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 US government agencies. On April 28, 2015, MIT and the Air Force signed a contract that extends this relationship until 2025.

Lincoln Laboratory's mission is to develop technology in support of national security. Most 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 are focused on developing and prototyping new technologies and capabilities to meet DOD needs that cannot be met as effectively by existing government or contractor resources.

The Laboratory maintains its relevance by continually leveraging its expertise to meet new challenges presented by the evolving needs of the nation and its military forces. This year, the Laboratory established a number of new groups to address areas in which DOD sees growing or emerging needs. The new Energy Systems Group will focus on developing innovative solutions to the nation's energy demands and on improving the security and resiliency of the nation's energy infrastructure. The Laboratory's work to develop acoustic and nonacoustic sensors, autonomous undersea vehicles, and undersea communication systems has been consolidated within the new Advanced Undersea Systems and Technology Group. The Humanitarian Assistance and Disaster Relief Group was formed to research and then develop advanced technologies that can enhance disaster response operations. Cyber security, critical to protecting vast amounts of diverse digital data, continues to be a growing mission area. Demand for intelligence, surveillance, and reconnaissance systems remains strong. The Laboratory is applying its competencies in advanced signal and image processing, electronics and optics, complex system analysis, and biological defense to developing advanced biomedical technologies and systems to address national healthcare needs and enhance soldier fitness and resilience. Rapid prototyping projects continue to be significant efforts across various mission areas.

For the fiscal year July 1, 2014, to June 30, 2015, Lincoln Laboratory received approximately $923.9 million in contracts to support the efforts of approximately 1,779 professional technical staff and 1,539 technical and administrative support personnel; outside procurement exceeded $560 million. While most of the research is sponsored by 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 standardized 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.

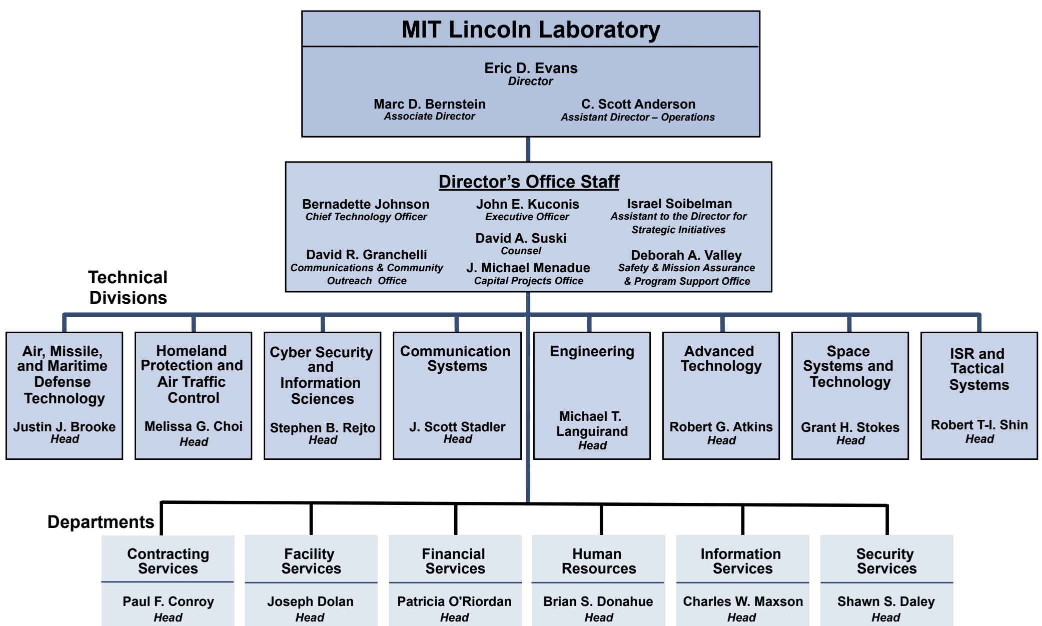

Figure 1. MIT Lincoln Laboratory's organizational structure as of July 1, 2015.

Leadership Changes

Air and Missile Defense Technology Division: Dr. Kevin P. Cohen was appointed assistant head of the Air and Missile Defense Technology Division (renamed the Air, Missile, and Maritime Defense Technology Division in August); formerly, he was assistant head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division.

Engineering Division: Dr. Michael T. Languirand was appointed head of the Engineering Division; formerly, he was assistant head of the division. Dr. Eliahu H. Niewood, the outgoing head of the division, accepted an Intergovernmental Personnel Act assignment to the US Air Force Rapid Capabilities Office in Washington, D.C. Dr. William D. Ross was named an assistant head in the Engineering Division; formerly, he was the leader of the Advanced Electro-optical Systems Group.

Homeland Protection and Air Traffic Control Division: Dr. Melissa G. Choi was named the head of the Homeland Protection and Air Traffic Control Division; formerly, she was an assistant head in the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division. Edward C. Wack was appointed assistant head of this division; formerly, he served as the leader of the Bioengineering Systems and Technology Group.

Organizational Changes

A number of organizational changes were made to align the Laboratory's research and development work with areas of increasing criticality to DOD.

The Aerospace Division underwent a number of organizational changes to broaden its activities in the development of space control systems and technologies and to undertake work on resilient space systems. The division was renamed the Space Systems and Technology Division. Groups within the division have been realigned to balance the focus on core space situational awareness programs with the evolving emphasis on space systems and their protection.

The Humanitarian Assistance and Disaster Relief Group, established in the Homeland Protection and Air Traffic Control Division, will leverage Lincoln Laboratory's expertise in sensors, signal processing techniques, communication systems, and decision support tools to develop technology that can improve domestic and international humanitarian aid and disaster response efforts. The growing frequency of natural and man-made disasters and the economic and political disruptions caused by such crises have made humanitarian assistance and disaster responses vital elements in safeguarding both national and global security.

The Energy Systems Group, formed within the Engineering Division, will work with DOD, DHS, and the US Department of Energy (DOE) to develop systems, architectures, test beds, and prototypes that will offer new options for energy sources and solutions for the security and resilience of the nation's energy infrastructure.

The Cyber Security and Information Sciences Division established the Secure Resilient Systems and Technology Group and the Cyber Analytics and Decision Systems Group. These two new groups realign efforts and staff from former groups to address the government's increasing emphases on secure resilient systems, analytics, and decision support systems.

Programs addressing DOD needs for improved undersea surveillance and communications will be consolidated in the Advanced Undersea Systems and Technology Group, which will reside in the Air, Missile, and Maritime Defense Technology Division. This group will work with the US Navy and other sponsors to develop acoustic and nonacoustic sensors, autonomous vehicles, new signal processing techniques, and new system architectures.

Two groups within the Communication Systems Division were reshaped to direct emphasis to emerging challenges in communications and networking. Airborne and tactical networking activities are being strengthened with their consolidation under the direction of the new Tactical Networks Group. The Advanced RF Techniques and Systems Group will merge the division's efforts in radio frequency (RF) technology, spectrum operations, and wideband communications with work in adaptive communications and signals intelligence to broaden the scope of communications research and development.

Staff

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

Professional technical staff	1,779
Support staff (including technical support personnel)	1,539
Subcontractors	529
Total Laboratory employees	3,847

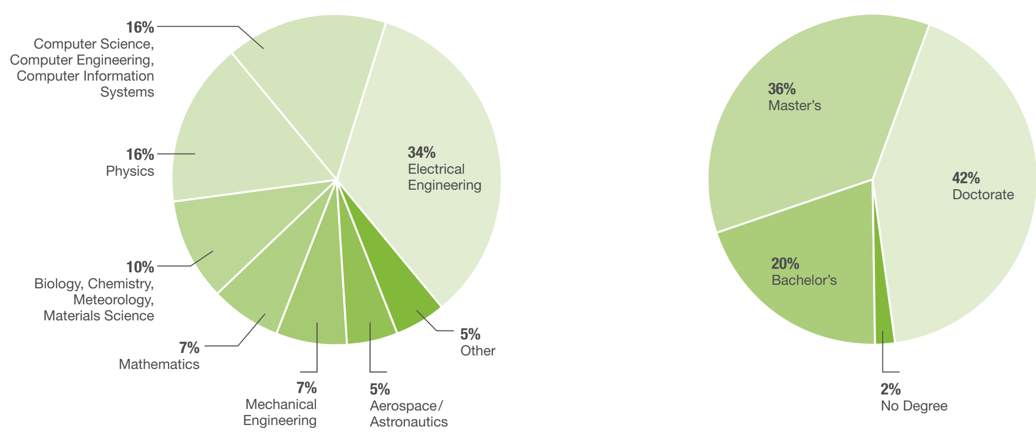

Figure 2. Composition of professional technical staff at MIT Lincoln Laboratory by (a) academic discipline and (b) academic degree.

