MISSION

Technology in Support of National Security

MIT Lincoln Laboratory employs some of the nation’s best technical talent to support system and technology development for national security needs. Principal core competencies are sensors, information extraction (signal processing and embedded computing), communications, integrated sensing, and decision support. Nearly all of the Lincoln Laboratory efforts are housed at its campus on Hanscom Air Force Base in Massachusetts.

MIT Lincoln Laboratory is designated a Department of Defense (DoD) Federally Funded Research and Development Center (FFRDC) and a DoD R&D Laboratory. The Laboratory conducts research and development pertinent to national security on behalf of the military Services, the Office of the Secretary of Defense, the Intelligence Community, and other government agencies. Lincoln Laboratory focuses on the development and prototyping of new technologies and capabilities to meet government needs that cannot be met as effectively by the government’s existing in-house or contractor resources. An emphasis is on R&D to address emerging DoD technology areas. Program activities extend from fundamental investigations through design and field testing of prototype systems using new technologies. A strong emphasis is placed on the transition of systems and technology to the private sector. Lincoln Laboratory has been in existence for 70 years. On its 25th and 50th anniversaries, the Laboratory received the Secretary of Defense Medal for Outstanding Public Service in recognition of its distinguished technical innovation and scientific discoveries.
Letter from the Director

In 2021, Lincoln Laboratory marked its 70th anniversary of developing advanced technology for national security. From the Laboratory’s early focus on a radar-based national air defense system to the current work in areas ranging from cybersecurity to biomedical applications, our talented staff have brought much technical depth and field-testing experience to bear on difficult problems. Throughout the COVID-19 pandemic, we sustained our R&D through creative, diligent efforts to make remote and hybrid work productive.

The Laboratory continues to evolve. This year, we established a Laboratory Digital Engineering Center to incorporate new digital engineering approaches into building advanced prototypes. The focus is on developing an integrated process that includes the digital modeling/simulation and data processing required to realize modern hardware and software systems.

Artificial intelligence (AI) continues to be a significant enabling technology in all our mission areas. We are exploring the potential for AI to enhance the decision support capabilities provided by the various systems we develop. This year, our centralized AI Technology Group conducted research to enhance the trustworthiness and mission-readiness of AI systems.

After several years of Laboratory development, a 3U small satellite (CubeSat) was launched by NASA to serve as a pathfinder for the constellation of these CubeSats designed for the NASA TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) program. When TROPICS is fully implemented, we will deliver vital measurements of a storm every six CubeSats, traveling in three low-Earth orbits over the global tropical belt, will deliver vital measurements of a storm every six CubeSats, traveling in three low-Earth orbits over the global tropical belt.

In collaboration with physicians at Mass General Brigham, we prototyped and tested a device that uses AI and handheld robotics to allow first responders to perform emergency vascular access on a patient at the scene of an injury.

In our continued work to develop a cyber-resilient operating system layer, we demonstrated an application to enable software-based high-assurance cryptography in platforms highly constrained by size, weight, and power needs.

The bidirectional space-to-ground laser communication system we built features a highly integrated mechanical and electrical design to provide a 10-megabits-per-second downlink from geosynchronous orbit and a 2-kilobits-per-second uplink from the ground.

Under sponsorship of the Federal Aviation Administration, we are developing algorithms that allow small unmanned aircraft systems (sUAS) to detect and avoid other aircraft, a key capability enabling commercial sUAS operations.

Nine technologies developed at Lincoln Laboratory won 2021 R&D 100 Awards; since 2010, the Laboratory has earned 75 of these awards recognizing technical innovation.

Many examples of our technical milestones, efforts to support an inclusive workplace, and educational and community outreach activities are described in this report. Our accomplishments continue to be enabled by our strong commitment to technical excellence, integrity, and service to the nation.

Sincerely,

Eric D. Evans
Director
MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. L. Rafael Reif
President
Dr. Martin A. Schmidt (left)
Provost
Dr. Maria T. Zuber (right)
Vice President for Research

Chief Technology Ventures Officer
Assistant Director – Operations
C. Scott Anderson
Dr. Israel Soibelman
Assistant Director
Dr. Justin J. Brooke
Dr. Bernadette Johnson
Assistant Director
Dr. Melissa G. Choi
Robert A. Bond
Dr. Eric D. Evans
Chevalier P. Cleaves

Chief Technology Officer
Heidi C. Perry
Assistant to the Director for Strategic Initiatives
Jaymie A. Durnan

Dr. Ripin has extensive experience directing major R&D efforts in vital national security areas, such as high-energy laser systems and advanced imager technology. As program manager of Lincoln Laboratory’s first Level-1 program, he demonstrated the ability to build and lead high-performing, highly collaborative teams. Recently, he served as co-lead of Lincoln Laboratory’s Long-Term Planning Panel for the COVID-19 Task Force and has been involved in promoting diversity and inclusion within the Laboratory community.

ORGANIZATIONAL CHANGES

Heidi C. Perry
Chief Technology Officer

As Chief Technology Officer, Ms. Perry will contribute to the office’s development of the Laboratory’s long-term technology strategy and the coordination of collaborative research with MIT campus. Ms. Perry was an Assistant Head of the Air, Missile, and Maritime Defense Technology Division prior to her appointment to the Technology Office. She served as the division’s Chief Innovation Officer and played an important role in enhancing the Laboratory’s naval systems and technology programs. She worked closely with the Technology Office on autonomy and artificial intelligence initiatives and was a division liaison to the Technology Ventures Office.

Jaymie A. Durnan
Assistant to the Director for Strategic Initiatives

Mr. Durnan has demonstrated significant expertise in leadership and management, strategy development and execution, policy development, programming and budgeting, and systems acquisition. His private sector experience includes service as a Senior Vice President and Special Counsel to the chairman of MacAndrews & Forbes Holding, Inc., and the Managing Member of a strategic advisory firm. His government service includes being an assignee to the staff of the Chairman of the Joint Chiefs of Staff, supporting arms control negotiations, and a military social aide to the President of the United States.

Gregory D. Berthiaume
Assistant Head, Space Systems and Technology Division

Dr. Berthiaume held several leadership positions in the Sensor Technology and System Applications Group prior to his division-level appointment. He is recognized as a leader in the science community for his contributions to microwave sounder algorithm development, grew the Laboratory’s NASA/National Oceanic and Atmospheric Administration portfolio, and held a two-year joint appointment with the MIT Kavli Institute for Astrophysics and Space Research, which led NASA’s Transiting Exoplanet Survey Satellite program. In 2019, he was awarded the NASA Exceptional Public Service Medal for his contributions to NASA space and earth science missions.

James A. Kennedy
Chief Security Officer and Head, Security Services Department

Mr. Kennedy has 37 years of experience in Department of Defense and Intelligence Community industrial security programs. He most recently served as Security Director for Lockheed Martin Military Space and Commercial Civil Space in Sunnyvale, California. His past security leadership roles include Security Director for General Dynamics Mission Systems and Harris Corporation, and Senior Corporate Director for Telecommunications Systems, Inc.

Derek W. Jones
Deputy Chief Security Officer

Since joining the Security Services Department in 2003, Mr. Jones has held positions in several areas, including personnel security, business operations, and industrial security. In 2019, he was appointed Assistant Department Head, with responsibility for overseeing the management of industrial security and special programs for Lincoln Laboratory’s main complex and its remote field sites. Currently, he is a member of the National Industrial Security Program Policy Advisory Committee (NISPPAC), serving as chair of the NISPPAC Policy Working Group and co-chair of the Federally Funded Research and Development Center/University Affiliated Research Center Policy Working and Operations.

Continues on page 6
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 ensuring 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 with the MIT Office of General Counsel. The office also serves as the primary Lincoln Laboratory interface with the MIT Audit Division.

David Suski
Head, Ethics and Compliance Assurance Office

Mr. Suski, who continues to be a member of the MIT Office of the General Counsel, leads the new ECAO’s efforts to advise on contractual issues arising out of Lincoln Laboratory’s national defense research and to maintain the Laboratory’s robust ethics program. He has significant expertise in national security law, government contracts, litigation, administrative law, government ethics, and congressional affairs. Before joining MIT, he served as Assistant General Counsel with the Central Intelligence Agency, where he served assignments at the Counterterrorism Center, the Office of Congressional Affairs, and the Special Activities Division.

Kenneth Sims
Assistant Head, Business Transformation Office

Mr. Sims began his career at Lincoln Laboratory as a business manager in the Security Services Department in 2012 and moved on to serve in business manager roles in two technical divisions. He has overseen all operations for procurement, facilities, human resources, and financial matters for the Advanced Technology Division and took a lead in growing the off-contract portfolio across the division. Recently, he served as the program manager for the S/4 HANA Financial Modernization effort that is part of the Laboratory’s overall Digital Enterprise Transformation.

Diane J. Shea
Assistant Department Head, Contracting Services Department

Ms. Shea joined MIT as the Associate Director of Procurement in 1995 and ultimately served as the Director of Procurement. She joined the Laboratory in 2010; her most recent role was as Senior Manager of Procurement. She and her team manage all aspects of operational contracting, in the Assistant Department Head position, she will be focused on acquisition.

Peter H. Babcock
Deputy Head, Ethics and Compliance Assurance Office

Continuing his role as the Assistant Ethics Officer at Lincoln Laboratory while serving as Deputy Head of the ECAO, Mr. Babcock leads a team that has oversight of conflict-of-interest situations, reviews whistleblower complaints, and maintains the Laboratory’s Ethics Hotline. Prior to joining the Laboratory, he worked as a civilian attorney for the U.S. government for more than 30 years. He also served as a Reserve Officer in the U.S. Air Force Judge Advocate’s Corps, attaining the rank of lieutenant colonel.

Establishment of the Digital Engineering Center

The new Digital Engineering Center will coordinate the development and adoption of modern digital engineering practices that enhance Laboratory prototyping capabilities, conduct novel research in digital engineering, and act as a resource for the Department of Defense (DoD) and the broader Laboratory sponsor community. Key technical emphases will include the further adoption and integration of model-based practices into end-to-end prototyping workflows, and the leveraging of shared data, models, enhanced simulation, and advancements from relevant fields, such as high-performance computing and artificial intelligence.

Denise A. Fitzgerald
Leader, Digital Engineering Center

Ms. Fitzgerald served as Assistant Group Leader in the Mechanical Engineering Group, where she managed the designer cell, spearheaded the transition to SolidWorks 3D computer-aided design, and led the selection and implementation of the product lifecycle management tool A ras Innovator. Recently, she has coordinated with external agencies to influence DoD platform implementation.

Stephanie H. Sposato
Associate Leader, Digital Engineering Center

Dr. Sposato led several data collection and analysis programs prior to her promotion to her previous role as Assistant Leader of the Fabrication Engineering Group. She served as the deputy program manager of the countermeasure programs and has been responsible for redlining fabrication processes to fully leverage available digital technology.

Christa N. Frey
Supervisor of Flight Test Operations, Flight Test Facility

Ms. Frey joined the Laboratory in January 2010 as a research test pilot at the Flight Test Facility. Her career spans more than 25 years in aviation as a research test pilot at the Flight Test Facility. Since being hired, she has flown the first flights on modifications to the Laboratory’s Twin Otter, Falcon 20, and Gulfstream test aircraft and is the lead airworthiness test pilot. He is type rated in five aircraft, has nearly 6,000 flight hours in 50 aircraft, and is an Associate Fellow in the Society of Experimental Test Pilots.

Christiaan M. Stone
Deputy Director, Policy, Compliance, Labor and Employee Relations, Human Resources

In 2008, Mr. Stone joined MIT as the Assistant Manager of Labor Relations. He joined the Laboratory in 2014, most recently as the Manager of Labor and Employee Relations. He and his team oversee all labor relations with the unionized staff at the Laboratory as well as employee relations for Lincoln Laboratory employees.

William P. Surrey
Assistant Department Head, Contracting Services Department

Most recently, Mr. Surrey was the Director of Contracting for the Rapid Capabilities Office of the U.S. Space Force. He is a retired colonel and a project management professional. He also served as the Deputy Director of Contracting at the Air Force Life Cycle Management Center, Hanscom Air Force Base, in 2017 and 2018. Mr. Surrey’s focus in this position will be logistics, compliance, and contracts.

Todd R. Lardy
Chief Test Pilot, Flight Test Facility

Prior to joining the Laboratory, Mr. Lardy was an engineering flight test pilot at Cessna Aircraft Company, where he was responsible for conducting developmental flight tests on the Citation XLS, Bravo, Encore, and CJ2. He joined Lincoln Laboratory in 2016 as a research test pilot at the Flight Test Facility. Since being hired, he has flown the first flights on modifications to the Laboratory’s Twin Otter, Falcon 20, and Gulfstream test aircraft and is the lead airworthiness test pilot. He is type rated in five aircraft, has nearly 6,000 flight hours in 50 aircraft, and is an Associate Fellow in the Society of Experimental Test Pilots.

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The Laboratory’s field-programmable imaging array (FPIA) chip has more than 6.6 billion transistors. An architectural innovation, the FPIA serves as a universal digital back end for optical detectors.
In 2021, Hurricane Ida struck Louisiana as a powerful Category 4 hurricane, bringing destructive storm surge, winds, and rainfall. An alarming feature of Hurricane Ida was how quickly the storm intensified. Scientists warn that such intensification is becoming more common with climate change, but the exact conditions that fuel this rapid growth are not yet well understood.

The TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) mission will increase the amount of data collected about tropical storms, enabling a deeper analysis of their evolution. Six small satellites, each about the size of a half-gallon milk carton, will be spread out in three low-Earth orbits to watch over the globe’s tropical band where these storms form. A satellite in the constellation will revisit a storm roughly every 45 minutes, a much higher rate than is possible today, and collect updated temperature, water vapor, precipitation, and cloud ice measurements.

Lincoln Laboratory proposed this first-of-its-kind mission to NASA as part of the Earth Venture Instrument competition. In 2021, NASA launched a test satellite, called the TROPICS Pathfinder. The six constellation satellites will follow in 2022.

The TROPICS satellites collect data by microwave radiometer. On current weather satellites, these instruments are the size of a washing machine. On TROPICS, they are the size of a coffee cup. Researchers at the Laboratory and the University of Massachusetts Amherst worked together over the last decade to achieve this miniaturization with little compromise in performance, with the goal of putting the instruments on small, inexpensive satellites for targeted weather observations.

Tiny Satellites Will Study Big Storms

On August 8, 2021, the TROPICS Pathfinder satellite captured its first global data, including a channel around 205 gigahertz (top), which is a completely new imaging channel for space-borne microwave radiometers.

Microwave radiometers work by detecting the thermal radiation emitted by oxygen and water vapor in the air. The TROPICS instrument measures these emissions at different heights throughout the atmosphere, corresponding to 12 RF channels between 90 gigahertz and 205 gigahertz. The 205-gigahertz channel is the highest frequency ever used on a space-borne microwave cross-track-scanning radiometer. It holds promise for scientists to learn more about mechanisms in the cloud formation process. For example, they can more closely observe the transition of liquid cloud droplets to ice cloud crystals, which are an important component in cloud formation processes and are not observed with sufficient fidelity by current microwave, infrared, or visible systems.

Soon after producing its first-light images in August, the TROPICS Pathfinder satellite provided insight into the structure of Hurricane Ida before and after its landfall. In 2022, the full constellation will enable even more frequent data collections and clues into how atmospheric conditions impact tropical storm intensity. The TROPICS team—which spans the Laboratory, NASA, National Oceanic and Atmospheric Administration, and several universities—expects that these observations will also improve forecasts, helping people get to safety sooner and protect critical infrastructure.
Disaster Management System Takes Root in the Western Balkans

After a five-year partnership between Lincoln Laboratory, the NATO Science for Peace and Security Programme, and the Department of Homeland Security Science and Technology Directorate, national emergency agencies in the Western Balkans are now fully equipped with the Next-Generation Incident Command System (NICS). The system, developed at the Laboratory, is helping the region coordinate its response to disasters in and across Croatia; Bosnia and Herzegovina; North Macedonia; and Montenegro.

Natural disasters frequently impact this part of the world. After devastating floods swept across the Balkans in 2014, NATO sought to improve crisis management in the region. At that time, the Laboratory had already developed NICS to improve the coordination of wildfire response in California. After learning about NICS at a conference, NATO officials initiated the Advanced Regional Civil Emergency Coordination Project to extend the technology to those Balkan countries that had expressed interest in the project.

At the center of NICS is an interactive incident map. On the map, responders can draw incident perimeters, designate evacuation zones, track their locations in real time, and share geotagged images or videos from the scene. Each incident map is associated with a collaboration room, through which responders and commanders can communicate. Because NICS was initially developed for wildfires, a key upgrade was making NICS flexible and user friendly for different, and simultaneous, types of responses, such as water rescues, urban searches, and chemical emergencies. To support this need, the incident map was adapted to filter data by response type and expanded to support tailored tracking of resources. These changes have allowed multiple emergency entities to both gain visibility into the entire incident and focus on their own area of interest.

Throughout this project, the NATO Euro-Atlantic Disaster Response Coordination Centre has held annual, large-scale disaster response exercises that have served as milestones for testing the technology. This year’s exercise, which was held in North Macedonia, marked the end of the Laboratory’s role in this program and the formal transition of NICS to the partner countries.

The process of transitioning NICS as an operational platform has been unique to each country. Bosnia and Herzegovina, eager to adopt the technology at the national level, has used it in more than four dozen emergency incidents. The Red Cross in North Macedonia recognized a need for NICS in the early days of the COVID-19 pandemic, and the country has since been using it to coordinate resources and communicate directly to the public about clinic locations and case numbers. A strong earthquake in Croatia at the end of 2020 mobilized their first real-world use of the system.

Today, Laboratory researchers are investigating other uses for NICS on sponsored programs. The developers are also hoping to engage organizations to build an active open-source community around the software. Such a community can help evolve and support the software for continued worldwide adoption.
In New York City’s Subway and Streets, Study Aims to Mitigate Chemical and Biological Airborne Threats

When the air harbors harmful matter, such as a virus or toxic chemical, it’s not always easy to promptly detect this danger. Whether spread maliciously or accidentally, how fast and how far could hazardous plumes travel through a city? What could emergency managers do in response?

These were questions that scientists, public health officials, and government agencies probed with an air flow study conducted in October 2021. At 120 locations across New York City, a team led by Lincoln Laboratory collected safe test particles and gases released earlier in the subway and on streets. The exercise measured how far the materials had traveled and what their concentrations were when detected.

The results are expected to improve air dispersion models and, in turn, help emergency management planners improve response protocols if a real chemical or biological event were to take place.

The study was performed under the Department of Homeland Security Science and Technology Directorate’s (DHS S&T) Urban Threat Dispersion Project. This exercise followed a similar, smaller study in 2016 that focused mainly on the subway system within Manhattan.

The particles and gases used in the study are safe to disperse. The particulates are primarily composed of maltodextrin sugar and have been used in prior public safety exercises. To enable researchers to track the particles, the particles are modified with small amounts of synthetic DNA that act as a unique “barcode” corresponding to the location from which the particle is released and the day of release. The particles that get trapped in filters set up throughout the city are later analyzed.

Approximately 5,000 samples were collected over the five-day measurement campaign. The data are feeding into existing particle dispersion models to improve simulations. One of these models, from Argonne National Laboratory, focuses on subway environments, and another model from Los Alamos National Laboratory simulates above-ground city environments, taking into account buildings and urban canyon air flows. Together, these models can show how a plume would travel from the subway to the streets. These insights will enable emergency preparedness managers in New York City to develop more informed response strategies, as they did following the 2016 subway study.

A team of nearly 175 personnel spanning the Metropolitan Transportation Authority, New York City Transit, New York City Police Department, Port Authority of New York and New Jersey, New Jersey Transit, New York City Department of Environmental Protection, New York City Department of Health and Mental Hygiene, National Guard Weapons of Mass Destruction Civil Support Teams, Environmental Protection Agency, and Department of Energy National Laboratories, in addition to S&T and Lincoln Laboratory, worked together on the exercise.

Now that researchers have learned more about how material transports through the subway system, a new program, called the Chemical and Biological Defense Testbed, is underway to investigate how to mitigate that transport in effective and safe ways. The goals of this test bed will be to develop architectures and technologies that could allow for a range of appropriate responses and to test the performance of new chemical and biological sensors.
Optical Lasers Make High-Speed Links Underwater

For the past few decades, Lincoln Laboratory has been at the forefront of space communications. NASA's Lunar Laser Communication Demonstration (LLCD) is one example, in which researchers made history by using laser beams to transmit video data between a satellite orbiting the Moon and a ground station in New Mexico, at a rate six times faster than the current state of the art in RF communications systems.

The optical beam technology that led to the LLCD’s success was developed at the Laboratory, and another team of researchers is now leveraging it for a new purpose in the LOTUS project. LOTUS stands for Lightweight Optical Telecommunication from Under Sea, and the program aims to deliver high-quality communications underwater.

Fast and efficient underwater communications is a tricky challenge. The main reason relates to how water degrades and disrupts signals in a way that air does not. Sound and radio waves are the usual go-to signals in the underwater domain, yet they suffer from low data rates, short ranges, lack of precision, and inefficiency.

Optical lasers have potential for alleviating these issues because visible light operates at a frequency where attenuation in water is lowest. But the mechanics for making optical technology work have caused a roadblock. Currently, underwater platforms that use optics to communicate sweep a wide beam over a large area so that the receiver has a better chance of finding and catching the transmitter’s signal. This strategy wastes a lot of energy and makes the system sensitive to background light. The receiver must have a wide lens to catch a wide beam, and too much extra light from the environment can blind the receiver and drown out the communications signal. As a result, these platforms can operate only at night.

LOTUS’s beam-steering mechanics came from the LLCD program—which required that team to send a beam to a receiver that was 239,000 miles away. For LOTUS, this precision is used to send the beam a much shorter distance but in a turbulent environment, where waves and currents cause the transmitter and receiver to be in motion. The capability to steer precisely enough to send and receive a narrow beam underwater is currently unique to Lincoln Laboratory.

Compared to other underwater communications platforms, LOTUS can communicate more than 100,000 times faster and with 100 times less battery consumption. The need for less battery also translates to a smaller platform design. In addition, because the beam is narrow and emits less power, it poses no danger to humans or surrounding wildlife.

In 2018, the team tested LOTUS in an indoor pool and sent communications between platforms that were separated by 20 meters. Given the results of their test, the team estimates they can link platforms that are up to 400 meters away in clear ocean water.

LOTUS’s narrow optical laser enables high-speed communications underwater.
Technology Investments

The Technology Office manages Lincoln Laboratory’s strategic technology investments and helps to establish and grow technical relationships outside the Laboratory. The office is responsible for overseeing investments in both mission-critical technology and potentially impactful emerging technology. To maintain an awareness of emerging national security problems and applicable technologies, the office interacts regularly with the Office of the Under Secretary of Defense for Research and Engineering and other government agencies. The Technology Office fosters collaborations with and supports university researchers, and aids in the transfer of next-generation technology to the Laboratory’s mission areas. The office also works to enhance inventiveness and innovation at the Laboratory through various investments and activities that promote a culture of creative problem solving and innovative thinking.

In 2021, pandemic-related work restrictions for Lincoln Laboratory and its campus collaborators presented challenges for applied research. However, the pandemic also created new opportunities for virtual interactions through the implementation of new digital tools. Given the new hybrid work environment, the ability to work remotely and with distant collaborators will only strengthen the Laboratory’s research capabilities going into the new normal.

INVESTMENTS IN MISSION-CRITICAL TECHNOLOGY

Enabling development of technologies that address long-term challenges and emerging issues within the Laboratory’s core mission areas

Cybersecurity
All branches of the U.S. government, including the Department of Defense (DoD), must continuously defend against diverse and persistent cyberattacks. Lincoln Laboratory conducts research and develops technology to secure, defend, operate, and ensure the resiliency of the nation’s cyber systems. Starting with detailed understanding and analysis of cybersecurity issues, the Laboratory executes advanced security research across the full spectrum of the cyber problem space, from secure software and hardware architectures to innovative algorithm development and vulnerability characterization.

In 2021, Lincoln Laboratory continued fundamental research in cybersecurity through the exploration and development of cybersecurity phenomenology, resilient systems, data-centric architectures, and system exploitation. Examples of this R&D are listed below:

- Designed the Lincoln Exploitation Exploration Tool to greatly increase the speed of vulnerability discovery. The tool applies techniques that check the flow of user inputs to discover software exploits.
- Investigated the use of advanced cryptographic techniques for system exploitation and to address privacy concerns with machine learning algorithms that use sensitive data.
- Invented a novel defense approach suitable for use in industrial control systems that have strict real-time requirements to ensure physical safety.
- Created a system architecture to enhance detection and situational awareness of illicit cryptocurrency transactions.
- Developed hardware and software approaches that compartmentalize Linux into smaller modules, each of which has the lowest privilege needed for its functionality. These approaches are expected to minimize the impact of cyber vulnerabilities in mission systems.

Resilient Mission Computer (RMC)
On MIT campus, the project team is addressing the root causes of cyber vulnerabilities in modern systems by focusing on three main pillars: building on security-aware hardware, incorporating safe programming languages, and reducing excess privilege in operating systems. The RMC and its follow-on project, called ARROWS for Advanced Resilient and Real-Time Open Weapon Systems, developed innovations and open-source prototypes that implement this vision across key layers of a computing stack. This project paves the way for future computer systems that are secure by design for use in the national power grid and nuclear command and control applications.

As a result of the RMC moonshot, the DARPA Information Science and Technology Study Group initiated a study called “Cyber Moonshot: Accelerating Security of Systems with Emerging Technologies.”

Co-chaired by Laboratory researcher Hamed Okhravi, the study will investigate advanced cybersecurity technologies and define future DARPA programs for deployment in critical defense systems.

At right, members of the Resilient Mission Computer (RMC) project (left to right: Hamed Okhravi, Samuel Mengerdahl, Jason Martin, Nathan Berzofsky) test a secure operating system design on a modern security-aware processor. To disseminate the RMC moonshot vision, the team published a cover article, far right top, in the prestigious IEEE Security & Privacy journal.
Optical Systems Technology

A ½U beacon payload has been developed under the Active Distributed Aperture Phasing Technology (ADAPT) project. This beacon payload is an on-orbit test bed for establishing ground-to-space optical links to correct for atmospheric turbulence effects by using a predictive adaptive optics technique. The ADAPT beacon carries a high-intensity laser diode to serve as a point-source phase reference, a photodiode to measure received optical power for validating an optical uplink, and a retroreflector to establish ground-to-space range measurements. The multibeam, multistatic, adaptive optics technique aims to measure received optical phase reference, a photodiode to improve resolution and sensitivity.

