the world's highest-complexity single-flux-quantum integrated circuits for energy-efficient, high-speed digital computation. The deep-submicron fabrication process supports a Josephson junction device layer and eight super-conducting niobium wiring layers.

The Laboratory has efficiently converted electrical power to hydraulic power by employing microcapillary arrays with a high surface-area-to-volume ratio and low-voltage electrowetting (Figure 3). This reversible, fast actuating process is being explored for high-energy-density actuators with strengths expected to exceed those of biological muscles.

Lasers

All-electronic laser beam steering at a 1 μm wavelength has been demonstrated from a two-dimensional phased array of dozens of optical fibers. This implementation allows rapid steering (kilohertz-class sweep rates) with a large fraction of the optical power confined to the main lobe of the beam in the far field.

The first monolithic photonic chip that integrates active and passive elements working in the long-wave infrared (LWIR) spectral region was demonstrated. This new chip technology will allow quantum-cascade lasers operating in the LWIR region to be combined with splitters, phase shifters, and other optical functions on the same chip and will enable a new class of point and standoff chemical sensors.

Imaging Technology

A prototype low-cost phased array millimeter-wave imager for detecting concealed explosives was fabricated and demonstrated on realistic threats in a radio-frequency (RF) test chamber. In future field testing, a real-time back-end processing chain will be used.

Lincoln Laboratory demonstrated the largest short-wave infrared focal plane array capable of time stamping single photons. The array, which is twice as large as those used in previous demonstrations, employs a laboratory-fabricated 256 × 128 Geiger-mode avalanche photodiode array hybridized with a custom CMOS digital readout integrated circuit.

A 640 × 480 digital-pixel focal plane array was integrated into the Airborne Wide-Area Infrared System for Persistent Surveillance. An experimental aircraft collected 850 megapixel LWIR images over the northeastern United States to calibrate the sensor and verify the technical quality of its imagery.

Air, Missile, and Maritime Defense Technology

Lincoln Laboratory is implementing a modernized telemetry system for the Reagan Test Site. The modernization includes state-of-the-art wideband receivers and configurable, flexible signal processing that uses a software-defined radio-based architecture. In addition, the Laboratory is integrating a digital-pixel focal plane array long-wave infrared camera into one of the site's optical sensor suites to provide an order-of-magnitude improvement in the sensors' sensitivity and dynamic range.

Working with MITRE, other federally funded research and development centers, and university-affiliated research centers, Lincoln Laboratory took on a leadership role as the technical direction agent for the Ground-Based Midcourse Defense program. The initial focus will be on Ground-Based Interceptor fleet reliability, technical assessment of options for a redesigned kill vehicle, and concept development for robust homeland defense.

The Laboratory has been upgrading hardware and processing on a number of high-frequency sensor systems. Efforts include improving RF and digital hardware and adding real-time processing capabilities. Additionally, technology to enhance the geolocation of near-vertical incident scatter transmitters is under development.

Several efforts for the US Navy are focused on electronic countermeasures to defend ships against advanced antiship missile threats. The highlight of these efforts is the completion of a prototype for an advanced offboard countermeasure for ship-based defense.

A multipurpose radar test bed is being developed to advance techniques for the next generation of airborne radars. The test bed will initially be used to study the performance of arbitrarily flexible waveforms.

To support the Missile Defense Agency's initiatives to improve homeland defense capabilities, the Laboratory is developing improvements in the Ballistic Missile Defense System that will provide a basis for the creation of future algorithms.

Lincoln Laboratory worked with the Aegis Ashore program office and Lockheed Martin to develop BMD technology that was deployed at the Pacific Missile Range Facility Aegis site in 2015. This technology will advance readiness levels for concepts proposed for future Aegis BMD capabilities.

A comprehensive bias model was developed for the Navy's E-2D surveillance radar. By reducing biases in radar measurements, this model increases the operating range of the system. The model was transitioned to the contractor for inclusion in the real-time operating system.

Lincoln Laboratory partnered with the Office of Naval Research and PipeWorks, a commercial game developer, to create a planning and training tool for the Navy. This interactive tool, Strike Group Defender, immerses users in a realistic environment to help them develop an understanding of the weapon options available to ships (Figure 4). Strike Group Defender was named the 2014 Serious Game of the Year at the Interservice/Industry Training, Simulation and Education Conference.

Figure 4. Strike Group Defender graphics simulate the naval environment.

Communication Systems

The Lincoln Laboratory Ka-band Test Terminal was upgraded with enhanced Ka-band instrumentation and will be used for post-launch on-orbit characterization of Wideband Global System Flight satellites.

A real-time network test bed developed by the Laboratory was deployed at Aberdeen Proving Grounds in Maryland. The test bed, which is operated by US Army personnel, is being used to evaluate the performance of vendor equipment and to optimize the configuration of tactical networks.

A novel adaptive array antenna design will give fighter aircraft enhanced communications capabilities in highly contested electromagnetic environments.

The Protected Tactical Waveform was demonstrated over the air. This test confirmed the viability of providing jamming resistance when the waveform is operating over existing military and commercial transponders.

Flight tests using the Laboratory's Boeing 707 airborne networking test bed aircraft were completed to support the development phase of the Air Force Family of Advanced Beyond-Line-of-Sight Terminals.

Lincoln Laboratory is transitioning operations of the Interim Command and Control Terminals to the US Air Force. These terminals are used to operate the nation's protected military satellite communications constellation.

A full network and waveform model of an advanced airborne waveform was developed and demonstrated. The waveform is designed to provide increased robustness and capacity while still being able to coexist with the military standard Link 16 tactical data link.

The Laboratory designed, implemented, and extensively tested a new group-centric networking protocol that promises to provide improvements in scalability and resilience over traditional mobile ad hoc networking protocols.

The final design of a prototype airborne laser communications terminal was completed. This terminal operates over a wide field through a conformal interface.

A command-and-control terminal for the Enhanced Polar System was delivered to the Clear Air Force Station in Alaska to support initial terminal checkout.

Lincoln Laboratory will fabricate an engineering model of a modular laser communications terminal suitable for low Earth orbit and scalable to deep-space applications (Figure 5). A flight prototype will be built for NASA and flown on a low-Earth-orbiting spacecraft as a user terminal for NASA's upcoming Laser Communications Relay Demonstration.

Figure 5. Engineering model of a laser communications terminal.

