Lincoln Laboratory

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

The laboratory's main facilities are in Lexington, MA, partly on Hanscom Air Force Base property. The laboratory operates radar facilities in Westford, MA, and a virtual reality environment in Billerica, MA. Space at an office park two miles from the main laboratory site provides additional offices for both technical and administrative work. In addition, to facilitate both interactions with government sponsors and in-field testing and evaluation of systems, Lincoln Laboratory has field offices in several locations around the United States, including Huntsville, AL; Fort Meade, MD; and Colorado Springs, CO.

Lincoln Laboratory's mission is to develop technology in support of national security. Research and development (R&D) conducted at the laboratory covers a broad range of domains, including space systems and technology, air and missile defense technology, cyber security, communication systems, bioengineering, maritime defense technologies, microelectronics, air traffic control, and intelligence, surveillance, and reconnaissance (ISR).

As an essential element of the nation's national security infrastructure, the laboratory has continued to work throughout the COVID-19 pandemic. The Lincoln Laboratory COVID-19 Task Force, assembled in March 2020, has continued collaboration with MIT Campus, adapted policies as needed, and provided resources for the laboratory community to stay safe. Many within the laboratory's workforce have worked effectively remotely, but a large percentage work on site for classified projects, hardware development, and other important needs. For those employees, strict social distancing guidelines and cleaning and sanitization steps were implemented to enhance health protection and safety. Staff at all levels demonstrated outstanding initiative and flexibility. Laboratory researchers also developed technologies and applied expertise to help counter the COVID-19 pandemic. Among these efforts were projects that explored methods for contact tracing, evaluated personal protective equipment, and predicted transmission spread.

Also notable was the establishment of a new division, Biotechnology and Human Systems, to address emerging threats to global and national security. The division is tapping the laboratory's deep understanding of systems and architectures to develop advanced technologies designed to improve chemical and biological defense, human health and performance, and global resilience to climate change, conflict, and disasters. The new division consolidates work that was previously spread across several technical groups.

Lincoln Laboratory's sponsored research and development continued to reach significant milestones: a team successfully integrated and tested the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Pathfinder CubeSat, which is equipped with an advanced compact

microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. The laboratory transitioned the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), the most advanced US airborne 3D foliage-penetrating LiDAR, to the US Southern Command. The laboratory also applied artificial intelligence (AI) techniques to develop advanced sensors and algorithms aimed at ensuring robust performance of the Missile Defense System against ballistic, hypersonic, and other advanced missile threats. More examples of this year's R&D are presented in the Technical Program Highlights section.

In fiscal year 2020 (October 1, 2019, to September 30, 2020), Lincoln Laboratory received approximately $1.104 billion in total funding to execute R&D on sponsored projects. While most of the research is sponsored by the DoD, funding is also received from the Department of Homeland Security (DHS), Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), and National Oceanographic and Atmospheric Administration. In addition, Lincoln Laboratory carries out noncompetitive research with industry under approved cooperative research and development agreements and other collaborative activities with academic institutions.

Organization

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

Establishment of Biotechnology and Human Systems Division

This new division will direct the laboratory's unique expertise in system and architecture analysis, computer modeling, and system prototyping and field testing toward technology development that addresses current and evolving threats in the biotechnology area. To advance the nation's defenses against biological threats and its responses to health crises such as a pandemic, the division will expand upon its work in the identification and early warning of pathogens, bioinformatics, molecular diagnostics, and synthetic biology. The division will also focus on R&D for improving human conditions, such as therapeutics for diseases and disabilities, humanitarian assistance, rapid disaster response, and the impacts of climate change.

Establishment of the Ethics and Compliance Assurance Office

This new office centralizes the activities involved in maintaining Lincoln Laboratory's high ethical standards and in assuring compliance with contractual and government regulations. The Ethics and Compliance Assurance Office (ECAO) within the Director's Office provides comprehensive, current information on ethics and compliance matters. The ECAO closely collaborates with the Security Services, Human Resources, and Contracting Services Departments, as well as the MIT Office of General Counsel. The office also serves as the primary Lincoln Laboratory interface with the MIT Audit Division.

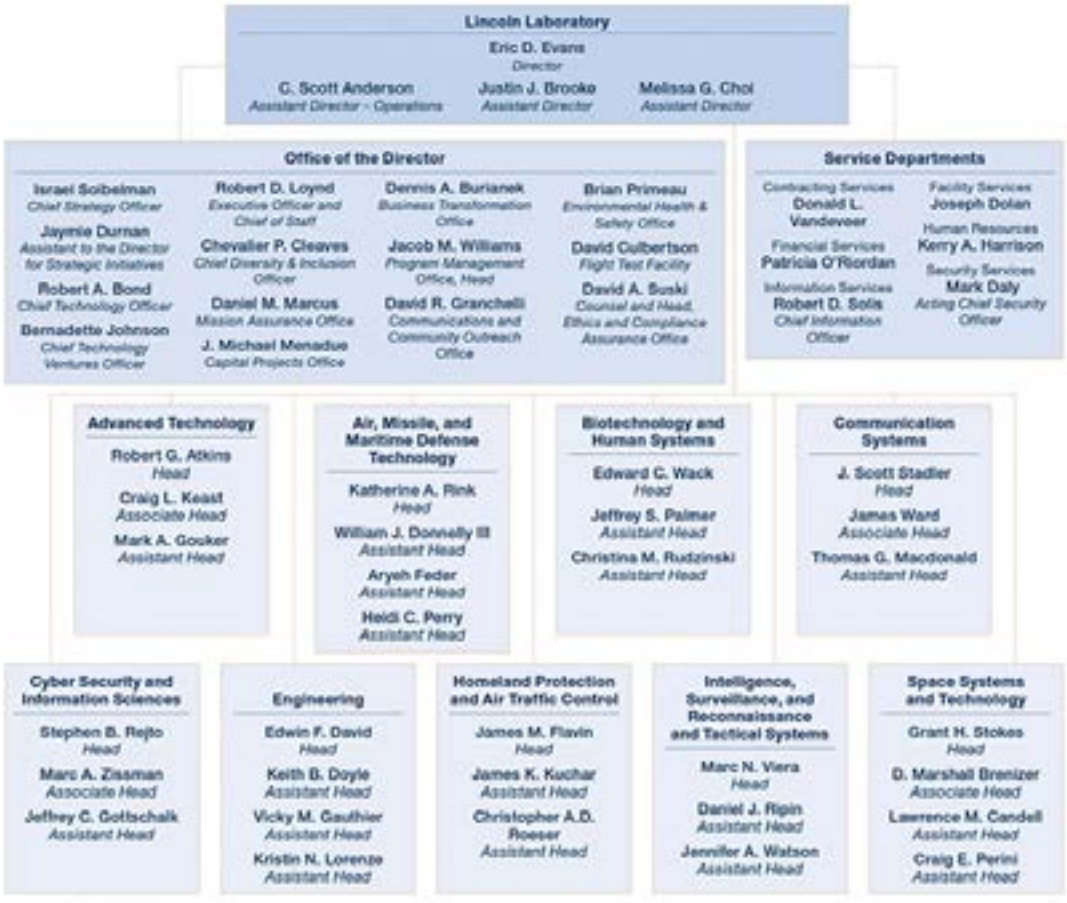

Figure 1. Lincoln Laboratory's organizational structure as of June 30, 2021.

Leadership Changes

Edward C. Wack was appointed as division head, Biotechnology and Human Systems; he was the former assistant head of the Homeland Protection and Air Traffic Control Division.

Jeffrey S. Palmer was promoted to assistant division head of Biotechnology and Human Systems; he was the former leader of the Human Health and Performance Systems Group.

Christina M. Rudzinski is now the assistant division head of Biotechnology and Human Systems; she was formerly leader of the Chemical and Biological Defense Systems Group.

Edwin F. David as appointed division head of the Engineering Division; he previously served as leader of the Homeland Protection Systems Group.