Research into optical systems technology enables future mission capabilities in intelligence, surveillance, and reconnaissance (ISR) and communications. The goal of this research is to fill critical technology gaps in emerging DoD threat areas. Projects emphasize research in lidar, high-energy lasers, imaging systems, optical communications, and novel optical components. In 2021, the Laboratory conducted several notable efforts in optical systems:

- Designed a multiwavelength, multistatic, high-altitude lidar system for unmanned aerial vehicles (UAVs), with the mission of improving climate sensing and providing continual coverage of regional phenomena, including aerosol characterization, water vapor measurements, and wind measurements.
- Developed a space-based, globally persistent ISR architecture designed to enable orders-of-magnitude improvement in area coverage rate. This improvement is achieved by exploiting satellite constellations that have high revisit rates (minutes to seconds) and large field-of-regard sensors that use new day/night-capable midwave infrared detectors to improve resolution and sensitivity.
- Invested in a number of novel mission-enabling concepts. For example, research was conducted on a fundamentally different type of RF phased array receiver based on laser probing of room-temperature vapor cells in order to monitor Rydberg atom transitions in a gas.

Radio-Frequency Systems

Research in the information, computation, and data exploitation domain addresses challenges in the application of emerging artificial intelligence (AI) and big-data computing for national security needs. Topics of current research are AI algorithms and workflows, novel mission applications, data-intensive big-data computing, compute infrastructure, and approaches to advancing Al engineering practices for AI assurance. Projects undertaken in 2021 included the following:

- Developed a resource-aware decision support framework for effective intervention and control of pandemics.
- Formulated new techniques that map AI applications to different classes of computing platforms such as embedded processors and large-scale data centers.
- Released as open-source a new software toolbox that enables the development of robust and reliable AI systems.

Information, Computation, and Data Exploitation

Research in the information, computation, and data exploitation domain addresses challenges in the application of emerging artificial intelligence (AI) and big-data computing for national security needs. Topics of current research are AI algorithms and workflows, novel mission applications, data-intensive big-data computing, compute infrastructure, and approaches to advancing Al engineering practices for AI assurance. Projects undertaken in 2021 included the following:

- Designed a small-sized, low-power communication system network protocols to provide interference and jamming-robust networking for swarms of small UAVs.
**Integrated Systems**
Projects in the integrated systems category bring together scientists and engineers to conduct applied research that accelerates the integration of advanced technologies into game-changing systems for national security. The goal is to demonstrate DoD-relevant system concepts that use novel architectures, recently developed component technologies, and new analytic methods. Several projects reached prototyping milestones in 2021:

- Developed a versatile satellite platform for rapid space technology demonstrations. This platform includes compact electric propulsion; automated guidance, navigation, and control for orbital maneuvers and station keeping; and a compact camera with on-board image processing. The satellite is designed to host experimental payloads (see ADAPT project on page 20) and is scheduled for its inaugural launch in spring 2022.
- Conducted towed helicopter flights of 3D diamond magnetometer navigation technology to measure magnetic, acoustic, and vibration noise. These data will help inform the design of the next-generation prototype. This magnetometer will enable platform navigation in environments where GPS is not available.
- Carried out studies of mission and application architectures to motivate advanced technology development for novel mission concepts. One example study is investigating a long-range X-ray inspection satellite for internal inspection of satellites on orbit.

**Technology Innovation**

**Influence operations in social media have grown to become a critical concern in the United States, both in society and for national security. The Laboratory is developing a toolkit of advanced technologies that can help to discover where and when influence operations are being used, as well as how influence is generated and how it propagates. While the initial focus is on developing effective detection and assessment techniques, future focus will expand to include effective countering tools. Below are example projects striving to develop technologies that will allow the nation to respond to this threat:**

**Fake Data Generation**
In 2021, the Technology Office hosted the FoolMe Challenge. Lincoln Laboratory staff were asked to submit ideas for the generation of a corpus of fake media/data of any type with relevance to national security. Two winners were funded to create, generate, or collect their proposed corpus of data, which will be used in a future hackathon-style challenge focusing on fake data detection and effects mitigation.

As machine learning is increasingly applied in the area of remote sensing, data-poisoning attacks can be developed to evade and mislead these systems. Data poisoning is an adversarial attack on a machine learning algorithm in which the data used to train the algorithm are manipulated or “poisoned” to cause the algorithm to fail in some manner. One of the FoolMe Challenge winners, the “Hiding in Plain Sight: Poisoning Attack to Remote Sensing Data” project, is using data-poisoning techniques that cause specific instances in a test set to be misclassified into a purposely inaccurate class.

In 2021, the Wafer-Scale Satellite team completed the assembly of the thruster module, consisting of an emitter chip with record-breaking emitter tip density. The increased emitter density increases thrust density while maintaining a compact form factor. An extractor is used to create a voltage difference, which causes an ion to emit from the emitter chip array and accelerate away from the array, thereby creating thrust. The team was able to keep extractor/emitter misalignments below 5 micrometers, which enabled the quantitative characterization of the ultradense electrospray thruster module. Initial diagnostics suggest that the module’s thrust densities are competitive with state-of-the-art electrospray thrusters and that further increases in thrust density are possible.

**Impact Assessment Tools**

The Reconnaissance of Influence Operations research team tested algorithms that assessed influence propagation against the known influence campaign carried out in the 2017 French presidential election. In the foreign Twitter propaganda network, algorithms classified network nodes (accounts) according to the degree of influence exhibited by each account. Circles indicate individual Twitter accounts, while larger red circles represent influential accounts that were likely part of the organized campaign to disseminate disinformation.

In 2021, the FoolMe Challenge winners, the “Hiding in Plain Sight: Poisoning Attack to Remote Sensing Data” project, is using data-poisoning techniques that cause specific instances in a test set to be misclassified into a purposely inaccurate class.

**Fake Detection Tools**
To better identify synthetic content before nefarious influence campaigns can use the content to spread disinformation, the Deepfake Gym project aims to strengthen the detection of deepfakes by addressing the poor performance of traditional techniques on novel instances, expanding new techniques to multiple modalities, and increasing the explainability of detection algorithms to increase user trust.
INVESTMENTS IN EMERGING TECHNOLOGY
Promoting research into technologies of growing importance to national security and the development of engineering solutions for projects in Lincoln Laboratory’s relevant mission areas

Advanced Materials and Processes

- Leveraged heteroepitaxial growth (i.e., growth of non-silicon films on a silicon substrate) to combine high-performance lasers, modulators, and detectors with passive components based on various silicon-nitride compounds, on low-cost silicon substrates. The ability to use light instead of copper as high-density electronic interconnects for future computing hinges on this ability to combine disparate materials.
- Continued to advance the Laboratory’s ability to synthesize diamond with precise control over its material properties. These tailor-made diamonds are candidates to make fundamental advances in next-generation qubits for quantum computing and novel electronics.
- Characterized first-generation single-flux quantum (SFQ) circuit components and designed a second-generation SFQ digital focal plane array (DFPA) pixel that can be integrated into a 2D-array format. Such SFQ-based DFPA readout circuits are expected to simplify the room-temperature electronics and lower the SWaP of systems incorporating superconducting detectors, such as X-ray and gamma-ray spectrometers.
- Continued developing a superconducting amplifier array that will enable the detection of neutrinos having energies less than 100 electron volts by using a new, highly sensitive process based on measuring the energy involved in coherent neutrino scattering. Neutrino detectors that have improved sensitivity and reduced detector mass will benefit a variety of applications, including nuclear monitoring and basic science.
- Made progress on the hybrid integration of thin-film lithium niobate onto a photonic integrated circuit platform to realize a novel optical modulator with 65-gigahertz bandwidth and state-of-the-art sensitivity. Chip-scale millimeter-wave photonic signal processors offer the potential of processing RF signals with higher fidelity and lower SWaP than all-electronic solutions.

Biomedical Science and Technology

- Applied advanced AI methods to accelerate the development of antibodies for use against emergent pathogens. The methods take inspiration from state-of-the-art AI human language models to predict potentially efficacious antibody protein sequences. Preliminary results are very encouraging and show strong correlation with experimentally measured efficacy data.
- Continued development of a closed-loop, fluent, and intuitive ankle exoskeleton to support operators and warfighters in real-world environments, with the goal of reducing fatigue and increasing performance. Use of a muscle energy model derived from simple ultrasonic measurements reduces personalization time to seconds instead of the typical hours of training time required.
- Made progress toward comprehensively characterizing breath samples in the aerosol and vapor regime. Such information could greatly improve researchers’ and the medical community’s understanding of disease detection, transmission, and potential mitigation strategies.
- The SWaP of chip-scale detectors and quantum sensors that require operation at cryogenic temperatures is limited by the large, inefficient refrigeration systems used to provide the cooling. The objective of the miniature cryocooler project is to reduce the SWaP of these cryo-refrigeration systems by developing microscale polymer fiber heat exchangers. The images show the fiber preform assembly (a) and the cross-section of the resulting fiber (b).
The Multi-agent Autonomous Space Technology project seeks to develop autonomous space technologies for future missions in the space domain.

To develop decision-making algorithms for the control automatic segmentation of satellite components, and by the simulator are used to train algorithms to perform scale training of AI algorithms. These data generated and interface with software architectures for large-engagements, rapidly generate high-fidelity sensor data, The simulator is designed to emulate complex autonomy elements.

Addressing these challenges, the Multi-agent Autonomous Space Technology (MAST) program is developing a space simulation tool to develop and train the necessary autonomy capabilities. While AI advancements are making it possible to achieve these tasks in space, testing such capabilities in space is expensive and difficult. To address these challenges, the Multi-agent Autonomous Space Technology (MAST) program is developing a space simulation tool to develop and train the necessary autonomy elements.

The simulator is designed to emulate complex engagements, rapidly generate high-fidelity sensor data, and interface with software architectures for large-scale training of AI algorithms. These data generated by the simulator are used to train algorithms to perform automatic segmentation of satellite components, and to develop decision-making algorithms for the control of satellite maneuvers and actions. While MAST is applying deep-learning-based object detection and pose-estimation algorithms to solve the perception problem, advanced reinforcement learning methods are being developed to enable automated decision-making when satellite behavior is challenging to predict.

Exploration of space autonomy capabilities will help inform the Laboratory and its sponsors about feasibility and fruitful future research directions. In a broader context, MAST is part of a larger strategic plan investing in technologies for greater mobility and autonomy in space. For example, the Agile MicroSat project is developing a 6U satellite that can station-keep and maneuver in low-Earth orbit; the Wafer Scale Satellite project is investing in electrospray thrusters for station-keep and maneuver in low-Earth orbit; the Wafer Scale Satellite project is investing in electrospray thrusters for station-keep and maneuver in low-Earth orbit; the Wafer Scale Satellite project is investing in electrospray thrusters for station-keep and maneuver in low-Earth orbit; the Wafer Scale Satellite project is investing in electrospray thrusters for station-keep and maneuver in low-Earth orbit.

Evaluated the benefit of interpretability in a human-aware AI teaming algorithm and prototyped a novel, personalized scenario generator for accelerated tactics and training development. A path to transition the teaming algorithms and scenario-generator to Navy training schoolhouses was also established.

Created sonar imagery of multiple shipwrecks by using a prototype surface-based, distributed multi-input multi-output underwater mapping sparse sonar array (24 feet x 24 feet). A full-scale version of this prototype array is being designed and developed to support deep ocean floor mapping with a resolution two orders of magnitude higher than is currently achievable.

Quantum Systems and Science

Quantum systems can enable significant advances in sensing, communication, and computing. The Technology Office is investing in these technologies, beyond the nearer-term focus of commercial efforts. In 2021, significant progress was made on a number of projects:

- Continued building of an entanglement-based optical quantum network linking the locations of Lincoln Laboratory, MIT, and Harvard University. Networks require not only transport of information but also storage or memory. The Laboratory has demonstrated photonically addressable quantum memories that use defect centers in diamond to temporarily store the information carried by the photons that are used to communicate over the network. This memory system allows the network to extend over longer distances and to operate at greater data rates.
- Demonstrated for the first time a 3D integration of superconducting qubits by bringing together a high-coherence qubit, superconducting interconnect, and routing layers in a single device. As nascent quantum computers push from few-qubit experiments to test beds of moderate size and beyond, the architecture for addressing and controlling these qubits must also evolve.
- Developed a novel microwave-based readout technology that enables high-fidelity readout of large ensembles of nitrogen-vacancy color centers in diamond as they transition between quantum states under the influence of magnetic fields. Such color centers have emerged as a quantum system that can provide promising 3D-magneticometer technology. This readout technique extends beyond nitrogen-vacancy defects in diamond to enable efficient readout for a broad family of microwave-addressable solid-state systems.

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Energy
Research in this area supports DoD energy needs, including remote power, advanced energy storage, in situ resource harvesting, and reliability for microgrid systems up to the national grid scale. This year’s work includes activities to address challenges such as advanced energy storage and novel platforms:

- Began development of an electrochemical power system based on liquid fluorinated reactants, which enable high energy density (33% higher than state-of-the-art lithium batteries) and intrinsically safe batteries tailored for undersea applications.
- Developed a high-voltage DC power train tailored for specific aerospace applications to reduce line losses and substantially reduce weight compared to AC/AC and AC/DC systems.
- Developed an affordable, secure, standardized, and easy-to-install set of devices to obtain telemetry from DoD facilities to support energy resilience exercises.
- Demonstrated two-phase heat transfer enhancements making use of microtexture, gasphilic surfaces that accelerate gas capture and release trapped vapors. This work was completed in association with the Varanasi Research Group on MIT campus.