Lincoln Laboratory developed an algorithm that enables tactical radios to synchronize timing without reliance on GPS. Future work will implement this algorithm as a protocol that can be run in software-defined radio platforms.

Using a custom-developed high-performance, capacity-achieving forward error correction code, the Laboratory demonstrated a world-record binary phase-shift keying communication performance rate of less than 1.5 photons per bit at a 2.88 Gbps data rate.

Cyber Security and Information Sciences

Cyber Security

Lincoln Laboratory conducted several large experiments in support of DoD's director of operational test and evaluation and the US Cyber Command's Project C. The experiments focused on the performance of the command's cyber protection teams. In addition, in conjunction with operational users from cyber centers at multiple combatant commands, the Laboratory tested cyber behavioral and temporal anomaly detection analytics.

The Laboratory completed in-depth cyber vulnerability assessments of multiple US tactical platforms.

Lincoln Laboratory led the design of a highly resilient key-management architecture for the next-generation Protected Tactical Satellite Communications Service. The Laboratory also developed and demonstrated a next-generation secure processor that has advanced key management capabilities, hardware-accelerated cryptography, and intrinsic support for volume protection.

Data integrity capabilities were developed for use in a key US Navy information processing system.

A tactical edge cyber-electromagnetic environment emulation was developed to support US Marine Corps training and exercises. Also in partnership with potential Marine Corps users, the Laboratory demonstrated the utility of its prototype wearable augmented-reality displays for a tactical urban setting.

Supercomputing

In April 2016, Lincoln Laboratory established a dedicated facility for supercomputing. The Lincoln Laboratory Supercomputing Center was developed to enhance computing power and accessibility for more than 1,000 researchers at the Laboratory and at MIT. This facility will support interactive supercomputing for high-performance data analysis and enable researchers to run complex simulations.

The MIT SuperCloud is the first cloud environment that delivers big data, database, supercomputing, and enterprise clouds on the same hardware without compromising performance. Lincoln Laboratory developed the SuperCloud in collaboration with the Beaver Works Engaging Supercomputing initiative.

The Laboratory's new hidden Markov model techniques allow recognition of time-varying patterns of behavior in transactional data, including potentially fraudulent financial transactions.

Human Language Technology

Deep neural network recognition techniques were successfully applied to language and speaker recognition and demonstrated significant performance improvements over previous state-of-the-art systems.

At an international competition in machine translation, Lincoln Laboratory scored highest in several tracks, including those for Arabic-to-English, Farsi-to-English, and Russian-to-English translation.

The VOCALinc speaker-comparison software tool was transitioned to the Federal Bureau of Investigation (FBI). VOCALinc is the first automated speaker-recognition system to be adopted and included in an FBI forensic standard operating procedure. VizLinc, an open-source software system developed by Lincoln Laboratory, integrates information extraction, search, graphical analysis, and geolocation for DoD and the intelligence community (Figure 6).

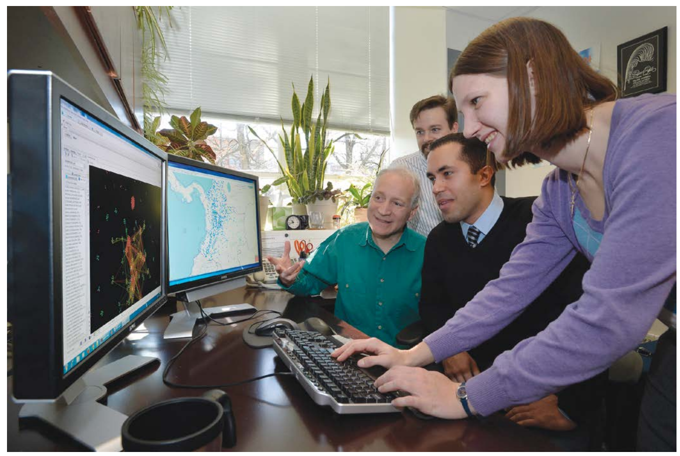

Figure 6. Researchers use VizLinc to explore extracted information.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Lincoln Laboratory assessed ISR operations in contested environments for the US Air Force and the Defense Advanced Research Projects Agency (DARPA). Architectures developed to address difficult targets included novel ISR concepts that can be applied to small satellites.

The Multi-Aperture Sparse Imager Video System (MASIVS) for collecting and analyzing wide-area motion imagery was integrated onto a second aircraft (Figure 7). Also, a new capability for counter-UAV (unmanned aerial vehicle) applications has been added to the Wide-Area Infrared System for 360° Persistent Surveillance.

Figure 7. The Lincoln Laboratory MASIVS sensor is fully integrated onto the US Army Constant Hawk aircraft.

The 3D Airborne Ladar Imaging Research Testbed concluded its overseas mission, during which it mapped more than 70% of Afghanistan. The Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), a next-generation 3D ladar designed to uncover clandestine activity in heavily foliated areas, has completed more than 160 sorties. This system's high area-surveillance rates are enabled by dual 64 × 256 Geiger-mode avalanche photodiode arrays and a high-power pulsed laser.

Working with DARPA, Lincoln Laboratory prototyped a distributed multiple-input, multiple-output (MIMO) radio for low-probability-of-exploitation RF communications. Also, the Laboratory, partnering with industry, fabricated a powerful digital system with a processing rate of 2 trillion operations per second for mobile MIMO radios and their base stations.

Researchers developed and field tested novel techniques in high-frequency electronic intelligence processing. Algorithms to detect and image moving targets in synthetic aperture radar (SAR) imagery will enable longer tracking of accelerating targets and enhanced SAR imaging in busy urban scenes. Improved inverse SAR algorithms were developed to support automatic classification of small boats.

The Laboratory prototyped advanced analytics for the DoD and the intelligence community. Distributed common ground system architectures were prototyped and evaluated. Red/blue exercises conducted with the Marine Corps explored emerging needs for real-time intelligence and operations integration.

A demonstrated approach to harnessing energy from the reaction of aluminum and water could greatly increase the energy capacity of unmanned undersea vehicles.

Lincoln Laboratory worked with multiple government sponsors to understand the best approaches for integrating open sources of data into intelligence analysis. Advanced techniques for ingestion and correlation of open-source data were developed and demonstrated.