Keith B. Doyle was named assistant division head of Engineering; prior to this role, he was leader of the Structural and Thermal-Fluids Engineering Group.

Kristin N. Lorenze was promoted to Assistant Division Head of Engineering; she formerly served as the head of the Program Management Office.

Christopher A. D. Roeser was appointed assistant division head of Homeland Protection and Air Traffic Control; he has had several group leadership positions and a senior staff position in the Advanced Technology Division.

Kerry A. Harrison was appointed as head of the Human Resources Department; her experience in human resources spans areas that include employee compensation and benefits, wellness programs, professional development, and performance metrics.

Daniel M. Marcus is now the head of the Mission Assurance Office; he previously worked with L3Harris, where he was the senior manager of mission assurance for the division specializing in high-precision optics and payloads for space.

Jacob M. Williams was appointed as head of the Program Management Office; he joins the laboratory from L3Harris, where he was director of programs for the Integrated Vision Solutions Sector and led advanced night vision device programs for the US Army.

David Suski was appointed as head of the Ethics and Compliance Assurance Office (ECAO); he is the on-site legal advisor for Lincoln Laboratory, where he focuses on legal matters arising out of the laboratory's national defense research. He will also serve as the head of the ECAO while remaining a member of the MIT Office of General Counsel.

Peter H. Babcock was promoted to deputy head of the Ethics and Compliance Assurance Office; continuing his role as Lincoln Laboratory's assistant ethics officer while serving as deputy head of the Ethics and Compliance Assurance Office, he leads a team that has oversight of conflict-of-interest situations, reviews whistleblower complaints, and maintains the laboratory's Ethics Hotline.

Christiaan M. Stone was appointed as deputy director of Policy, Compliance, Labor and Employee Relations of Human Resources; he and his team manage all labor relations with the unionized staff at the laboratory as well as employee relations for Lincoln Laboratory employees.

Diane J. Shea appointed as assistant department head in Contracting Services Department; she has been in the acquisition profession with MIT for 39 years with 11 of those years being at Lincoln Laboratory.

Alex W. Lupafya was hired as the deputy chief diversity and inclusion officer; he joined the Diversity and Inclusion Office from Staples Inc., where he was responsible for building their Office of Diversity and Inclusion for this global corporation of 16,000 employees.

Technical Program Highlights

Research and development at the laboratory focuses on national security problems across a broad range of mission areas: tactical and ISR systems; air, missile, and maritime defense; space security and space systems; chemical and biological defense; homeland defense; communications; cyber security and information sciences; and advanced electronics technology. In addition, the laboratory undertakes work in related nondefense areas, such as air traffic control, weather sensing, and environmental

monitoring. A principal activity of the laboratory's technical mission is prototyping, which involves the development of components and systems for experiments, engineering measurements, and tests under field operating conditions.

This year, Lincoln Laboratory worked on 832 programs that range from large-scale hardware projects to small seedling initiatives. Notable highlights for each mission area are listed below.

Space Systems and Technology

Space Surveillance Telescope Station Harold E. Holt in Australia is undergoing final tuning and system acceptance testing before its transition to operations by the Royal Australian Air Force and maintenance by industry.

The TROPICS Pathfinder CubeSat was successfully integrated and tested and is scheduled to be launched in June 2021. The Pathfinder vehicle is the qualification development unit built for the NASA Earth Venture Instrument's TROPICS constellation. Launch and on-orbit demonstration of the vehicle will serve as a risk-reduction flight test ahead of the full TROPICS constellation launch scheduled for early 2022. TROPICS CubeSats are equipped with an advanced compact microwave sounder technology to provide high-revisit observations of precipitation, temperature, and humidity in tropical storms.

The Situational Awareness Camera Hosted Instrument (SACHI) program is developing two identical hosted-payload space situational awareness (SSA) sensors. SACHI leverages ORS-5 (SensorSat) technologies to provide a rapid development and delivery sensor system that has significant onboard SSA data processing capabilities. After a successful Critical Design Review, researchers are procuring, fabricating, assembling, and testing the payload subsystems for planned delivery in 2022.

Figure 2. The Space Surveillance Telescope, shown under the exquisitely dark skies of Northwestern Australia, achieved first light in February 2020 following relocation from New Mexico. The new location will allow improved surveillance of deep-space objects in the Asia-Pacific region.

A portfolio of activities is delivering critical space domain awareness information and tools to the National Space Defense Center in Colorado and the Combined Space Operations Center in California. The laboratory is leading the modernization of networking, data architecture, and processing capabilities of legacy space surveillance sensors to improve the timeliness of missions. Prototypes of net-centric data libraries have enabled a universal data library that allows Space Force operators to leverage commercial space domain awareness data. An evaluation of the commercial data may lead to an increased capacity and diversity of sensors in the network.

Systems and mission analyses continue to motivate new concepts leveraging advanced technologies at US space organizations. In 2020, several prototypes were field-tested, and initial resilient architectures are planned for a 2023 delivery.

Air, Missile, and Maritime Defense Technology

Lincoln Laboratory continued to develop advanced sensors and algorithms to ensure robust performance of the Missile Defense System (MDS) against ballistic, hypersonic, and other advanced missile threats that might employ intentional and unintentional countermeasures. Increasingly, the laboratory is applying its expertise in AI systems to enhance threat discrimination and is working to establish AI robustness as a key performance consideration.

Figure 3. Researchers deployed a technology demonstrator of an undersea mapping sparse sonar array. The array is a novel surface-based, distributed multi-input multi-output sparse aperture sonar to support deep ocean floor mapping with a resolution two orders of magnitude higher than is currently achievable.

Sponsored by Defense Advanced Research Projects Agency (DARPA), the laboratory developed hypersonic computational fluid mechanics algorithms to advance hypersonic vehicle modeling, design, and flight characteristics.

The laboratory tested and evaluated a prototype capability utilizing advanced signal processing techniques to enable distributed radar sensing for eventual use by forward-deployed forces.

To inform future maritime infrared sensing, the laboratory developed and deployed a reconfigurable infrared sensor test bed system featuring both analog and digital focal plane array cameras, as well as conventional and multiplexed imagers.

Lincoln Laboratory was a central contributor to the Next Generation Interceptor program initiation through its support to the GM Technical Direction Agent and is providing subject-matter expertise to the Air Force's Ground-Based Strategic Deterrent program.

The laboratory continues to lead the development of algorithms to provide real-time assessment of electronic warfare decoy performance and to discover the algorithms' operational effectiveness through the use of serious game environments.

To enhance the performance of the submarine combat system, the laboratory has been developing improved electronic warfare, sonar automation, and signal processing capabilities.

Communications waveforms that simultaneously transmit and receive data while also being used as radar waveforms to detect and track moving objects achieved good communications and radar performance during a field test.

Communication Systems

Lincoln Laboratory decommissioned the Lincoln Experimental Satellite-9 on May 20, 2020. Launched in 1976, LES-9 was the longest continuously operating communications satellite in US history.

The laboratory's instrumentation-grade terminals were used to make first contact with and calibrate Advanced Extremely High Frequency satellites AEHF-5 and AEHF-6.

Figure 4. Photonic integrated circuit (PIC) optical matched filters achieved excellent filter extinction (>45 dB) and highly Gaussian lineshape. Coupled with advanced digital signal processing, PIC technology will dramatically reduce the size, weight, power, and cost of future lasercom terminals.

Lincoln Laboratory completed prototyping modems for the Protected Tactical Service Field Demonstration. The waveform was tested over the Wideband Global System and with international partners over the Skynet satellite.

Flight demonstrations were conducted for a new content-aware data distribution architecture. The approach enables dynamic mission execution across disparate networks by distributing tailored data to subscribers over the best available paths. The prototype implementation operates over military tactical radios as well as commercial wireless and satellite networks.

A prototype of an advanced signal processing applique and new apertures will add resiliency to a legacy tactical data link.

The laboratory characterized the ability of Bluetooth Low Energy signaling to determine the proximity of cell phones. This characterization will be instrumental in helping public

health professionals develop effective cell phone applications for automated contact tracing for the COVID-19 pandemic.