Lincoln Laboratory is developing a propulsion system and novel hull design utilizing liquid fuel cells, which will enable extended ranges for electrically powered autonomous underwater vehicles. Unlike on fixed-hull craft, the fuel in the Laboratory’s hull design is stored in elastic bladders, which progressively shrink as the reagents are consumed and bio-composable products are exhausted to the sea. As the mass is consumed, the vehicle’s diameter decreases. This shrinkage creates a more streamlined and lower-drag vehicle, resulting in multiplicative improvements in range and endurance compared to a traditional rigid hull.

Engineering
The Laboratory depends on state-of-the-art engineering capabilities to facilitate the development of advanced prototype systems. In the engineering area, technological investments are made in new tools and processes with the potential to enable new applications and to provide cross-cutting prototyping capabilities with broad applicability to Laboratory mission areas. In 2021, several efforts complemented this diverse portfolio:

- Continued the multiyear investment to develop a digital engineering toolset known as LLIMAS (Lincoln Laboratory Integrated Modeling and Analysis Software) that integrates solid models with aero, thermal, structural, and optical design and analysis tools.
- Developed a prototype 3D printer that can embed copper-carbon nanotube composite conductors within complex thermoplastic structures to embed electronics within 3D-printed structures.
- Demonstrated two-phase heat transfer enhancements making use of microtexture, gasphilic surfaces that accelerate gas capture and release trapped vapors. This work was completed in association with the Varanasi Research Group on MIT campus.

In 2021, a research team used the output of temperature and precipitation modeling as inputs to preliminary agriculture modeling of key crops in Bangladesh over a 30-year timespan. This work provides predictions of crop-yield impacts as a function of economic and transmission risks.

- Continued developing an analysis architecture to assess the impact of urban air mobility on city/regional airspace and provided guidance on air traffic infrastructure requirements. Improvements in 2021 include the addition of hourly weather forecasting to capture gate hold and dynamic rerouting.

Homeland Protection, Air Traffic Control, Humanitarian Assistance, and Disaster Relief
Investments in these areas emphasize both foundational research and infrastructure development needed to produce advanced capabilities applicable to a diverse set of critical national security needs. Investments support solutions to national challenges in air and ground transportation, land border and maritime security, chemical and biological defense, critical infrastructure protection, humanitarian assistance, and disaster response. Projects span research in advanced sensors and architectures, signal processing, data fusion, and decision support, as well as the development of experimental test beds and infrastructure needed to explore advanced concepts. Highlights from 2021 include such diverse projects as the following:

- Built an immersive pandemic simulator of passenger traffic within airports. The simulator includes infectious agent dispersion models and allows critical stakeholders to evaluate response strategies as a function of economic and transmission risks.
- Developed autonomous flight logic for a “chase drone” that tracks hostile autonomous unmanned systems back to their pilots and transmits photo/video for law enforcement identification.
- Continued developing an analysis architecture to assess the impact of urban air mobility on city/regional airspace and provided guidance on air traffic infrastructure requirements. Improvements in 2021 include the addition of hourly weather forecasting to capture gate hold and dynamic rerouting.
INVESTMENTS IN INNOVATIVE RESEARCH
Providing support for R&D into foundational concepts and their applications in new systems

Seedlings
Through investments in seeding projects, the Technology Office allows staff to pursue innovative technology ideas and feasibility demonstrations. Seedlings encourage exploration of radically new approaches and technologies that could benefit Lincoln Laboratory’s mission space.

Advanced Concepts Committee
The Advanced Concepts Committee (ACC) provides funding and technical and programmatic guidance for the development of basic and applied technology concepts that address important technical problems. The ACC funds a breadth of highly innovative, high-risk research that, if successful, has the potential for significant impact on the Laboratory’s mission areas. A few notable 2021 projects are included below:

- Began working on a computational framework for predicting optimal designs and build paths of a space-based computer numerical control wire-bending concept to create multimaterial trusses that are strong, stiff, and thermally stable.
- Developed new, universal tools intended to counter and keep pace with the rapidly advancing field of deep learning-based steganography, a method of hiding data within images or audio files.
- Developed a wearable weave of stem-cell-seeded, biocompatible scaffold material to enable expedited recovery of injuries without sacrificing mobility.

Conventional planar focal plane arrays require complex optics to reduce spectral distortion and intensity roll off at the edges of the array. A curved focal plane array would require simpler optics that could result in reduced size and weight for wide-field-of-view imaging applications. This ACC project, a collaboration between MIT, the University of Virginia, and Lincoln Laboratory, aims to demonstrate imaging arrays, such as the one shown above, that use novel flexible III-V detector material as a path toward curved imaging arrays.

A Doppler cloak seeding project reduces the detectability of targets by spreading their radar return across Doppler bins. A proof-of-concept array was built and tested, demonstrating the basic Doppler cloak phenomenology with pulse repetition frequency-rate modulation. Higher speed modulation can spread the radar return over range bins as well.

- Developed a wearable weave of stem-cell-seeded, biocompatible scaffold material to enable expedited recovery of injuries without sacrificing mobility.

FOSTERING INNOVATION AND COLLABORATION
Encouraging staff to discover and develop innovative technology by engaging in technical interchange meetings, conferences and seminars, and Technology Office challenges

Invited Speakers
In 2021, the Technology Office hosted virtual seminars to spark curiosity, creativity, and collaboration at the Laboratory. The speakers are renowned in their respective fields. Talks this year covered a diverse range of topics:

- Ramin Hasani from MIT’s Computer Science and Artificial Intelligence Laboratory discussed novel continuous-time neural network models, called liquid time-constant networks.
- Reva Schwartz and Elham Tabassi of the National Institute of Standards and Technology discussed ways of identifying and managing bias in AI.
- Karen Riedl from Daimler presented on human-machine teaming and its role in vehicle production.
- Simon Knowles from Graphcore discussed the Cosossus Mk2 processor, the M2000 Machine, and Graphcore’s advancements in processors for machine intelligence.

Technology Office Challenges
The University of Virginia, and Lincoln Laboratory, aims to demonstrate imaging arrays, such as the one shown above, that use novel flexible III-V detector material as a path toward curved imaging arrays.

The UnBIAS Challenge was launched to explore the emerging issues of algorithmic bias and fairness in the rapidly evolving world where AI applications are appearing widely.

Each year, the Technology Office invites staff to participate in challenges that explore topics relevant to the nation and the Laboratory’s mission areas. In 2021, the Technology Office launched the Understanding Bias in Algorithms and Society (UnBIAS) Challenge, which focuses on educating the Lincoln Laboratory community about algorithmic bias, its manifestations, and its emerging impact on national security.

The initial phase of this challenge spans multiple months and consists of inviting speakers and holding virtual group discussions, coined the TO Coffee Talk series. The TO Coffee Talks are informal discussions with the Laboratory community on emergent topics of interest. Conversations are meant to encourage the sharing of thoughts and opinions and to foster a community of creativity and innovation.
**ARTIFICIAL INTELLIGENCE AT THE LABORATORY**

Research and development of AI-based capabilities spans all of Lincoln Laboratory’s mission and technology areas. The Technology Office has undertaken the role of coordinating and strategically guiding various Laboratory-wide AI initiatives.

### Al Snapshot Tool

Recognizing the strong potential for cross-cutting impact from advances in AI, the Technology Office put together a tool that captures AI initiatives at the Laboratory and highlights prevailing research thrust areas, the kinds of datasets that exist across mission areas, and associated technology readiness levels. Along with tracking the evolution and emergence of AI across mission areas, this tool helps inform researchers, developers, managers, and leaders about AI-related gaps, opportunities, and needs, which in turn helps shape future directions and investments.

The AI Snapshot tool facilitates taking stock of the technology scope and paradigm of AI algorithm development and enhancement of AI model robustness, resilience, and explainability. Tools recently developed include components for uncertainty-aware learning for detecting outliers, anomalies, attacks, and distribution shifts.

- Developed open and interpretable interfaces for machine learning-based decision support systems in operational workflows. In collaboration with Air Force CyberWorx, the Laboratory developed a framework for characterizing stakeholder explainability needs.
- Conducted a comprehensive study of AI ethics, using security clearance processing as a use case, and created a set of best practices for improving fairness and transparency in the design, development, and assessment of AI systems.

### Laboratory-wide AI Initiative

To facilitate intersecting technology development, in 2018, the Laboratory stood up the AI Technology Group under the direction of the Technology Office. Since then, Lincoln Laboratory’s strategic initiative in AI technology has made substantial progress in advancing AI technologies and has continued to address complex challenges facing the nation and the world. This year in particular, the Laboratory has continued to address complex challenges facing the nation and the world. This year in particular, the Laboratory has continued to address complex challenges facing the nation and the world.

The Laboratory has developed a framework for characterizing stakeholder explainability needs.

Informed AI Seedling

A strategic study was conducted to position the Laboratory to better understand how to leverage AI techniques that exploit both data and domain expertise (including scientific knowledge). In particular, informed deep learning techniques promise to further advance the state of the art in AI via significant performance improvements, and to broaden AI’s applicability beyond its current reach across Laboratory mission areas.

- **AI Technical Interchanges**
  - **RAAINS Workshop**
    - The Laboratory virtually hosted the second annual Recent Advances in Artificial Intelligence for National Security Workshop (RAAINS), which focused on the state of the art in key areas of AI, recent advances applied to national security, and future directions in AI that are specifically of interest to the DoD and the Intelligence Community. The workshop engaged a diverse audience with excellent keynote speeches, presentations, and virtual posters. Attendees were also offered the opportunity to take several online courses in natural language processing, computer vision, autonomy, human-machine collaboration, and AI for biology.
    - This year, the Human Machine Collaboration for National Security Workshop was hosted in conjunction with RAAINS. The workshop focused on the theme of human-machine teaming and addressed intelligent AI-based solutions, the interface with humans, and a radical rethinking of mission workflows as AI assumes a peer relationship with operators.

- **Human-Machine Teaming Technical Interchange Meeting**
  - Recognizing that learning between human and machine is a critical aspect for many AI systems and that AI-based technologies are being developed across all Laboratory mission areas, the Technology Office hosted a Laboratory-wide technical interchange meeting to share insights into the roles and relationships between human and machines in current and future national security systems. The meeting engaged a diverse Laboratory audience with overview presentations by each division and lightning talks that shared future concepts of enabling technologies.

**Department of the Air Force–MIT Artificial Intelligence Accelerator**

The Laboratory, with the Air Force, has continued to engage with MIT to create new algorithms and AI solutions that will improve Air Force operations while also addressing broader societal needs. Several projects are underway that span a wide range of AI topics and applications, including an effort to help train and strengthen the DoD AI workforce. The Department of the Air Force–MIT AI Accelerator (AIA) launched a new exploratory project called Know-Apply-Lead that aims to advance educational research activities that promote maximum learning outcomes at scale for learners with diverse roles and educational backgrounds, ranging from Air Force and DoD personnel to the general public. The project team will research and evaluate various pedagogical practices and learning benefits associated with training Air Force personnel in AI topics over a variety of existing courses, map out the landscape of educational needs and competencies, and pilot experimental learning experiences with the goal of outlining early prototypes for innovative technology-enabled training and learning. The research is expected to provide insights that will benefit AI learners across the nation while supporting the DoD’s objective to develop elite and world-class AI-ready services.

**AI R&D**

- **Communication and/or Actuation**
  - **Planning**
  - **Knowledge**
  - **Reasoning**
  - **Perception**
  - **Serving and/or Data Collection**

**Technology Scope 1 vs. Paradigm 1**

- **Logistic-Based**
  - **Knowledge-Based**
  - **Probatistic Methods**
  - **Machine Learning**
  - **Entangled Intelligence**
  - **Search and Optimization**

**The AI Snapshot tool takes stock of the technology scope and paradigm of AI algorithm development and enhancement of AI model robustness, resilience, and explainability. Tools recently developed include components for uncertainty-aware learning for detecting outliers, anomalies, attacks, and distribution shifts.**
R&D 100 Awards

R&D World magazine presented 2021 R&D 100 Awards to nine technologies developed by Lincoln Laboratory researchers, either solely or in partnership with other organizations. These awards recognize 100 groundbreaking technological innovations developed by research institutes and companies worldwide and introduced during the prior year. From hundreds of nominees, the winners are selected by an international panel of expert judges from academia, industry, and national laboratories.

**Free-space Quantum Network Link Architecture**
A system that enables the generation, distribution, and remote interaction of entangled photons across free-space links.
LINCOLN LABORATORY TEAM: Jakub Kozdziel, project lead; Hern Cichy

**Field-Programmable Imaging Array**
A universal digital back end for camera systems which, when hybridized to an image detector array, results in a flexible and powerful digital processing system in-package.