Tactical Systems

Lincoln Laboratory completed a study of US Air Force fighter aircraft performance and limitations versus current and anticipated future foreign-threat fighters. This assessment included systems analyses (backed by laboratory and flight testing) of advanced infrared and RF sensor kill chains, electronic attack and electronic protection, and missile systems. The findings have been reported to senior DoD leaders to inform their decision-making processes with respect to future system capabilities and technology investments.

Technical evaluations of the impact of exporting advanced military systems were performed for Congress and the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics to help guide decisions on major export programs.

Lincoln Laboratory continues to provide a comprehensive assessment of options for US Air Force airborne electronic attacks against foreign surveillance, target acquisition, and fire-control radars. This work includes systems analyses of proposed options, development of detailed models and prototypes of threat radars, and testing of various electronic attack systems.

The Laboratory is rapidly prototyping advanced sensors and systems to counter various insurgency operations. A novel modular sensor kit was developed and integrated onto an unmanned aerial vehicle to provide tactical ISR capability. This system is being transitioned to the operational community for evaluation outside the continental United States. In addition, two advanced airborne signal intelligence capabilities were upgraded and transferred to the operational community and industry.

Advanced architectures and technologies are being developed for use in next-generation electronic attack systems for countering improvised explosive devices (IEDs). The Laboratory is conducting field demonstrations and technology transitions of advanced capabilities for future counter radio-controlled IED electronic warfare systems.

A novel approach to SAR imaging is enabling the detection and localization of slow-moving vehicles by using a dynamic motion model to focus radar returns. Because of the aperture limitations of the radar used for traditional moving target indication (MTI), these vehicles have been undetectable. The Laboratory's new approach, which has been demonstrated on radar data acquired through the sensors of the Lincoln Multimission ISR Testbed, is transitioning to a development effort to support small-aperture SAR/MTI for tactical systems.

Figure 8. The Airborne Countermeasures Test System team gathers with its newest aircraft, the HU-25 Falcon Jet.

The Airborne Countermeasures Test System, an instrumented platform, plays a vital role in the Laboratory's assessments of air-to-air and air-to-ground electronic attacks. This year the system team celebrated its 100th test flight on the Lincoln Laboratory Flight Test Facility's newest airframe, an HU-25 Falcon Jet (Figure 8).

Space Control

In response to a US Strategic Command need for space situational awareness, the US Air Force's Operationally Responsive Space Office tasked Lincoln Laboratory to build SensorSat, a microsatellite that will collect unresolved visible imagery of resident space objects in geosynchronous orbit from a novel low Earth orbit. SensorSat has completed its preliminary and critical design reviews and the second of several capability demonstrations.

Technology upgrades to DARPA's Space Surveillance Telescope are nearing completion. An advanced wide-field camera focal plane array and camera electronics, in conjunction with a second-generation control and data processing system, are expected to double the telescope's synoptic search rate while maintaining its detection sensitivity.

The Micro-sized Microwave Atmospheric Satellite-1 (MicroMAS-1) CubeSat, jointly developed by Lincoln Laboratory and the MIT Space Systems Laboratory, was deployed from the International Space Station in March 2015 to begin its technology demonstration flight. MicroMAS-2 is being fabricated for a follow-on demonstration flight, incorporating lessons learned from MicroMAS-1.

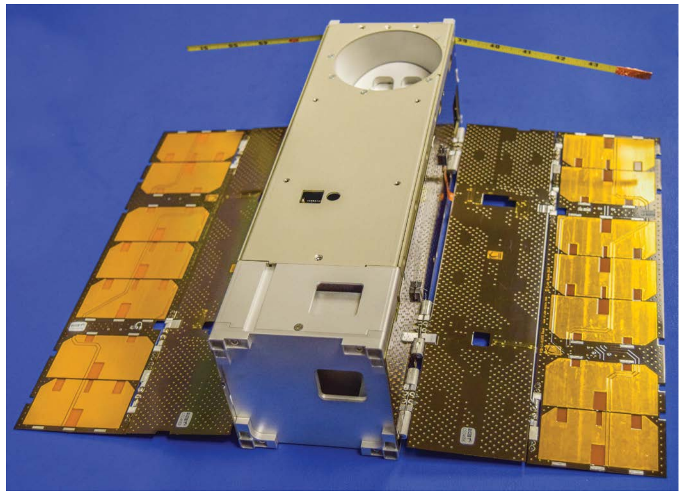

Figure 9. Mockups of the deployed solar panels and ultra-high-frequency antennas for the MiRaTA satellite have been completed.

Detailed design and testing of key flight hardware components of the Microwave Radiometer Technology Acceleration (MiRaTA) satellite have been completed (Figure 9). This joint effort between Lincoln Laboratory and the Space Systems Laboratory is a follow-on mission to MicroMAS-1 that will use a tri-band radiometer and GPS radio occultation technology to provide calibrated observations of atmospheric temperatures, water vapor, and cloud ice.

Lincoln Laboratory continued to support the development and testing of the US Air Force Space Fence radar system. The system's capabilities were successfully demonstrated in the Laboratory's modeling and simulation environment. A plan for using test equipment to emulate space objects will enable early testing of the fully functional scaled prototype of the system.

Optically cued radar tracking and monitoring of high-interest objects on tactical time lines are now operational at the Millstone Hill radar, Advanced Research Projects Agency Long-Range Tracking and Instrumentation Radar, and Target Resolution and Discrimination Experiment radar facilities. Development of an automated processor for high-interest object monitoring will significantly increase the throughput of the radars and provide timely indications and warnings of space events.

Several experiments were successfully conducted to evaluate the potential benefits of advanced sensor hardware, processing software, and operational techniques for improving US space situational awareness and satellite survivability. Various sensing modalities and opportunistic space events were leveraged to demonstrate new architectures and ways of creating decision support information.

Homeland Protection

Bioengineering

Partnering with the US Army Research Institute of Environmental Medicine, Lincoln Laboratory successfully demonstrated the first phase of ultra-low-power wearable physiological monitoring systems that can operate securely in tactical environments.

A prototype forensic measurement and analysis technique that uses next-generation DNA sequencing to reliably identify a suspect's DNA in complex, multiple-contributor sample mixtures has been demonstrated.

A multimodal immersive laboratory is being built for use in noninvasive cognitive and physiological monitoring research. The laboratory's 27-foot virtual-reality dome features 360-degree visualization and motion-capture capabilities and a dual-belt, force-plate treadmill.