Staff Honors and Awards

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

Dr. Eric D. Evans was elected to the National Academy of Engineering for his contributions to the engineering discipline. Election to the Academy, a nonprofit organization providing technical expertise to the US government, is one of the highest distinctions accorded to American engineers. Dr. Evans was also named a 2015 fellow of the American Institute of Aeronautics and Astronautics (AIAA) for "sustained and outstanding technical leadership in the application of advanced technology and system architectures to critical national security problems."

Dr. Marc D. Bernstein was named an associate fellow of the AIAA for contributions to the science or technology of aeronautics.

Dr. Keith B. Doyle received a 2015 SPIE Technology Achievement Award in recognition of "outstanding contributions to integrated analysis of optical systems." SPIE is an international society "advancing an interdisciplinary approach to the science and application of light."

Dr. William S. Song was elected a 2015 fellow of the Institute of Electrical and Electronics Engineers (IEEE) for "contributions in high-performance low-power embedded processors."

The 2014 MIT Lincoln Laboratory Technical Excellence Awards were presented to Dr. David O. Caplan for "his outstanding technical contributions to optical communications; leadership in developing advanced high-sensitivity optical transceivers for terrestrial and space-based applications; and innovations in multi-rate signaling formats and flexible free-space laser communication architectures," and to Dr. Vyshnavi Suntharalingam for "her deep technical knowledge of and contributions to the field of advanced imaging technology; creativity in developing silicon-based imagers, innovative charge-coupled devices, and active pixel sensors; and leadership of projects in imager design and fabrication that have had significant impact on Laboratory systems."

The 2014 MIT Lincoln Laboratory Early Career Technical Achievement Awards were presented to Dr. Matthew T. Cornick for his work in the development and operational support of a novel ground-penetrating radar and his exceptional analysis and project leadership skills, and to Dr. Hamed Okhravi for his development of a critical road map and associated analytical tools for cyber resiliency analyses of moving target systems.

Dr. William J. Blackwell and Dr. Adam B. Milstein received the 2014 MIT Lincoln Laboratory Best Paper Award for "A Neural Network Retrieval Technique for High-Resolution Profiling of Cloudy Atmospheres," published in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Vol. 7, No. 4, April 2014).

Dr. Mark S. Veillette, Dr. Haig Iskenderian, Dr. Marilyn M. Wolfson, Christopher J. Mattioli, Earle R. Williams, Eric P. Hassey, and Patrick M. Lamey received the MIT Lincoln Laboratory Best Invention Award for the development of offshore precipitation capability, for which a patent application was filed in May 2014.

Allison J. MacDonald and John E. Bilodeau received 2015 MIT Lincoln Laboratory Administrative Excellence Awards, and Heather A. Wilcox and Eric P. Carrera received 2015 MIT Lincoln Laboratory Support Excellence Awards.

2015 MIT Excellence Awards were presented to Dr. Robert K. Cunningham in the Bringing Out the Best category; to Joseph N. Masello in the Serving the Client category; and to Chiamaka O. Agbasi-Porter, Richard C. Gervin, and Dr. Marc A. Zissman in the Unsung Hero category. Two teams were given awards in the Innovative Solutions category: the Gulfstream GII APU Root Cause Investigation Team, Kenneth L. Burkett, Richard Coveno, Brandon J. Dilworth, Todd R. Lardy, Robert J. Longton, Robert L. Maynard, Kenneth S. McKenna, Christopher P. McNeil, Lance F. Michael, Todd M. Mower, Robert A. Murray, and Melissa S. Nelson; and the Lincoln Laboratory Prime Contract Team, Susan Dawson, Michael Greenidge, Daniel R. Kay Jr., Stephen P. Kent, Stephanie Leonardi, Kristin N. Lorenze, Patricia M. O'Riordan, Frank D. Schimmoller, David A. Shumsky, David Suski, and Steven Tran.

Dr. Mordechai Rothschild and Dr. David C. Shaver shared the 2015 Edwin H. Land Medal with Dr. Joseph Mangano of the Defense Advanced Research Projects Agency (DARPA). The award recognizes their contributions to the development of the argon fluoride excimer laser and modern, deep-ultraviolet photolithography for the semiconductor industry.

Michael L. Stern, a Lincoln Scholar pursuing an MEng degree at MIT, received the MIT Mechanical Engineering Department's 2015 Luis de Florez Graduate Design Award. This award is given for a research project that shows outstanding ingenuity and creativity.

The 2015 Nelson P. Jackson Aerospace Award was presented by the National Space Club to the Lunar Laser Communications Demonstration team, composed of members from NASA's Goddard Space Flight Center and MIT's Lincoln Laboratory. The award recognizes the team for "record-breaking achievement using broadband lasers for space communications."

Dr. Thomas F. Quatieri, Dr. James R. Williamson, Brian S. Helfer, and Gregory A. Ciccarelli of the Bioengineering Systems and Technologies Group, and Dr. Daryush Mehta of Massachusetts General Hospital, the team that developed technology for detecting depression levels from vocal and facial biomarkers, earned first place in a depression-estimation subchallenge at the 2014 Audio/Visual Emotion Challenge and Workshop.

Professional Development

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

The Human Resources Department coordinates programs in graduate education, technical education, professional leadership development, and computer and software training. For highly qualified candidates, the 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. In fiscal year 2014, 24 staff members were enrolled in the Lincoln Scholars program.

The part-time graduate studies program helps staff members to 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 or classes offered outside traditional work hours. 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 ones in computer networks, cryptography, and software engineering, can be taken independently or as part of a certificate or master's degree program. Since 2012, 113 Laboratory staff members have enrolled in BU's Master of Science in Computer Science program.

The technical education program offers semester-length courses taught by Lincoln Laboratory technical staff or by outside experts, often professors from MIT. The 2014–2015 schedule included the following courses:

- Advanced Robotics
- Defense System Analysis
- Developing Serious Games at MIT Lincoln Laboratory
- Electromagnetic Simulation Using CADFEKO
- Information Theory
- Introduction to Digital Signal Processing
- Introduction to Cyber Security
- Introduction to Radar Systems
- Laser Physics, Technology, and Applications
- Machine Learning
- Optical Engineering Overview
- Radio Frequency Design Techniques
- Theory and Methods of 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, and so on), programming, and technical software (MATLAB, Simulink, VMware, and so on) is offered on-site throughout the year.

The Technology Office coordinates an extensive program of seminars presented at the Laboratory by both in-house speakers and researchers from other universities and from industry. The seminars are chosen to reflect current and leading-edge trends in today's technology. The Technology Office Seminar Series invites today's leading scientists to present their ideas to Laboratory staff throughout the year. Highlights of the 2014–2015 seminar program included the following:

- "The Giant Magellan Telescope—An Overview and Status Update," Dr. Eric C. Pearce, Giant Magellan Telescope Project
- "CLARITY and Beyond: Tools for Integrated Brain Mapping," Professor Kwanghun Chung, Institute for Medical Engineering and Science, MIT

- "DOD Climate Change Technology Study Results," David A. Radue, Fabrication Engineering Group, Lincoln Laboratory, and Dr. Gary J. Rucinski, Homeland Protection Systems Group, Lincoln Laboratory
- "Progress, Prospects, and Challenges in the Water-Energy-Land Research Nexus Under Global Change," Dr. C. Adam Schlosser, MIT Center for Global Change Science
- "Electronic, Optical, and Magnetic Materials Platforms for Neural Recording and Interrogation," Professor Polina Anikeeva, Department of Materials Science and Engineering, MIT
- "MIT SuperCloud: A Unified System Architecture for the Internet of Things," Dr. Jeremy Kepner, Secure Resilient Systems and Technology Group, Lincoln Laboratory

Diversity and Inclusion

The Laboratory fosters an inclusive workplace that leverages and supports the talents and perspectives of the Laboratory's staff. Recruitment at a broad 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.

