Director, Lincoln Laboratory

Lincoln Laboratory is a US 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.

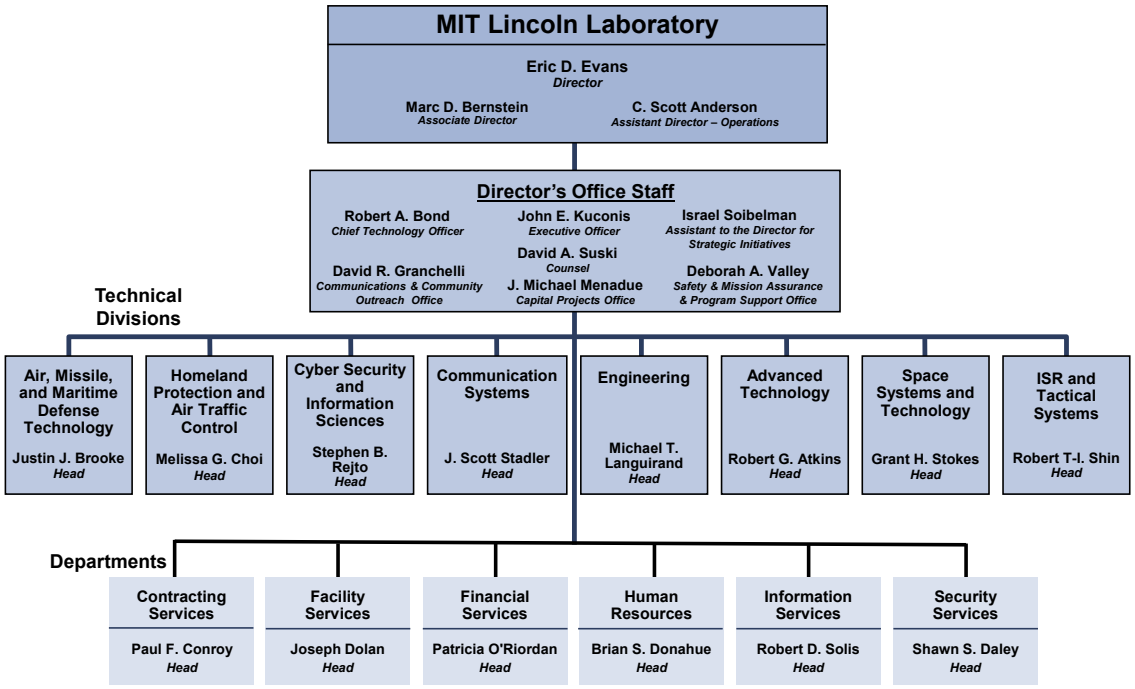
Lincoln Laboratory's mission is to develop technology in support of national security. Research and development conducted at the laboratory covers a broad range of domains, including space control, air and missile defense technology, cyber security, communication systems, bioengineering, maritime defense technologies, microelectronics, air traffic control, and intelligence, surveillance, and reconnaissance. The laboratory's strengths and deep experience in sensors and information extraction (signal processing and embedded computing) are applied to all these domains, as well as to new areas, such as energy and humanitarian assistance and disaster relief. The laboratory focuses on creating prototypes of new technologies and capabilities to meet DoD needs that cannot be met as effectively by existing government or contractor resources.

Lincoln Laboratory is continually leveraging its expertise to meet new challenges presented by the evolving needs of the nation and its military forces. In the past year, the laboratory undertook programs to develop technologies that the US Navy will use for maritime defense, investigated microgrid technology as a solution to protecting the critical electrical infrastructure, demonstrated the navigational capability of the largest-to-date swarm of small autonomous aircraft, and extended the range and data rate of laser communication systems. The establishment of the Lincoln Laboratory Supercomputing Center—and the acquisition of a new petaflop-scale supercomputer that consists of 41,472 processor cores and can compute 10^{15} operations per second—enabled researchers from across all the laboratory's divisions to tackle problems requiring the processing of massive amounts of data. Technical staff from the Cyber Security and Information Sciences Division are helping US Cyber Command develop an architecture for the nation's critically important cyber operations. To further its research into technologies designed to improve soldier fitness and resilience to injury, the laboratory opened the Sensorimotor Technology Realization in Immersive Virtual Environments Center, a world-class immersive virtual reality dome that allows researchers to assess prototype biomedical sensors under simulated real-world conditions. More highlights of this year's research and development work are presented later in this report.

For the fiscal year July 1, 2016, to June 30, 2017, Lincoln Laboratory received approximately $858 million in total funding to support the efforts of 1,823 professional technical staff members, 1,712 technical and administrative support personnel, and 516 subcontractors. Although 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 US Department of Homeland Security (DHS), and the National Oceanographic and Atmospheric Administration (NOAA). Lincoln Laboratory also carries out noncompetitive research with industry under approved cooperative research and development agreements with government agencies and other collaborative activities with academic institutions.

Organization

Lincoln Laboratory's three-tiered organizational structure—Director's Office, divisions and departments, and groups—encourages interaction between staff and line management. Sponsors' interest in conducting research into 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.



Lincoln Laboratory's organizational structure as of July 1, 2017.

Leadership Changes

In the Technology Office, Robert A. Bond was named Lincoln Laboratory's chief technology officer. Prior to this appointment, he was the associate head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division. Deborah J. Campbell was appointed an associate technology officer; she formerly was a member of the technical staff in the laboratory's Chemical and Biological Defense Systems Group.

Katherine A. Rink was appointed associate head of the Air, Missile, and Maritime Defense Technology Division; she previously served as an assistant head in the division.

Richard M. Heinrichs was appointed assistant head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division; before this appointment, he completed an Intergovernmental Personnel Act assignment at the Defense Advanced Research Projects Agency (DARPA) and served as the leader of the Active Optical Systems Group within this division.

Advanced Technology Division: William D. Oliver was named a Lincoln Laboratory Fellow within the Quantum Information and Integrated Nanosystems Group of this division. He was recognized for his exceptional technical achievements in quantum information science, superconducting electronics, and complementary metal-oxide semiconductor technology operated at cryogenic temperatures. William Oliver was also appointed the associate director of the MIT Research Laboratory of Electronics.

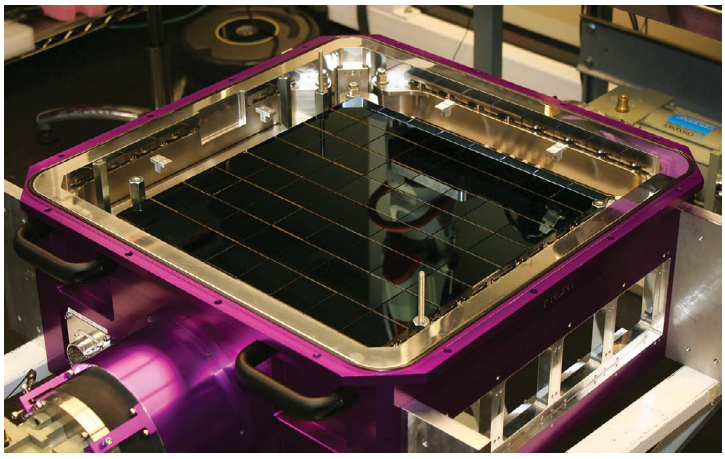
Technical Program Highlights

Research and development at the laboratory focuses on national security problems across a broad range of mission 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 prototyping, which involves the development of components and systems for experiments, engineering measurements, and tests under field operating conditions.

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

Advanced Technology

In the Joint Biological Point Detection System (JBPDS) Joint Technology Refresh program, the rapid agent aerosol detector was integrated into the JBPDS. The rapid agent aerosol detector is a bioaerosol detector that dramatically reduces JBPDS life cycle costs and false alarms. The system was undergoing testing to the JBPDS performance specification and was being prepared for whole-system, live-agent, biological warfare agent testing.



This 1.45-gigapixel focal plane array, composed of 23-megapixel charge-coupled devices, will be used on the second Panoramic Survey Telescope and Rapid Response System telescope located in Maui, Hawaii. The Panoramic Survey Telescope and Rapid Response System will be the world's leading facility for new asteroid and comet discoveries.

A beam-combined fiber laser system demonstrated record brightness. The coherently combined beam was generated from 10 s of optical fiber amplifiers and had near-ideal beam quality and high beam-combining efficiency.

The laboratory demonstrated a 1024 × 1024–pixel passive imager that is based on the three-dimensional (3D) integration of Geiger-mode avalanche photodiodes and photon-counting readout circuits. The readout circuit was fabricated in the laboratory's fully depleted silicon-on-insulator complementary metal-oxide semiconductor process. Using the laboratory's precision alignment and wafer bonding process, researchers 3D-integrated the circuit to the silicon avalanche photodiode arrays.

Lincoln Laboratory fabricated the largest reported superconducting integrated circuits, including a 73,000-junction circuit that has been successfully tested and a 144,000-junction circuit. Additionally, the laboratory's process advancements have reduced the critical feature dimensions and increased the number of wiring layers available to designers of superconducting circuits.

The laboratory realized two significant steps toward a scalable architecture for trapped-ion quantum computing. The first step was coherent control of the ion. This step was accomplished by using a laser beam that was delivered via an integrated photonic waveguide and grating coupler. The second step was the demonstration of a two-dimensional array of trapped ions that can load a new ion into a site without disrupting coherent control of an ion in an adjacent site.

A distributed Bragg reflector slab-coupled optical waveguide laser (SCOWL) was developed at a wavelength of 780 nm, which is the shortest wavelength at which the laboratory's SCOWL technology has been demonstrated. This demonstration was the first of a monolithic integration of a distributed Bragg reflector grating on the SCOWL platform. This class of laser is expected to benefit atom-based sensors and processors for quantum-information applications.