A prototype high-frequency communications digital phased array was expanded to include dual signal polarizations and adaptive beamforming. The array was demonstrated with beyond-line-of-sight voice traffic during military tactical training exercises.

In a collaboration with MIT, techniques were developed for a novel RF spectrum analyzer that leverages machine learning algorithms to decompose a congested spectral band into its component signals and classify them individually.

Cyber Security and Information Sciences

The Lincoln Laboratory Supercomputing Center deployed the most powerful AI supercomputer at any university in the world. The new system enables rapid prototyping, scaling, and application of AI systems across DoD missions.

The laboratory developed technology to improve the design integrity of microelectronic chips against supply chain cyberattacks. The technology enhances the detectability of attempts to tamper with the security-critical components of a digital circuit design.

Figure 5. The ROGUESAINT project is developing a next-generation cyber system and associated capabilities for the Federal Bureau of Investigation. The research requires a multidisciplinary approach of strategy development, low-level systems exploitation, and prototype development.

Lincoln Laboratory demonstrated initial operation of its secure operating system Magnetite. Magnetite is implemented in a memory-safe language called Rust and leverages a formally verified microkernel called seL4. The system is designed to provide fine-grained resource isolation, recovery mechanisms, and cyber resilience for embedded platforms.

The Applied Resilience for Mission Systems initiative is guiding the cyber resilience of DoD missions. The laboratory published guidance that advises programs to adopt modern development, security, and operations practices; integrate commercial and open-source components; and leverage automated observability and infrastructure tools.

A state-of-the-art speech enhancement system that employs the latest in machine learning advancements was transitioned to the US government.

Lincoln Laboratory developed a methodology to make adversarial activity a critical component of AI software testing. This methodology has been applied to evaluate and mitigate threats to decision support systems.

Working with cyber operators from multiple combatant commands, the laboratory identified a common workflow architecture for cyber situational awareness and developed technology-implementation strategies. A prototype capability is being assessed as part of the Joint Cyber Warfare Architecture.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Lincoln Laboratory transitioned the most advanced US airborne 3D foliage-penetrating LiDAR to the US Southern Command. The MACHETE 2.0 LiDAR system, which achieves a five-fold increase in area coverage rate over MACHETE 1.0, has already provided significant value to the counterterrorism and counter-narcotics intelligence communities.

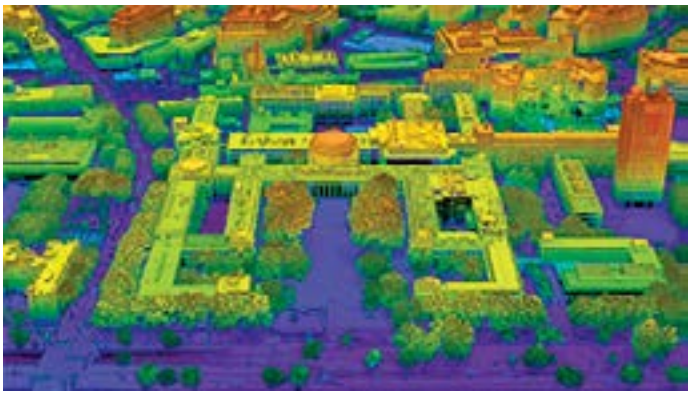

Figure 6. 3D image of MIT Killian Court was taken with the upgraded MACHETE 2.0 LiDAR system.

The laboratory has developed advanced AI algorithms that can automatically identify trails, riverbeds, and other communication lines that can be indicators of human activity in highly foliated scenes.

The laboratory is prototyping a distributed maritime reconnaissance system for use in contested environments. Sponsored by the Office of Naval Research, the system completed four flight experiments with operational P-3C and P-8A maritime patrol aircraft.

Leveraging its integrated research environment for developing large-scale, graph-analysis technology, the laboratory created a novel formulation of the subgraph matching kernel targeting advanced high-performance accelerators for important DoD and commercial applications.

Researchers at Lincoln Laboratory have analyzed the use of quantum-based vector magnetic field sensors for the detection of Earth's magnetic field. Through correlation of the measured field with a previously collected database, the researchers can discern the absolute location of the sensor.

In collaboration with researchers at the Jet Propulsion Laboratory (JPL), Lincoln Laboratory designed a proof-of-concept real-time low-size, low-weight, and low-power LiDAR mapping system to support a future Europa Lander.

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

Tactical Systems

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

Prototyping of advanced technologies for airborne signals intelligence continues. Two major systems were successfully field tested. One represented a significant technical upgrade to an existing capability, and the second demonstrated a new capability for operators. Both systems and the relevant designs were transitioned to an industry partner for production and fielding.

Figure 7. The Airborne Seeker Test Bed is a customized aircraft used in flight testing radio-frequency and infrared sensors. To carry these sensors, the aircraft is modified with wing pylons, a nose radome, forward chin-pods, and computer and instrumentation racks in the interior.

Software researchers continued to refine a software and cyber security architecture to support logistics systems for advanced US fighter platforms, incorporating modern software design patterns and leveraging commercial best practices.

State-of-the-art transfer-learning techniques enabled machine characterization of US Army tactical communications data, pointing the way for tactical operations accelerated by artificial intelligence.

In a series of joint US Air Force–Army exercises, the laboratory demonstrated how open software architectures and machine-to-machine interoperability will enable next-generation joint all-domain command and control.

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

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

Advanced Technology

Researchers working on ReImagine, a program to create reconfigurable imaging systems, completed the design of a second-generation integrated circuit. This technology brings the flexibility of field-programmable gate arrays (FPGAs) to digital focal plane imagers that are transforming DoD imaging systems. The circuit has six billion transistors.

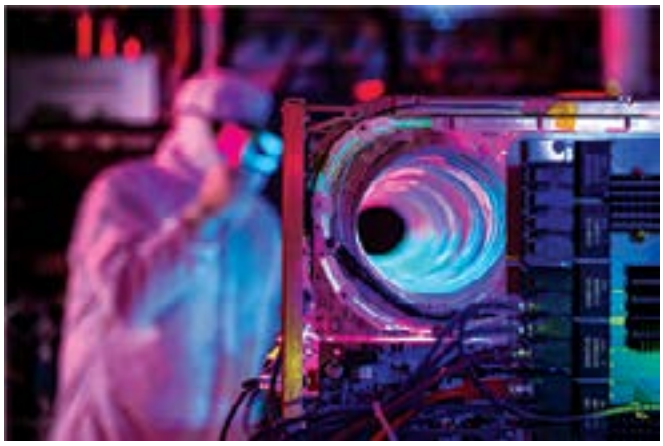

Figure 8. Lincoln Laboratory demonstrated a 46-kilowatt coherently combined high-energy laser system with the highest brightness per unit mass in the world. This demonstration of a packaged high-power optical phased array paves the way for testing on size-, weight-, and power-constrained platforms.

The laboratory has begun work to add functionality to textile fibers, giving new capability to fabrics and other systems that the fibers compose. One of these activities is focused on integrating electronics into these textile fibers. In particular, power and communication buses are integrated into the fiber and can individually communicate with functional nodes on the fiber. The goal is to create one-dimensional systems with lengths on the order of a kilometer to perform sensing and communication functions.

The use of gallium-nitride (GaN) power transistors is revolutionizing radio-frequency communication and radar systems. Ongoing work is focused on fabricating GaN transistors on a silicon substrate to both reduce cost and provide a pathway to integrate complex logic and control circuitry with the power transistors. Recent measured results of an X-band transmit/receive front-end monolithic microwave integrated circuit showed performance comparable to the more expensive GaN-on-SiC (silicon carbide) process.

The laboratory completed the construction and qualification of its Photon-Counting Camera (PCC), which will be integral to enabling a laser communication link to the spacecraft being launched to the Psyche asteroid in 2022. The PCC is part of the JPL's Deep Space Optical Communications (DSOC) program. The goal of the DSOC program is to demonstrate both ground and space technologies for future bidirectional laser communication systems to deep-space missions.