For the second consecutive year, Lincoln Laboratory's neurocognitive team won an international competition for its estimation of depression severity from audio and video recordings. The recognition highlighted the efficacy of the Laboratory's speech processing techniques for psychological health assessments based on phoneme-dependent speaking rates and lack of coordination of vocal tract articulators.

Homeland Defense

Lincoln Laboratory continues to lead the development of technology and architectures for countering a broad range of weapons of mass destruction. Activities include measurement-based threat phenomenology studies, technology assessments, critical infrastructure remediation, and IED forensics development.

The Laboratory, in collaboration with the Joint Program Executive Office for Chemical and Biological Defense and its international partners, conducted a series of measurements to improve understanding of chemical and biological threat agents and to enable the development of technologies needed to counter such threats.

Prototypes developed by Lincoln Laboratory are advancing the capabilities for humanitarian assistance and disaster response operations. The Next-Generation Incident Command System, a command-and-control software platform funded by the DHS Science and Technology Directorate (S&T), is improving situational awareness among firefighters in California and emergency managers in Victoria, Australia. Other decision support tools are enabling better preparation for and responses to coastal hurricanes.

Figure 10. In an effort to develop technology for detecting and tracking UAVs, researchers measure the acoustic signature of a commercial UAV in an urban environment.

In partnership with the DHS Homeland Security Advanced Research Projects Agency, Lincoln Laboratory is assessing and developing UAV detection architectures and technologies to help protect critical infrastructures and special-event sites.

The Laboratory is also working with the DHS Science and Technology Directorate to develop a capability for reliably detecting and tracking UAVs (Figure 10). This capability is needed to safely integrate such vehicles into US airspace.

Next-generation video-analysis capabilities for law enforcement, mass transit security, and border patrol are being developed with an emphasis on accelerating video reviews by humans and cueing operators to unusual targets.

Air Traffic Control

System studies and antenna panel development continued for the Multifunction Phased Array Radar. Lincoln Laboratory constructed a mobile 10-panel prototype array that will be used to refine system requirements and quantify dual-polarization performance for weather observations. Results from this analysis will be used to refine the design of a full-scale 76-panel advanced technology demonstrator array. The Laboratory plans to build this array in partnership with FAA and NOAA.

An effort was initiated to build a prototype small airport secondary surveillance sensor that has the potential to provide low-cost terminal-area surveillance. A prototype aperture has been developed to demonstrate real-time surveillance performance.

Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a global radar-like view of convective weather beyond the coverage of radars (Figure 11). In the upcoming year, NOAA and FAA will assess the quality and operational suitability of OPC information.

Lincoln Laboratory is playing a key role in developing the NextGen Airborne Collision Avoidance System X (ACAS X), which will support new flight procedures and aircraft classes. A flight test conducted by the Laboratory, FAA, and NASA using NASA's Ikhana aircraft successfully demonstrated an ACAS X variant for unmanned aircraft systems. Standards development for ACAS X has been initiated, and plans to conduct a full system test with FAA are under way.

Figure 11. The Offshore Precipitation Capability provides a real-time depiction of weather beyond the range of radars, filling in key coverage gaps in the Gulf of Mexico, the Caribbean, and other regions.

The Laboratory is developing standards and algorithms for unmanned aircraft system sense-and-avoid (SAA) capabilities for DoD, DHS, and FAA. The Laboratory worked with the SAA Science and Research Panel to publish a "well clear" separation standard for unmanned aircraft.

Analyses are being conducted to guide FAA on wind information needs with respect to a range of NextGen applications, including four-dimensional trajectory-based operations and interval management procedures. These analyses are guiding the establishment of performance requirements and standards for enabling concepts of operations, technologies, and information sources.

Operational improvements are being developed to reduce fuel burn and mitigate the environmental impacts of aviation. For airport surface operations, Lincoln Laboratory has developed and assessed decision support tools that reduce taxiway congestion and efficiently balance queues of aircraft at departure runways. Methods to save fuel and reduce emissions, including modified procedures to optimize the cruise altitude and speed of aircraft and to delay their deceleration as they approach the runway for landing, are being explored with a range of stakeholders.

Engineering

A variety of new tools are enabling the design and fabrication of prototypes. Design and analysis tools for freeform optics (i.e., optical elements with arbitrary surfaces), used in conjunction with the Laboratory's diamond-turning machine, are supporting the development of optical systems that can achieve higher imaging resolution than that possible with conventionally designed systems of the same size and weight. A direct metal laser sintering machine is enabling the rapid fabrication of parts with complex geometries. Integrated modeling software tools for coupling structural, thermal, fluid, optical, and control simulations were utilized on a number of programs to optimize system design variables while maintaining system performance. In addition, a laser scanning digital microscope, flash diffusivity instrument, rheometer, x-ray photoelectron and auger electron spectrometer, tabletop universal test system, digital-image-correlation software, and other materials testing tools are enhancing the development and evaluation of advanced materials.

Researchers are exploring and evaluating methods of human-robot interaction in the recently completed Lincoln Laboratory Interactive Virtual Environment, a three-dimensional motion-capture theater that enables researchers to play out mission scenarios with human actors and robots and to test advanced sensing capabilities and autonomy algorithms developed to streamline human-robot teaming (Figure 12). This work is motivated by DoD's growing interest in using autonomous systems to enhance warfighter situational awareness.

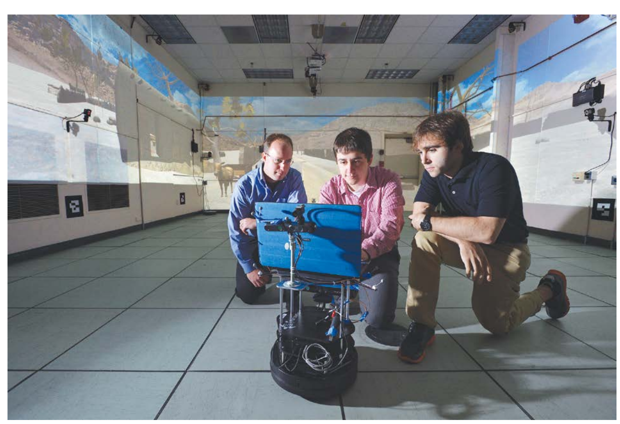

Figure 12. Researchers are assessing human-robot interactions in the Lincoln Laboratory Interactive Virtual Environment.