Air, Missile, and Maritime Defense Technology

At the Reagan Test Site (RTS), Lincoln Laboratory continued to lead the development of advanced sensors and processors to improve range system capability, flexibility, and scalability. The laboratory leveraged a modular open-architecture design and modern hardware to complete computer upgrades to the RTS sensors. The suite of optical sensors at RTS was also upgraded. The laboratory completed the initial phase of the RTS Automated and Decision Support capability and is transitioning the technology to a contractor.

The DoD is exploring the development of weapon systems that use hypervelocity projectiles launched from railguns or powder guns for a range of defense missions. Lincoln Laboratory performed a physics-based independent assessment of the concept and briefed findings and recommendations to senior DoD leadership.

To upgrade US submarine and fixed-sensor sonars, the laboratory developed improved adaptive beamforming, detection processing, and automation algorithms. The laboratory also completed a characterization of the Navy's submarine electronic surveillance direction-finding antennas and demonstrated calibration and signal processing techniques that could significantly improve performance.

The laboratory is upgrading hardware and processing on several deployed high-frequency sensor systems. Advanced digital hardware, digital beamforming, and other real-time processing capabilities will enhance system performance.

The Advanced Sensor and Technology Applications program developed, installed, and is operating a ground-based risk-reduction sensor prototype. Analysis of the collected data demonstrates that the sensor is operating as designed and has future ballistic missile defense mission capability.

The laboratory completed system-level assessments of the vulnerabilities of US submarines, leveraging extensive design, modeling, fabrication, and exploitation expertise to inform leadership of improved tactics and system development options. A new study has begun evaluating the potential impact of emerging autonomous systems in the undersea and cross-domain realms.

Last year, the Ground-based Midcourse Defense program office established a team, co-led by Lincoln Laboratory, to provide technical expertise and objective guidance for the office's development and acquisition programs. The laboratory team has played a critical role in the development of requirements for the Missile Defense Agency's redesigned kill vehicle program and has provided important analysis for other key ground-based midcourse defense system components.

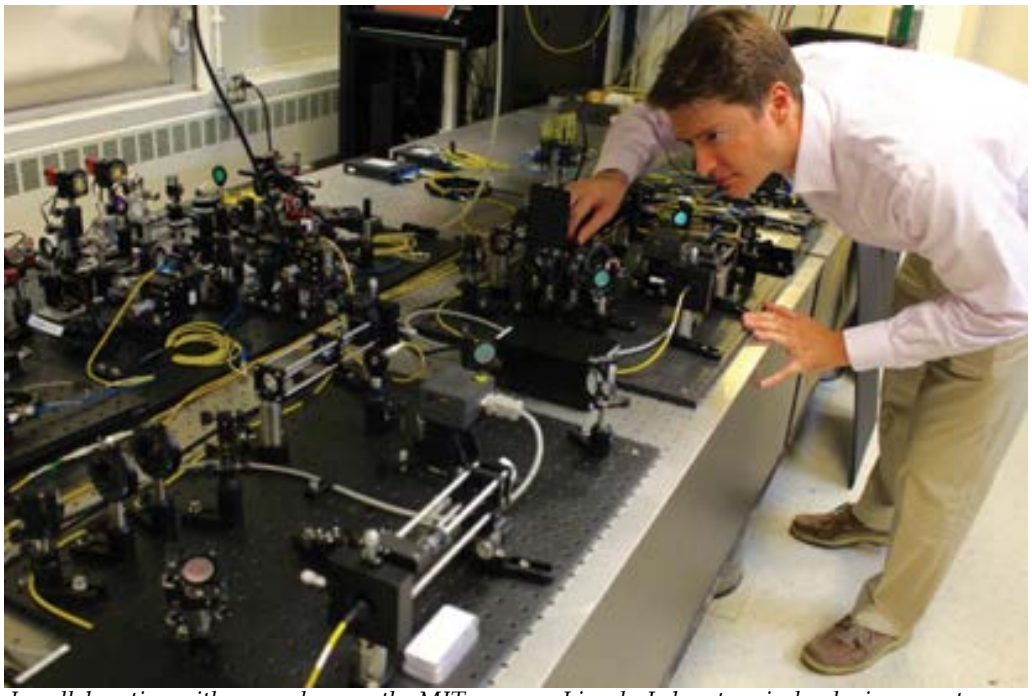
To facilitate technology transition, the laboratory installed a sidecar at the Aegis Ashore Missile Defense Test Complex. The sidecar provides a critical test bed for prototypes of mitigation techniques against both electronic and physical countermeasures.

Communication Systems

In collaboration with researchers on the MIT campus, Lincoln Laboratory developed a compact prototype eight-channel transmitter and high-sensitivity frequency-shift keying optical receiver suitable for photonic integration. The laboratory developed an architecture that enables a small spacecraft in low Earth orbit to downlink more than 100 terabits per day to a small ground receiver. Critical risk-reduction activities for this technology included a feasibility demonstration of ultralow size, weight, and power integrated fiber telecommunications transceivers for use in turbulent free-space communications links.

The advanced extremely high frequency test infrastructure continues to support the development and proliferation of protected military satellite communications capabilities. Activities over the past year include supporting the Very Important Person Special Air Mobility terminal and the characterization of the Presidential and National Voice Conferencing system.

The laboratory demonstrated high-sensitivity, coherent field detection and lossless combining of four independent optical apertures. This digital optical system can track millisecond-scale phase and intensity changes.



In collaboration with researchers on the MIT campus, Lincoln Laboratory is developing quantum network source, detector, and qubit processing technologies that will be used to demonstrate entanglement distribution over deployed optical fiber between the laboratory and MIT campus.

Designs for extending the F-35 multifunction advanced data link to improve network performance were implemented in simulation and in a prototype software-defined radio architecture.

Algorithms for multichannel adaptive beamforming were tested against collected field measurements to verify expected performance. Prior to these algorithms' transition to tactical aircraft radio receivers, they are implemented in high-fidelity simulations and prototype hardware.

Lincoln Laboratory completed the integration and development test activity for a prototype compact airborne laser communications terminal that utilizes an aerodynamic interface and operates over a wide field of regard. The terminal supports robust spatial tracking and near-theoretical communications performance against a low-average-power burst-mode signal.

A wireless network system to support advanced aircrew combat training was developed and demonstrated on prototype hardware in the laboratory and on Lincoln Laboratory's test aircraft. And Lincoln Laboratory successfully conducted initial tests demonstrating real-time multiantenna adaptive interference suppression for megabit-per-second, terrestrial non-line-of-sight radio frequency (RF) links.

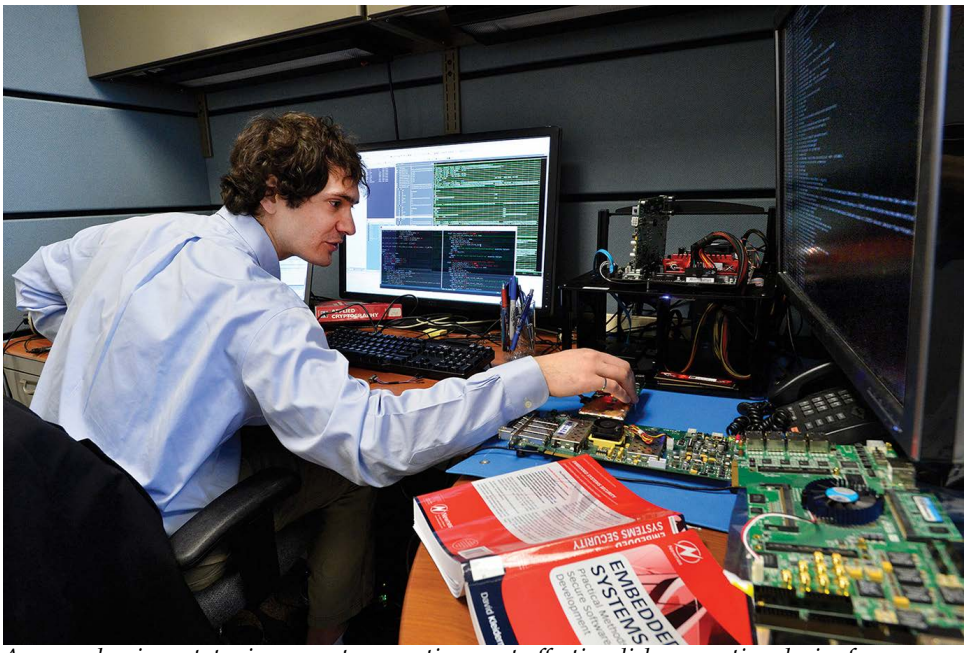
Cyber Security and Information Sciences

Lincoln Laboratory's embedded key-management system processor successfully underwent the National Security Agency's security verification testing.

A quantitative, threat-based, cyber modeling and simulation capability was developed and applied to the evaluation and assessment of nationally recommended cyber defensive mitigations.

Lincoln Laboratory led a comprehensive, multiparticipant study on the cyber defense of satellite communications. Conducted for the assistant secretary of defense for research and engineering and DoD's Office of Net Assessment, the study assessed the problems of cyber protection for satellite communications and identified concrete high-impact solutions.

Lincoln Laboratory defined and developed a tactical cloud security architecture for the US Navy. The laboratory also developed the Tactical Cyber Range to emulate a cyber-electromagnetic warfare environment. The range was deployed in the Marine Expeditionary Force's Bold Alligator and Dawn Blitz fleet amphibious exercises.



A researcher is prototyping a next-generation, cost-effective disk encryption device for protecting classified data in forward-deployed tactical mission systems.