Mentorship Programs

Four formal mentoring programs were phased in during 2011–2012. The New Employees Guides, Early Career Mentoring, Circle Mentoring, and New Assistant Group Leader Mentoring provide employees with support during different stages of their careers. Since the program's inception, 1,338 individuals have participated in the programs; from July 1, 2014 through June 30, 2015, 420 people were engaged in the programs as either mentees or mentors. The mentoring programs enhance employees' professional development, help foster a welcoming environment, and contribute to the Laboratory's ability to retain a diverse workforce.

Employee Resource Groups

Employee resource groups at Lincoln Laboratory help create an inclusive environment. Currently, seven resource groups are active, engaging in professional development activities, volunteering at educational and charitable outreach programs, and providing support to members of the Laboratory community: Lincoln Employees with Disabilities, Lincoln Employees' African American Network (LEAN), Out Professional Employee Network, Lincoln Laboratory New Employee Network, Lincoln Laboratory Technical Women's Network, Lincoln Laboratory Hispanic and Latino Network, and Lincoln Laboratory Veterans' Network.

Diversity Events

On February 18, to commemorate Black History Month, LEAN hosted the Laboratory's second annual Martin Luther King Jr. Breakfast at the Minuteman Commons Community Center on Hanscom Air Force Base. Three keynote speakers addressed the question, "What does Dr. King's life and legacy mean to you?" The speakers were Dr. Edmund W. Bertschinger, Institute Community and Equity Officer at MIT; Dr. Shannon Roberts, a technical staff member in the Laboratory's Cyber Analytics and Decision Systems Group; and Ms. Alyce Johnson, Staff Diversity and Inclusion Manager at MIT. Among the 200 attendees at the breakfast were distinguished guests Colonel Christopher Faux and Lieutenant Colonel Thatcher Kezer, both of the Massachusetts Air National Guard, and Professor Raheem Beyah of the Georgia Institute of Technology, who later presented a seminar on computer password security. Also in February, MIT Professor Clapperton Mavhunga presented a talk entitled, "What Do Science, Technology, and Innovation Mean from Africa?" He discussed how Africans rely on traditional knowledge to acquire and make technology.

On March 12, during Women's History Month, Niaja Farve, a PhD candidate and researcher in the Fluid Interfaces Group at MIT's Media Lab, delivered a talk, "Wearable Applications for Improved Well-Being," that illustrated how wearable devices can positively affect people's behaviors and habits.

The National Graduate Education for Minorities Consortium

Through partnerships with universities and industries, the National Graduate Education for Minorities (GEM) Consortium provides support to students from underrepresented groups who are seeking advanced degrees in science or engineering. In August 2014, Eric Evans, director of Lincoln Laboratory and president of the GEM Executive Committee; Frank Schimmoller, a member of the Laboratory's executive staff and the vice president of finance for GEM; and William Kindred, the manager of the Laboratory's diversity and inclusion programs, attended the GEM annual board meeting and conference in San Diego. The GEM officers and partnering organizations discussed strategies for transforming how the United States is preparing the next generation of engineers and scientists. At the event, Schimmoller was honored with an award for Executive Committee Member of the Year, and Kindred was named an Employer Representative of the Year.

Technical Program Highlights

Research and development efforts at the Laboratory focus on national security problems in diverse areas: tactical, intelligence, surveillance, and reconnaissance systems; air and missile defense; space situational awareness; chemical and biological 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 for government agencies, including the FAA, NASA, and NOAA. 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 2014–2015, the Laboratory worked on approximately 720 sponsored programs that ranged from large-scale hardware projects to small seedling initiatives. Notable highlights for each mission area are listed below.

Advanced Technology

Electronics and Microelectronics

Lincoln Laboratory developed a novel photochemical process that is expected to enable the additive manufacturing of three-dimensional siloxane-based microfluidic devices, thus widely expanding the capabilities of biological and biomedical lab-on-a-chip applications.

First-generation, high-pixel-count, indium phosphide–based Geiger-mode avalanche-photodiode arrays were successfully fabricated with sizes of 256 × 128 (50 μm pitch) and 256 × 256 (25 μm pitch) pixels. This technology will enable wide-field-of-view system applications. A new micro-fuse technology was also developed and demonstrated on 256 × 256–pixel devices. Fuses integrated at the pixel level will provide chip-level robustness and enhance overall system reliability.

A coherent, two-channel microwave-photonic receiver was developed to downconvert microwave signals from X band to an intermediate frequency with a bandwidth of 1.1 GHz. The spur-free dynamic range of the microwave-photonic downconversion process was shown to be 20–30 dB better than that of a high-quality microwave electronic mixer.

Lasers

A new power record for coherently combined fiber laser systems was attained. A first-ever coherent combining of quantum-cascade lasers was also demonstrated.

Biological and Chemical Detection

Several engineering development units of the Rapid Agent Aerosol Detector (RAAD) were completed. RAAD may provide an upgrade to the Joint Biological Point Detection System, enabling improved performance and reduced maintenance in comparison with other bioaerosol triggers. Methods for real-time detection of vapors at concentrations of less than one part per trillion were developed and are being used to understand chemical-agent releases and to improve canine training in the detection of trace chemicals.

Radio Frequency Systems

Initial operation of the multifunction phased array radar (MPAR) was successfully demonstrated. MPAR is a prototype for the next-generation FAA and NOAA integrated air traffic control and weather radar system.

A simultaneous-transmit-and-receive system for look-through electronic attack was developed and demonstrated. The system provides more than 85 dB of transmit-to-receive isolation on a moving ground vehicle by employing a high-isolation antenna and adaptive RF and digital cancellation techniques.

Quantum Systems

The Laboratory fabricated superconducting qubits and achieved state-of-the-art performance in coherence times for both two-dimensional (35 microseconds) and three-dimensional (140 microseconds) transmon qubits.

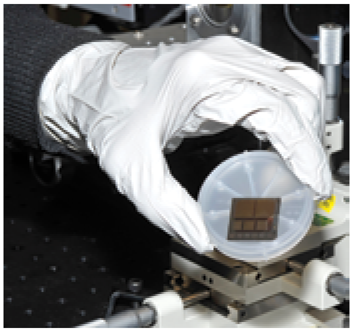

Figure 3. The liquid-crystal imager, shown here in various array formats, has the potential to achieve lower cost, better sensitivity, and greater pixel scalability than current microbolometer-based imagers.

Air and Missile Defense Technology

As Aegis Ballistic Missile Defense (BMD) advanced technology development agent, the Laboratory continues to work within the government team to help establish Aegis BMD system requirements and technology needs for future combat systems. The Laboratory is using the digital-pixel focal plane array in its development of an integrated dewar cooler assembly for potential use in future missile seekers. In leading the architecture engineering and analysis efforts for the command, control, battle management, and communications system requirements review, the Laboratory addressed the areas of track processing, sensor resource management, weapons coordination, and planning.

Under the optics modernization project for the Reagan Test Site (RTS), the improvements at two of the optical sites were completed; four of the five sites are now fully upgraded. The RTS Automation and Decision Support project and the telemetry modernization effort both underwent successful system requirements and preliminary design reviews.

The Laboratory continued to extend the capabilities of a test asset used by the Navy to serve as a surrogate for a threat missile seeker. The asset, integrated onto a Navy P-3 aircraft, is being used to support tests of new capabilities for countering anti-ship missile threats. The asset was used to collect data on multiple test campaigns conducted through the year. In addition, a new seeker front-end will be used in an assessment of capabilities for countering a land-attack missile.

The Laboratory's role in risk-reduction activities for a new solid-state S-band air and missile defense radar being developed by the Navy included prototyping and testing the radar's end-to-end ballistic missile defense discrimination architecture.