A respirator test facility provided efficacy data for more than 100 foreign-sourced N95 filtration masks. Data provided to the Commonwealth of Massachusetts guided the distribution of these respirators to frontline workers during the COVID-19 pandemic.

Homeland Protection

A prototyping facility was established for the US Air Forces in Europe command that leverages the laboratory's expertise in regional air defense and supports the DoD priority of base defense worldwide.

Figure 9. A radar system integrated on an unmanned ground vehicle can detect disaster survivors trapped under rubble. The radar extracts a breathing rate and wirelessly transmits the data and the location to rescue teams. Future work will focus on unmanned air vehicle integration.

A long-range radar and AI algorithms were deployed for recognizing and tracking vessels that may be illegally transporting material across border waterways.

A modern cloud-based data architecture was defined to support rapid integration and demonstration of new sensing and response technologies for North American Aerospace Defense Command and US Northern Command homeland air defense objectives.

The laboratory provided characterization, technology assessments, and prototypes to counter small–unmanned aerial system (sUAS) threats to the homeland and military bases.

A novel layered sensing architecture is being developed to fuse data from multiple sensors to recognize the transport of concealed threats in mass transit and other public settings.

The laboratory supported the development and integration of a counter-sUAS system for the Pentagon Force Protection Agency through operational evaluations, in-depth data analysis, and technology recommendations.

A novel activated aluminum solid fuel was developed by Lincoln Laboratory and is being used to explore new operational concepts for US infantry.

Energy resilience readiness exercises performed for the DoD identified interdependent infrastructure important to critical missions. The assessment technology and systems approach were transitioned to the private sector.

An end-to-end system was prototyped to detect hostile foreign narratives, classify accounts engaged in influence operations, and determine the most influential spreaders.

Assessments were performed on gap-filling sensors being considered to mitigate the spectrum impact of windfarms located near joint-use air surveillance systems.

Biotechnology and Human Systems

Lincoln Laboratory performed rapid analyses to help the medical, public health, and other communities respond to the COVID-19 outbreak. These activities included modeling the outbreak and the potential demand for personal protective equipment.

The laboratory worked with the MIT campus, the public health community, and industry to develop the Private Automated Contact Tracing mobile app architecture and served as a technical advisor to state and federal personnel.

Recent advances in 3D plume reconstruction are enabling better estimates of chemical and biological threat hazards and sensor performance needs.

A holistic analytical framework to assess medical countermeasures for priority biothreats was developed to inform strategic investments for the DoD.

A novel blood-brain barrier in vitro culture device, designed to be compatible with high-throughput assays, successfully emulated physiological conditions.

The laboratory led a data collection event in Boston, MA, to evaluate chemical and biological sensors and obtain measurements of background chemical levels in urban environments.

Figure 10. Staff are developing a near-infrared spectroscopy system that leverages our unique Geiger-mode avalanche photodiodes to improve measurements of brain activity. This project is a collaboration with Massachusetts General Hospital and is funded by the National Institutes of Health.

At DHS Transportation Security Laboratory, Lincoln Laboratory staff demonstrated methods to enhance explosive trace–detection systems by inducing minor chemical changes in the explosives presented to the instrument.

The laboratory fully transitioned the web-based HURREVAC system to the Federal Emergency Management Agency as the official hurricane evacuation platform utilized by the United States and around the world.

A suite of AI algorithms was developed to automate a process for using remote-sensing data to assess damages resulting from disasters.

Air Traffic Control

Lincoln Laboratory completed demonstrations of the Small Airport Surveillance Sensor and initiated technology transfer with the FAA and industry partners.

The Airborne Collision Avoidance System X (ACAS X) for manned aircraft was incorporated into international standards and is proceeding toward worldwide deployment. Development continues for ACAS X variants for unmanned aircraft systems and rotorcraft.

The laboratory completed an upgrade and technology transfer of the Ground-Based Sense-and-Avoid System to six US Army and six Air Force sites.

Figure 11. Lincoln Laboratory's Ground-Based Sense and Avoid system, operational at 12 military installations, provides maneuvering guidance to unmanned aircraft system operators to help them avoid nearby aircraft.

The laboratory supported the acquisition of FAA Next Generation Weather systems, including rapid update weather radar mosaics and storm prediction technology, through contractor build and test cycles.

The Offshore Precipitation Capability, developed for the FAA to depict storms beyond the range of land-based weather radars, is being evaluated at several Air Route Traffic Control Centers. A related program, under Air Force sponsorship, is extending the technology to provide global coverage.

The Airport Capacity Evaluation and Prediction Tool was deployed to Toronto to assist NAV CANADA with air traffic management. The MIT Integrated Risk Analysis Tool was released to the FAA to help develop decision support to assist with the safe and efficient integration of commercial space operations.

The laboratory continues to develop methodologies for cyber threat identification and mitigation for air traffic control and aircraft systems. These methods include AI techniques for detecting malicious activities on FAA networks.

Using machine learning and AI-based methods, the laboratory continues to develop data management and analytical tools to support mission planning and predictive maintenance for the US Transportation Command.

Engineering

Lincoln Laboratory continued its digital engineering transformation and increased the use of state-of-the-art model-based systems engineering; advanced simulation tools that run on Lincoln Laboratory's supercomputing resources; and complex, model-driven fabrication. The laboratory is successfully supporting pilot programs on the new digital engineering platform, which provides a common space for all hardware development activities.

The development of autonomous vehicles was enhanced by the creation of an open data architecture that provides shared access to terabytes of sensor data. The architecture better enables the development of data-driven autonomy capabilities.

Figure 12. The sensor assembly for the Situational Awareness Camera Hosted Instrument is being placed in a thermal-vacuum chamber by a technical staff member in the Structural and Thermal-Fluids Engineering Group to replicate the environmental conditions of space where the instrument must operate.

The laboratory is helping organizations identify capability gaps and solutions for warehouse modernization and automation. An automated ground vehicle test bed was developed to collect sensor data that helped define requirements for automated ground vehicles. The data will be used to evaluate navigation algorithms for autonomous operations at warehouses.

Using a new activated aluminum energy source, the laboratory is helping solve the logistical challenges of the Marine Corps' new operational concepts for austere environments. Aluminum-fueled prototypes are producing gas for lifting stratospheric balloons, filling high-pressure tanks for unmanned aerial vehicles, and reducing the battery burden for infantry.

The laboratory is developing lightweight composites for 3D printing that will increase structural performance. Powders alloyed from metal and ceramic were designed and manufactured for printing by laser consolidation. These powders were printed at virtually full density with higher specific stiffness than existing printable materials.

Utilizing advanced manufacturing techniques, the laboratory fabricated complex microfluidic channels inside millimeter-scale polymer fibers that enabled the integration and testing of miniature, lightweight recuperative heat exchangers and Joule-Thomson expanders for low-size, low-weight, and low-power cryogenic applications.

Technology Transfer

A core mission of Lincoln Laboratory is the development of advanced prototype technologies and their transfer to the government and industry. These transfers include the delivery of hardware, software, algorithms, designs, or other technical data to government sponsors; to the commercial sector; and to other not-for-profits, national laboratories, and universities for research purposes. The laboratory also publishes numerous technical reports and articles in peer-reviewed journals and hosts and presents at technical conferences and workshops on a variety of topics germane to national security. Working with MIT's Technology Licensing Office, the laboratory has developed a rich patent portfolio and works to broadly license dual-use technologies for the benefit of government sponsors and for the economic benefit of the United States.