The laboratory developed advanced graph analytics to rapidly detect communities of threat actors within communication networks.

Lincoln Laboratory researchers completed an independent assessment of a major, national-level intrusion detection and prevention system. The final report identified several paths toward improving the protection provided by the system.

Working closely with the US Cyber Command's leadership, the laboratory helped to define and establish a Capabilities Development Group that will develop rapid operational capabilities for the nation's Cyber Mission Force.

Lincoln Laboratory delivered technology that substantially increases the efficiency of foreign language proficiency tests at the Defense Language Institute Foreign Language Center. Pioneering laboratory research in the analysis and exploitation of the acoustics of the lower vocal tract is enabling new techniques for forensic speaker characterization.

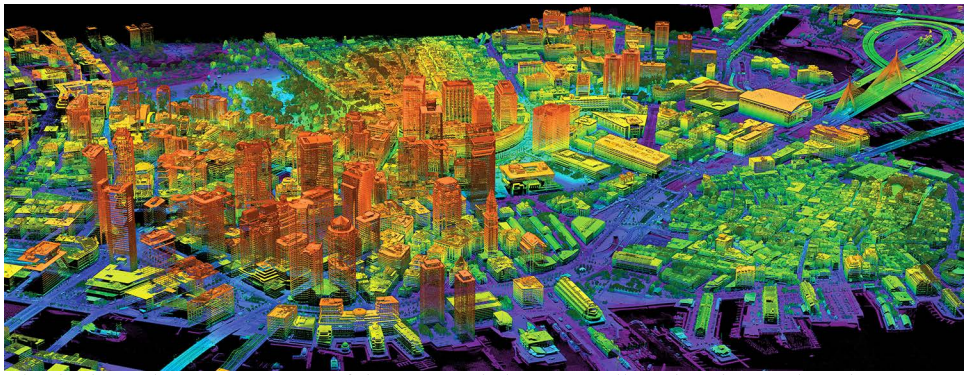
New techniques for named-entity resolution and linking, developed by the laboratory with support from DARPA, will be employed to help resolve the identities of refugees.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Lincoln Laboratory's continued evaluation of intelligence, surveillance, and reconnaissance (ISR) operations for contested environments includes assessments of new platform and payload capabilities to provide surveillance, acquisition, and handover of time-critical targets.

The Airborne Wide-Area Infrared System for Persistent Surveillance demonstrated 500-megapixel, long-wave infrared, wide-area motion imagery at one frame per second. Also, a miniaturized high-pixel-count situational awareness sensor that was designed for rapid deployment on a tethered multirotor unmanned aerial vehicle (UAV) completed its first flight campaign.

The Multi-Look Airborne Collector for Human Encampment and Terrain Extraction 3D laser detection and ranging (ladar) system, designed to uncover clandestine activity in heavily foliated areas, has completed more than 294 sorties. Novel noise-filtering and data-aggregation algorithms were deployed this year to produce imagery that is of much higher quality than that generated by an earlier, similar system.



This high-resolution, 3D image of the Boston skyline was collected with Lincoln Laboratory's airborne ladar, which uses state-of-the-art large-format detector arrays that are sensitive to single photons. This image, representing a fraction of the full 9 km2 collection, demonstrates approximate 3D resolution of 25 cm, which is about the diameter of a volleyball.

Promising results were achieved on a 3D microladar system that has measurement rates that are comparable with those of much larger operational systems. This microladar system fits in a package that is compatible with a small hand-launched UAV.

Work continued on Open Mission Systems for the US Air Force. Open Mission Systems is an open architecture for avionics that facilitates development, integration, and capability upgrades. Recent accomplishments included the release of new standards and the establishment of a systems integration laboratory.

The laboratory made a prototype of a computer for sparse graph processing targeted at ISR and cyber security computing. A prototype demonstrated a 100-fold improvement in performance-to-power ratio over conventional systems.

Working with DARPA on wireless communication technologies, the laboratory successfully fabricated a 2-trillion-operations-per-second system on a chip that enables radio system operation in challenging environments. The chip was integrated into handheld radio prototypes whose use in field experiments over several months demonstrated a measured performance that matched the expected theoretical performance.

Lincoln Laboratory provided technical evaluations to the US Air Force's Joint Surveillance and Target Attack Radar System recapitalization program and the US Navy's Triton program. Enhancements to airborne radar target detection and classification were transitioned to operational radars. The laboratory developed test systems to enable the development of novel approaches to making radars more robust to electronic attack. Work also began on an airborne radar test bed for prototyping advanced RF and processor technology and novel radar modes.

New architectures for open-source intelligence exploitation were developed and demonstrated. Research into network graph exploitation and deep-learning techniques was conducted, with an emphasis on providing real-time intelligence to tactical analysts.

Tactical Systems

Lincoln Laboratory completed multiple assessments of US Air Force aircraft performance and limitations against current and future foreign threats. These assessments included systems analysis, backed by laboratory and flight testing, of advanced infrared and RF sensor kill chains, electronic attack and electronic protection, and missile systems. The findings were conveyed to DoD leadership to inform their decision making process for future system capabilities and technology investments.

The laboratory continues to provide comprehensive evaluation of options for the US Air Force's airborne electronic attack plan against foreign surveillance, target acquisition, and fire-control radars. This work involves systems analysis of proposed options, development of detailed models, fielding prototypes of threat radars, and testing various electronic attack systems. The laboratory demonstrated a coordinated autonomous formation of 103 Perdix miniature UAVs after they were dispensed from three F/A-18 Super Hornets.

Lincoln Laboratory developed and analyzed new system concepts for enhancing US Air Force air dominance in future contested environments. These concepts incorporated advanced hardware and signal processing technology to expand capabilities in wide-area surveillance and counter-air kill chains.

The laboratory has continued to conduct overarching assessments of the US Air Force's family of systems architecture. Mission-based assessments were performed to provide input on force structure requirements for tactical ISR and strike aircraft, as well as on needed communications, sensors, and weapons systems in future stressing scenarios.

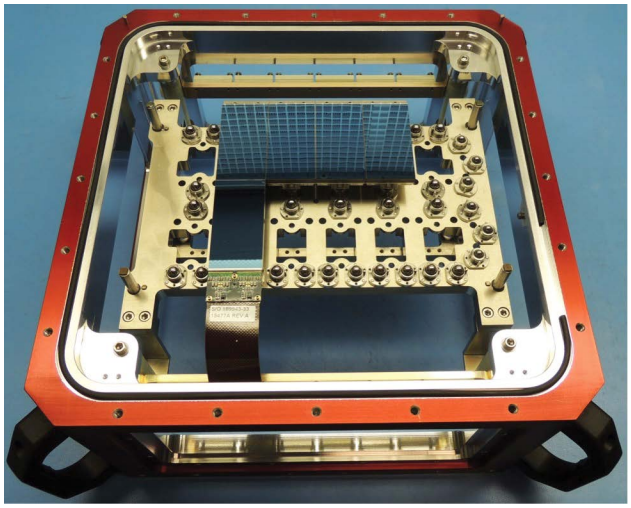
Lincoln Laboratory continues its prototyping of advanced technologies for airborne signals intelligence. Significant technical upgrades were made to an existing system; the upgraded capabilities are currently under transfer to an industrial partner for production and fielding. In addition, a novel sensor system was successfully tested and demonstrated for an operational assessment of its potential for law enforcement applications.

The laboratory has begun a new counterterrorism focus area. The effort is to develop novel sensors and algorithms in the areas of ground-penetrating radar, active seismic imaging, and electromagnetic gradiometry for the detection of deep improvised tunnels. For example, Lincoln Laboratory conducted a field test in Toronto, Canada, of a new ground-penetrating radar design for deep tunnel detection applications. The antenna has RF-absorbing tiles on the antenna, which improve the radiation performance of the radar.

Blue Team systems analyses conducted by the laboratory for the US Air Force considered new concepts for air dominance and space ISR that will help inform DoD's strategy for the development of future capabilities. The laboratory is leveraging advanced technologies to develop novel system designs and is performing detailed engineering and mission-based analyses to evaluate the feasibility and value of these new concepts.

Space Control

Performance upgrades to the Space Surveillance Telescope's Wide-Field Camera-2 were demonstrated during a successful DARPA evaluation period. The telescope was transferred from DARPA to the Air Force Space Command on October 18, 2016.



The upgraded Space Surveillance Telescope Wide-Field Camera -2 contains 12 Lincoln Laboratory charge-coupled devices integrated into a precision dewar to create a focal plane array assembly. Shown is the dewar partially populated with development charge-coupled devices during a fit check.

The laboratory has completed the procurement, fabrication, and assembly of all major subsystems for the ORS-5 SensorSat, a small satellite for the Operationally Responsive Space Office. Flight space vehicle hardware integration and testing are under way.

For the Transiting Exoplanet Survey Satellite (TESS) payload, Lincoln Laboratory finished the fabrication, assembly, and subsystem integration of the four camera lenses, electronics, and focal plane arrays. The laboratory provided the detector arrays, optical subsystem, system engineering, integration and testing, and program management for the science payload, which was jointly developed with the MIT Kavli Institute for Astrophysics and Space Research for NASA.

The Microwave Radiometer Technology Acceleration cubesat, developed by MIT's Space Systems Laboratory and Lincoln Laboratory, was delivered to NASA in June 2017, following its successful integration and testing in March 2017. The cubesat uses multiband radiometer measurements and Global Positioning System radio occultation for weather and climate forecasting.

Commercial subsystems for the Micro-sized Microwave Atmospheric Satellite-2 cubesat were procured, and the satellite's payload fabrication was completed. The compact microwave sounder will provide high-resolution images of tropical cyclones and other severe weather formations.