The Laboratory continued to assist the Navy in the checkout of the new E-2D Advanced Hawkeye airborne early-warning system and played a key role in the diagnosis and remediation of several problems discovered in data collections from the system design and development aircraft. The Laboratory is working with the contractor on modifications to address the problems and with the Navy on a set of future capabilities for the E-2D system.

A set of assessments related to the anti-access/area denial (A2/AD) problem was conducted for the Office of the Assistant Secretary of Defense for Research and

Engineering. These assessments included studies of options for defense of land bases, for ship defense, and for countermeasures to adversary capabilities.

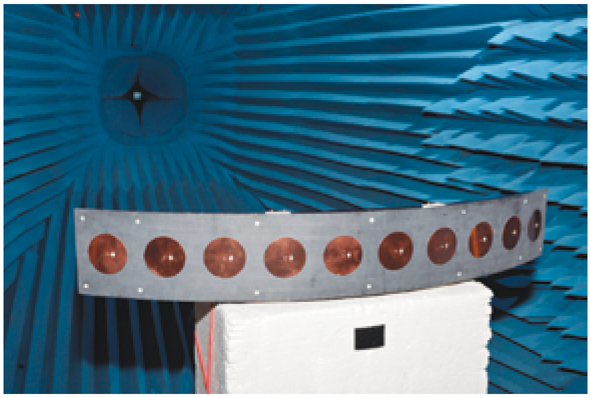

Figure 4. Lincoln Laboratory is investigating 3D printing techniques utilizing dielectric and metallic material deposition to create unique phased arrays, such as the two pictured here, for use in various mission applications. Potential uses include wing- and hull-mounted conformal arrays for aircraft and ships and extremely compact arrays for unmanned aerial vehicles and electronic warfare payloads.

Communication Systems

The Lunar Laser Communication Demonstration successfully achieved reliable communications between a satellite in lunar orbit and Earth. The link represents the longest laser communication link (385,000 km) and the highest-rate link (622 Mbps) achieved by a system flown to the Moon. All objectives were satisfied during the mission, validating Lincoln Laboratory's overall laser communications, system engineering, communications, and pointing–acquisition–tracking methodology.

The demonstration of active frequency control of distributed feedback laser diodes to better than ±20 MHz (root mean square) is helping enable the simplified design of high-sensitivity optical receivers. A high-fidelity laser communication terminal test bed that emulates free-space channel propagation effects and local platform disturbances will be used to verify link interface compliance and functional requirements in optical performance, acquisition, tracking, and communication.

A world-record 2-photon-per-bit sensitivity was demonstrated in an optically preamplified, coherent laboratory modem operating at 10 and 20 Gbps.

New network- and transport-layer protocols enabled efficient transport of data over communications links degraded by outages caused by mobility or jamming. The protocols increase throughput by a factor of 10 while maintaining the reliability of traditional networking protocols.

A flight demonstration showed the possibility of adapting emerging commercial satellite communications services to suit the needs of the Very Important Person Special Air Mission fleet while drastically reducing cost. The system enables rapid switching between military and commercial satellites without interrupting the user applications.

The Laboratory developed a prototype implementation of a dynamic-link adaptation capability for the advanced extremely high-frequency terminals that demonstrated significant benefits in throughput and robustness.

A series of flight tests characterized RF propagation over water at low elevation angles for airborne satellite surrogates and demonstrated viable operating ranges for this architecture.

Extensive performance measurements and functional testing of the Air Force family of advanced beyond-line-of-sight terminals on the 707 airborne test bed were conducted.

The Laboratory worked with DARPA to prototype an airborne communications radio architecture designed to enable the rapid insertion of new technology into future air-dominance applications

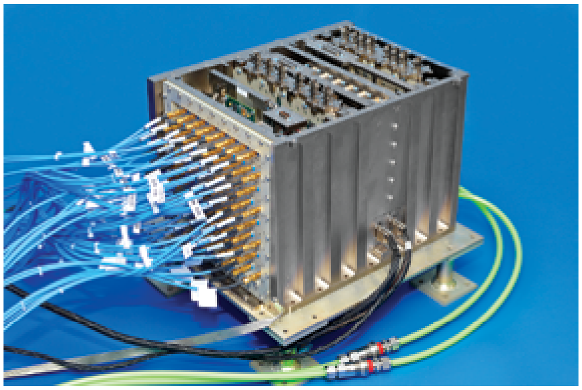

Figure 5. Lincoln Laboratory partnered with industry to design and build a space-qualified switch that will be transferred to NASA for the Laser Communications Relay Demonstration.

Cyber Security and Information Sciences

The Cyber Analytical Station was deployed to multiple Department of Defense Combatant Command Joint Cyber Centers. The technology provides operators with the ability to proactively identify and locate network threats, and increases the timeliness of the information while decreasing the number of analysts needed.

Lincoln Laboratory supported and hosted a series of realistic cyber offense and defense exercises to quantify the performance of newly formed Cyber Protection Teams and National Mission Forces. A new cyber range tool suite, released to the cyber testing and training community, significantly improves the ability to rapidly instantiate realistic range environments extending from enterprise to tactical levels.

In addition, the Global Pattern Search at Scale unstructured-data discovery tool was transitioned to the National Geospatial-Intelligence Agency. This tool enables analysts to discover events, causal factors, and sentiment trends without prior detailed knowledge of data content.

The Laboratory improved cyber security by accrediting the first-ever high-to-low multilevel security system based on data provenance.

A secure and resilient cloud test bed was established to measure and quantify technologies that can lead to secure cloud computing.

The new Lincoln Laboratory SuperCloud, a "green" computing center installed at Holyoke, Massachusetts, near a hydroelectric power station, offers world-class computing capabilities while providing economies in power consumption and cost.

The Laboratory developed the VizLinc system, an open-source software suite that integrates automatic information extraction, search, graph analysis, and geolocation for interactive visualization and exploration of large data sets, which include text, speech, video, and other data. VizLinc has been submitted to and included in the DARPA open-source software catalog for big data.

Lincoln Laboratory researchers presented a weeklong class on big data analytics and high-performance computing to analysts from the intelligence community. The class covered the fundamentals of handling large data sets, including methods for ingesting, validating, and optimizing the processing of large volumes of data.

The annual cyber Capture the Flag game held on the MIT campus expanded to 170 students representing 25 teams and nine universities, giving local-area college students the opportunity to learn about cyber security and cutting-edge research. This year's competition included defensive technology from DARPA's Clean-Slate Design of Resilient, Adaptive, Secure Hosts (CRASH) program

Figure 6. Lincoln Laboratory hosted a series of cyber defense tests for the United States Cyber Command and the Director of Operational Test and Evaluation. From across the country, more than 60 military personnel from active duty, reserve, and guard units assigned to the US Cyber Command's newly operational Cyber Protection Force and Cyber National Mission Force participated in the exercise.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

The Wide-Area Infrared System for Persistent Surveillance was deployed for airborne counterterrorism; ground- and ship-based systems were further developed for force protection. The Multi-Aperture Sparse Imager Video System for collecting wide-area motion imagery was augmented with improved onboard processing and reach-in exploitation tools to support active deployments. An immersive imaging capability was developed and deployed to support the Boston Police Department's event protection activities.

The Laboratory developed the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) three-dimensional ladar, which is designed to uncover clandestine activity in heavily foliated areas. The system's high area collection rates are enabled by dual 64 × 256 Geiger-mode avalanche photodiode arrays. MACHETE was integrated on a DHC-8 aircraft and underwent field tests before its transition to operations. The Laboratory developed the onboard and ground processing, including algorithms to facilitate timely exploitation of imagery.

Working with DARPA, the Laboratory supported the development of a distributed multiple-input, multiple-output radio for high-data-rate RF communications with low probability of exploitation. The Laboratory led work on an application-specific integrated circuit (ASIC) for a small-form-factor implementation of the radio. The ASIC should achieve world-class performance for communications applications, delivering more than 1.7 trillion operations per watt.

Alternative approaches to radar target detection and classification are improving detection probability and correct classification while lowering false-alarm rates. Electronic protection techniques were developed to improve radar detection, tracking, and imaging of surface objects.