**Guided Ultrasound Intervention Device**
A handheld tool, utilizing real-time AI software, that enables a medic to rapidly and accurately catheterize a central vein or artery in a pre-hospital environment.
LINCOLN LABORATORY TEAM: Laura Braitian and Brian Telfer, project leads; Nancy DeLois, Jay Gupta, Matthew Johnson, and Joshua Westbin

**Global Synthetic Weather Radar**
A technology that provides radar-like weather imagery and radar-forward forecasts in global regions where actual weather radar are not deployed or are limited in range.
LINCOLN LABORATORY TEAM: Haig Iskenderian and Mark Veillette, project leads; Ashish Banerjee, Richard Ferris, Richard Knowles, Nikhil Kotacha, Patrick Lamey, Aylym Manvelyan, Danielle Morse, Alexander Prosucilsky, Shihi Reagopob, and Mark Worris

**Motion Under Rubble Measured Using Radar**
An all-glass, monolithic fiber array launcher that is smaller and more robust than standard arrays.
LINCOLN LABORATORY TEAM: Daniel Miller and John Novak, project leads; Gregory Cappiello, Jeffery Fuller, Patrick Hassett, Christopher Holt, Christopher Hwang, Eric Lapsos, George Ni, and Joshua Oldsby

**Microhydraulic Motors**
A scalable, electrowetting-based actuation platform with a torque density two orders of magnitude higher than that of electric motors.
LINCOLN LABORATORY TEAM: Robert Murphy, project lead

**Monolithic Fiber Array Launcher**
An all-glass, monolithic fiber array launcher that is smaller and more robust than standard arrays.
LINCOLN LABORATORY TEAM: Daniel Miller and John Novak, project leads; Gregory Cappiello, Jeffery Fuller, Patrick Hassett, Christopher Holt, Christopher Hwang, Eric Lapsos, George Ni, and Joshua Oldsby

**Motion Flow Impact Tool**
A tool for air traffic control managers that predicts and displays impacts to airspace capacities and traffic flow rates during convective weather.
LINCOLN LABORATORY TEAM: Michael Matthews, Mark Veillette, Joseph Venuti, and Mark Worris, project leads; Kim Caiden, Bradley Crowe, Richard DeLaura, Peter Erickson, James Evans, Fulvio Fabrizi, Richard Ferris, James Kuchar, Danielle Morse, Leuran Osirota, James Pelagatti, and Tom Reynolds

**Spectrally Efficient Digital Logic**
A set of digital logic families that operate with intrinsically low electromagnetic interference emissions.
LINCOLN LABORATORY TEAM: Robert Murphy, project lead

**Universal Digital Back End**
A universal digital back end for camera systems which, when hybridized to an image detector array, results in a flexible and powerful digital processing system in-package.

**Global Synthetic Weather Radar**
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Technology Transfer

Lincoln Laboratory engages in the development and demonstration of advanced prototype technologies and systems, with the overall objective of transferring these capabilities to the government, industry, and private sector. These transfers include hardware, software, materials, technical data, and subject-matter expertise and provide a diverse and resilient set of national security capabilities while contributing to the economic, environmental, and social wellbeing of the United States.

Leading and directing mission-based research at the intersection of government, academia, and industry requires Laboratory staff to publicize research results in technical reports, in peer-reviewed journal articles, and at conferences and technical seminars. Staff members are encouraged to promptly disclose new subject inventions and software, and, working with MIT’s Technology Licensing Office, have developed a strong portfolio of patents and copyrighted materials in all the Laboratory’s primary technical domains. Inventions and copyrighted works carry certain government-use rights and are frequently also promoted for transition to the private sector via open-source or commercial licensing. These activities promote information sharing and accelerate innovations from concept to practice, closing the gap between the research and the technology’s adoption for national security and societal benefit.

THE TECHNOLOGY VENTURES OFFICE
The Technology Ventures Office (TVO) was established in 2018 to provide strategic coordination for technology transfer–related activities at the Laboratory.

The TVO works to promote the broadest possible impact of Lincoln Laboratory innovation by facilitating the inflow and outflow of advanced technology. The TVO focuses in a few distinct but related areas:

- Facilitating and tracking sponsor-directed technology transition so that the Laboratory products of government-funded R&D can be rapidly accessed by others
- Engaging the commercial sector in collaborative R&D that creates new markets for Laboratory-developed technologies and that invites new (often nontraditional) businesses to work with the Laboratory in support of its national security mission
- Formulating intellectual property strategies that, through commercialization, promote government and private-sector access to Laboratory-developed capabilities
- Leveraging nonfederal funding opportunities to expand the societal and environmental impact of Laboratory expertise, knowledge, and technologies

SPONSOR-DIRECTED TECHNOLOGY TRANSITION
Lincoln Laboratory has a history of commitment to developing prototype technologies that support government acquisition program and procurement contract awards. The Laboratory is also frequently called on to deliver quick-response capabilities to respond to urgent operational needs and humanitarian emergencies.

Since the TVO was established, one of its foci has been to optimize the process by which the Laboratory effectively transitions its technologies to others at the government’s request. In the TVO’s first two years, new guidelines and a simplified government-directed transfer agreement process were established to facilitate such actions, and all transfers were recorded and tracked in a dedicated database. The database allows the TVO to conduct analytic assessments and supports more sophisticated portfolio analyses by benchmarking transfer activities and identifying trends. In 2021, the TVO’s third year, the emphasis has been on capturing technology transfer intent at the beginning of a program so that industry partners are readily available for handoffs and so that industry best practices can be deployed early in the technology development lifecycle.

This focus resulted from conversations with government sponsors and from observations of the value in forming a transition plan early in the program and identifying and resolving barriers.

In addition, the TVO consulted with Federally Funded Research and Development Centers (FFRDCs), University Affiliated Research Centers (UARCs), and other nonprofit peer institutions throughout the year to identify best practices at similar organizations that could be adopted at Lincoln Laboratory. These collaborations have promoted the dissemination of collective strategies and facilitated creative solutions for chronic and newly identified issues, including those surrounding patent-cost reimbursements and licensing of federally funded research products.

LEADERSHIP (Left to right)
Dr. Teresa Fazio, Ventures Officer
Dr. R. Louis Bellaire, Deputy Technology Ventures Officer
Dr. Bernadette Johnson, Chief Technology Ventures Officer
Jennifer A. Falciglia, Program Manager

Spotlight: Accelerated ISR Capability Acquisition
The Laboratory’s Mode Development Kit (MDK) accelerates the integration of new sensors and subsystems and promotes flexible acquisition of future intelligence, surveillance, and reconnaissance (ISR) capabilities. The MDK is based on the Common Open Architecture Radar Programs standard, whose general goal is rapid and cost-effective capability acquisition and improvement. Providing the software infrastructure, tools, and examples, the MDK reduces barriers to entry (such as cost and access) to third-party developers and encourages broader engagement, increased competition, and new capabilities. The sponsor-directed transfer of the MDK software has benefitted 10 commercial and nonprofit organizations in 2021 alone.

Shown at left is open-architecture, real-time radar mode software being exercised on the Airborne Radar Testbed.
Spotlight: Quantum Computing

CRADAs

The Laboratory developed and delivered to research partners traveling-wave parametric amplifiers like the one shown above.

MIT has developed the world’s most advanced integrated circuit fabrication process for superconducting electronics. With consent from government sponsors, the Laboratory has delivered more than 200 traveling-wave parametric amplifiers to 50 leading strategic quantum research partners in the United States and internationally. These CRADA partners seek to ascertain the utility of these superconducting amplifiers in enabling broadband, high-efficiency readout of multiple quantum bits (qubits). Advances in this technology are a key stepping stone to creating large-scale quantum computers.

Spotlight: Defense Innovation Accelerator

The Department of Defense’s National Security Innovation Network Defense Innovation Accelerator matches cutting-edge technologies sourced from the Defense Laboratory Enterprise with entrepreneurs to facilitate technology transition to the private sector. From a pool of more than 450 technologies submitted in the FY21 solicitation, 22 were enrolled into a nine-month accelerator program, including three technologies from Lincoln Laboratory: MoBILE (Mobility and Biomechanics Insert for Load Evaluation), Cyber Sensing for Detecting Power Outages, and AI-Enabled Sonar Detection of Underwater Objects. ELVEE, the nascent startup team based on MoBILE, won the Pitch Day competition at the end of the program.

Spotlight: Smiths Detection Receives Expanded CANARY Technology License

Smiths Detection, a global leader in threat detection and security screening technologies, has expanded the company’s field-of-use licensing of the CANARY (for Cellular Analysis and Notification of Antigen Risks and Yields) biosensor technology developed by MIT and Lincoln Laboratory staff. This technology, originally developed to combat bioterrorism, is capable of rapidly detecting pathogens with high sensitivity and specificity. Smiths’ expanded exclusive commercial license will enable new point-of-care diagnostic applications initially focusing on a SARS-CoV-2 biosensor.

The photo at left shows Smiths Detection’s BioFlash Biological Identifier, which uses CANARY technology. Image: Smiths Detection

Interacting with the Commercial Sector

Lincoln Laboratory engages with the commercial sector on several fronts to maximize the economic and societal impacts of its research by transitioning prototype innovations into real-world products. Partnering with industry can create new value and new markets as federally funded capabilities are adapted to private-sector needs and vice versa. In FY2021, the Laboratory conducted collaborative R&D with 16 companies under Cooperative Research and Development Agreements (CRADAs). These R&D partnerships are funded by industry to advance dual-use or commercial technology development. CRADAs are an important mechanism by which the private sector benefits from original investments by the U.S. government. The Laboratory also executed 23 Collaboration Agreements with multiple not-for-profit institutions and an additional 25 research collaborations directly with MIT faculty and research staff. These collaborations often advance the state of early-stage technology development for applications that encompass all the Laboratory’s mission areas.

One important form of commercial engagement is the Laboratory’s direct partnerships with qualified small businesses to conduct R&D that addresses specific government needs. In 2021, Lincoln Laboratory executed 16 Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) projects under sponsorship from government agencies such as the U.S. Navy, DARPA, NASA, Department of Energy, and U.S. Special Operations Command. The Laboratory continues to directly support small businesses through R&D subcontracting. Since 2018, the Laboratory has implemented a customized variant of the Commercial Solutions Openings (CSOs), which are flexible technology development solicitations and standard contractual agreements, explore mechanisms for collaborative engagements, and browse SBIR/STTR collaboration topics that align with areas of Laboratory expertise. The Laboratory is growing outreach activities by participating in industry-focused events, including those directed at small businesses, and publicizing on the website dual-use technologies available for licensing or further development.

MIT has delivered more than 200 traveling-wave parametric amplifiers to 50 leading strategic quantum research partners in the United States and internationally. These CRADA partners seek to ascertain the utility of these superconducting amplifiers in enabling broadband, high-efficiency readout of multiple quantum bits (qubits). Advances in this technology are a key stepping stone to creating large-scale quantum computers.

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TECHNOLOGY INNOVATION

Intellectual Property Management

MIT is one of the world’s leading institutions in intellectual property disclosures and patenting. MIT’s Technology Licensing Office works closely with the TTO to implement strategies and policies for protecting federally sponsored intellectual property. In 2021, 14% of MIT’s technology disclosures were submitted by Lincoln Laboratory; on average, 69% of Laboratory disclosures result in at least one patent filing, and 72% convert to at least one patent grant. Copyright-protected software and non-software technical data comprised 52% of all disclosures in 2021. Approximately 58% of this year’s disclosures were submitted by first-time contributors, highlighting the Laboratory’s ongoing effort to create a vibrant and inclusive community for inventors and authors.

In accordance with objectives and guidance from the Department of Defense, sponsors continue to make significant use of open source as a licensing and distribution method. By open-source licensing of key technologies, technical priorities are signaled; ecosystems are built; emerging technology solutions and standards are promoted; and methods and practices are created through collaborative engagement with academic, government, and commercial partners. In 2021, the Laboratory added 33 new open-source projects, growing the portfolio by one-third.

The Common Evaluation Platform (CEP) provides an extensive, open-source, hardware-verification environment for system-on-a-chip security. CEP allows the Department of Defense, in partnership with industry and academia, to design and test security mechanisms to prevent, deter, or detect realistic hardware threats, including malicious functionality hidden within microelectronic designs.

Airspace encounter models have been distributed via open source and are in use by NASA, the Federal Aviation Administration (FAA), and industry. This suite of statistical models, datasets, and algorithms was primarily developed by Lincoln Laboratory, with contributions from the Stanford Intelligent Systems Laboratory and the FAA Center of Excellence for Unmanned Aircraft Systems (UAS). The suite provides a safety assessment framework for developing small and large UAS restrictions and requirements for safe flight in the national airspace.

The open-source software project Try-Once Real-Time Software Transactional Memory (STM), or TORTIS, has been distributed as the first, retry-free memory synchronization approach for multicore, safety-critical systems. TORTIS helps improve complex, concurrent, multithreaded task scheduling central to autonomous vehicles, networked medical devices, and smart grids. A companion article won an outstanding paper award at the Real-Time Systems Symposium, a leading IEEE conference.

Outreach and Entrepreneurial Education Efforts

There is a growing recognition within the government and the defense innovation community in general that the private investment engine driving the U.S. economy has not adequately focused on “tough tech”—the typically hardware-based, high-risk/high-payoff technology development that requires years of nurturing, expensive and/or specialized equipment, and a high degree of subject-matter expertise. As one means of addressing this problem, Lincoln Laboratory, in partnership with Lawrence Berkeley National Laboratory, supported its second cohort of entrepreneurial research fellows in a fellowship program that incubates new companies focused on advanced electronics development. The Defense Advanced Research Projects Agency funds the fellows, and the fellowships are administered by the nonprofit organization Activate. Each fellow embarks for a period of two years at the Laboratory and has access to unique facilities and resources and extensive technical and entrepreneurial mentorship.

The TTO has undertaken a wealth of activities designed to promote entrepreneurial education among Laboratory staff members. These efforts are geared toward teaching what it means to create transferable technology, how customer needs influence research goals, and what the real-world challenges inherent in starting a new tech-focused company are. Custom online learning opportunities and MIT’s Innovation Corps (I-Corps) Spark serve as flagship staff education platforms. More than 115 Laboratory staff members have now graduated from the I-Corps program.