Lincoln Laboratory has established a Space Blue Team to execute systems analysis and architecture assessments to help guide US national security space investments. The Space Blue Team has conducted assessments and studies focused on constellation coverage and capacity, system designs, space mission resiliency metrics and employment concepts, and defensive operations for current and future space systems.

In response to the national need to develop a space battle management capability quickly, Lincoln Laboratory created a battle management, command, control, and communications testbed to develop mission-critical decision support tools. These tools perform key functions, such as rapid event detection and dynamic scheduling of space surveillance assets, to develop courses of action. The facility provides a real-time environment to ensure interoperability of service-oriented-architecture systems, to evaluate and make operational the contributions of new sensors and sources; to develop and assess the performance of new decision support algorithms; and to provide a simulation capability for Red Team versus Blue Team exercises.

Homeland Protection

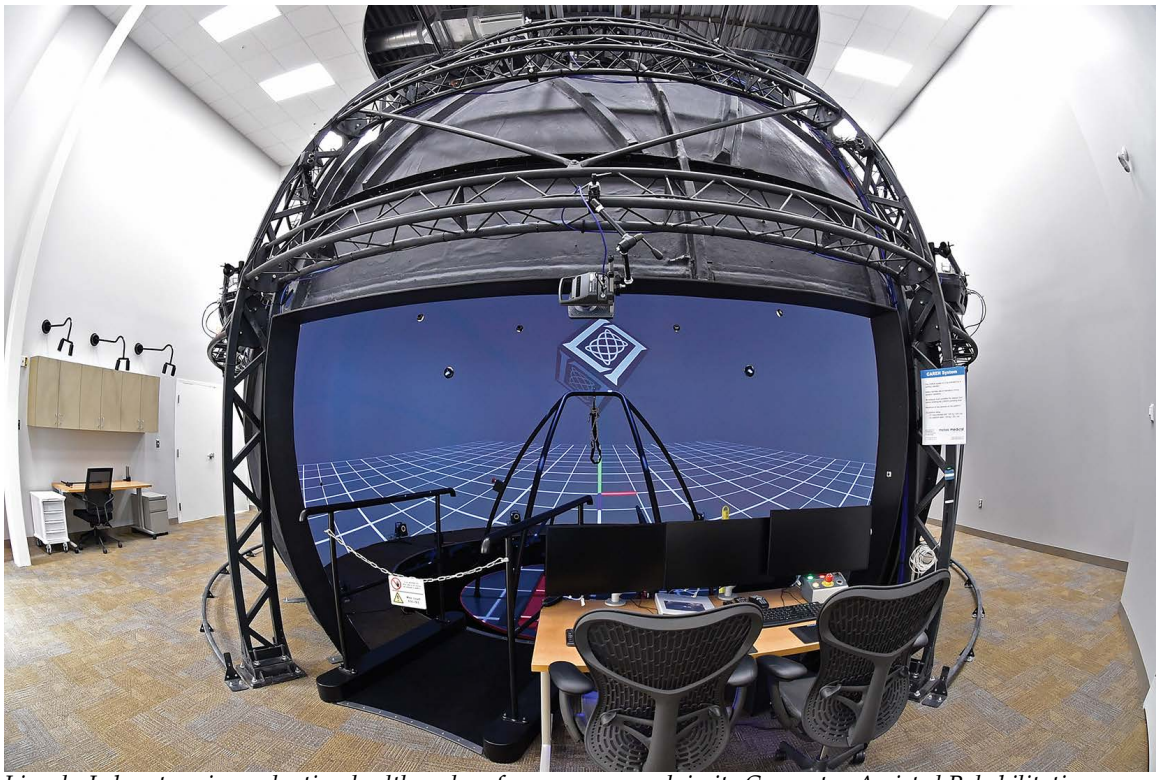
Bioengineering

Lincoln Laboratory hosted its first workshop on neurodegeneration and hearing injury to help expose cross-service leadership to technical innovations that may reduce the impact of noise-induced hearing injury on warfighter health and performance. The laboratory also created algorithms based on noninvasive physiological signatures (e.g., heart rate, temperature, and blood pressure) that provide warning of viral infection before the onset of fever.

Through a partnership with the US Army Research Institute of Environmental Medicine and the Marine Expeditionary Rifle Squad, the laboratory conducted a successful field demonstration of an ultralow power wearable physiological monitoring system that monitors warfighter heat strain in real time and operates securely in tactical environments.

In synthetic biology work, the laboratory designed and prototyped cell-based biochemical sensors that reduce sensor response time from hours to seconds.

A multimodal immersive laboratory was built for noninvasive cognitive and physiological monitoring research. The facility includes a virtual-reality dome that features 360-degree visualization, motion capture through 18 cameras, a reversible, dual-belt, high-acceleration treadmill with integrated force plates and six degrees of freedom actuation, and wearable sensors.



Lincoln Laboratory is conducting health and performance research in its Computer-Assisted Rehabilitation Environment dome in the new Sensorimotor Technology Realization in Immersive Virtual Environments Center. The rehabilitation environment dome can comprehensively quantify an individual's physical and cognitive responses that take place in realistic operational environments or rehabilitation scenarios.

Homeland Defense

Video analysis automation for law enforcement, border patrol, and mass transit security has been developed to accelerate significantly the ability of operators to extract information from videostreams. Operational pilots were deployed to drive system refinement.

The Lincoln Laboratory, in collaboration with the US government's Chemical and Biological Defense Program and its international partners, continued to conduct a series of measurements of the impacts of weapons of mass destruction; these measurements will inform the development of advanced technology to counter such weapons.

Activities include measurement-based threat phenomenology studies, technology assessments, critical infrastructure remediation, and development of forensic techniques for improvised explosive devices.

In collaboration with DoD's Joint Improvised-Threat Defeat Organization, the laboratory developed technologies and measurement capabilities that enhance asymmetric threat detection, defeat, and attribution.

In support of the DHS Science and Technology Directorate and the Federal Emergency Management Agency's efforts to insert new technology into national hurricane-evacuation decision support tools, the laboratory initiated the rebuilding and expanding of web-based prototypes to develop new decision analytics, improve training through an integrated serious games platform, and create planning tools for evacuation zones. Lincoln Laboratory also led architecture development and technology assessments for the national capital region's air defense system.

Air Traffic Control

The recently constructed 10-panel MPAR prototype is being used to refine requirements and quantify dual-polarization performance for weather observations. In partnership with FAA and NOAA, the laboratory built a full-scale 76-panel array and conducted near-field measurements with the system.

The laboratory developed the portable 10-panel MPAR prototype (left), which was deployed to the National Severe Storms Laboratory in Norman, OK. Work continues on a full-scale 76-panel Advanced Technology Demonstrator array, which will be installed in the blue radome (right). The Advanced Technology Demonstrator will be used in conjunction with a nearby next-generation radar site to collect weather data.

Development work was initiated on a small airport surveillance sensor that has the potential to provide low-cost terminal-area surveillance. Two prototype apertures have been developed to demonstrate real-time passive surface surveillance of aircraft.

Algorithm improvements continued for the offshore precipitation capability effort, which uses lightning, satellite, and meteorological model data to generate a global radar-like view of convective weather that is beyond the coverage of radar. The laboratory will continue to expand the offshore precipitation capability domain, using data from the next-generation Geostationary Operational Environmental Satellite–R series.

Lincoln Laboratory is playing a key role in developing the Airborne Collision Avoidance System X, which will support new flight procedures and aircraft classes. In collaboration with the FAA's Technical Center, the laboratory conducted a full system test of the Airborne Collision Avoidance System X architecture. The successful flight test allowed the program to begin operational evaluation.

Standards and algorithms were being developed for unmanned aircraft system sense-and-avoid capabilities for DoD, DHS, and FAA. The laboratory is working to extend the "well clear" separation standard, initially developed for large unmanned aircraft systems (more than 55 lb) to small systems (less than 55 lb).

The laboratory completed the development of ground-based sense-and-avoid systems and is transferring them US Army and US Air Force sites. This transition will make the first general-purpose sense-and-avoid systems for unmanned aircraft in the national airspace system.

Lincoln Laboratory is conducting analyses to guide the FAA on wind information needs for Next Generation Air Transportation System applications, including four-dimensional trajectory-based operations and interval management procedures. These analyses are guiding performance requirements and standards for efficient procedures in the new system.

Operational improvements are being developed to mitigate the environmental impacts of aviation. The laboratory is developing and assessing decision support tools that reduce taxiway congestion, efficiently balance queues of aircraft at departure runways, save fuel, reduce emissions, and mitigate noise during aircraft approach.

The laboratory is supporting the FAA in assessing potential cyber security risks on commercial transport aircraft. It is also working with the FAA Cybersecurity Test Facility to enhance their test and evaluation capabilities for protecting systems within the National Airspace System.

Engineering

Lincoln Laboratory continues to take advantage of the unique fabrication geometries provided by additive manufacturing technology. Three-dimensional printed plastic parts are now widely used in prototype systems. The laboratory acquired a new selective laser melting machine for metal parts and has focused research efforts on understanding the properties of metals produced by selective laser melting. In collaboration with MIT, the laboratory is developing a multimaterial printer that uses micron-scale particles.

High-precision pointing of an airborne optical terminal requires highly integrated optomechanical designs. These requirements entail close collaboration among mechanical designers, thermal and structural engineers, and optical experts. Here, an optical terminal is being integrated into a high-altitude WB-57 aircraft for pointing and navigation testing.

The laboratory is investing in test equipment to meet the demands of current programs and to provide capabilities for the Engineering Prototyping Facility. Equipment acquisitions included a selective-laser-melting additive manufacturing printer, a 20,000 lb vibration shaker, and a thermal vacuum chamber for testing space payloads.