The Laboratory developed automation and sonar signal processing algorithms for operational submarine, surface ship, and distributed undersea surveillance systems. Advanced tracking, association, and localization approaches improve operator situational awareness and effectiveness in high-clutter conditions.

An unprecedented 128 dB spur-free dynamic range was achieved for an analog-to-digital converter that uses digital linearization techniques. The system injects a special waveform into the input of the converter to remove high-order nonlinearities, and then employs digital nonlinear equalization to remove the remaining low-order nonlinearities.

Working with the intelligence community, Marine Corps, Army, and Air Force, the Laboratory developed advanced processing, exploitation, and dissemination software tools and open architectures. Red Team–Blue Team exercises assessed software operational effectiveness, and architectures for distributed common ground systems were prototyped and evaluated.

Figure 7. Lincoln Laboratory helped to define an open-systems architecture and supported the development of advanced algorithms for the US Air Force's Dismount Detection Radar (DDR) prototype. The DDR pod was integrated onto a Scaled Composites' Proteus aircraft and underwent development testing at the Mojave Air and Space Port and Edwards Air Force Base in southern California.

Tactical Systems

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

Technical assessments 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 inform the decision-making process for major export programs.

The Laboratory continued a detailed analysis of the impact of digital RF memory-based electronic attack on air-to-air weapon system performance. Results from flight testing, systems analysis, and hardware-in-the-loop laboratories have been used to improve US ectronic protection systems and to inform senior DOD leadership's decision making for future system capabilities and technology investments.

Overarching system assessments of the Air Force's family of systems architecture focused on protected communications; integrated intelligence, surveillance and reconnaissance, and strike capabilities; and mission effectiveness and survivability. Results of these studies were used in a series of way-ahead briefings for senior DOD leadership, who are using the information to develop the future acquisition strategy and concepts of operations.

The Laboratory continued to rapidly develop prototypes of advanced sensors and systems to counterinsurgency operations. A vector sensor developed to provide tactical geolocation capability from a man-portable, unmanned aircraft system successfully completed local testing and is transitioning to the operational community for evaluation outside the continental United States in fiscal year 2014. Also, a prototype low-frequency magnetic gradient sensor was integrated on multiple platforms for field-test evaluation, and a miniature, low-cost sensor system was flight tested for the Army on a Shadow unmanned aircraft system.

The Laboratory is developing advanced architectures and technologies for use in next-generation electronic attack systems for countering improvised explosive devices (IEDs). This year's activities culminated in field demonstrations and technology transition of a significantly advanced capability intended for use in future counter radio-controlled IED electronic warfare systems.

Two novel airborne signals intelligence capabilities were developed and demonstrated and an existing capability was upgraded. Robust prototypes for all three efforts were transitioned to operational use and the technologies are being transitioned to industry

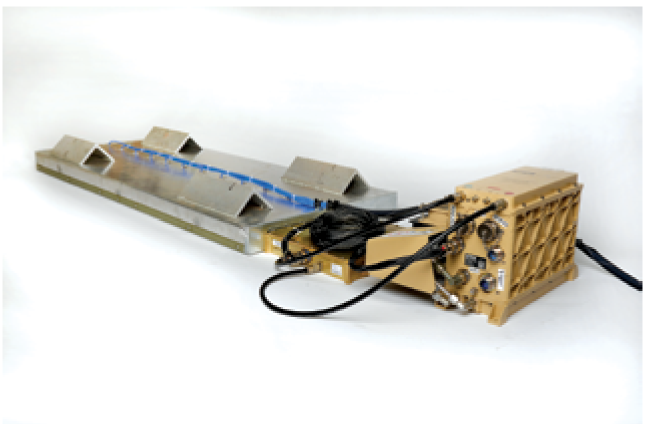

Figure 8. Lincoln Laboratory's robust localization sensor, the localizing ground-penetrating radar, provides real-time global-position estimates for autonomous vehicles even under adverse weather or road conditions. Seen here is the five-foot-wide radar antenna array (left-hand silver object). Attached on the right are the switch and the hardened chassis containing the radar electronics and computer.

Space Control

The 3.5-meter Space Surveillance Telescope has been providing data on the deep-space debris environment. The telescope recently completed a military unit assessment for the US Air Force. Efforts are under way to develop a data-reduction pipeline for NASA's asteroid and minor-planet discovery missions.

Integration and testing of the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) were completed. After a successful Air Force Space Command operational trial period, HUSIR became the most recent addition to the US Space Surveillance Network. With its new 8 GHz bandwidth and 3 mm wavelength W-band capability, HUSIR is now the highest-resolution imaging radar in the space surveillance network, supporting the US Strategic Command's space situational awareness mission.

In support of NASA's orbital debris measurement program, two of the Lincoln Space Surveillance Complex radars—the HUSIR X-band radar and the Haystack Auxiliary (HAX) Ku-band radar—provided high-precision metric data on very small (5 mm to 10 cm) debris in a large number of orbital regimes. More than 1,000 hours of data collected from HAX were used to update the orbital debris size distribution model. Data collected from HUSIR were transferred to NASA's Orbital Debris Office at the Johnson Space Center for validation and application.

Initial steps were taken to transfer technologies and concepts developed under the tactical space situational awareness initiative to the Joint Space Operations Center of the Joint Forces Combatant Command. This initiative integrates operational space surveillance sensors and the Laboratory's sensor technology programs in a net-centric, multisensor fusion, foundational architecture as a prototype tactical space command-and-control system. Tactical handoffs from optical search sensors to radars and tactical custody of high-interest space objects are routinely demonstrated as part of the initiative.

The Laboratory continued to transition technology and to provide technical expertise to the Joint Space Operations Center Mission System acquisition program, which is delivering a modernized, net-centric command-and-control system to enable multiple Joint Space Operations Center missions in support of the US Strategic Command and its combatant commanders.

Lincoln Laboratory, jointly with the MIT Space Systems Laboratory, developed, tested, and delivered for flight a 30 × 10 × 10 cm CubeSat carrying a nine-channel passive microwave radiometer. This CubeSat, the Micro-sized Microwave Atmospheric Satellite, is a compact, low-cost, low-power system that was deployed from the International Space Station in March 2015 to begin a demonstration flight.

Figure 9. The tactical space situational awareness initiative is utilizing the Space Surveillance Telescope (above, inset) and the Haystack Ultrawideband Satellite Imaging Radar and Millstone Hill Radar (above) to demonstrate data fusion and sensor handoff approaches for improving the timeliness of the US Space Surveillance Network, with the objective of achieving tactical command-and-control responsiveness.

Homeland Protection

Bioengineering and Chemical and Biological Defense

The Laboratory continues to lead technology and architecture development for countering chemical threats and weapons of mass destruction. Accomplishments include threat phenomenology and measurements, gap and technology analysis, and design and testing of new capabilities for warfighters and the homeland.

Working with the US Army Research Institute of Environmental Medicine, the Laboratory is developing advanced physiological monitoring sensors, signal processing algorithms, and open architectures that will reduce heat casualties, noise-induced hearing loss, and musculoskeletal load injuries in service members. In partnership with the institute, the Laboratory successfully demonstrated the first phase of ultralow-power, wearable physiological monitoring systems, including signal processing algorithms and tactical communications.

Lincoln Laboratory developed a helmet-worn, acoustic-environment dosimeter with world-class dynamic range. The successful fielding of the device by the US Marine Expeditionary Rifle Squad in Afghanistan resulted in the DOD's first high-fidelity quantification of warfighters' noise exposure on the battlefield.

The Laboratory's neurocognitive team won an international competition for the estimation of depression severity from audio and video recordings. This win highlighted the efficacy of the Laboratory's speech processing tools for psychological health assessments on the basis of phoneme-dependent speaking rate and lack of coordination of vocal tract articulators.

A prototype forensic DNA measurement and analysis technique was developed that utilizes next-generation DNA sequencing to reliably identify a suspect in complex, multiple-contributor sample mixtures.