Technology Transfer by the Numbers

Transfer mechanism	FY2020
Articles in technical journals	98
Papers in published proceedings	83
R&D 100 awards	8
Lincoln Laboratory–hosted conferences	12
Technology disclosures filed	148
US patents issued	65

Technology Ventures Office

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

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

Lincoln Laboratory engages with the commercial sector on several fronts to maximize the economic and societal impacts of research by transitioning prototype innovations into real-world products. In 2020, the laboratory conducted collaborative R&D with 17 companies under Cooperative Research and Development Agreements (CRADAs), which are R&D partnerships funded by industry to advance dual-use or commercial technology development. CRADAs are an important mechanism by which the commercial sector and the public benefit from original investments by the US government. The laboratory also executed 24 collaboration agreements with not-for-profit institutions and an additional 27 sponsor-supported research collaborations with MIT departments. These collaborations advance the state of early-stage technology development for a variety of applications.

One important form of commercial engagement is the laboratory's direct partnerships with small businesses to address specific government needs. In 2020, Lincoln Laboratory executed 10 Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) projects under sponsorship from government agencies such as the US Army, Navy, Air Force, and Department of Energy. The laboratory has created a customized variant of the Commercial Solutions Openings (CSOs), which are flexible technology development solicitations and contract awards that support small and nontraditional companies under R&D subcontracts. The CSOs allow the laboratory to apply the best available commercial technology for rapidly and cost-effectively addressing pernicious challenges confronting the laboratory's diverse sponsor base.

In 2020, approximately 15% of MIT's technology disclosures originated at Lincoln Laboratory, and close to half of them resulted in patent filings. About 20% of the laboratory's technology disclosures represent copyright-protected software and non-software technical data, with an increasing demand for open-source distribution coming from our government sponsors. By open-sourcing key technology capabilities, laboratory staff are sharing their technical priorities; building ecosystems; promoting emerging technology solutions and standards; and contributing to methods and practices through collaborative engagement with academic, government, and commercial partners.

Over the past year, the TVO has worked to increase laboratory transitions via open sourcing in accordance with objectives and guidance from the DoD. Activities have included partnering with peer organizations to learn and promulgate best practices, establishing criteria to flag candidate projects, streamlining practices for releasing new projects, and contributing to open-source communities. The laboratory's open-sourcing initiatives progressed significantly in 2020, with more than twice as many new project offerings compared to 2019.

In the future, the TVO aims to add value to its sponsor-directed technology transfer by defining and gathering metrics that will allow Lincoln Laboratory to estimate the impact its transition activities are having on national security and US economic competitiveness. The TVO is growing the laboratory's intellectual property portfolio, including open-source software and non-software copyrightable works, and is developing a strategy that will promote rapid licensing, especially for dual-use technologies. The TVO also aims to expand educational efforts for the laboratory community and laboratory sponsors and will continue to consult with peer organizations so that all parties can benefit from lessons learned.

Technical Workshops

The dissemination of information to the government, academia, and industry is a principal activity of Lincoln Laboratory's technical mission. One way this goal is achieved is through annual workshops and seminars that bring together members of 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 virtually between July 1, 2020, and June 30, 2021. To reduce the COVID-19 health risks, many annual conferences and workshops were cancelled or postponed.

- Robustness of AI Systems Against Adversarial Attacks
- Human–AI Interaction Workshop
- Human–Machine Collaboration for National Security Workshop
- Advanced Prototype Engineering Technology Symposium
- Anti-access/Area Denial Systems and Technology Workshop
- Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
- Homeland Protection Workshop Series
- Recent Advances in Artificial Intelligence for National Security
- Counter-Human Trafficking Technology Workshop
- Defense Technology Seminar for Military Fellows
- Artificial Intelligence for Cyber Security
- Human Language Technology Workshop
- Advanced Technology for National Security Workshop
- Cyber Technology for National Security
- Graph Exploitation
- Space Control Conference
- Air Vehicle Survivability Workshop
- Lincoln Laboratory Communications Workshop
- Next-Generation Identification & Awareness Technology Workshop
- Air, Missile, and Maritime Defense Technology Workshop

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

Publications

Technology transfer is also achieved through the diverse venues in which Lincoln Laboratory researchers publish. Technical staff members publish articles in journals, both peer-reviewed and general; present at national technical conferences, such as the IEEE Radar Conference and the International Conference on Acoustics, Speech, and Signal Processing. Between July 1, 2020, and June 30, 2021, Lincoln Laboratory staff published 71 papers in proceedings from conferences, 102 articles in technical journals, 11 self-published E-prints of technical articles, and 6 major technical reports available through the Defense Technical Information Center.

Research Collaborations

Technical staff at Lincoln Laboratory collaborate on projects with faculty and scientists at universities throughout the country; most collaborations are with researchers from MIT. The Advanced Concepts Committee provides short-duration grants to MIT faculty and Lincoln Laboratory staff for focused research in basic and applied science and in technology areas of potential interest to the laboratory. These grants are awarded on a rolling basis throughout the year. In 2020, nine collaborations were funded under the Advanced Concepts Committee and included ones ranging from superconducting discrete integrated circuit electronics to techniques for fabricating curved focal plane arrays and harnessing flexoelectricity for broadband photo-detection and energy creation.

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 fall 2020, the laboratory welcomed 26 military officers from the US Army, Navy, and Air Force in various technical groups under fellowships. Because of the COVID-19 pandemic, the program's 2020 cohort conducted their work remotely.

Courses for External Audiences

Lincoln Laboratory hosts a number of multiday courses for user communities with which the laboratory interacts. These courses for invited military officers and DoD civilians enhance understanding of current research and the systems developed at the laboratory. In 2020–2021, the laboratory offered Introduction to Radar Systems. The annual courses offered in Networking and Communications, and ISR Systems and Technology were cancelled because of the coronavirus pandemic.

In addition, through a program with the Naval War College in Newport, Rhode Island, technical staff present courses for naval officers; each term, courses are selected to address the college's needs. The courses scheduled in 2020–2021 were in cyber security, ballistic missile defense, and space technology.

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

2020 R&D 100 Awards

R&D World magazine presented 2020 R&D 100 Awards to eight technologies developed by Lincoln Laboratory researchers. These awards recognize 100 groundbreaking technological innovations developed by research institutes and companies worldwide and introduced during the prior year.

- Cyber Sensing for Power Outage Detection: A system that uses data on internet traffic to rapidly estimate and map the extent and location of power outages across geographic boundaries.
- Defensive Wire Routing for Untrusted Integrated Circuit Fabrication: Techniques that deter an outsourced foundry from maliciously tampering with or modifying the security-critical components of a digital circuit design.
- Forensic Video Exploitation and Analysis: A suite of tools that enables users to efficiently analyze video captured by existing large-scale closed-circuit television systems.
- Keylime Advanced Tenant Management System: An open-source key bootstrapping and integrity management software architecture that is designed to increase the security and privacy of Edge, Cloud, and Internet of Things devices.
- Large-scale Vulnerability Addition: A technique that injects numerous bugs into a program at known locations and constructs triggering inputs for each to create ground truth for evaluating bug-finding systems.
- Reconnaissance of Influence Operations: A software system that automates the detection of disinformation narratives, networks, and influential actors to address the growing threat posed by adversaries using social media for political objectives.
- TeraByte InfraRed Delivery: An optical communications technology that enables error-free transmission of data from low Earth–orbiting satellites at a rate of 200 gigabits per second.
- Timely Randomization Applied to Commodity Executables at Runtime: A technique that protects Windows applications against cyber attacks by automatically and transparently re-randomizing the applications' sensitive internal data and layout every time an output is generated.

Notable 2020 Technology Transfer Activities

MIT collaborated with partners worldwide on the Private Automated Contact Tracing (PACT) project. They developed open-source software, datasets, and a crowdsourced algorithm with the aim of accurately identifying people at risk of infection from the novel coronavirus and advising public health authorities on how to limit the spread of COVID-19.

Lincoln Laboratory, in partnership with Lawrence Berkeley National Laboratory, supported its first cohort of entrepreneurial research fellows in a multiyear program that incubates new companies focused on advanced electronic development. DARPA funds the fellows, and the fellowships are administered by the technology development nonprofit organization Activate.