Environmental testing of the TESS instrument was coming to a close toward the end of AY2017; the instrument will be shipped for integration onto the spacecraft late in 2017. The Lincoln Laboratory had responsibility for lens design, fabrication, test, and environmental qualification for TESS and the charge-coupled device packaging.

A small satellite cell was established to support the laboratory's efforts in developing small satellite concepts and prototypes. Projects completed this year include the Advanced Radiometric Calibration Satellite, Operationally Responsive Space–5 SensorSat, and two cubesats for weather forecasting. In addition, research is being conducted on hydrogen peroxide propulsion and deployable antenna concepts for cubesats.

In the field of computational imaging, new types of optical sensors are being developed. Laboratory efforts focus on an array camera with digital super-resolution that can achieve a reduction in the size of the optics; optically multiplexed imaging to increase field of view and resolution; and time-encoded multiplexed imaging to turn a digital focal plane array into a multidimensional imager.

The Energy Systems Group continues to focus on advancing critical DoD and national capabilities, including tactical microgrids and energy solutions for soldiers and unmanned vehicles. Recent work includes an emphasis on enhancing the resiliency of the regional electric grid.

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 the 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.

Patents

Between July 1, 2016, and June 30, 2017, 24 US patents were granted to MIT for technologies developed by Lincoln Laboratory technical staff. These patents span a wide range of technologies. Some unique technical advances that were patented include a technology that uses the evaluation of the scattered light profile from a single particle to determine the presence or classification of an airborne particle; a processor that performs matrix operations on large data sets; and barcodes that employ a technique using spatially and spectrally encoded polymer microparticles to label articles and tissues. The goal is to prevent the distribution of counterfeit items or medicines.

2016 Research and Development 100 Awards

The R&D 100 Awards, presented annually since 1962, recognize the 100 technology products judged by a panel of R&D Magazine editors and outside experts to be the most significant new developments of the year. Lincoln Laboratory innovations in air traffic safety, biomedical devices, and magnetic field detection earned R&D 100 Awards in 2016. The six winning technologies were developed either solely by laboratory researchers or collaboratively with scientists from partner organizations.

Three of Lincoln Laboratory's 2016 award-winning technologies addressed challenges in air traffic safety:

- The Airborne Collision Avoidance System for Unmanned Aircraft processes multisensor data to allow unmanned aircraft to detect and track nearby aircraft and to enable ground operators to direct safe separation between unmanned vehicles and other air traffic.
- Offshore Precipitation Capability is a system, developed with contributions from the FAA, that provides weather information for air traffic controllers by generating radar-like depictions of storms in offshore regions that are outside radar coverage.
- The Small Airport Surveillance Sensor, a low-cost secondary surveillance system, provides airport tower controllers with situational awareness of aircraft on the airport surface and in nearby airspace.

Two winners offer innovative technology for improving health care:

- EnteroPhone™ is a wireless, ingestible device that monitors heart and breathing rates by listening to the body's sounds and that senses core temperature, all from within the gastrointestinal tract. Lincoln Laboratory scientists partnered with MIT researchers to develop this device.
- Laserscope, a tool set that offers surgical navigation and precise laser targeting within the spinal cavity, may enable treatment of back pain with an outpatient procedure instead of with open back surgery. A neurosurgeon from Massachusetts General Hospital was on the development team.

The sixth winning technology, developed in partnership with MIT researchers, expands the functionality and efficiency of current magnetometers. The device, which uses broadband magnetometry and temperature sensing with a light-trapping diamond waveguide, is an ultrasensitive magnetic-field detector and temperature sensor that is a thousand times more energy efficient than previous diamond-based magnetometers.

Technology Transfer Activities

During the past year, Lincoln Laboratory transitioned several technologies to industry or to government sponsors. These included a self-contained cryptography and key-management solution that is applicable to any crypto-based system or device, and is well suited to applications with strict size, weight, and power restrictions. This processor was transferred to a commercial partner in support of a US Air Force effort to develop foundations for agile and resilient embedded systems.The Lincoln Laboratory's adaptable real-time information assurance testbed was transferred to a commercial startup company.

To support the Missile Defense Agency's initiatives to improve homeland defense capabilities, the laboratory has been developing prototype flight articles that can be used to test the ballistic missile defense system. This year, the laboratory successfully built and flight-tested prototype hardware. These designs are being transferred to industry for production and deployment on future flight tests.

Several continuing efforts for the US Navy are focused on electronic countermeasures to defend ships against advanced antiship missile threats. A prototype for an advanced offboard countermeasure for ship-based defense has been completed, and technology from that prototype has been transferred to the Navy.

The fifth-generation advanced training waveform specifications and models, and the prototype implementation, were transferred through the Air Force Research Laboratory to defense industry participants in the Air Force's Live, Virtual, and Constructive Advanced Technology Demonstration program.

Lincoln Laboratory has transferred to NASA a modem and optical terminal technology that was developed under multiple prototyping programs. This technology will support the development of terminals for NASA's Laser Communications Relay Demonstration mission. The laboratory worked with multiple industry vendors to validate subsystems that NASA will use for the demonstration's terminal.

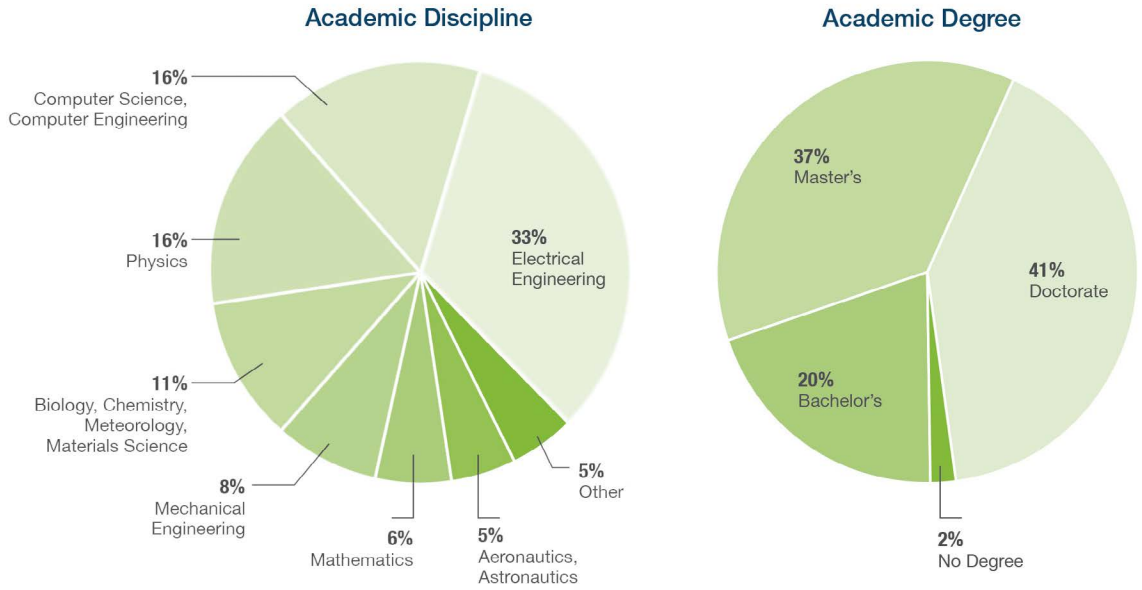
Lincoln Laboratory built and environmentally tested space-compatible differential phase-shift keying modems that provide near quantum-limited communication performance over a very wide dynamic range of received input power. The design is being transferred to NASA and industry.

Staff

Lincoln Laboratory's staff of highly talented scientists and engineers is key to maintaining the laboratory's technical excellence. 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 Lincoln Laboratory staff by degree and academic discipline is shown below.

Lincoln Laboratory Staff Demographics

Staff type	Count
Professional technical staff	1,823
Support staff (including technical support personnel)	1,712
Subcontractors	516
Total Laboratory Employees	**4,051**



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

Awards and Recognition

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

- Five members of the technical staff were named fellows of the Institute of Electrical and Electronics Engineers (IEEE): Robert K. Cunningham, for leadership in computer security; Paul W. Juodawlkis, for contributions to optically sampled converters and waveguide amplifiers; Daniel E. Oates, for contributions to high-temperature superconductors and applications to RF receiver technology; Frank C. Robey, for leadership in development of advanced

radar systems; and Steven T. Smith, for contributions to statistical signal processing and applications to radar and sonar.