Novel sensing, vision processing, and autonomy algorithms are guiding small unmanned aerial vehicles operating at very low altitudes. Integration of photon-to-digital imaging with tightly coupled planning algorithms enabled the UAVs to perform high-speed obstacle avoidance in complex environments. Scene depth derived from stereo cameras was used to alter a multirotor's GPS trajectory.

Military and commercial interest in Lincoln Laboratory's localizing ground-penetrating radar (LGPR) has grown. The Laboratory is currently investigating the use of the LGPR in GPS-denied localization and collaborating with the US Military Academy at West Point to design a vehicle mount that automatically moves the radar out of the way of obstacles during off-road operations.

The Energy Systems Group is focusing on the development of microgrid systems, advanced energy technology, and portable, energy-efficient capabilities for soldiers. Collaborations with the Advanced Technology Division and the MIT campus concentrate on improving photovoltaic, battery, electronic, and control technologies.

2015 R&D 100 Awards

Three Lincoln Laboratory technologies were named 2015 recipients of R&D 100 Awards, presented annually by *R&D* magazine in recognition of the 100 most technologically significant innovations introduced during the previous year. The winning technologies listed below represent work in cyber security, missile defense, and homeland protection, respectively:

- Platform for Architecture-Neutral Dynamic Analysis: an open-source, plug-in software analysis framework that enables computer engineers to observe codes as a program executes so that they can understand and mitigate code vulnerabilities or faults
- Self-Defense Distributed Engagement Coordinator: an automated decision support tool that guides naval personnel on how to efficiently allocate resources in response to anti-ship missile threats
- Video Content Summarization Tool: a software application that creates summary views of long-duration surveillance videos so that analysts can quickly identify activities of interest

Technology Transfer

The culmination of many of Lincoln Laboratory's development projects is the transfer of technology to government agencies, industry, or academia. The mechanisms for this transfer include licensing of patents; delivery of hardware, software, algorithms, or advanced architecture concepts to government contractors under the auspices of a government sponsor; small business technology transfer projects, which are joint research partnerships with small businesses; and cooperative research and development agreements, which are privately funded by businesses to transfer the Laboratory's technology.

Between July 1, 2015, and June 30, 2016, 19 US patents were granted to MIT for technologies developed by Lincoln Laboratory technical staff. These patents span a wide range of technologies. Of particular note are "Methods and Apparatus for In-Pixel Filtering in Focal Plane Arrays Including Apparatus and Method for Counting

Pulses Representing an Analog Signal," which extends the capabilities of the innovative digital focal plane array technology underpinning a number of Lincoln Laboratory's imaging systems; "Assisted Video Surveillance of Persons of Interest," which has been successfully demonstrated to facilitate rapid analysis of lengthy video streams used in monitoring crowded public spaces; and "Optimized Transport Layer Security," which enhances the capacity to secure communications between multiple devices.

Lincoln Laboratory transferred a software implementation of the Dynamic Link Exchange Protocol to a group of three companies developing advanced communication systems. The protocol, which is undergoing standardization by the Internet Engineering Task Force (an international community of network researchers), will provide improved queuing and flow control for wireless networks.

An advanced algorithm for fast computation of wireless communications interference in radio networks was transitioned into two commercial wireless network simulation software frameworks. These frameworks are widely used in commercial and defense industry communications engineering to model wireless systems and to evaluate the performance of network and routing protocols.

LARIAT, a cyber range technology developed at Lincoln Laboratory for assessing cyber security tools and techniques, was recently licensed to SimSpace Corporation for commercial use in its products and services.

As part of its program for upgrading US submarine sonars, Lincoln Laboratory transitioned adaptive beam-forming, detection processing, and ranging algorithms, as well as improved collision warning indicators, to the Navy.

The Laboratory delivered several advanced software capabilities to the Air Force Research Laboratory to enhance processing, exploitation, and dissemination capabilities for the Air Force Distributed Common Ground System.

Lincoln Laboratory developed a tactical intelligence, surveillance, and reconnaissance sensor for small UAVs. The sensor, which is intended to fulfill a force-protection role at the company level, provides actionable information in real time, significantly improving response times over current systems. The sensor has been integrated onto a tactical UAV platform in cooperation with industry partners, and hardened prototypes have been transitioned to the Army for operational use. Work is continuing to extend the payload for use on both moving and stationary platforms.

Lincoln Laboratory is supporting the transition of a prototype ground-based sense-and-avoid system to the US Army. The system will be deployed to five Army Gray Eagle operational sites this year. Future technology transfer will be supported on an annual basis.

Decision support tools are being transferred into FAA's Traffic Flow Management System. These tools provide short-term forecasts of convective weather effects on terminal arrival routes and use wind, ceiling, and visibility forecasts and airport-specific operating procedures to aid in setting airport arrival rate targets.

Knowledge Exchange

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 this year:

- Advanced Research and Technology Symposium
- Advanced Technology for National Security Workshop
- Air and Missile Defense Technology Workshop
- Air Vehicle Survivability Workshop
- Anti-access/Area Denial Systems and Technology Workshop
- Cyber Endeavor
- Cyber and Netcentric Workshop
- Defense Technology Seminar
- Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
- Lincoln Laboratory Communications Conference
- Mechanical Engineering Technology Symposium
- Software Engineering Symposium
- Space Control Conference
- Homeland Protection Workshop Series (two one-day seminars held in Virginia)
- Air Traffic Control Workshop (coordinated with the Federal Aviation Administration and held in Washington, DC)

In addition, Lincoln Laboratory is a technical partner for the IEEE High Performance Extreme Computing Conference and the IEEE International Symposium on Technologies for Homeland Security.

Publications

Knowledge dissemination is also achieved through the diverse venues in which Lincoln Laboratory researchers publish. Technical staff members publish articles in peer-reviewed journals and present at national technical conferences such as the IEEE Military Communications Conference and the International Conference on Acoustics, Speech, and Signal Processing. Between July 1, 2015, and June 30, 2016, Lincoln Laboratory staff published 111 papers in proceedings from such conferences, 76 articles in technical journals, and 12 technical reports available through the Defense Technical Information Center.

The Laboratory publishes the *Lincoln Laboratory Journal*, which contains comprehensive articles on current major research and journalistic pieces highlighting novel projects. In spring 2016, a special issue on cyber security research at the Laboratory covered a range of initiatives, including the development of moving target techniques to thwart cyber attacks, an investigation of social media discussions to discover potential cyber intrusions, and the use of cryptographic technology to secure transmission of data.