One important form of commercial engagement is the laboratory's direct partnerships with small businesses to address specific government needs. In 2020, Lincoln Laboratory executed 10 SBIR and STTR projects under sponsorship from government agencies such as the US Army, Navy, Air Force, and Department of Energy.

Staff

Key to maintaining technical excellence at Lincoln Laboratory is its 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.

As of February 2021, total number of Laboratory employees is 4,058, with 1,776 professional technical staff, 1,261 support staff (including technical support personnel), and 489 subcontractors.

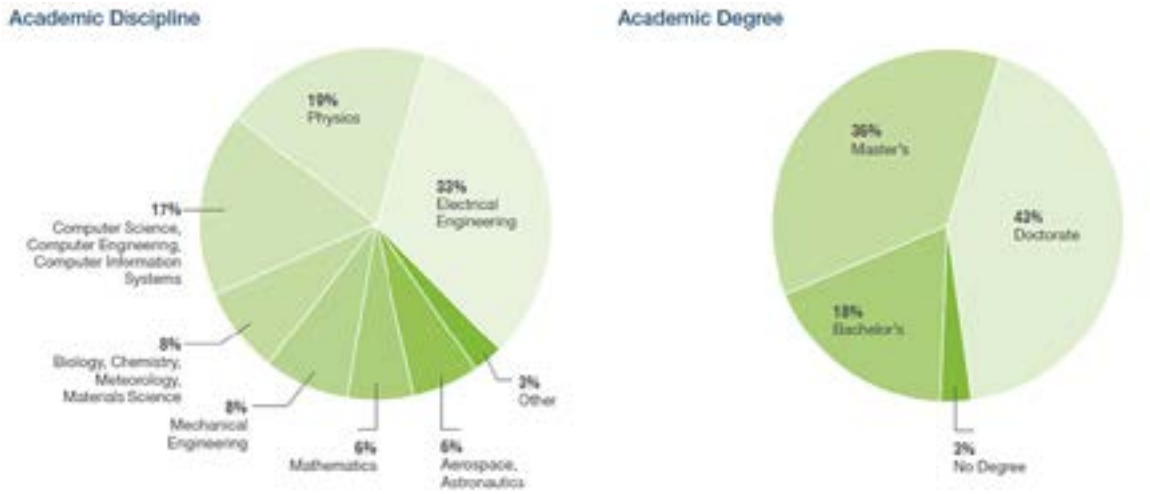

Figure 13. Composition of professional technical staff at Lincoln Laboratory by academic discipline and academic degree.

Awards and Recognition

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

Nicholas D. Hardy and Meghan E. Ramsey received the 2020 Lincoln Laboratory Early Career Technical Achievement Award.

Marija Ilic was named a member of the prestigious National Academy of Engineering for her contributions to electric power system analysis and control. Maria also received the IEEE Power & Energy Society Outstanding Power Engineering Educator Award for contributions to mentorship and education on modeling and control.

Robert T-I. Shin was named an IEEE Fellow for leadership in electromagnetic modeling of radar systems and in microwave remote sensing.

Nathan Falkiewicz was named 2021 IEEE Associate Fellow for exceptional contributions to the arts, sciences, or technology of aeronautics or astronautics.

Jeremy Kepner was named a 2021 Fellow of the Society for Industrial and Applied Mathematics for contributions to interactive parallel computing, matrix-based graph algorithms, green supercomputing, and big data.

Todd R. Lardy, a pilot at the Lincoln Laboratory Flight Test Facility, was elevated to 2020 Associate Fellow of the Society of Experimental Test Pilots. This international organization in recognition of his many years of experimental flight testing.

Martine M. Kalke and Jonathan D. Pitts won the MIT Excellence Award in the Bringing out the Best category; Alice Lee won in the Embracing Diversity, Equity, and Inclusion category; Rajan S. Gurjar and David F. Johnson both won in the Outstanding Contributor category; and Zachary Sweet won in the Serving Our Community category.

Yari Golden-Castano was one of 91 women with ties to Massachusetts who have been selected by Massachusetts Senate President Karen Spilka to be featured in the Massachusetts HERstory project display and video. The project acknowledges these women's roles as trailblazers in their given fields and selected these women of color who have inspired young people to work for a better world.

The Lincoln Laboratory Cultivating Leadership, Achievement, and Success career development Symposium Awards were bestowed upon Alice Lee for Employee Resource Group (ERG) excellence; to Martine M. Kalke and Heather E. Rogers for advancing organizational culture; to Bonita J. Burke for championing equity; and to David Maurer and Dr. Bryan Ward for outstanding mentorship. Ngaire K. Underhill was awarded the peer award for culture. The strength in unity award was given to the Our Voices, Our Vote Committee.

Kathleen L. Cable and Steve S. Salsberry received 2021 MIT Lincoln Laboratory Support Excellence Awards, and Kristi H. Wakeham and Joseph W. Orender received 2021 MIT Lincoln Laboratory Administrative Excellence Awards.

Lincoln Laboratory was one of the organizations recognized by the Department of Labor with a 2020 Honoring Investments in Recruiting and Employing American Military Veterans (HIRE Vets) Gold Medallion for "exemplary efforts in recruiting, employing, and retaining our nation's veterans."

Lincoln Laboratory was presented with a 2020 Dwight D. Eisenhower Award for Excellence in the Research and Development category by the US Small Business Administration. This annual award recognizes a large federal government prime contractor that excels in partnering with small business subcontractors and suppliers.

Lincoln Laboratory was selected by the Federal Laboratory Consortium for Technology Transfer as the Northeast region's winner of its award for Outstanding Achievement in Technology Transfer. The award recognized the laboratory's work with Sync Computing to commercialize a computing system designed to solve combinatorial optimization problems.

Professional Development

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

For highly qualified candidates, Lincoln Laboratory offers the opportunity to apply to the Lincoln Scholars program 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. From July 1, 2020, to June 30, 2021, 11 staff members were enrolled in the Lincoln Scholars program. Almost 200 staff members have pursued full-time technical graduate work through this program.

The Part-Time Graduate Studies program enables staff members to continue to work at the laboratory while earning master's degrees in fields that are relevant to laboratory mission areas or business needs. Staff members can take courses toward their degrees through universities' part-time programs that may include classes offered online and/or outside traditional work hours. Lincoln Laboratory staff are also eligible to take courses in computer science offered at Hanscom Air Force Base by Boston University (BU). These courses, which include computer networks, cryptography, and software engineering, can be taken independently or as part of a BU certificate or master's program. From July 1, 2020, to June 30, 2021, 20 people participated in these programs.

The technical education program offers both short-term and semester-length courses taught by Lincoln Laboratory technical staff or by outside experts. The 2020 fall semester offered 12 courses on topics including amateur radio, electromagnetics, deep learning, machine learning, radar systems, mathematics of big data, high performance computing, protected communications, and systems analysis.

The professional and leadership development program sponsored courses in a broad range of professional and leadership effectiveness topics, including managing time and priorities, building high trust teams, project management, mastering critical conversations, presentation skills, and team leadership. Lincoln's Respectful Workplace Program featured courses on harassment awareness, active bystander skills, leading in uncertain times, difficult conversations, and emotional intelligence.

As always, computer training has been available in Microsoft Office desktop applications, programming languages, and technical software tools. The Human

Resources and Information Services Departments partnered during the summer of 2020 to offer a comprehensive training program during the roll-out of Microsoft Office 365, Teams, Sharepoint, and OneDrive, which was planned in response to the pandemic.

During the past year, all training courses have been offered online due to the pandemic, which has also prompted increased access of training available through MIT's LinkedIn Learning portal.