- Christine A. Wang received the 2017 American Association for Crystal Growth Award "for seminal and innovative contributions to epitaxial crystal growth of III-V compound semiconductors and the design of high-performance OMVPE [organometallic vapor phase epitaxy] reactors."
- The 2016 MIT Lincoln Laboratory Technical Excellence Awards were presented to Gregory D. Berthiaume, for 25 years of outstanding technical contributions to the development, integration, test, and operations of space and ground-based systems that range from the soft X-ray through the thermal infrared; and to Jeffrey S. Herd, for sustained innovation of radar antennas and advanced, highly digitized phased arrays, and for his leadership in building a world-class enterprise for the development of RF technology at MIT Lincoln Laboratory.
- Francesca D. D'Arcangelo, Emily E. Fenn, and Vijay N. Gadepally were named by the Armed Forces Communications and Electronics Association International to its annual list of 40 individuals under the age of 40 who have shown exceptional leadership and made significant, innovative contributions to the fields of science, technology, engineering, and mathematics by using information technology.
- Curt A. Heintz and Irene Oliver received 2017 MIT Lincoln Laboratory Administrative Excellence Awards. Erin M. Jones-Ravgiala and Robert S. McLaren received 2017 MIT Lincoln Laboratory Support Excellence Awards.
- Raoul O. Ouedraogo and Alexia Schulz received MIT Excellence Awards in the Bringing Out the Best category; Edison W. Arana, Katherine Barlett, Benjamin R. Nahill, Aida Riley, and Jeffrey S. Stewart received MIT Excellence Awards in the Outstanding Contributor category.
- Thirteen people from Lincoln Laboratory were on the Geostationary Operational Environmental Satellite-R Series team that was honored with a NASA Agency Honor Award in the Group Achievement category: Peter S. Armstrong, William J. Blackwell, Kristin A. Clouser, Monica M. Coakley, David P. Marden, Sundie L. Meroth, Adam B. Milstein, Frederick J. Rich, Danette P. Ryan-Howard, Michael W. Shields, F. John Solman, John A. Taylor, and M. Robert Wezalis.
- The U.S. Air Force Red Team, whose large membership includes staff from both the Air Force and MIT Lincoln Laboratory, was awarded the Assistant Secretary of the Air Force for Acquisition Team Award for Innovation. From more than 100 teams nominated, this team was selected as the 2016 award recipient for its successful execution of several projects that significantly impacted decisions about the acquisition of air, space, and cyber systems.

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. The Human Resources Department coordinates programs in graduate education, technical education, professional leadership development, and computer and software training.

For highly qualified candidates, Lincoln Laboratory offers the opportunity to apply to the Lincoln Scholars program that 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 2017, 21 staff members were enrolled in the Lincoln Scholars program.

The part-time graduate studies program enables staff members to continue to work at the laboratory while earning master's degrees in fields that are relevant to laboratory mission areas or business needs. Staff members can take courses toward their degrees through universities' part-time programs, which may include classes offered online or outside traditional work hours. Lincoln Laboratory staff are also eligible to take courses in computer science offered at Hanscom Air Force Base by Boston University. These courses, which have included instruction in computer networks, cryptography, and software engineering, can be taken independently or as part of a Boston University certificate or master's degree program. In 2017, 51 people participated in these programs.

The technical education program offers both short-term and semester-length classes taught by Lincoln Laboratory technical staff or by outside experts. The academic year 2017 schedule included these classes: Adaptive Antennas and Phased Arrays; Additive Manufacturing; Build a Radar; Build Anything; Custom Integrated Circuit Design; Electromagnetics; Electromagnetics and Antennas; Electronic Warfare ISR; Mathematics of Big Data; Matrix Methods in Data Analysis, Signal Processing, and Machine Learning; Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot; Radar I; Radio Frequency Signals Intelligence; Space Control; Statistical Learning and Signal Processing; and Systems 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. A new offering this year was a tutorial on nonparametric Bayesian methods.

Technology Office Seminars

The Technology Office directs a program of seminars presented at the laboratory by both in-house speakers and researchers from other universities and from industry. The seminars are chosen to reflect current and leading-edge trends in today's technology.

Highlights of the AY2017 program include the following seminars:

- "Pluto Revealed! Latest Results from NASA's New Horizons Mission," Professor Richard Binzel, Department of Earth, Atmospheric, and Planetary Sciences
- "Lincoln Limb: A Printlab Project," Luke Johnson, MIT Lincoln Laboratory
- "Terahertz Quantum Cascade Laser Frequency Combs: Spectroscopy and Physics," David Burghoff, MIT Research Laboratory of Electronics
- "Enabling the First Interstellar Missions," Professor Philip M. Lubin, University of California Santa Barbara, Department of Physics

- "Reinvention of Education," Professor Anant Agarwal, chief executive officer, edX
- "Enhancing Human Capability with Intelligent Machine Teammates," Professor Julie A. Shah, Department of Aeronautics and Astronautics, April 13, 2017

Technology Office Challenges

Each year, the Technology Office and Technology Advisory Group creates technical challenges and invite the laboratory staff to compete to devise the most creative, viable solutions. The objectives of these challenges are to address difficult problems of relevance to one or more mission areas, to foster cross-divisional collaboration, and to engage staff in innovative problem solving from idea generation through prototype demonstration.

In 2017, the two challenges were a fake-media hackathon and an autonomous UAV race. The "Breaking News or Broken News?" hackathon addressed the problem of so-called fake news, the dissemination of unreliable media content that undermines democracy through the erosion of public trust and misunderstanding of important information. The hackathon required teams to exploit machine learning techniques to build detectors that automatically identify unreliable media of diverse types—for example, text, images, and hypertext markup language metadata. Five teams competed in the final hackathon. The winning team, Tor News Network, composed of five people from three divisions, earned the overall highest score on the basis of several criteria, including the ability to recognize the test data articles as reliable or unreliable, effective teamwork, the novelty of the detector's features, and the detector's potential to be developed into a full end-to-end system.

The autonomous UAV race was designed to allow participants to explore ways to improve autonomy for UAVs, which are envisioned as the future deliverers of goods and services for both the military and the commercial sector. The race, to be held in late August, challenges teams to program quadrotor drones so that these UAVs can quickly and autonomously navigate a "slalom" course of gates of varying heights in a prescribed sequence.

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 broad range of universities, programs in mentoring, employee resource groups, and flexible work options are contributing to the hiring and retaining of a more diverse workforce.

The nine established employee resource groups promote professional development activities, encourage volunteering at educational and charitable outreach programs, and provide support to all members of the laboratory community—Lincoln Employees with Disabilities, Lincoln Employees' African American Network, Out Professional Employee Network, Lincoln Laboratory New Employee Network, Recent College Graduates, Lincoln Laboratory Women's Network, Lincoln Laboratory Hispanic and Latino Network, Pan Asian Laboratory Staff Network, and Lincoln Laboratory Veterans' Network.

Lincoln Laboratory is a member of the National Graduate Education for Minorities Consortium, which, through partnerships with universities and industries, provides support to students from underrepresented minority 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 2017, Lincoln Laboratory hired 18 GEM Fellows as interns. In the past three years, the laboratory has hired five GEM Fellows as technical staff members.

The laboratory regularly holds events intended to promote an inclusive environment. For example, in celebration of Hispanic Heritage Month, Lincoln Laboratory's Hispanic and Latino Network invited the laboratory community to a buffet of ethnic foods on October 20, 2016. Jaime Peraire, the H. N. Slater Professor of Aeronautics and Astronautics at MIT and director of the Aerospace Computational Design Laboratory, was the keynote speaker at this lunchtime event, held at the Minuteman Commons on Hanscom Air Force Base.

On November 4, 2016, Lincoln Laboratory held its annual Veterans' Day Appreciation Luncheon. At the event organized by the Lincoln Laboratory Veterans' Network, veterans who were active-duty personnel between November 1, 1955, and May 15, 1975, were honored with DoD commemorative lapel pins. The awarding of these pins was part of the national Vietnam War commemoration program, which was established to thank and honor Vietnam-era veterans and their families for their service and sacrifice.

Four employee groups—the Advanced Concept Committee, Climate (ex)Change, Lincoln Laboratory Veterans' Network, and the Personal Sustainability Interest Group—sponsored the showing of the film *The Age of Consequences*, which depicts the challenges to global security resulting from the effects of climate change on food and water shortages, international conflicts, and population migration. Sophie Robinson, executive producer from the film's maker, PF Pictures, conducted a question-and-answer session after the viewing.

To commemorate the Lunar New Year, Pan Asian Laboratory Staff Network celebrated on January 26, 2017, with foods and traditional music and dance from a variety of Asian cultures. The MIT Bhangra, an Indian folk-dance troupe, performed at the celebration.

To commemorate Black History Month, the Lincoln Employees' African American Network hosted the Martin Luther King Jr. Luncheon at the Minuteman Commons Community Center on Hanscom Air Force Base. The keynote speaker was General Lester Lyles, US Air Force (retired), who previously served as vice chief of staff of the US Air Force and commander, Air Force Materiel Command, Wright-Patterson Air Force Base, Ohio.

On April 21, Lincoln Employees with Disabilities sponsored presentations by Tom Williams and Jason Wilson, professors in the Department of Computer Science at Tufts University; they spoke about innovative ways that robotics is assisting people with disabilities. Williams described how the integration of two software architectures, one for spatial recognition and one for language processing, created a robotic wheelchair that can use natural-language directions to navigate an environment. Wilson explained the design of a robot that sorts medications for patients whose neurodegenerative conditions limit their dexterity.

In May, Asian-Pacific American Heritage month, the Pan Asian Laboratory Staff Network (PALS) invited the laboratory community to a celebration of Holi, the Hindu welcome to spring, also called the festival of colors. This event featured a collaborative art project to decorate a large rangoli, traditionally a design that is created on a floor or courtyard with colored rice, sand, or flower petals, but created at the laboratory with paints on a large banner for display in the main lobby. On May 25, PALS co-hosted a seminar with the Lincoln Laboratory Women's Network that was aimed at reflecting on the Asian immigrant experience. Professor Emma Teng, head of MIT Global Studies and Languages, spoke about the challenges faced by the first Chinese students at MIT. Titled "Piercing through the Great Wall of Isolationism: MIT's Pioneering Chinese Students," the talk described the strong anti-immigrant feelings these students endured in the late 1800s.

On June 22, at the invitation of the Lincoln Employees' African American Network, Steven L. Richardson, MIT Martin Luther King Jr. Visiting Professor and a physicist and professor of electrical and computer engineering at Howard University, presented "Using Supercomputers to Design New Quantum Materials for Computing and Communications." Richardson discussed the potential of new materials, such as graphene and germanium, to replace silicon in the manufacture of the very fast microprocessors that will be needed to handle the big data of the future.