In a partnership with the MIT Press, Lincoln Laboratory established a book series to present its fundamental research conducted in support of national security. Authored by Lincoln Laboratory experts, often with contributions from eminent 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. The first two books were published in spring 2015: *Perspectives on Defense Systems Analysis* and *Ultrawideband Phased Array Antenna Technology for Sensing and Communications Systems. In August 2015, Decision Making Under Uncertainty*, an introduction to the development of automated decision support systems, was released. Applied State Estimation and Association will be available in summer 2016.

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. There are multiple mechanisms for direct support of cooperative projects, with the Technology Office coordinating the majority of such mechanisms.

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 2015–2016, 10 collaborations were funded through the Advanced Concepts Committee, including efforts in terahertz computational imaging, fabrication of high-density electrospray thrusters, electroquasistatic imaging of 3D doping profiles, high-frequency radio astronomy CubeSat mission planning, and integrated magneto-optical isolators for infrared and visible wavelengths.

Longer collaborative mission-focused projects are supported directly through funding from the Office of the Assistant Secretary of Defense for Research and Engineering, with funds distributed after a call for proposals each April. External program sponsors in the Department of Defense, the Department of Energy, NASA, and other government agencies also support a wide range of program activities.

Seminars

The Technology Office directs a program of seminars presented at the Laboratory by both in-house speakers and researchers from universities and industry. The seminars are chosen to reflect current and leading-edge trends in today’s technology. Highlights of the 2015–2016 seminar program include the following:

- "MIT's Entry in the DARPA Robotics Challenge," Professor Russ Tedrake, MIT Computer Science and Artificial Intelligence Laboratory (August 7, 2015)
- "Underwater Wireless Communications," Professor Milica Stojanovic, Department of Electrical and Computer Engineering, Northeastern University (November 17, 2015)
- "Sony's SmartEyeGlass," Hiroshi Mukawa, Sony Corporation (November 19, 2015)
- "Fundamental Physics through Laser Ranging to the Moon," Professor James Battat, Department of Physics, Wellesley College (December 3, 2015)
- "Our Robots, Ourselves: Robotics and the Myths of Autonomy," Professor David Mindell, MIT Department of Aeronautics and Astronautics (February 9, 2016)
- "Additive Manufacturing of Micro- and Nanosystems," Luis Fernando Velásquez-Garcia, MIT Microsystems Technology Laboratories (March 9, 2016)

In addition, the office arranges for Lincoln Laboratory staff to deliver presentations at MIT. This year, Vladimir Liberman spoke on aluminum plasmonics, Hamed Okhravi discussed the Laboratory's work in evaluating moving target techniques for cyber security, and Vijay Gadepally outlined recent high-performance computing initiatives.

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 2015–2016, 45 military officers worked in various technical groups under fellowships. In addition, in summer 2015, 55 cadets and midshipmen from the US military academies participated in an internship program at the Laboratory.

Courses

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. During the past year, 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; one course is scheduled each semester, and the topics vary to address the college's needs. Courses in cyber security, ballistic missile defense, and space technology have been offered in the past few years.

Lincoln Laboratory technical staff led activities offered during MIT's Independent Activities Period (IAP), a four-week term in January 2016. During the 2016 intersession, David Sun Kong taught 20.S952 Fluidics for Synthetic Biology: Prototyping Microbial Communities, a for-credit course offered by the MIT Department of Biological

Engineering. Lincoln Laboratory staff members also developed and led the following non-credit offerings in 2016: Build a Small Radar System, Designing Systems for Humanitarian Assistance and Disaster Relief, Hands-on Holography, Introduction to Lasercom—Build a Laser Audio Link, RACECAR—Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot, Software Radio, and Software Reverse Engineering.

MIT Lincoln Laboratory Beaver Works Center

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. 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 (MechE) in collaboration with Lincoln Laboratory, investigated the potential use of aluminum as a fuel source. Other capstone projects with MechE developed a forward-deployed energy and communications outpost and a prototype for a high-energy-density portable power pack. In conjunction with courses in the Department of Aeronautics and Astronautics, students investigated a long-endurance UAV design and planetary penetrators. Capstones on time-series analytics for decision making and a communications system for autonomous swarms were conducted through the Department of Electrical Engineering and Computer Science, while a capstone offered through the Department of Civil and Environmental Engineering researched the development of a strategy for intelligent, constraint-based autonomous tasking.

Beaver Works's fabrication and classroom facilities were also used for most of the IAP courses led by Lincoln Laboratory technical staff. In addition, members of Lincoln Laboratory's technical staff volunteered to direct a number of K–12 educational outreach activities at Beaver Works, including a robotics workshop for an all-girl FIRST (For Inspiration and Recognition of Science and Technology) LEGO League team, a hands-on camera-building activity for high school girls, and a one-day radar workshop for middle school students.

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 summer 2015, two 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. In addition, the Laboratory employs students participating in the Undergraduate Research Opportunities Program (UROP), SuperUROP, and the

Undergraduate Practice Opportunities Program; in summer 2015, 19 students worked under these programs.

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. In 2016, the Laboratory hired 219 undergraduates and graduate students from 88 different schools to work as interns. Throughout the year, cooperative education students from area colleges such as Northeastern University and Wentworth Institute work at the Laboratory. During fall 2015 and spring 2016, 60 cooperative education students from area schools were employed in technical divisions and service departments.

Infrastructure

Lincoln Laboratory's service departments continue to augment the infrastructure that supports the research and prototyping activities of the technical divisions.

Contracting Services Department

The Contracting Services Department supported Lincoln Laboratory's federally funded research by issuing more than 57,000 procurement transactions with a value of $599.2 million in fiscal year 2015 and more than 41,000 procurement transactions with a value of $419.5 million through the first three quarters of fiscal year 2016. To maximize business process efficiencies, the Laboratory encouraged the use of electronic procurement tools; between July 2015 and June 2016, staff from outside the Contracting Services Department directly placed approximately 37,000 procurement transactions through the use of e-catalogs and electronic procurement cards.

Through its Small Business Program, the department continues to maximize opportunities for innovative small businesses. A comprehensive outreach program included 52 demonstrations and visits made by small businesses to the Laboratory. Consequently, small businesses were the recipients of approximately 58% of outside procurement funds issued in the past year.