It is equally important that others learn of the capabilities being developed at the Laboratory, and Laboratory staff members participated in multiple events whose objectives were to expose the external community to technology transfer and collaborative research opportunities. In FY21, these events included CyberWeek, Innovation Studio’s Venture Café, and MIT Industrial Liaison Program’s topical R&D webinars. At these events, technical staff gave “lightning talks” on technologies such as free-space laser communication, artificial intelligence, DNA forensics, resilient safety-critical systems, lightweight antenna arrays, and aviation technology. Finally, two Laboratory technologies—Forensic Video Exploitation and Analysis, and Keylime—earned Northeast Regional Federal Lab Consortium awards for excellence in technology transfer.

Looking Ahead

The TTO continues to ensure that the Laboratory’s government sponsors and their partners have access to available technologies developed at the Laboratory. Recognizing that commercialization also serves the government’s interests, the TTO will expand its focus on attracting licensees and creating a robust licensing pipeline. The TTO expects to grow its entrepreneurial fellowship opportunities and is in the early planning stages of developing an off-site office/lab presence designed for staff engagements with startups in the national security sector. The TTO will also continue to grow its intellectual property portfolio, including non-software copyrightable works and open-source software. The TTO aims to expand educational efforts for the FFRDC-UARC community and Laboratory sponsors, and will continue to consult with peer organizations so that everyone can benefit from the lessons learned. Finally, in support of the standup of a dedicated Climate Change Initiative at the Laboratory, the TTO will focus on nonfederal opportunities—including with nonprofits and the commercial sector—to help address critical adaptation, mitigation, and sustainment strategies related to climate change.
U.S. Patents Granted to Lincoln Laboratory Inventors, 1 October 2020–30 September 2021

<table>
<thead>
<tr>
<th>Patent Number</th>
<th>Description</th>
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<tr>
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<td>Wide Field of View Narrowband Imaging Filter Technology</td>
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<td>Methods and Apparatus for Photonic-Enabled Radio-Frequency (RF) Cancellation</td>
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<td>Multipolarized Vector Sensor Array System for Radio Astronomy Applications</td>
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<td>Dual Polarized Notch Antenna Having Low Profile Stripline Feed</td>
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<td>Block Copolymer Ink Formulation for 3D Printing and Method of Making a 3D Printed Radiofrequency (RF) Device</td>
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<td>Focal Plane Array Processing Method and Apparatus</td>
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<td>Surface Penetrating Radar and Battery Systems</td>
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<td>Spectrally Efficient Digital Logic (SEDL) Analog to Digital Converter (ADC)</td>
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<td>Foam Radiator</td>
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<td>Microwave Interferometric 3D Imaging System and Technique for Munitions</td>
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<td>U.S. Patent 10,961,534</td>
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Efficient Operations

In 2021, Lincoln Laboratory continued to simplify processes, build new capabilities, and modernize technology to enable employees to excel in the business of research. Upgrades to information services continued to support employees working remotely amid the COVID-19 pandemic. Progress continued on the Laboratory’s multiyear Digital Enterprise Transformation initiative.

Enhancing Information Technology and Services

The Information Services Department (ISD) led and completed several key initiatives in 2021:

- Health and safety applications. ISD collaborated with Laboratory departments to roll out a COVID-symptom reporting kiosk, streamline manual health reporting for visitors, and aid the Laboratory’s vaccination reporting program. A modified paid family medical leave process was implemented.
- Information technology enhancements. Laboratory email and personal data were migrated to the cloud, setting the stage to leverage the full power of integrated, cloud-based systems. ISD also migrated applications that were based on Adobe Flash to newer platforms. New online tools are simplifying the purchase of Laboratory equipment and streamlining the reporting and tracking of Laboratory projects.
- Security for information technology. ISD initiated several important security enhancements in 2021, including the deployment of a streamlined endpoint-management program. New vulnerability management dashboards were implemented, and a new enterprise collateral network was built and rolled out. ISD also offered new platforms that helped enhance existing applications and continued SAP analytics and cloud implementations.
- Upgraded website capabilities. The Laboratory’s intranet homepage received key upgrades, including a new event-management system. ISD also refreshed or created websites for several Laboratory groups and offices, such as the Flight Test Facility and Office of Diversity and Inclusion, and created the Laboratory’s 70th Anniversary website.
- Workforce management improvements. ISD was instrumental in rolling out a new workforce management application, SAP Fieldglass, and in gaining the Laboratory’s Contingent Worker Distribution Certification. A new-badge request application was also streamlined. In support of the Laboratory’s diversity and inclusion principles, ISD enabled the ability for employees to display their preferred name on Laboratory communication platforms and business applications.
- Infrastructure augmentations. Rollouts of infrastructure-as-a-service and storage-as-a-service were completed. In addition, remote Laboratory sites were migrated to a less expensive internet network.
- Assistance for other Laboratory entities. ISD continues to collaborate on projects across the Laboratory, playing instrumental roles in such projects as warehouse management, special programs reporting, and research programs, including a multidomain radar system.

Transforming the Digital Enterprise

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 five main objectives:

1. Advance a culture of ownership, accountability, and deliberate continuous improvement
2. Enable the workforce with new capabilities aligned with a digitally mature organization
3. Simplify and improve core business processes
4. Inform decisions with data-driven insights, and rely on metrics and key performance indicators to identify challenges and successes
5. Optimize and expand technology solutions

In 2021, the BTO partnered with department heads and project owners to make progress on several DET initiatives:

- Finance modernization and SAP S/4. Phase 1 of this initiative, led by the Financial Services Department, is focused on delivering one trusted financial source and a scalable business platform to drive decision-making and direction setting for the Laboratory. In 2021, the critical design review was completed; S/4 functionality was implemented; and testing, training, and communications were initiated for going live in April 2022.
- External workforce services (EWS) and SAP Fieldglass. Since March 2021, the EWS team has been providing full-service support for hiring managers and managing supplier relationships and performance. The EWS team, with the Contracting Services Department (CSD), also launched SAP Fieldglass. This application automates the end-to-end external labor hiring process, allows visibility between suppliers and workers, provides alerts and dashboard reporting, and has mobile capability. Improvements due to EWS and SAP Fieldglass include the following:
  ✓ Reduced duplication of efforts
  ✓ Increased supplier accountability for their performance
  ✓ Earlier initiation and tracking of subprocesses
  ✓ Reduced administrative burden
  ✓ Faster cycle times from job posting distribution to offer
- Continuous improvement. The BTO is establishing a framework for continuous improvement in support of the DET. As part of this effort, the BTO is hosting workshops to guide process owners through the business process management framework. These workshops have already yielded results:
  ✓ CSD reported a time savings of 10% in the steps of their shipping process, and eliminated paper by moving to electronic solutions.
  ✓ The Human Resources Department removed a major source of waste by implementing a fax-to-email inbox capability.

The Digital Enterprise Transformation program aims to streamline processes across the Laboratory, at MIT, C. Scott Anderson, Assistant Director for Operations, shares a presentation about the program’s guiding principles of focusing on the enterprise, sharing knowledge, designing for the customer, cultivating strategic thinking, and empowering employees.

Digital Engineering Center

Digital engineering enables organizations to solve complex problems accurately and efficiently. The U.S. government is increasingly recognizing the importance of digital engineering for developing next-generation national security systems. In response, the Laboratory established the Digital Engineering Center to improve prototyping capabilities, conduct research in digital engineering, and serve as a resource for the government. A main focus is on leveraging a platform called Innovator, which connects all of a program’s information, from models and specifications to decision points and data, together in one system. In addition, a mentorship program will help employees understand how digital engineering can benefit their particular job functions and programs.
This laser communications (lasercom) ground terminal transmits data back and forth between the Earth’s surface and satellites in geostationary orbit. Laboratory engineers designed both the ground and space terminals for this lasercom system.
Space Security
Ensuring the resilience of the nation’s space enterprise by designing, prototyping, operating, and assessing systems to provide space domain awareness, resilient space capability delivery, active defense, and associated cross-domain battle management.

Principal 2021 Accomplishments

- The Space Surveillance Telescope (SST), relocated to the Naval Communication Station Harold E. Holt in Australia, completed the Australian demonstration testing. The SST will begin U.S. Space Force Operational Acceptance Testing in anticipation of becoming operational as part of the Operational Space Surveillance Network in 2022.
- The Situational Awareness Camera Hosted Instrument (SACHI) program is developing two identical hosted-payload space domain awareness sensors. SACHI leverages ORS-5 (SensorSat) technologies to provide a rapid development and delivery sensor system that has significant onboard space situational awareness data processing capabilities. SACHI successfully completed assembly and testing of the engineering development unit, and researchers are now assembling and testing the two hosted-payload sensors. The two flight units will be delivered to Japan for satellite integration in 2023.
- A portfolio of activities continues to deliver 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 tactical missions. Laboratory-built prototypes of net-centric data libraries have enabled a universal data library that allows Space Force operators to leverage commercial space domain awareness data. Laboratory researchers are evaluating commercial data to increase the capacity and diversity of sensors in the network.
- Systems and mission analyses continue to motivate new concepts leveraging advanced technologies at the Space Rapid Capabilities Office, the Space Development Agency, and the Space Enterprise Architect at Space Command. In 2021, several of these concepts were prototyped and tested in the field, with flight programs expected to deliver initial resilient space architectures in 2023.

TROPICS Pathfinder CubeSat
The TROPICS (Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats) Pathfinder CubeSat was launched into a 525-kilometer polar orbit on June 30, 2021. The Pathfinder space vehicle is the qualification development unit built for the NASA Earth Venture Instrument’s TROPICS constellation. Launch and on-orbit demonstration of the vehicle is a risk-reduction flight test ahead of the full TROPICS constellation launch, scheduled for early 2022. TROPICS CubeSats contain advanced compact microwave sounders that provide high-revisit observations of precipitation, temperature, and humidity in tropical storms. At right, a Laboratory staff member makes final adjustments to the flight vehicle prior to pre-launch testing.
Air, Missile, and Maritime Defense Technology

Investigating system architectures, prototyping pathfinder systems, and demonstrating these advanced, integrated sensor systems that are designed for use on maritime and airborne platforms to provide defense against missiles and other threats.

Principal 2021 Accomplishments

- The Laboratory supported a Missile Defense Agency (MDA) study to define an effective and survivable architecture for defending Guam against advanced threats in the Pacific theater.
- Sponsored by the Air Force Life Cycle Management Center Digital Directorate, the Laboratory is studying system requirements, evaluating operational site locations, and developing preliminary technical designs for advanced high-frequency over-the-horizon radar systems for homeland defense.
- The Laboratory is applying its artificial intelligence (AI) systems expertise to Missile Defense System threat discrimination and establishing AI robustness as a key performance metric.
- To enhance U.S. undersea warfare capability performance, the Laboratory has been developing improved sensing architectures, electronic warfare techniques, and signal processing capabilities. The Laboratory has also been exploring new integrated approaches leveraging AI and machine learning to display, label, and classify sonar data.
- In support of the Office of Naval Research, the Laboratory continued developing and testing a distributed multidomain radar capability and advanced signal processing techniques for eventual use by forward-deployed forces.
- The Laboratory developed an ocean state estimation system to provide nowcasts of temperature, salinity, and currents to undersea vehicles. The nowcasts are computed on a single-board computer by combining a reduced-order model with measurements from onboard sensors. The system will be deployed in Arctic gliders later this year for a demonstration.
- Radar data were collected along the California coast to validate advanced clutter-mitigation algorithms—which separate slow-moving targets of interest from the sea surface—for radar maritime surveillance.
- A low-cost localization system with custom distributed, adaptable-response transponders for communications-constrained environments like building interiors was prototyped and demonstrated.
- Lincoln Laboratory co-received the Innovation Team Award from the Missile Defense Agency for developing an extremely wide field-of-view sensor. A prototype was transitioned to the U.S. Army Aviation and Missile Center for testing as a government reference sensor for future space programs.

Future Outlook

Hypersonics pose an emerging threat to the United States and its allies. Lincoln Laboratory is working with the MDA to define a defense architecture and develop advanced technologies to counter such threats.

The Laboratory will continue system analysis and advanced concept development to ensure U.S. dominance in the undersea domain. The focus on enabling technologies for unmanned undersea vehicles includes research and development in advanced sensors, high-capacity energy systems, and autonomy-facilitating algorithms.

To deter aggression in regional conflicts, forward-deployed forces may benefit from longer-range, cross-domain engagement webs enabled by new sensing and engagement paradigms. The Laboratory is defining distributed architectures and developing sensor prototypes to support these engagements.

Radiation-Tolerant Focal Planes

The U.S. government’s interest in proliferated constellations of small imaging satellites is driving a need for radiation-tolerant focal plane technologies. The Laboratory designed, fabricated, and packaged hybridized digital electro-optical and infrared focal planes (like the array pictured at right) and tested device performance in representative radiation environments. The results provided insights into the optimum design of radiation-tolerant high-performance focal planes.

MIT Lincoln Laboratory
Communication Systems

Advancing communication capabilities for national security and space exploration through technology development in satellite communications, robust networking, laser communications, quantum systems, and agile spectrum operations.

Principal 2021 Accomplishments

- Lincoln Laboratory successfully conducted airborne demonstrations of scalable, resilient, line-of-sight networking techniques that enable Department of Defense platforms to reliably connect and share data.