Knowledge Exchange

Technical Workshops

The dissemination of information to the government, academia, and industry is a principal activity of Lincoln Laboratory. One way this goal is achieved is through annual workshops and seminars that bring together members of the defense and technical communities. These multiday events foster a continuing dialogue that enhances technology development and provides direction for future research. The following workshops were held in in academic year 2017:

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

In addition, Lincoln Laboratory is a technical partner for the IEEE 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 or make presentations. 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, 2016, and June 30, 2017, Lincoln Laboratory staff published 146 papers in volumes of conference proceedings, 61 articles in technical journals, and nine major technical reports available through the Defense Technical Information Center.

In a partnership with MIT Press, Lincoln Laboratory established a book series to present its fundamental research. Written by Lincoln Laboratory experts, often with contributions from colleagues in academia and industry, the volumes in the MIT Lincoln Laboratory Series are intended as resources for researchers, engineers, and university educators and students. In June 2017, MIT Press published the fifth book in the series, *Perspectives in Space Surveillance*, an overview of more than 30 years of research and development that Lincoln Laboratory began in the 1970s to enable the detection and tracking of the growing array of man-made objects in deep space.

Research Collaborations

Although technical staff at Lincoln Laboratory collaborate on projects with faculty and scientists at universities across the country, most collaborations are with researchers from MIT. There are a number of mechanisms for direct support of cooperative projects; the Technology Licensing Office coordinates 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 2017, six collaborations were funded under the Advanced Concepts Committee. These collaborations included ones in building interpretable neural network models, investigating an all-electronic sub-terahertz/mm-wave molecular clock, and building compact ultra-narrow linewidth lasers for space-based lidar, optical atomic clocks, and quantum processing systems.

Longer collaborative mission-focused projects are supported directly by the office of the Assistant Secretary of Defense for Research and Engineering. Funding is distributed after a call for proposals each April. This year's innovative projects included the following:

- A collaboration among researchers at Lincoln Laboratory, elsewhere at MIT, and the University of Colorado at Boulder to explore a new approach to RF electronics that will greatly reduce the cost of building state-of-the-art phased arrays while enabling new capabilities. The team is developing an integrated circuit process technology with gallium nitride and complementary metal-oxide semiconductor transistors, all fabricated on silicon substrates.

- Researchers at Lincoln Laboratory and MIT have been exploring the development of a processor architecture that exploits cryptographic techniques to help secure data in use, in transit, or at rest. This key-centric architecture integrates the cryptographic key management with the processor's execution pipeline to permit distinct software codes to both coexist and interact while a high level of confidentiality is maintained through the use of a public key infrastructure engine and mandatory code and data decryption.
- A partnership of Lincoln Laboratory, the US Army Natick Soldier Systems Center, the Commonwealth of Massachusetts, and Advanced Functional Fabrics of America, a Manufacturing USA institute, is enabling the establishment of the Defense Fabric Discovery Center, which will house a state-of-the-art, end-to-end prototyping facility for developing advanced fiber and fabric technology. This facility is part of a planned national network of five fabric discovery centers. The center at Lincoln Laboratory will focus on fabrics that have military applications, such as providing soldiers with garments that can sense RF and optical signals, store electrical energy, and monitor heart or heat stress.
- Researchers from Lincoln Laboratory and MIT's Computer Science and Artificial Intelligence Laboratory have been developing a database management system that allows software developers and database administrators to efficiently exploit multiple databases. Called BigDAWG, this open-source technology is dubbed a polystore system because it interfaces with multiple, heterogeneous storage engines so that developers can access needed information contained in disparate databases. People from Intel and from several universities—Brown University, Northwestern University, Portland State University, Carnegie Mellon University, the University of Chicago, the University of Washington, and the University of Tennessee—are working with the laboratory and MIT to make BigDAWG the solution that organizations will adapt to easily to be able to effectively use data that are spread across several storage systems.

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 AY2017, 42 military officers worked in various technical groups under fellowships. In summer 2017, 68 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. In AY2017, the laboratory offered Introduction to Radar Systems, Networking and Communications, and a one-day course on intelligence, surveillance, and reconnaissance systems and technology.

In addition, through a program with the Naval War College in Newport, RI, the laboratory's technical staff present courses for naval officers; each term, courses are selected to address the college's needs. The courses scheduled in 2016 were in cyber security, ballistic missile defense, and space technology.

Lincoln Laboratory technical staff led activities during MIT's 2017 Independent Activities Period, a four-week term from January 9 to February 3. During this semester intersession, Lincoln Laboratory staff members developed and led seven non-credit offerings:

- Build a Small Radar System
- Free-Space Laser Communications
- Hands-on Holography
- Mathematics of Big Data
- RACECAR: Rapid Autonomous Complex-Environment Competing Ackermann-Steering Robot
- Software Radio
- Technology Innovation Accelerator

Beaver Works

Beaver Works, a joint venture between Lincoln Laboratory and the MIT School of Engineering, facilitates project-based learning (a hallmark of an MIT education) and leverages the expertise and enthusiasm of MIT faculty, students, and researchers, and Lincoln Laboratory staff to broaden research and educational partnerships. A key component of Beaver Works is the capstone project, which is typically associated with a two-semester design-and-build class that challenges students to develop an engineering solution to a real-world problem. This year, students in the MIT undergraduate courses Engineering Systems Design and Engineering Systems Development, offered by the Department of Mechanical Engineering in collaboration with Lincoln Laboratory, are developing an emergency power pack that uses an aluminum-water fuel, an aluminum-powered autonomous undersea vehicle, and an aluminum-fueled sport utility vehicle. In conjunction with courses in the Department of Aeronautics and Astronautics, students investigated the design of a planetary penetrator, that is, a vehicle that can fly and emplace itself on a planetary surface, and designed and built a large (24-foot wingspan) UAV that can sustain flight for five days without refueling. A capstone on time-series analytics for decision making continued under 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 autonomous tasking for small unmanned air systems.

University Student Programs

Lincoln Laboratory offers a variety of research and internship opportunities to university students. Candidates in MIT's 6-A Master's 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 Lincoln Laboratory engineers and MIT faculty members. In 2017, five students chose to do their thesis research at Lincoln Laboratory. The laboratory also typically employs about a dozen other research assistants from across MIT's engineering departments.

Each summer, the laboratory hires undergraduate and graduate students from top universities as interns in technical groups. In addition to participating on technical projects, the students attend in-house demonstrations and seminars and give final presentations on their work to the laboratory community. Throughout the year, cooperative education (co-op) students from area colleges, such as Northeastern University and the Wentworth Institute, work at the lab. This year, 85 co-op students from area schools were employed in technical divisions and service departments.

Infrastructure

Lincoln Laboratory's service departments work closely with the technical divisions to support research and prototyping activities.

Contracting Services Department

The Contracting Services Department supported the laboratory's federally funded research by issuing more than 60,000 procurement transactions with a value of $462.1 million in the laboratory's fiscal year 2016 (October 1 to September 30) and more than 41,000 procurement transactions with a value of $350.5 million through the first three quarters of fiscal year 2017. To maximize business process efficiencies, the laboratory encouraged the use of electronic procurement tools. Between July 2016 and June 2017, employees who were not staff in the Contracting Services Department were able to place approximately 39,000 of procurement transactions directly through the use of electronic catalogs and electronic procurement cards.

Through its Small Business Program, the department continues to maximize business opportunities for innovative small businesses. A comprehensive outreach program included 61 demonstrations and visits made by small businesses to the laboratory. Consequently, small businesses were the recipients of approximately 55% of outside procurement dollars issued in the past year.

The department formally implemented a Better Buying Power program two years ago to maximize efficiencies and to optimize value to the laboratory's federal sponsors. As a result of the implementation of this program, more than $6.5 million in documented cost savings were realized in the laboratory's fiscal year 2016 through the use of reverse auctions, competition, price negotiations, and prompt payment discounts. Through the first three quarters of fiscal year 2017, Lincoln Laboratory achieved approximately $3.9 million in cost savings by employing similar techniques.

Facility Services Department

The Facility Services Department (FSD) manages the operations and maintenance of more than 2.2 million square feet of laboratory and general-use facilities. Core services include operations and maintenance of all facilities; renovation and construction projects; and custodial, mail, food, transportation, hazardous-material handling, and parking services.

In fiscal year 2017, the department went beyond its normal scope of small renovation, rehabilitation, and infrastructure modernization efforts and completed a renovation of the laboratory's cafeteria. This multi-million-dollar effort shut the cafeteria down for a four-month overhaul. The project design included adding an auxiliary conference room capability, thus expanding the building's footprint; redistributing the floor plan to achieve a much more efficient layout; modernizing the architecture; replacing the entire serving space; replacing nearly all of the mechanical, electrical, and plumbing systems; replacing the roof; and outfitting the cafeteria with new equipment and furnishings. During this construction, the department also managed a temporary food service operation. FSD set up temporary serving areas strategically dispersed throughout the laboratory and arranged contract food-truck operations to keep the staff fed throughout the renovation.

Another large project the department tackled successfully was the construction of a photovoltaic power plant on top of the laboratory's parking garage. The project was coordinated with contractors and completed in less than three months. In addition to gaining environmental efficiencies from this effort, the laboratory realized the ancillary benefits of additional covered parking and significantly reduced costs for pavement maintenance and snow removal on the top floor of the garage.

Financial Services Department

In fiscal year 2017, the transition of programs to the new prime contract was a major focus area for the Financial Services Department; execution on the old contract ends during fiscal year 2018. The majority of Lincoln Laboratory's funding and expenses are now to be on the new contract. The funding mechanism for the facilities modernization plan (FMP) has been fully integrated into the laboratory's cash management process. The renovation of the cafeteria was the first major project funded and executed using FMP funds.