The department formally implemented its Better Buying Power Program in the past year to maximize efficiencies and optimize value to the Laboratory's federal sponsors. The implementation of this program led to more than $6.2 million in documented cost savings in fiscal year 2015 through the use of reverse auctions, competition, price negotiations, and prompt payment discounts. Through the first three quarters of fiscal year 2016, Lincoln Laboratory achieved approximately $3.7 million in cost savings by employing similar techniques.

Facility Services Department

The Facility Services Department manages the operations and maintenance of more than 2.2 million square feet of laboratory and general-use facilities. Core services include the operation and maintenance of all facilities, renovation and construction projects, and custodial, mail, food, hazardous materials, and parking services.

In fiscal year 2016, the department executed more than $20 million of project work. One of the largest projects was to bring chilled water from the main plant into Lincoln Laboratory's main data center. This chilled water feed now serves as the primary cooling source for the data center, adding a layer of redundancy as the existing local system continues to be a backup cooling source. Another critical project was the installation of two new soft-wall clean rooms. These clean rooms are needed to support two new thermal vacuum chambers that will be operated by the Laboratory's Engineering Division.

The Facility Services Department also manages the Laboratory's transportation services and commuter support programs. Lincoln Laboratory has received numerous awards for its excellence in promoting green commuting options as a way to reduce traffic congestion and greenhouse gas emissions. In 2016, Lincoln Laboratory received a Massachusetts Excellence in Commuter Options Award from the Massachusetts Department of Transportation. In addition, the Laboratory and Hanscom Air Force Base jointly received an environmental merit award from the Environmental Protection Agency for their commuter program.

Financial Services Department

A major focus area for the Financial Services Department was operationalizing the new prime contract signed in April 2015. This effort included working closely with the Air Force and Lincoln Laboratory's business and contracting communities to find efficiencies in processing and to provide training and communication for laboratory personnel and sponsor groups on the new requirements of this contract. Another area of focus was assisting with the financial aspects of the Facilities Modernization Plan, which was approved during the year. In addition to help with the planning aspects of this modernization plan, the process for paying for implementation of the plan was approved and made operational during the year. Efforts continued in expanding the vendor base for electronic invoicing and Automated Clearing House payments.

Security Services Department

The Security Services Department (SSD) led the effort that earned Lincoln Laboratory its 10th consecutive "superior" security rating from the US Air Force's 66th Air Base Group Information Protection Office. In calendar year 2015, SSD successfully prepared Lincoln Laboratory groups for 39 government security-related audits conducted by multiple government agencies. The department also successfully completed multiple sponsor inspections supporting special programs.

The department led an effort to comply with the Defense Federal Acquisition Regulation Supplement (DFARS) by executing a gap analysis, implementation planning, and tabletop exercise to protect the Laboratory's unclassified controlled technical information in accordance with National Institute of Standards and Technology guidelines. In addition to working on initiatives to maintain and enhance the security of information systems throughout the Laboratory, the department continued to influence security policy at the national level as it relates to new government regulations on insider threat, clearance processing, and DFARS.

SSD partnered with the Information Services Department to deploy the IBM Endpoint Manager on all systems connected to the Lincoln Laboratory local area network. The department is facilitating the visibility of the system patch status and lowering the risk of data loss.

During the implementation of the Laboratory's IBM BigFix asset tracking capability, the department provided significant policy guidance to the Information Services Department. As a result, manual efforts to protect sensitive unclassified Laboratory data have been significantly reduced.

Using a computing vulnerability assessment, department personnel tracked and validated all remediation efforts for network vulnerabilities and provided recommendations based on the findings of the assessment.

In partnership with the Information Services Department and Cyber Security and Information Sciences Division, SSD implemented the Cyber Threat Analysis Cell as a central point to collect, share, and analyze threat information relevant to the security of the Laboratory's networks. Also, the department is collaborating with the Cyber Security and Information Sciences Division to design and implement advanced insider threat analysis and detection techniques.

The department responded to numerous high-visibility information security incidents, including the US Office of Personnel Management (OPM) data breach, and conducted enhanced network enclave security reviews in response to the OPM data breach revelations. The department continues to monitor updates related to this breach.

The Security Services Department provides various training and support to Lincoln Laboratory. Over the past year, it strengthened the Laboratory's emergency preparedness program by conducting multiple seminars and exercises including active shooter sessions, building-evacuation drills, an insider threat tabletop exercise, a cyber security exercise, force protection condition change drills, and workplace violence education seminars. The seventh annual Security Education and Awareness Week emphasized counterintelligence in the workplace, active threat awareness, and cyber threats and trends. The department leveraged technology, automation, and process improvements to enhance the delivery of services, including automated emails to manage the North Atlantic Treaty Organization's Defense Biometric Identification System credential issuance and renewal processes and use of the data security planning process as a Laboratory-wide replacement for several disparate manual processes. Training for the transition from traditional National Industrial Security Program Operating Manual certification and accreditation to the Risk Management Framework will ensure that the Laboratory is prepared for the October 2016 transition. Department personnel provided security services to enable the success of several high-profile, large-scale Laboratory-hosted conferences and sponsor-requested technical review days accommodating more than 10,000 visitors.

Information Services Department

The Information Services Department continued to execute its strategic plan of becoming a customer-focused organization that delivers information technology (IT) services enabling Lincoln Laboratory staff to do their jobs effectively and efficiently. The department deployed Laboratory-wide service and infrastructure enhancements, including major cyber security improvements. Business systems and processes were also upgraded to accommodate major new requirements and to streamline administrative support across the Laboratory.