- Partnering with several government laboratories, the Laboratory experimented with network topologies for long-range, high-frequency links. High-frequency networks can provide beyond-line-of-sight communications through ionospheric refraction without the need for satellites.

- The Laboratory demonstrated a prototype of a new communications capability that leverages airborne multifunction apertures to communicate to multiple users on low-size, weight, and power platforms.

- The Laboratory developed a novel pump-forwarding architecture for synchronization within quantum networks. The approach was validated by using a 3.2-kilometer free-space link.

- A prototype of a new content-aware network architecture to distribute a mission-tailored operational air picture to a ground station was demonstrated at Northern Edge 2021, a U.S. joint field training exercise.

- The Laboratory demonstrated high-rate, blue-green optical communications through the air-water interface at the Field Research Facility pier operated by the U.S. Army Corps of Engineers in Duck, North Carolina.

- Optical receiver architectures that enable coherent processing of optical signals in the digital domain were developed. The approach was used in prototypes of a coherent multiformat modem and a system that forms a large aperture from multiple smaller apertures.

Silicon-Nitride Photonic Integrated Circuit

Lincoln Laboratory is developing an architecture and the component technologies for a scalable quantum network. Shown at right is a silicon-nitride photonic integrated circuit used in quantum memory modules to interface silicon vacancies in diamond-based memories to a fiber network. The chip, designed by Lincoln Laboratory and MIT campus and fabricated at the Laboratory, has a novel through-top oxide socket for memory integration and low-loss edge couplers to connect to optical fibers.

Future Outlook

- New commercial communications technology, such as 5G, will be evaluated and enhanced to provide cost-effective, reliable communications to the warfighter.

- New artificial intelligence approaches to efficiently manage highly dynamic links and networks in dynamic environments will be developed and prototyped.

- Working with MIT and Harvard University, the Laboratory will mature architectures and technologies for fiber and free-space quantum networks and integrate them into space and terrestrial experiments.

- The Optical Terminal Verification Testbed is an instrumented facility run by an experienced team that provides impartial assessment of laser communication terminal capabilities. The facility will host formal tests of Laboratory, government, and aerospace contractor-developed terminals.
Cyber Security and Information Sciences

Conducting research, development, and evaluation of cyber components and systems, and developing solutions for processing large, high-dimensional datasets acquired from diverse sources, including speech, imagery, text, and network traffic.

Principal 2021 Accomplishments

- The Laboratory produced an initial operational technology to analyze and identify software applications in encrypted network traffic. The system is built on artificial intelligence (AI) advancements made in partnership with MIT’s Computer Science and Artificial Intelligence Laboratory.
- The Laboratory continued to develop its cyber-resilient Magnetite operating system layer and demonstrated an application to enable software-based high-assurance cryptography in platforms highly constrained by size, weight, and power needs.
- Researchers continued to advance the state of the art in malware similarity analysis on behalf of the U.S. Cyber Command and other sponsors.
- The Supercomputing Center added 40,000 processing cores and 10 petabytes of storage to sustain its world-leading interactive supercomputing capability.
- An automated cyberthreat intelligence labelling and extraction system was delivered to the Department of Defense. Leveraging advances in natural language processing, the tool is able to label indicators of compromise in unstructured threat reporting.
- The Laboratory supported a Defense Advanced Research Projects Agency (DARPA) program to develop automated machine learning tools that enable subject-matter experts to create state-of-the-art predictive models without the aid of data scientists.
- The Laboratory delivered several versions of its key management system prototype to the Air Force’s Space and Missile Systems Center and the prime contractor to serve as a baseline for a live capability.
- The Department of the Air Force Cyber Red Team, in conjunction with the 16th Air Force, conducted adversarial vulnerability assessments of major weapon systems. The assessments led to improvements in system survivability and mission assurance.
- Researchers working on a Navy project showcased their automated waveform classification prototype at Fort Devens, Massachusetts. The prototype uses generative and discriminative machine learning algorithms to detect and classify RF signals.

Future Outlook

The Laboratory will develop algorithms and a counter-influence operations test bed that will permit the development, demonstration, and assessment of new technology and concepts of operations for detecting and mitigating foreign adversary influence operations.

The Laboratory will integrate cyber into all-domain operations (ADO) to provide cyber situational awareness, effects, and defense to advance ADO and to secure data and systems upon which ADO missions depend.

The Resilient Mission Computer team will continue to advance a secure-by-design computer system. A compartmentalized version of the Linux operating system that supports legacy applications is being developed. The team’s vision of a foundationally secure computer sparked a new DARPA study.

Defensive Design

To protect against malicious “backdoor” supply-chain attacks, the Laboratory is developing design technologies to secure outsourced integrated circuit fabrication. These technologies include inspection ports and guard wires (shown in green in the left-side photo), which defensively route wires within a design to make malicious modifications both more challenging to achieve and more detectable after fabrication. A demonstration circuit fabricated with these design technologies is shown in the right-side photo. Assuring the integrity of circuit designs that are fabricated in untrusted foundries is a growing national security priority.
**ISR Systems and Technology**

Conducting research and development in advanced sensing, signal and image processing, decision support technology, and high-performance embedded computing to enhance capabilities in intelligence, surveillance, and reconnaissance

**Principal 2021 Accomplishments**

- The Laboratory demonstrated a low-power, self-reconfigurable processor with built-in security and trust for machine learning. While still meeting operational requirements, the processor minimizes power consumption by adapting resources depending on the necessary computations.
- The Laboratory led the initial airborne data collection campaign with PHOENIX High CASTLE—an advanced, first-ever zoom-enabled Geiger-mode avalanche photodiode (GmAPD) 3D lidar system—for the U.S. Army Engineer Research and Development Center Geospatial Research Laboratory.
- The Next Generation Sensors program demonstrated a prototype open architecture to enable integrated coherent multisensor signal and artificial intelligence (AI) processing for on-platform tactical-edge scenarios. The associated software development kits will allow third parties to efficiently integrate new mission capabilities.
- The Laboratory continued to remotely enhance capabilities for the premier foliage-penetrating 3D imaging lidar system, Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) 2.0, which has completed more than 275 sorties in South America since 2019. AI-based analysis tools were introduced with the aim of expanding our capacity to interpret and utilize imagery.
- The Laboratory pursued techniques to improve the ranging precision of state-of-the-art GmAPD-based lidars. The Laboratory also explored advanced electro-optical and RF detection techniques based on quantum optical effects.
- The Europa Lidar for Situational Awareness program completed design and component verification of a real-time, high-resolution mapping lidar for deep-space landing missions in which sensor mass is extremely limited. Specialized algorithms optimized for embedded computing will enable the system to autonomously provide 10,000 square meters of imagery with a resolution better than 5 centimeters within one second.
- Two versions of the Airborne Radar Testbed were used simultaneously to create a dataset for developing and evaluating bistatic radar modes for ground moving target indication.

**Future Outlook**

The Laboratory continues to lead the Department of Defense (DoD) community in applying machine learning (ML) to radar. This year, the Laboratory built and tested a polarimetric synthetic aperture radar platform to explore applications of polarimetry to ML, and created and curated a one-of-a-kind dataset of multipolarization signatures of a variety of ground platforms to support ML development across the DoD community.

The Active Optical Systems Group has developed revolutionary lidar and passive sensing systems that have been deployed with great success in semipermissive environments. The group is pivoting toward prototyping active optical systems to operate under challenging circumstances to identify and classify objects of interest in nonpermissive environments. Pioneering disruptive systems for space domain dominance in the DoD and non-DoD arenas will be an additional focus.

**Airborne Radar Testbed**

The Laboratory’s Airborne Radar Testbed (ARTB) has been installed onto its new host aircraft, a Saab-340B (top image). This aircraft can accommodate the size, weight, and power required to integrate ARTB with other sensors systems and a tactical communications system. With these capabilities, ARTB provides the DoD with a low-cost, open-architecture system to test and demonstrate not only new radar technologies (bottom image) but also future multidomain, multisensor concepts of operation.
Tactical Systems

Improving the development of tactical air and counterterrorism systems through systems analysis to assess the impact of technologies on real-world scenarios; rapidly developing prototype systems; and conducting precise instrumented testing of systems

Principal 2021 Accomplishments

- An ongoing project with the U.S. Army’s Ground Vehicle Systems Center is to pair autonomous ground vehicles, such as the MRZR ATV seen here, with autonomous unmanned aerial vehicles (UAVs), like the Kraken UAV shown in the background, to improve the ATV’s off-road navigation.

- Lincoln Laboratory researchers continued 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 included investigations of missile system performance, electronic attack and electronic protection, and RF and advanced infrared kill chains.

- The Laboratory assessed the Next Generation Air Dominance platform to ensure future U.S. air superiority, focusing on identifying system requirements to counter evolving adversaries in a diverse mission set. These studies combine understanding of adversary capabilities and U.S. technologies to inform future Department of the Air Force acquisition decisions.

- Several studies to improve survivability of U.S. Army forces operating in the United States European Command were completed. The studies inform prototyping of novel camouflage, concealment, and decoy capabilities, as well as rigorous test and measurement campaigns.

- Analysis efforts expanded to incorporate autonomy and artificial intelligence (AI), including studies of novel teaming concepts for air superiority to support the nation’s air defense and examination of adversary implementation of AI approaches to enhance sensing. The Laboratory also continued to examine the impact of air and space integration and joint force operations on air vehicle survivability.

- Researchers developed and demonstrated a grammar-based automatic speech recognition proof of concept in a lab for the Boeing F-15EX platform that enables voice control of an Open Mission Systems-compliant subsystem.

- The Laboratory continues to prototype, test, and transition autonomous systems capabilities that enable operation in challenging and contested environments. Researchers prototyped an unmanned aerial vehicle (UAV) to map a region in front of autonomous ground vehicles (AGVs), allowing them to navigate off road and with real-time navigation assistance. The UAV/AGV team will refine the system’s capabilities through future field tests.

Future Outlook

- Lincoln Laboratory is increasing focus on U.S. Army maneuver forces and on applying technologies to increase survivability in heavily contested environments. Assessment of peer adversary kill webs will guide prototyping of new camouflage, concealment, and decoy capabilities and their transition to the warfighter.

- Work continues on developing autonomous systems capabilities for the warfighter. Future efforts will focus on robust multi-agent teaming algorithms for contested environments, navigation in GPS-denied environments, and novel system-level architectures for unmanned vehicles.

- The Laboratory will continue supporting the U.S. Air Force by performing systems analyses, prototyping advanced capabilities, and demonstrating capabilities through measurement campaigns.

High-performance Infrared Lens for Airborne Radiometry

This custom-designed lens is a key component of a new airborne camera system that accurately measures the brightness of image features in infrared light. The folded configuration of the lens is driven by the space constraints of its mounting location. Infrared light enters the lens through the large aperture on the left and emerges on the right, where an infrared detector array will be positioned. The reflective covering is the outer surface of an insulating blanket that isolates the lens from the temperature extremes encountered during flight.
Advanced Technology

Leveraging solid-state electronic and electro-optical technologies, materials science, advanced RF technology, and quantum information science to develop innovative system applications and components

Principal 2021 Accomplishments

- In partnership with MIT’s Space Propulsion Laboratory and institute for Soldier Nanotechnologies, researchers developed electrospay thrusters for propulsion of small-scale satellites in space. By using advanced silicon micromachining techniques in the Microelectronics Laboratory, the team increased the emitter density of the thrusters by 10 times compared to the state of the art. Further, the densified thrusters successfully completed ground testing by rotating a magnetically levitated CubeSat in an Earth-bound test environment.

- The Laboratory deployed high-frequency vector sensor instruments to the island of Palau for a study led by the Office of Naval Research. The study is investigating the impact of equatorial anomaly and of spread-F, an ionospheric phenomenon, on radio propagation. From a small-form-factor instrument, the vector sensor can determine the propagation angle and polarization of radio waves.

- Directed-energy systems using high-energy lasers will be an important addition for Department of Defense (DoD) systems. With the successful demonstration and transition of the Laboratory’s fiber amplifier-based systems, work is turning to panel-based approaches using semiconductor laser amplifiers.

- Quantum sensing is likely to have impact for DoD applications long before quantum computing does. Field tests and prototype systems for magnetometers, electrometers, and clocks will increase over the next few years.

- A resurgence in microelectronics research is focused on keeping the United States’ technical advantages in this field. Work is increasing in device technology beyond complementary metal-oxide-semiconductor, next-generation computer architectures, advanced packaging, and microsystems.

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Microhydraulic Actuators

The Laboratory developed an electric motor that is based on electrical capacitance actuation. The actuation is achieved via electrowetting, in which surfaces electrically change from hydrophobic to hydrophilic. The motors are constructed by layering polymer sheets with microfabricated electrodes. A pattern of oil and water droplets form between the electrodes, and the sheets move by sequencing voltages on the electrodes, causing alternating hydrophilic and hydrophobic response from the droplets. At right is an image of a prototype motor with a rotor diameter of 6 millimeters and thickness of 200 microns. These motors are especially attractive for small-scale systems needing high mechanical power and efficiency.
MISSION AREAS

Homeland Protection

Innovating technology and architectures to help prevent attacks on the U.S. homeland, to reduce the vulnerability of the nation to terrorism, and to improve the security and resiliency of critical infrastructure, including energy systems, against natural and human-made threats

Principal 2021 Accomplishments

- To support the Department of Homeland Security Science and Technology Directorate’s Screening at Speed vision for improved airport security, the Laboratory developed methods for rapidly assessing image quality and detecting threats within data from body and accessible property scans.
- Energy resilience readiness exercises expanded in scope and impact to include control system cyber impacts to Department of Defense installations. The Laboratory continues transitioning energy resilience technology to outside partners to increase mission readiness.
- The Laboratory continued to develop, deploy, and transition artificial intelligence–enabled decision support systems for maritime, air, and waterway border security applications.
- A highly sensitive radar system was integrated on an unmanned ground vehicle for detection of disaster survivors trapped under rubble. Future plans include integration of this system on an unmanned air vehicle.
- A prototype multisensor air defense system that leverages the Laboratory’s expertise in regional air defense was demonstrated in high-profile exercises for the U.S. Air Forces in Europe command.
- A low–size, weight, and power multistatic receiver is being developed to mitigate the impact of wind farms located near joint-use air surveillance systems. A final report was completed on wind farm layout optimization strategies.
- The Laboratory developed and demonstrated an experimental framework and evaluation environment for measuring and building public resilience against hostile foreign influence operations.
- A video analytics software tool to enhance security operations in critical infrastructure command centers was improved and transitioned to private industry.