Technology Office Seminars

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

The 2020–2021 program included the following seminars:

- A Deep Dive in the Deep Web: Insights from Eight Years of Online Anonymous Marketplaces Measurements
- Biology & AI: Trends and Implications for US National Security
- Design and Economics of the Climate Observing System of the Future
- Quantum Engineering of Superconducting Qubits and Quantum Computers
- Brain Inspired Research: Understanding Liquid Time-Constant Networks
- Human-Machine Teaming at the Heart of Vehicle Production: The Future of Flexible Automation
- GraphCore Colossus MK2 IPU & M2000 Machine
- Harnessing the Random Properties of Resistive Memory Technologies through Bayesian Machine Learning

The Technology Office also offered special interest group seminars on Machine Learning, Science, Cyber Operations, Climate/Environmental Science, and Perspectives on Computing, as well as timely discussions on Coded Bias; COVID-19 and the Future of International Conflict; and The Capitol Riot and the Threat of Domestic Terrorism.

Staff and Division Seminars

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

Diversity and Inclusion

The laboratory continues to foster an inclusive workplace that supports the talents and perspectives of its staff. Recruitment at a broader range of universities, programs in

mentoring, employee resource groups, and flexible work options contribute to the hiring and retaining of a more diverse workforce.

Nine employee resource groups promote an inclusive workplace by increasing awareness of various cultures, communities, and identities—Lincoln Employees with Disabilities (LED), Lincoln Employees' African American Network (LEAN), 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 (LLVETS).

Lincoln Laboratory is an active member of the National GEM Consortium, which, through partnerships with universities and industries, provides support to students from underrepresented groups who are seeking advanced degrees in science or engineering. The cornerstone of this effort is the internship program, which connects graduate students with employment opportunities at organizations engaged in technology development. In 2021, Lincoln Laboratory hired approximately 22 GEM Fellows as interns, a welcomed boost from 2020, during which GEM internships were cancelled to decrease coronavirus risks.

Events Highlight July 2020–June 2021

For Hispanic Heritage Month in September 2020, our Hispanic Latino Network invited three keynote speakers to discuss their scientific work and contributions. Ricardo Baeza-Yates, director of Graduate Data Science Programs at Northeastern University, spoke about bias on the web. Maria De-Arteaga, an assistant professor at McCombs School of Business at the University of Texas at Austin, explained how societal biases encoded in data may be compounded by machine learning models and offered solutions to this issue. Natalia Villanueva Rosales, an associate professor at the University of Texas at El Paso, discussed how her work aims to improve the efficiency and effectiveness of the discovery, integration, and trust of scientific resources.

The eighth Annual Martin Luther King Jr. Luncheon was hosted by LEAN in February to celebrate the impact that Dr. King's legacy had on increasing diversity and inclusion within the technical domain. LEAN invited Karl Reid, Executive Director of the National Society of Black Engineers, to deliver the keynote address at the MLK Celebration event. His talk, entitled, "Towards Inclusive Excellence: Fulfilling the Dream with Courage and Hope," asked what Dr. King's dream would look like today. LEAN further celebrated Black History Month by hosting a seminar by Reginald Brothers, former deputy assistant secretary of Defense for Research at the DoD, who presented, "The Future of Work at the Human-Technology Frontier."

The Pan-Asian Laboratory Staff employee resource group hosted three virtual events to celebrate Asian Pacific American Heritage Month in May 2021. Poet Adrienne Su discussed her collection of poetry that reflects immigration and spirit of invention. MIT Professor Emma Teng presented an overview of the history of Asian Americans, focusing on experiences of racial discrimination and the rise in anti-Asian violence since the onset of the COVID-19 pandemic.

Lincoln Laboratory Out and Proud Employee Network (LLOPEN) collaborated with other Laboratory ERGs and the Diversity & Inclusion (D&I) Office to create joint efforts promoting the idea of solidarity and acceptance across a wide range of differences. LLOPEN also worked with the Director's Office and the Facility Services Department to create the laboratory's first all-gender restroom. Throughout June, the LLOPEN Committee sent daily emails highlighting individuals and events that have been influential in LGBTQ+ history. They also hosted weekly discussion panels on Zoom, viewing and discussing TED talks that covered an important LGBTQ+ topic.

The Lincoln Employees with Disabilities group celebrated the 31st Anniversary of the Americans with Disabilities Act in July with a series of TED talks to raise awareness about disabilities and inclusion, such as "Why Design Should Include Everyone," "Mainstreaming Disability," and "Rosie King: How Autism Freed Me to Be Me." LED is also planning a Run, Walk, or Roll 5K to celebrate camaraderie and an understanding of the difference in people's abilities, achievement, and efforts.

The 10th Annual LLVETS Memorial Day Recognition Event was hosted virtually, allowing veterans from both the laboratory and remote locations to participate. Rear Admiral Richard Seif, Commander of the US Navy's Undersea Warfighting Development Center, delivered a keynote that highlighted the importance of the bond of service that is shared between members of the armed forces and the laboratory community.

Other D&I efforts in this timeframe included the following:

- Picture A Scientist: A documentary that chronicles the groundswell of researchers who are writing a new chapter for women scientists.
- New Book Titles in our Knowledge Services Group: A wide variety of books available to borrow that focus on leadership development, diversity and inclusion, the history of structural racism, unconscious bias, and self-development.
- Cultivating Leadership, Achievement, and Success (CLAS) Symposium: The theme of this third annual CLAS career development symposium was innovation through inclusive leadership. The virtual sessions focused on helping attendees develop the skills necessary for the work-from-home environment, such as how to improve listening skills in an increasingly virtual work environment and how to become an emotionally intelligent leader. This year's symposium featured Deborah Lee James, former Secretary of the US Air Force, as the keynote speaker.

In response to civil unrest related to systemic and structural racism, our Diversity and Inclusion Office created an initiative called RE^{2}AcT—Research. Educate. Empathize. Act. Transform—to help create conditions for sustainable organizational success and to provide a safe space where staff could openly discuss the multitude of topics covered throughout the program. The goals of RE^{2}AcT are to develop relational equity, increase familiarity with new concepts and vocabulary, practice centering on the African American experience, foster greater cultural fluency, identify challenging areas that require increased focus, and cultivate strategic resilience.

During the year, a variety of virtual events and resources were offered to the laboratory community through the RE²AcT program, including TED Talk and documentary screenings; online articles; and live seminars featuring prominent professors, activists, and writers. Topics ranged from the US prison-industrial complex to biases and racism. These events were typically followed by discussion sessions during which participants were encouraged to express their thoughts about the subject material in a safe and open environment.

To celebrate the centennial of the adoption of the 19th Amendment, the Diversity and Inclusion Office formed a committee to host events throughout August, the month in which the amendment was adopted, as part of the "Our Voices, Our Vote! A Century of Women Leading Change" Initiative. The events recognized the achievements of women at the laboratory and encouraged the laboratory community to reflect on the advances and setbacks along the path toward achieving gender equality.

Efficient Operations

Like many organizations, Lincoln Laboratory had to quickly adapt as the COVID-19 pandemic impacted its ability to work and convene in traditional ways. A large fraction of the laboratory's workforce was empowered to work remotely, an enormous change enabled by hard work across departments and divisions. At the same time, the laboratory continued its efforts to simplify business processes, build new capabilities, and modernize technology so that all employees have the skills and tools needed to excel in the business of research.

Modernizing Operations

Lincoln Laboratory is modernizing the way it works as part of the Digital Enterprise Transformation (DET). The Business Transformation Office (BTO) continues to lead this multiyear initiative to achieve its five main objectives:

- Simplify and improve core business processes
- Utilize integrated technology solutions
- Inform decisions with data-driven insights, and rely on metrics and key performance indicators to identify challenges and successes
- Advance a culture of ownership, accountability, and deliberate continuous improvement
- Enable new capabilities aligned with a digitally mature organization for the laboratory's employees

In 2020, the BTO partnered with department heads and project owners to make progress on several DET initiatives:

- SAP S/4 finance modernization—This initiative is providing the laboratory with one trusted financial source and a scalable business platform that can grow with the laboratory. The project will provide a simplified user experience, streamlined financial business processes, and improved accuracy and visibility of data.