Homeland Defense

Advanced video analytics technology and related software platforms for hosting on-demand video analytics being developed for DHS are targeted at mass transit, border security, and cross-jurisdictional urban applications.

Figure 10. Protective equipment for avoiding heat casualties from chemical, biological, radiological, nuclear, and explosive threats is field tested with the Massachusetts National Guard 1st Civil Support Team at Hanscom Air Force Base.

In collaboration with the Federal Emergency Management Agency (FEMA), the Laboratory is creating serious-gaming technologies to improve the effectiveness of FEMA's disaster-response preparedness exercises. Key areas include game development and quantitative assessment of players' decision performance.

The Laboratory prototyped and demonstrated an incident command system for enhanced US Coast Guard collaboration and response in port environments.

The Laboratory provided systems analysis and architecture assessment support to the DHS Science and Technology Directorate Homeland Security Advanced Research Projects Agency. This support focused on informing technology investment directions, strategies, and risk-reduction needs for priority missions.

Air Traffic Control

System studies and antenna panel development to mitigate risks associated with cost and performance continued for the multifunction phased array radar. The Laboratory constructed a 10-panel prototype array that was integrated into a demonstration radar to quantify dual-polarization performance for weather observations and to refine system requirements. On behalf of the FAA, the Laboratory also conducted a feasibility study of a complementary secondary surveillance phased array radar. Use of modern digital processing techniques and a relatively small, low-cost sparse array would enable performance equaling or exceeding that of today's rotating secondary surveillance radars.

In a follow-up to the successful deployment of the Route Availability Planning Tool (RAPT) at several airports in major US cities, other decision support technologies are being developed to aid in arrival route management and to improve the accuracy of airport acceptance rates used in establishing traffic management initiatives.

The NextGen Weather Processor (NWP) consolidates multiple legacy FAA weather processing platforms and introduces new functionality, such as a zero-to-eight-hour thunderstorm-forecasting technology developed by Lincoln Laboratory. The Laboratory is leading efforts to define requirements for NWP, to develop a reference technical architecture, and to provide technical evaluations of industry proposals. This year, core acquisition documentation was delivered in support of the source-selection process.

Lincoln Laboratory continues to play a key role for the FAA in developing the NextGen Airborne Collision Avoidance System, ACAS X, which will support new flight procedures and aircraft classes. Data from flight tests of an ACAS X prototype are being utilized in the development of standards and international harmonization requirements.

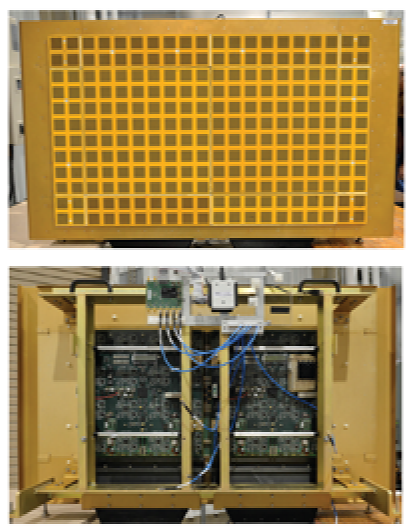

Figure 11. These photos show the front (top) and back (bottom) views of the 128-element dual-polarization multifunction phased array radar. Lincoln Laboratory is currently building a mobile demonstration radar with a 640-element array that will be deployed for field testing.

Analyses are being conducted to guide the FAA on wind information needs for a range of NextGen applications, including four-dimensional trajectory-based operations and interval management. Opportunities for near-term aircraft operational improvements to mitigate environmental impacts are also being identified.

The Laboratory is developing standards and algorithms for unmanned aircraft system sense-and-avoid capabilities for DOD, DHS, and FAA. This year, accredited modeling and simulation analyses were delivered to the Navy to support their airborne sense-and-avoid systems safety case. The Laboratory also led a technical study to develop the unmanned aircraft system "well clear" separation standard, a key requirement for unmanned aircraft sense-and-avoid systems.

Lincoln Laboratory developed and transferred algorithms to perform automated microburst detection, as well as icing and hail hazard identification, for the NextGen Radar weather-sensing radar system.

Engineering

In partnership with the MIT Kavli Institute for Astrophysics and Space Research, Lincoln Laboratory began the flight hardware development phase of the Transiting Exoplanet Survey Satellite (TESS), selected for launch in 2017 by NASA. The Laboratory is building the four telescopes and focal planes for TESS, which will map out the entire sky in search of exoplanets.

Work began on developing rapid perception and planning solutions for a novel low–size, weight, and power (SWaP), high-speed sensor for small unmanned aerial vehicles flying in crowded environments at low altitude. In addition, a new ground vehicle test bed was built with several state-of-the-art sensors, including a novel localizing ground-penetrating radar.

Continuing to support the development and demonstration of intelligent power management for future tactical microgrids, the Laboratory designed and built prototype microgrid power distribution hardware that will be integrated into its forward operating base microgrid test bed. The test bed, which was expanded to include applications for tactical energy storage, will be used to demonstrate power-management architectures that increase energy security and efficiency on the battlefield.

The Laboratory's work with the MIT Department of Aeronautics and Astronautics on developing the micro-sized microwave atmospheric satellite included testing and integration of the satellite, which was delivered to the International Space Station in July 2014.

The use of additive manufacturing was expanded to applications for numerous programs, including airborne and space payload developments. One development was the Variable Airspeed Telescoping Additive Unmanned Air Vehicle, constructed almost entirely with parts produced by a three-dimensional printer.

The Laboratory continued to invest in cutting-edge fabrication and electronic assembly tools, including a fatigue-testing machine for characterizing advanced materials, diamond turning tools for the fabrication of precision mechanical and optical parts, an automated pick-and-place machine for creating circuit boards, and an advanced X-ray inspection tool.

The fourth annual Mechanical Engineering Technology Symposium was held at Lincoln Laboratory in September 2014. Sessions focused on advanced materials, additive manufacturing, integrated engineering analysis, environmental testing, and microsatellite mechanical design. Laboratory presentations described work performed under the engineering technology initiative on topics such as integrated optomechanical analysis, pyrotechnic shock testing, laser vibrometry, and the mechanical behavior of additive metals.

Figure 12. The Laboratory's new ground vehicle test bed is supporting current and future unmanned autonomous systems work in localization, perception, and mapping. A novel Lincoln Laboratory–designed localizing ground-penetrating radar positioned under the vehicle enables three-centimeter-level real-time localization to a prior map at travel speeds of up to 60 mph. A lidar mapping sensor, camera, and dual differential global positioning systems were also integrated into the mobile test bed to provide accurate mapping and localization capabilities.

Technology Transfer and Knowledge Exchange

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 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. In fiscal year 2014, the Laboratory's technology transfer activities included the following.

Communication Systems

The Advanced Extremely High-Frequency Interim Command and Control terminals were transitioned to operation by subcontractors and will be transferred to military operators. The Laboratory continues to transfer design elements of the compact airborne laser communications terminal to industry.

Homeland Protection

The NextGen Incident Command System, developed with the California Department of Forestry and Fire Protection and sponsored by the DHS Science and Technology Directorate, was deployed to more than 400 first-responder organizations.

Air Traffic Control

The Route Availability Planning Tool, a decision support technology that improves the management of flight departures at airports during thunderstorms, was installed at additional sites. Initially deployed at New York and New Jersey airports, RAPT has since been transferred for operational use in the Chicago, Philadelphia, and Potomac terminal areas.

Lincoln Laboratory is supporting the transition of a prototype ground-based sense-and-avoid system to the US Army for a 2015 initial operating capability. Future technology insertion and technology transition will be supported on a yearly basis.

Engineering

Following an extensive hardware and software development effort and the associated environmental qualification of the Rapid Agent Aerosol Detector (RAAD) system, the Laboratory delivered five prototype systems to the Army sponsor. RAAD provides a robust, reliable capability for identifying the presence of biological agents in ambient air. Transfer of RAAD’s design may lead to industry’s rapid production of future systems.

Technical Workshops

The 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 FAA and held in Washington, DC)

In addition, Lincoln Laboratory is a technical partner for the IEEE High Performance Extreme Computing Conference, the IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference, and the IEEE International Symposium on Technologies for Homeland Security.