Key IT services and procedures were improved through a number of major initiatives:

- Remote support and collaboration: As work locations expand beyond the Laboratory's main complex, it is important to support the needs of our remote users. An enhanced immersive video teleconference (VTC) capability now provides a more realistic VTC experience between users at Lincoln Laboratory's Wood Street location and its Washington, DC, office. This self-service model is integrated with the Laboratory's VTC network to allow collaboration, and the service supports advanced VTC capabilities for other Lincoln Laboratory field locations. In addition, remote desktop support gives technicians the ability to troubleshoot and resolve end-user issues from any location.
- Efficient infrastructure operations and risk management: Improvements to the Laboratory's major data center (the F1 Data Center) allow full shutdown and startup of the center and associated IT services to support more efficient cooling via the Hanscom Air Force Base chilled water system. The installation of continuous infrared scanning has improved the monitoring of critical electrical equipment. These enhancements, completed over the Patriots' Day weekend, required extensive collaboration among the Information Services Department, the Facility Services Department, and the Laboratory's IT community.
- Advanced business operations: The Business Applications Governance Board, established in 2015, facilitated the successful completion of a number of projects. A project focusing on rights and markings statements led to the development of an online tool that helps create accurate marking statements for Lincoln Laboratory work products generated under the Laboratory's prime contract or through off-contract activity; these products (e.g., documents, graphics, multimedia, software) must be properly labeled with US government–designated markings when they are provided to any non-Laboratory party.
- Paperless, Auditable Release Review Online Tool (PARROT2): PARROT2, the application through which submissions to Lincoln Laboratory's release review process are managed and approved, was updated in conjunction with the rights and markings statements project. This review process ensures that work products generated by Laboratory employees are appropriately released to parties with whom the Laboratory does not have a contractual relationship and protects the interests of the government and MIT.
- Other improvements to business procedures: These improvements included the introduction of a streamlined process to simplify reporting of foreign travel and contacts and the implementation of an enterprise-wide training and tracking

application to support employee training needs and compliance with training requirements.

- Cyber security improvements: In response to the increasing cyber threat environment and requirements for rapid response capabilities, the department has increased its cyber security team's capabilities to offer "around the clock" on-site support for the Laboratory's cyber protection systems. The Laboratory has initiated a pilot service for multifactor authentication to reduce the risk of lost or stolen end-user credentials. While multifactor authentication has been in use for remote access, this new pilot will support stronger authentication procedures for users from the Laboratory's networks.
- Project management: The department's project management office has continued to improve its services with improved risk management practices and integration of agile project management methodology.

Community Outreach

Education

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

The Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) summer program offered 18 students from across the country a two-week project-based course on radar fundamentals. The program included 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 (Figure 13). In April 2016, two staff members who have been instructors for the LLRISE program offered a three-day version of the course to engineering students at the University of Puerto Rico at Mayagüez. The 2016 program began in July.

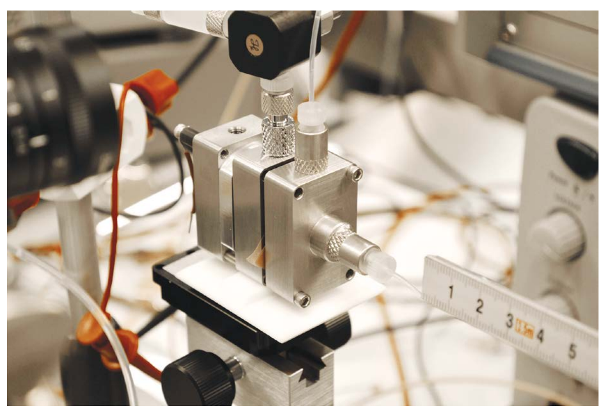

Figure 13. Students in the 2015 LLRISE summer program work in teams to build small radar systems.

Lincoln Laboratory Cipher, a program started in 2015, offers high school students an introduction to cryptography. This weeklong program, conducted by members of the Laboratory's technical staff, will take place in August 2016.

Lincoln Laboratory staff from the Cyber Security and Information Sciences Division and the Communications and Community Outreach Office mentored three teams of high school students who competed in cyber defense challenges run by the Air Force Association's CyberPatriot program. All three teams advanced from the state to the regional competitions.

Through Lincoln Laboratory's robotics initiative, Robotics Outreach at Lincoln Laboratory (ROLL), technical staff members continue to mentor teams in the US FIRST competitions. In the past year, Lincoln Laboratory sponsored 16 teams that competed in FIRST events.

Science on Saturday, the Laboratory's first STEM program, is still drawing 700 K–12 students, parents, and teachers to each of the science demonstrations given by technical staff members during the academic year. Offerings in 2015–2016 were a hands-on engineering "fair" and demonstrations on robotics, cyber security, and liquid nitrogen. The Laboratory's other established educational outreach programs—internships for students from local high schools, engineering workshops for middle school–aged girls, and the Ceres Connection that names asteroids in honor of science fair winners—are all continuing.

Lincoln Laboratory is continuing its partnership with the MIT Department of Engineering's Office of Engineering Outreach Programs (OEOP). The Laboratory sponsors students in each of four OEOP programs, provides tours of Lincoln Laboratory's unique facilities to the student groups, and offers courses or presentations given by members of the technical staff.

Community Service

LLCO helps increase Laboratory employees' awareness of events sponsored by charitable organizations. Laboratory participants in the September 2015 Memory Walk for the Alzheimer's Association raised more than $37,000 to provide services to patients in Massachusetts and New Hampshire; in addition, a team of cyclists raised approximately $15,500 in the July Ride to End Alzheimer's. Laboratory employees also walked, ran, and bicycled for a number of other causes this year: the American Heart Association Heart Walk, the AIDS walk/run, and the CancerCare walk. Five bicyclists from Lincoln Laboratory completed the Pan-Mass Challenge, a two-day bicycle trek that raises money for cancer research and patient care; the team raised $41,879.

The annual holiday clothing, food, and gift drives brought in warm coats, food, and gift items. Approximately 250 toys were donated by Lincoln Laboratory employees to the MIT Federal Credit Union's annual Toys for Tots drive. 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; each year, program volunteers box and send dozens of "care" packages to the troops.

Summary

Last year, Lincoln Laboratory established new programs to address emerging demands for technology solutions to national concerns in the areas of cyber security, resilient space systems, autonomous systems, energy, undersea systems, and humanitarian assistance and disaster relief. This year, the Laboratory has been growing these new programs while continuing to strengthen its core mission areas such as air and missile defense, communications, and ISR and tactical systems. The Laboratory's research and development portfolio is well balanced, with programs ranging from large-scale system developments and rapid prototyping efforts to innovative, often multidisciplinary, research projects.

Technology transfer is strongly emphasized in all mission areas. Through its transfer activities, the Laboratory helps ensure that the US military has access to advanced, useful 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 valued at Lincoln Laboratory. Educational outreach programs that encourage young people to consider careers as scientists and engineers are seen as part of our national security mission. Also, many employees appreciate the Laboratory's support for the charitable activities in which they engage.

Lincoln Laboratory is well positioned to take on the challenges of its mission of "technology in support of national security."

Eric D. Evans
Director