- Business process management—This effort has identified nearly 300 core processes across the laboratory and enabled process owners to identify stakeholders and customers and to document the steps, systems, and key data needed to execute processes.
- External workforce services—A new team was established that is dedicated to managing the lifecycle, from recruiting to offboarding, of contracted workers. The team is a liaison to vendors and provides partnership and support to hiring managers.
- Improved travel experience—The laboratory launched Concur, a single system that integrates business travel booking and expense reporting.
- Organizational change management—This effort ensures that our leaders, teams, and community are informed about and able to support DET changes. The initiative will focus on consistent DET messaging, leadership engagement, and user training at all levels.
- MADOps challenge—An invitation was extended to the research community to submit proposals for projects that could use existing methodologies in machine learning, AI, or data analytics to improve operations (MADOps) and be applied to a key laboratory business area. More than ten proposals were received, of which five were funded.

Adapting to a Pandemic

Improvements to information technology services streamlined everyday processes, enhanced communication capabilities, and allowed the laboratory to continue to function—and even thrive—during COVID-19 pandemic conditions. The Information Services Department (ISD) moved rapidly to provide capabilities required to facilitate remote work. Efforts were focused in the following critical areas:

- Amplified collaboration tools. Zoom for Government, Microsoft 365 Teams, the IX Workplace soft phone, and other applications that enabled communication between remote coworkers were implemented. Webinar training and support were provided for those learning to use these new technologies. To facilitate meetings in which some participants were at the facility while some were at home, ISD upgraded conference rooms with Owl technology, providing a more in-person meeting experience for all.
- Increased remote-support availability. Enhanced remote desk-side support capabilities ensured that all employees received technology support when needed. Two question-and-answer sessions—Training Tuesdays and Thursday Coffee Breaks—were also offered weekly to the community.
- Improved processes and workflows. Everyday procedures had to adjust for remote work, and ISD responded with numerous process enhancements. Efficiencies were gained in areas such as domestic and international travel-approval workflows, and secure, health-conscious methods to onboard new employees remotely. ISD modified computer-patching and data-backup

schedules to avoid work hours and keep the laboratory network and remote computers running at optimal speed. New computer-power and network-connection configurations ensured computers were available when patches and backups occurred.

- New health and safety applications. Novel leave-tracking systems were implemented within Human Resources technology to protect those whose health and work conditions were affected by COVID-19. ISD also collaborated with MIT to implement a health attestation application, which employees completed every day before they could access facilities. This application interfaced with MIT Medical and Security Services Department technology systems, working together to stop the spread of COVID-19 in the laboratory community.
- Enhanced technology systems. The laboratory's pre-pandemic infrastructure primarily focused on providing excellent onsite services. With the majority of the workforce now remote, ISD worked tirelessly to adapt these systems. The local network, virtual private network, and voice services were enhanced, and secure areas were updated with communication/video-teleconferencing capabilities. ISD also enacted endpoint protection enhancements, security operations modernization measures, and virtual desktop service expansions, further promoting the ease and security of remote work.

Community Outreach

Educational Outreach for University Students

The abrupt move in March to remote working/learning because of the COVID-19 pandemic limited some aspects of outreach efforts Lincoln Laboratory typically offers. Mentors transitioned to an online learning format and continued to provide guidance virtually, while students continued to practice hands-on learning and collaborative teamwork despite the difficulties of participating in a virtual environment.

Beaver Works

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

A key component of Beaver Works is the capstone project, which is associated with a two-semester design-and-build class that challenges students to develop an engineering solution to a real-world problem. This year, two unique capstone projects were undertaken by undergraduate students in the Engineering Systems Design and the Engineering Systems Development courses offered by the MIT Department of Mechanical Engineering in conjunction with Beaver Works. One team designed a variable-temperature cryo-cooler, and a second team developed a fast underwater glider.

University Student Programs

Lincoln Laboratory offers a variety of research and internship opportunities to university students. Candidates in MIT's 6-A Master of Engineering Thesis Program 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 2021, six 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. In summer 2021, the laboratory hired 133 undergraduates and graduate students to work as interns. Because of the pandemic, 85% of the interns worked remotely in accordance with public health recommendations.

Throughout the year, cooperative-education (co-op) students from area colleges, such as Northeastern University and Wentworth Institute, work at the laboratory. Approximately 66 co-op students from area schools are employed in technical divisions and service departments at the laboratory each year.

Educational Outreach for K–12 Students

Recognizing the importance of preparing young people for careers in STEM, Lincoln Laboratory Community Outreach (LLCO) converted many of its outreach programs to an online format and still administered a significant program of STEM activities.

In the fall, laboratory volunteers in a collaboration with MITRE and Harvey Mudd College offered three virtual workshops to encourage high school girls to try engineering. On Saturdays from October through December, 66 junior girls learned how to build a Cubesat, how to program a mini autonomous racecar, or how to hack code while learning about embedded security. These workshops were offered by the Beaver Works Summer Institute to provide crash courses just for girls. Plans are underway to offer these courses to underrepresented students from Boston and Cambridge, Massachusetts.

Because of the COVID-19 emergency, this year's Beaver Works Summer Institute—a four-week hands-on STEM learning experience for high school seniors—carried on in a virtual format, offering seven classes to 178 students from 26 states across the country and Canada. The classes presented this year were Autonomous RACECAR, Autonomous Cognitive Assistant, Data Science for Health and Medicine, Build a CubeSat, Embedded Security and Hardware Hacking, Remote Sensing, and a new course called Serious Game Design and Development with AI. The program also offered its first-ever independent project, called pi-PACT. For this project, 176 students chose an aspect of a contact tracing application to evaluate, such as collection and characterization of data, in addition to developing algorithms to enable proximity detection between individuals. Hands-on learning remained a key component of the program. The push to bring the program online has opened new avenues for making the course materials available to the public.

The Beaver Works Summer Institute launched a new class for high school students on Kwajalein Atoll. The course, Serious Game Development with Artificial Intelligence, taught students how to address real-world problems by using game design and AI. This

was a unique opportunity to take advantage of the isolation and COVID-19-induced travel ban to engage the island students with a rigorous STEM program. Fourteen students enrolled in the program, which included in-person classes and virtual meetings with laboratory staff. At the end of the course, the students presented their work at a live poster session.

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

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

Community Service

The LLCO helps increase laboratory employees' awareness of events sponsored by charitable organizations. Laboratory employees donate funds annually for the American Heart Association, Ride to End Alzheimers, CancerCare, Toys for Tots, Boston Children's Hospital, Jimmy Fund, Bedford Veterans Hospital, Lowell Humane Society, Pan-Mass Challenge, Coats for Kids, and the American Foundation for Suicide Prevention. A few new charities, like Boston Friends of the Homeless, Torch Foundation, and Lexington Education Foundation, were supported this year. Our field sites work to help charities in their local areas in the form of giving trees, island clean up, and helping fund school lunch programs.

In 2020–2021, employees at our Kwajalein Field Site were especially determined to assist the Marshall Islands deal with the coronavirus pandemic. A team of Lincoln Laboratory scientists investigated how to bring telemedicine to the Ebeye Hospital in an effort to continue the hospital's efforts to continue medical care for islanders, but also to invite medical specialists to assist island residents with particular health care issues. The laboratory donated sewing equipment and high-quality materials to Kwajalein Atoll to support local seamstresses in making face masks to help with COVID-19 spread prevention. One dedicated employee increased efficiency of this effort by 3D-printing a sewing machine jig to hold fabric pleats in place while the seamstresses were sewing the masks.

Summary

Lincoln Laboratory's portfolio of technology R&D programs continues to grow and is strategically balanced with programs that conduct large-scale system development, that perform rapid prototyping of new systems, and that involve innovative, often

multidisciplinary, research projects. Mission areas across the laboratory are pursuing answers to new challenges created by today's reliance on big data, cyber security, satellites, and AI.

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

Ongoing improvements to administration and infrastructure, a strong professional development program, a commitment to outreach and giving, and the continued promotion of an inclusive workplace, are all enabling the laboratory to maintain technical excellence in its work and its status as a desirable employer.

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

Eric D. Evans
Director