Publications

Knowledge dissemination is also achieved through publications. Technical staff members publish articles in peer-reviewed journals and make presentations at national technical conferences, such as the IEEE Military Communications Conference and the International Conference on Acoustics, Speech, and Signal Processing. Between July 1, 2014, and June 30, 2015, Lincoln Laboratory staff published 79 papers in proceedings from such conferences and 61 articles in technical journals. The Laboratory also supplies sponsoring agencies with technical reports, some of which are available through DOD's 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 fall 2014, a special issue on the Haystack radar facility was issued to celebrate Haystack's 50th anniversary. In addition to historical overviews of the contributions that the Haystack radar system and MIT Haystack Observatory have made to national security and astronomy, the issue covered the extensive upgrade that converted Haystack from an X-band system to one that has both X- and W-band capabilities. This new system, the Haystack Ultrawideband Satellite Imaging Radar, is the highest-resolution, long-range space-object characterization radar in the world.

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 for the Army's Training with Industry program, or who are working toward advanced degrees. This program helps the Laboratory establish cooperative relationships with military officers and allows researchers to gain constructive insight from the frontline experiences of the officers who are assigned to technical programs within the Laboratory. In 2014–2015, 38 military officers worked at the Laboratory under fellowships. In addition, in summer 2014, 35 midshipmen from the US Naval Academy, four cadets from the US Air Force Academy, 14 cadets from the US Military Academy at West Point, and one cadet from the US Coast Guard Academy participated in an educational exchange program at the Laboratory.

University Student Programs

Lincoln Laboratory offers a variety of research and internship opportunities to university students. Candidates in MIT's VI-A Master of Engineering Thesis Program may 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 Laboratory engineers and MIT faculty. In spring 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, usually during the summer, the Laboratory employs students participating in MIT's Undergraduate Research Opportunities (UROP), SuperUROP, and Undergraduate Practice Opportunities programs; in summer 2014, 16 students worked under these programs.

Each summer, the Laboratory hires undergraduate and graduate students from top universities as interns in technical groups. In summer 2015, 235 undergraduates and graduate students from 79 different schools worked at the Laboratory. Throughout the year, cooperative-education students from area colleges, such as Northeastern University and Wentworth Institute, work at the Laboratory. Between fall 2014 and spring 2015, 42 cooperative-education students from area schools were employed in technical divisions and service departments.

Collaboration with MIT Campus

Initiatives supported by MIT campus and Lincoln Laboratory promote research collaborations, foster knowledge exchange, and enhance professional development. Below are some of the cooperative initiatives that strengthen research at both institutions.

MIT Lincoln Laboratory Beaver Works Center

The Beaver Works is a joint venture between Lincoln Laboratory and the MIT School of Engineering that is envisioned as an incubator for research and innovation. The Beaver Works 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.

Lincoln Laboratory has been engaged in ongoing collaborations with departments and centers at MIT to provide project-based educational experiences to undergraduate and graduate engineering students. The Beaver Works has a 5,000-sq-ft center in Technology Square in Cambridge, Massachusetts, where areas for collaborative brainstorming, workshops and tools for the fabrication of prototype systems, and space for classroom-style instruction are offered. The Beaver Works supports student involvement in a range of research and educational pursuits, including two-semester, course-based capstone projects; joint and individual research initiatives; and UROP internships.

In fall 2014 and spring 2015, two Beaver Works capstone courses were conducted:

- Mobile Tactical Power Systems (Engineering Systems Design and Engineering Systems Development, offered by the Department of Mechanical Engineering). The course challenge was to develop novel energy options that reduce or eliminate a logistics burden faced by deployed military units: the transport of diesel fuel to power generators at forward bases.
- Environmental Awareness in the Maritime Domain (for credit as either the Department of Aeronautics and Astronautics' Flight Vehicle Engineering course or the Department of Mechanical Engineering's Engineering Systems Design and Development course). This cross-department project is to design, build, and demonstrate an autonomous seaplane along with a buoy system that recharges

batteries and exchanges data. This buoy will enable the seaplane to accomplish long-endurance surveillance operations in marine environments.

The Beaver Works center has become a popular venue used by many MIT classes and programs. The fabrication areas offer ready access to tools and high-tech equipment, such as three-dimensional printers and a laser cutter, that support hands-on construction of prototypes by students not only from the engineering departments but also from groups such as the MIT Robotics Club and the MIT UAV Club.

In January, Independent Activities Period activities led by Lincoln Laboratory staff were conducted at Beaver Works. In the "build" space, students assembled small radar systems and laser transmitters. In the classroom, instructors led participants through an innovation workshop and holography demonstrations. Open areas were excellent places for students to collaborate on developing software for an autonomous racecar and a GPS receiver.

On February 28, approximately 70 MIT undergraduate and graduate students participated in the Assistive Technologies Hackathon (ATHack) at Beaver Works. Teams of students, who had in the weeks preceding ATHack met with local people who live with disabilities, prototyped engineering solutions to problems faced by their "clients," creating such devices as a voice-activated cane and a hands-free walker.

The Beaver Works is also extending project-based learning opportunities to local schoolchildren in grades from kindergarten through high school (K–12). Between fall 2014 and spring 2015, nine groups were involved in different science, technology, engineering, and mathematics (STEM) programs held at the center. Among these offerings have been a one-day build-a-radar workshop directed by instructors from the Lincoln Laboratory Radar Introduction for Student Engineers; weekly practices for the Lincoln Laboratory teams that participate in the national CyberPatriot computer network security challenges; and an ongoing mentorship program with the Community Charter School of Cambridge.

Research Collaborations

There are multiple mechanisms for direct support of and collaboration with MIT campus researchers. Campus Collaborations are three-year renewable grants to MIT faculty and research staff working on topics of relevance to Lincoln Laboratory's primary mission areas. These grants are intended to foster the development of long-term working relationships between Laboratory staff and other MIT researchers. In addition, 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. Collaborative mission-focused projects are also supported directly from funding from the Assistant Secretary of Defense for Research and Engineering as well from external program sponsors in DOD, DOE, NASA, and other government agencies.

Infrastructure

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

The Contracting Services Department supported the Laboratory's federally funded research by issuing more than 51,000 procurement transactions with a value of $384.4 million in fiscal year 2014 and more than 41,000 procurement transactions with a value of $419.5 million through the first three quarters of fiscal year 2015. To maximize business process efficiencies, the Laboratory encouraged the use of electronic procurement tools; between July 2014 and June 2015, staff who were not in the Contracting Services Department directly placed approximately 34,000 of the procurement transactions through the use of eCatalogs and electronic procurement cards.

The Contracting Services Department and its supporting Prime Contract Team members renewed the Lincoln Laboratory's prime contract between MIT and the Air Force. The contract term covers a five-year base period, with an option for an additional five years. The total ceiling amount for the contract, including the option, is $8.3 billion.

Lincoln Laboratory nominated Metateq as the US Small Business Administration's (SBA) Small Business Subcontractor of the Year. Metateq was selected as the SBA Region 3 2015 Small Business Subcontractor of the Year.

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 2015, as part of its annual capital investment program, the department completed an upgrade of the Laboratory's gas and chemical storage facility. This upgrade included outfitting the building with up-to-date ventilation and air conditioning systems, replacing the roof, and making numerous improvements to the functional layout of the facility. Under the deferred maintenance program, the department executed more than $8 million of project work that was primarily focused on upgrading outdated infrastructure systems throughout the aging facilities.

Lincoln Laboratory entered into an agreement with SunEdison to provide a photovoltaic solar array on the roof of the main parking garage. Design for the project was initiated; installation will be completed in fiscal year 2016. The solar array will produce in excess of 1 million kilowatt hours per year and provide an estimated first-year savings of $60,000. The installation will also be utilized by Laboratory groups in ongoing research on solar power.

The Facility Services Department also manages the Laboratory's transportation services and commuter support programs. In 2015, Lincoln Laboratory received a Massachusetts Excellence in Commuter Options Award from MassCommute, a nonprofit organization promoting transportation options that reduce carbon emissions.