The department is working with an outside vendor to create digital images of purchase-order invoices and travel vouchers in an effort to make more operations paperless. This move to digital paperwork will allow the department to respond more quickly to divisional and audit requests for backup data. The department is also working with the Information Services Department to co-lead the laboratory's digital enterprise transformation program; this multiyear effort to review and improve the laboratory's business process will include an update to the laboratory's Enterprise Resource Planning system platform in 2018.

Information Services Department

The Information Services Department (ISD) continued to execute its strategic plan to provide innovative enterprise technology solutions that enhance the ability for all Lincoln Laboratory staff to perform their roles effectively in support of the laboratory's national research mission. The department has taken steps to strengthen information technology (IT) governance by restarting the IT Executive Council. This year, ISD established the Enterprise Infrastructure Core Services Governance Board, a governing body that rounds out the existing governing bodies of Business Applications and Information Security. These governance boards were established to advance decision making processes regarding IT investments laboratory-wide. The IT Executive Council initiated the effort to create a multiyear IT strategy that will guide ISD in shaping future IT services across Lincoln Laboratory.

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

- Supporting the mobile workforce: As the workforce becomes increasingly more mobile, it is important to provide tools and technologies to support this demand. Apple Inc.'s iOS has now become the standard platform for all smartphones at the laboratory. Additional features and capabilities enable mobile access to the laboratory's intranet and search functions. Enhancements to wireless services throughout the laboratory are the foundation to support the mobile strategy. The file/synchronize/share application, the laboratory's own private cloud, is now available for all devices. Skype for Business supports one-on-one video chat or larger video teleconferences. Collaboration tools continue as a strong area of focus for ISD.
- Advanced business operations: The Business Applications Governance Board, established in 2015, facilitated the successful completion of a number of projects. The Supplier Relationship Management project developed a capability for attaching documents to "shopping carts." This enhancement streamlines cart approvals and processing and promotes green business practices. The FSD work request application offers a unified request tool for all facility-related work; this one tool for requesting all facilities work also coordinates appropriate workflow approvals. In partnership with the Financial Services Department, ISD has embarked on a multiyear, multiphase digital enterprise transformation program to assess current business processes, identify process improvements, and develop a transformation road map to implement. Migration to SAP HANA, a cloud-hosted database and application development platform for processing large amounts of data, is under way; as a result, the laboratory's business applications will be more agile and able to meet current and future business needs.
- New communication channels: ISD held the first ISD Connections event showcasing new technologies, devices, applications, and tools. This walk-in event provided laboratory employees with the opportunity to meet ISD staff, ask questions, and try out new service offerings. The Hot Topics banners on the ISD webpage are another communications channel for ISD to share trending IT topics and information.
- Network and cyber security improvements: Advanced network segmentation has been deployed across all networks to protect laboratory information systems by offering both improved monitoring and control capabilities. This new architecture allows for faster cyber incident response time. In collaboration with the Security Services Department, ISD is working on multifactor authentication that would read a personalized smart card—that is, a badge equipped with a public key infrastructure chip—and that would also require a private PIN number. This new procedure will support stronger authentication requirements for user access to systems on the laboratory's networks.

Security Services Department

The Security Services Department (SSD) led the effort that earned Lincoln Laboratory its 11th consecutive "superior" security rating from the US Air Force's 66th Air Base Group Information Protection Office. During 2016, SSD prepared 12 groups within the laboratory

for 38 government security-related audits conducted by multiple government agencies. The department also completed multiple-sponsor inspections that support special programs.

Training and support provided by the department to help strengthen the laboratory's emergency preparedness program included several seminars and exercises: active threat sessions, building-evacuation drills, an insider threat tabletop exercise, suspicious package training, a cyber security exercise, drills on force protection condition changes, an internet shutdown exercise, emergency communication drills, and workplace violence education seminars. During the eighth annual Security Education and Awareness Week, speakers from both the laboratory and government agencies conducted sessions on counterintelligence in the workplace, active threat awareness, and cyber threats and trends.

This year's activities included the following:

- In April 2017, Shawn Daley, Lincoln Laboratory's chief security officer, was elected to the chair of the board of directors of the Security Leadership Council of federally funded research and development centers/university affiliated research centers. The Security Leadership Council was formally recognized as a professional security forum under the federal government's National Industrial Security Program. This council encourages collaboration between government and industry to create an effective set of security standards across the industrial base.
- The laboratory-wide rebadge initiative is under way. All employees are receiving new badges, dubbed Smart Cards, that include a public key infrastructure contact chip for logical network access. This initiative is a part of the Two-Factor Authentication Project, conducted with ISD, and was recognized with a Lincoln Laboratory 2017 team award.
- The department created and implemented an Insider Threat Program Plan for MIT and Lincoln Laboratory.

Several projects are helping to ensure that information and information systems are not subjected to cyber attacks.

- Working with ISD, SSD continued the implementation of technical control requirements for safeguarding information, as defined by the Defense Federal Acquisition Regulation Supplement (DFARS). Because of changes to the laboratory's prime contract, SSD updated DFARS requirements to National Institute of Standards and Technology (NIST) 800-171 standards and notified the DoD Chief Information Officer of the laboratory's state of compliance. The department also updated numerous information systems security policies to comply with heightened DFARS information security requirements and developed a DFARS search methodology for specific NIST 800-171 controls in policy.
- SSD updated policy, developed a risk assessment methodology, and provided deployment guidance to staff to facilitate the laboratory's use of cloud technology.
- The department initiated a Command Cyber Readiness Inspection Review Program that includes scoping, preparing, baselining, and system alignment for re-architecturing and enhancing inspection readiness of the secret internet protocol router network.

- The transition to the Risk Management Framework for Special Programs Information Systems was completed.

The department provided communications security support to multiple projects, including the Prototype Airborne Contested Environment Communication Relay program, the US Navy's first Enhanced Polar Satellite program in Alaska, and the Navy's Northern Edge training exercise in Nevada and Alaska. Department personnel also increased the availability of the Joint Worldwide Intelligence Communications System to more members of Lincoln Laboratory.

Security Services personnel also provided security services to enable the success of several high-profile, large-scale conferences hosted by Lincoln Laboratory and a number of sponsor-requested technical reviews. The department accommodated more than 10,000 visitors this year.

Community Outreach

Education

Recognizing the importance of preparing young people for careers in science, technology, engineering, and mathematics (STEM), Lincoln Laboratory Community Outreach administers a significant program of STEM activities. Science on Saturday, the laboratory's first STEM program, drew approximately 2,800 K–12 students, parents, and teachers to science demonstrations given by technical staff members during academic year 2017. Offerings for that season included demonstrations about the science of weather and music, sounds of the jungle, and robotics. Audience volunteers participated in several demonstrations.

Audience volunteers observed a Science on Saturday experiment on weather from up close.

The Lincoln Laboratory Radar Introduction for Student Engineers summer program provides 18 high school students from across the country with a two-week, project-based course on radar fundamentals. The program includes instructional sessions on the basics of radar systems and radar imaging, workshops for building radar systems that can perform range-Doppler imaging, and opportunities to demonstrate the performance of the radars built during the workshops. The 2017 radar introduction program began on July 10. This year, two high school teachers from Michigan participated in the program, evaluating the possible incorporation of this hands-on workshop into their physics classes and teaching the introduction to radar portion of the course.

Beaver Works introduced the MIT Beaver Works Summer Institute in 2016. The summer STEM program taught talented rising high school seniors how to program miniature racecars to navigate a complex racetrack autonomously. The 2017 Beaver Works Summer Institute added supplementary online lessons and new courses on autonomous air vehicles and cognitive assistants. Students demonstrated their projects to the public at a final racing competition and exhibition event in early August.

Three graduating high school seniors were interns at Lincoln Laboratory as part of the Armed Forces Communications and Electronics Association international program. Laboratory technical staff mentored the interns. Two interns helped with the testing of an aircraft collision avoidance system; one worked in the Active Optical Systems Group.

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

Community Service

Lincoln Laboratory Community Outreach helps increase laboratory employees' awareness of events sponsored by charitable organizations. Laboratory participants in the American Heart Association's Heart Walk raised $5,000. The Lincoln Laboratory cycling team raised more than $10,000 for Alzheimer's research in the Ride to End Alzheimer's, and 46 members of the laboratory raised $44,832 in the Walk to End Alzheimer's. Laboratory staff also walked and cycled for the CancerCare walk and the Pan-Mass Challenge.

The Lincoln Laboratory Hispanic and Latino Network sponsored a "No Hunger Summer" food drive to help offset the increased summertime demand on the Merrimack Valley Food Bank. More than 157 pounds of food were collected and delivered to the food bank's warehouse. Support Our Troops, one of Lincoln Laboratory Community Outreach's first community giving programs, is an ongoing campaign to collect and mail food, toiletries, and books to US soldiers overseas. In academic year 2017, Lincoln Laboratory sent 200 care packages and 150 signed holiday cards to the troops. Laboratory employees also donated hundreds of items to Toys for Tots, Cradles to Crayons, and a pet supply drive for pets displaced by flooding in Louisiana.

Summary

Lincoln Laboratory continued to see strong support for its core mission areas as advancements expand the applications of its technologies. Missions such as space control, ISR, tactical systems, communications, and air, missile, and maritime defense are pursuing answers to new challenges created by today's reliance on big data, cyber security, satellites, and electronic warfare. The laboratory's research and development portfolio is well balanced, with programs that range from large-scale system developments and to rapid prototyping efforts to innovative, often multidisciplinary, research projects.

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

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

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

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

Eric D. Evans
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