In 2015, the Information Services Department (ISD) executed its strategic plan and continued its migration to an IT-as-a-service and a service-catalog model. The department deployed Laboratory-wide service and infrastructure enhancements, including major cyber security improvements. The department also expanded its focus on service delivery and relationship building across the Laboratory through partnerships with the research divisions. Key business systems and processes were also upgraded to accommodate major new requirements and to streamline administrative support across the Laboratory.

Key information services were improved through a number of major initiatives:

- Contract transition—Production roll-out of modifications for the SAP-based financial and business support systems incorporated requirements of the Laboratory's new base contract.
- SAP Supplier Relationship Management procurement module—A major upgrade and improved business processes were completed.
- Business Applications Governance Board—This new governance board, chaired by the assistant director for operations, was established to oversee investment prioritization for the Laboratory-wide portfolio of business applications.
- Core laboratory network—A comprehensive refreshing of the Laboratory's core network and cyber security systems was executed. The equipment upgrades provide next-generation capabilities for a robust, secure network environment.
- Network security design—In collaboration with Laboratory researchers, ISD developed an innovative approach to network segmentation to provide enhanced security and efficiency of the network.
- Asset management—The IBM Endpoint Manager was deployed to enable Laboratory-wide cyber security situational awareness and consistent hardware and software inventories of IT computing assets.
- Service catalog portal—An overall catalog of ISD services was developed to provide a customer-focused viewpoint for the Laboratory community.
- Intranet search tool—A new tool developed and deployed by ISD successfully aggregates data from multiple repositories within the Laboratory environment.
- Document management—A parallel instance of the Laboratory's document management system was created to handle classified material; a complete research-division repository was migrated to the new system.
- Embedded system administrators—A program was initiated to embed ISD systems administrators within each research division to assist with IT security compliance and to maintain a better understanding and tracking of customer environments.

The Security Services Department led the effort that earned Lincoln Laboratory its ninth consecutive "Superior" security rating from the US Air Force's 66th Air Base Group Information Protection Office. In calendar year 2014, security services successfully prepared MIT Lincoln Laboratory groups for 35 government security-related reviews conducted by multiple government agencies.

The Security Services Department strengthened its program at the Laboratory by accomplishing the following strategic goals:

- Led an effort to comply with Defense Federal Acquisition Regulation Supplement 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 standards.
- Earned an average customer service rating of 9 out of 10 on the basis of more than 70 interviews conducted with a wide range of personnel throughout the Laboratory.
- Partnered with ISD to deploy the IBM Endpoint Manager on all systems connected to the Lincoln Laboratory local area network. This enterprise initiative will facilitate the visibility of the system patch status and lower the risk of data loss.
- Responded to numerous high-visibility information security incidents, including the US Office of Personnel Management data breach, Heartbleed, and Shellshock.
- Facilitated and coordinated the issuance of replacement government credentials for the Laboratory community to maximize effectiveness and security of MIT research.
- Improved efficiency and execution by leveraging technology, automation, and process improvements to further enhance the delivery of quality services, such as automated emails to manage the Common Access Card and Defense Biometric Identification System credential issuance processes.
- Provided security support to enable the success of several high-profile, large-scale Laboratory-hosted conferences and sponsor-requested technical review days, accommodating more than 10,800 visitors.
- Planned and executed the sixth Security Education and Awareness week; this year's activities emphasized insider threat indicators, counterintelligence awareness, information security best practices, and operations security.
- Continued to strengthen the Laboratory's emergency preparedness program by hosting multiple active threat seminars, an insider threat tabletop exercise, suspicious package trainings, a cyber security exercise, force protection condition change drills, and a natural disaster tabletop exercise.
- Improved Lincoln Laboratory's line management awareness in several key business areas as a result of creating service dashboards; examples include dashboards for security clearance and commercial background investigation processing.

Community Outreach

Education

Recognizing the importance of preparing young people for STEM careers, Lincoln Laboratory Community Outreach (LLCO) administers a significant program of STEM activities. Highlights of 2014–2015 educational outreach included the following activities.

In summer 2015, the Lincoln Laboratory Radar Introduction for Student Engineers program provided 18 soon-to-be high-school seniors from across the country with 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. For the duration of the program, students were housed in a dormitory at MIT. On campus, they attend sessions to learn more about the college application and financial aid processes. Trips to the Laboratory's radar field site in Westford, Massachusetts, and to Boston attractions round out the students' experience.

Lincoln Laboratory Cipher is a new program that offers high-school students an introduction to cryptography. This week-long program was conducted by members of the Laboratory's technical staff in August 2015 at the Beaver Works facility in Cambridge, Massachusetts.

This year, 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. At the end of this year's competition season, one of these teams was the New England Regional Champion.

Through Lincoln Laboratory's robotics initiative, Robotics Outreach at Lincoln Laboratory (ROLL), technical staff members continue to mentor teams in the US For Inspiration and Recognition of Science and Technology (FIRST) competitions. Lincoln Laboratory sponsored two teams in the FIRST Tech Challenge competitions, which are geared to participants in grades 7 to 12. The Laboratory coached 12 teams that engaged in the FIRST Lego League challenges, which are designed for children in grades 4 to 8. Youngsters in kindergarten to grade 3 can explore the activities offered by the Junior FIRST Lego League program; three teams in this category were guided through model building by Laboratory mentors. In addition, ROLL volunteers assisted FIRST teams from schools in Boston, Waltham, Lexington, Weston, and Shrewsbury, Massachusetts, by providing technical guidance and staging scrimmages.

Figure 13. At the Science on Saturday robotics demonstrations in January, attendees watched how small robotic systems performed a series of tasks on a tabletop course.

Science on Saturday, the Laboratory's first STEM program, is still drawing 700 K–12 students, parents, and teachers to each of the five annual science demonstrations given by technical staff members during the academic year. This year, Science on Saturday went on the road to present a demonstration of radar technology to attendees at the STEM Fair at the Lilla G. Frederick Pilot Middle School in Dorchester, Massachusetts. Other offerings for the 2014–2015 season were a hands-on engineering fair and demonstrations on robotics, computer security, electricity, ions, and chemistry.

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.

The Laboratory's other established educational outreach programs—internships for six high-school students, engineering workshops for middle-school-age girls, and the Ceres Connection, which names asteroids in honor of science fair winners—are all continuing.

Community Service

The LLCO helps increase Laboratory employees' awareness of events sponsored by charitable organizations. Laboratory participants in the 2014 Memory Walk for the Alzheimer's Association raised more than $36,562 to provide services to patients in Massachusetts and New Hampshire. In addition, a team of cyclists raised approximately $9,000 in the Ride to End Alzheimer's, which kicked off in Devens, Massachusetts, on July 12. LLCO again facilitated participation in the September 2014 Bike and Hike the Berkshires event, which raises funds for the Multiple Sclerosis Society; $7,420 was raised by the bike and hike team. 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, the CancerCare walk, and the Harbor to Bay bicycle ride for AIDS. Five Laboratory bicyclists 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 300 toys were donated by Lincoln Laboratory employees to the MIT Federal Credit Union's annual drive for Toys for Tots. Support Our Troops, one of the LLCO's first community-giving programs, is an ongoing campaign to collect and mail food, toiletries, and books to US soldiers overseas; this year, program volunteers sent approximately 200 "care" packages to 35 troops.

Summary

Lincoln Laboratory's research and prototype development continued to address Department of Defense needs effectively. Emerging national concerns are driving research and development in new areas such as cyber security, autonomous systems, energy, undersea systems, and humanitarian assistance and disaster relief. The Laboratory's range of programs is well balanced with system development in the core missions, innovative research projects within the technical groups, and large-scale interdivisional programs. 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 support the Laboratory's ability to achieve technical excellence in its work.

Lincoln Laboratory's educational outreach program is committed to helping prepare the next generation of scientists and engineers and is seen as part of the Laboratory's national security mission. Lincoln Laboratory employees are also encouraged to become involved in charitable activities that provide needed resources to local communities and organizations. The Communications and Community Outreach Office works to facilitate opportunities for employees to participate in both educational and community outreach events.

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

Eric D. Evans
Director