Lincoln Laboratory developed an airborne edge computing test bed to develop autonomous unmanned aircraft system (UAS) functions for homeland security missions. Above, the team field tested a “chase” UAS that autonomously follows a threat drone back to its point of origin to locate the controller.

Novel Multistatic Receivers for Enhancing Air Surveillance

Lincoln Laboratory is developing novel, low-cost receivers to enhance the capabilities of existing air surveillance radar systems. Multiple receivers can be deployed around regions of high-priority airspace to improve sensitivity for small targets, to increase resolution, and to reject ground clutter from wind turbines and other sources. Laboratory researchers are testing custom antennas, as shown in the photo at right, to measure direct-path and reflected signals from current radar systems and are developing real-time multistatic processing algorithms.

Future Outlook

Securing the nation and responding to emerging threats will necessitate new architectures for sensing hostile activities and characterizing environmental conditions. The Laboratory will provide novel sensors leveraging advances in low-cost, size, weight, and power electronics.

Open architectures for leveraging data, applying AI techniques, and providing secure cyber environments in the cloud will enable advanced command-and-control systems for homeland air defense, humanitarian assistance and disaster response, and security of land border and maritime environments.

Critical infrastructure protection and domestic resilience will compel advancements in novel areas beyond sensing and decision support, including cybersecurity, advanced energy, and defense against hostile foreign influence operations.

Mr. James M. Flavin
Division Head

Dr. Chris A.D. Roeser
Asst. Division Head

Dr. James K. Kuchar
Asst. Division Head

Leadership
Biotechnology and Human Systems

Advancing technologies and systems for improved chemical and biological defense, human health and performance, responses to the impacts of climate change, and resilience to both natural and human-made disasters.

Lincoln Laboratory started developing a decision support architecture and software system to improve the efficiency of international humanitarian assistance through tracking and monitoring of food aid shipments.

The Laboratory developed novel analytics that automate post-hurricane infrastructure damage assessments from remotely sensed data and prioritize response efforts.

In response to the COVID-19 pandemic, the Laboratory deployed a national-scale model of demand for personal protective equipment. This model was adapted from one originally built by Laboratory researchers for the state of Massachusetts.

The Laboratory continued to work with the government to develop and field chemical and biological defense systems, focusing on multiple test beds and data collections in the New York City metropolitan area.

Lincoln Laboratory is building cloud-based platforms for analyzing physiological data taken from wearable sensors on tens of thousands of participants that will enable novel algorithms for early warning of COVID-19 infection.

Laboratory staff began building a polymerase chain reaction–based sensor for use on unmanned systems to rapidly and accurately identify biological threats in the environment.

Lincoln Laboratory prototyped a system for determining whether a person should be evaluated for post-traumatic stress disorder (PTSD) using only their voice. This new capability leverages a novel processing pipeline that captures speech, evaluates the speech signal’s quality, and implements a machine learning model. The system will allow care providers with varying levels of expertise to screen for PTSD in clinical settings.

Laboratory researchers created a semi-automated, large-scale brain mapping system, enabling new opportunities to understand neuronal interactions associated with cognitive functions and disorders. This work uses an active machine learning pipeline and yields improved fidelity and processing speed over previous methods.

Future Outlook

Improving humanitarian assistance, global health, and disaster response activities, as well as reducing the security impacts of global climate change, will motivate work on advanced architectures, sensors, and analytics.

The Laboratory will develop advanced technologies and system architectures for chemical and biological threats, which include pandemics, to protect deployed forces and civilians.

Improving soldier health and performance will require advances in brain-related technologies, physiological sensors, and engineered and synthetic biology.

Artificial intelligence will be leveraged to interpret vast amounts of biological and health data, assist in decision-making, and provide insights for new discoveries.

Artificial Intelligence–Guided Ultrasound Intervention Device

Future conflicts will require wounded warfighters to be cared for on the battlefield for a day or more before evacuation to a hospital. To save lives, battlefield medics will need to halt massive blood loss by inserting a catheter into a deep blood vessel. Lincoln Laboratory and Massachusetts General Hospital have prototyped and tested a new device, the Artificial Intelligence–Guided Ultrasound Intervention Device (AI-GUIDE), that uses real-time AI and handheld robotics to help guide medics to perform needle insertion on the battlefield. The photo shows AI-GUIDE inserting a needle and guidewire quickly and accurately into a central blood vessel in a vascular access system replica.
Air Traffic Control

Developing advanced technologies and decision support architectures for aircraft surveillance, integrated weather sensing and processing, collaborative air traffic management, information security, and optimization to support the nation’s air transportation system.

Principal 2021 Accomplishments

- The Laboratory continued technology transfer of the Small Airport Surveillance Sensor with the Federal Aviation Administration (FAA) and industry partners.
- The Airborne Collision Avoidance System X (ACAS X) for large unmanned aircraft systems (UAS) was finalized and is undergoing deployment to a cloud computing environment.
- The Global Synthetic Weather Radar was tested at six U.S. Air Force facilities and is undergoing deployment to a cloud computing environment.
- The Laboratory continued to develop technologies for advanced aviation cyber threat assessment, detection, and mitigation. A 2021 highlight was the demonstration of an algorithm for the detection of malicious lateral movement within a cloud computing environment.
- The Laboratory continued to develop tools to support mission planning, operational readiness, and force health protection for the U.S. Transportation Command. Recent highlights include a scheduling tool to optimize aerial refueling operations, a cost-estimation model for sealift missions, and a physiological status monitoring capability for the detection of an immunological response to COVID-19.

Future Outlook

The Laboratory will continue to develop future aviation system concepts, including trajectory-based operations, collision avoidance, weather impact mitigation, new entrants (e.g., commercial space, high-altitude operations, and urban air mobility), and environmental impact reduction. Cybersecurity efforts will address potential vulnerabilities in aviation systems. Innovation in weather capabilities will focus on sensing technologies and algorithms for managing airspace capacity. Meteorological surveillance of severe storms will continue to improve, and a next-generation all-digital back end phased array system will be built and deployed. Advanced techniques will be leveraged to forecast weather and system demand and to allocate resources more efficiently and effectively for civilian and Department of Defense transportation applications. The Laboratory will continue to develop standards, safety evaluation methods, and threat-avoidance algorithms.

Airborne Collision Avoidance System X

Under FAA funding, the Laboratory is developing ACAS X algorithms that allow small UAS (sUAS) to detect and avoid other aircraft. The design of the resulting system, called ACAS sXu, will be completed in 2022 and will be a key capability enabling commercial sUAS operations. In support of this program, Lincoln Laboratory develops and validates algorithms and conducts flight tests by using its sUAS test bed. At right, Laboratory staff integrate sensors, communications, and autonomy components into one of several sUAS used in validation and flight test activities.
Principal 2021 Accomplishments

- The Digital Engineering Center was established to lead the Laboratory’s development and adoption of model-centric approaches to prototype development, conduct novel research in digital engineering, and work with national agencies to drive digital engineering initiatives and studies.
- The Laboratory adopted a lean operations strategy to enhance mechanical and electrical parts fabrication.
- The development of future hypersonic interceptors and systems was enhanced by the development of unique modeling and design techniques. A state-of-the-art integrated simulation framework that optimizes the shape and materials of a vehicle on the basis of its aerodynamic and thermal behavior was prototyped over the past year. This algorithm capability is being actively transitioned and adopted by various external organizations.
- The Laboratory created flight software and firmware to accelerate the development of unmanned aerial vehicles (UAVs). State-of-the-art algorithms have been implemented to run on a single central processing unit without the use of a microcontroller to provide unified support for all common UAV types, including multirotors, fixed wings, and vertical take-off and landings.
- Using in situ closed-loop feedback error correction during diamond turning of optical substrates, the Laboratory developed techniques that allow increased resolution of optical systems with the use of freeform designs.
- The Laboratory increased its use of augmented and mixed reality technologies—including during assembly, integration, and testing—to enhance remote collaboration on projects and to accelerate the development of prototype hardware.
- The Laboratory is helping organizations identify capability gaps and solutions for warehouse modernization and automation by performing readiness assessments for technologies including inventory drones, automated storage, and autonomous material handling, such as self-driving forklifts and robotic arms enabled by machine learning.

The Laboratory will increase its use of digital engineering to accelerate prototyping by integrating model-based practices into end-to-end prototyping workflow; leveraging shared data, models, and enhanced simulations; and using high-performance computing and artificial intelligence. The Laboratory will also extend connections to relevant Department of Defense strategic efforts to streamline the development of fully integrated platforms and deliver capabilities more rapidly with digital engineering practices.

The new Engineering Prototyping Facility is scheduled to open in 2027 and will provide a modern building that will more efficiently and effectively support the increasingly complex and challenging prototyping needs of the nation. The division is working with architecture firms that will provide the detailed design of the building and manage equipment moves. Construction is expected to start in 2025.

Future Outlook

Mustang

Mustang is a bidirectional space-to-ground laser communication system built by Lincoln Laboratory that features a highly integrated mechanical and electrical design that provides a 10-megabits-per-second downlink capability from geosynchronous orbit and a 2-kilobits-per-second uplink capability from the ground. The payload mass is less than 5 kilograms, and it requires approximately 11 watts of unregulated bus power to operate. A microgimbal on the payload enables a large 2π steradian field of regard with a pointing stability of 20 microradians. A technology demonstration unit was delivered in July 2021.
Mollie Schwartz makes adjustments to a dilution refrigerator. When in operation, dilution refrigerators provide an extreme cryogenic environment needed for quantum bit circuits to function.
Research and Educational Collaborations

MIT MINI OCEAN GLIDER
Jean Sack, a technical staff member in Lincoln Laboratory’s Energy Systems Group, and David Larson, an MIT graduate student, developed a low-cost mini ocean glider that can be used for underwater exploration and data collection. The gliders, which were initially conceived as part of a Beaver Works capstone course, are intended to be an open-source, inexpensive, and configurable system that can easily maneuver up and down in the water.

The glider’s design is based on Blue Robotics’ 4-inch watertight enclosure for remotely operated vehicles. The body of the glider consists of an acrylic tube, two wings on the outside for maneuvering, and a syringe that fills with water to raise the glider to the surface. The outside for maneuvering, and a syringe that fills with water to raise the glider to the surface. The inside of the glider—which includes a Raspberry Pi computer, GPS, inertial measurement unit, and lithium-ion battery pack mounted to a laser-cut acrylic structure—is customizable and reconfigurable to a variety of sensors. External ports include a temperature/pressure sensor, switch, and vent, with the option to add additional sensors as needed.

Because the basic glider costs less than $1,000 and can be built from commercial off-the-shelf parts, Sack believes it has many potential applications—for example, a swarm of gliders could be used to identify a point of interest underwater such as a wreck or oil spill.

“The gliders have a lot of potential for low-cost, low-power underwater sensing applications where you don’t need to go very fast but want to sample the water column,” Sack said. “You could imagine sending out a bunch of these gliders, collecting a little bit of data, logging when you find something interesting, and then focusing your resources with more expensive sensors on that point of interest.”

The glider has undergone testing at the MIT fitness center’s pool and demonstrated a diving capacity of 5 meters, and with some modifications, it has the potential to dive to 30 meters.

A TUNABLE METASURFACE FOR MINIATURIZED OPTICS
With the collaboration of Lincoln Laboratory researchers, engineers from MIT advanced their design of a tunable-metasurface optical device that can be electrically activated to change its material structure and, therefore, its optical properties. Key to this advancement was the discovery of a new phase-change material (a material that changes its atomic structure in response to heat) that is transparent to infrared light. Conventional phase-change materials are opaque, impeding their use in optical devices.

The new material is composed of germanium, selenium, antimony, and tellurium (GSST). To create the tunable metasurface device, the researchers produced an ultrathin, square film of GSST, patterned some 100,000 nanoscale structures into it, and integrated it onto a silicon chip. When the material is electrically heated, these nanostructures change their configuration. In optical applications, this reconfigurability could allow a laser beam to be precisely steered back and forth without the use of mechanical parts, or a single lens to be tuned to a desired focal length, replacing the need for an assembly of lenses. While this device is described by the inventors as a proof of principle, Laboratory researchers have demonstrated the scalability of this approach to large-area optics that could couple with existing systems, such as night-vision technology. The team is continuing to enhance the design of the device and hopes to eventually extend the transparency of the device to the visible spectrum.

A ROADMAP TO QUBIT CONTROL
Lincoln Laboratory has been a leader for several decades in the development of quantum computing systems that may one day outperform modern computers. Last year, the Laboratory joined the Quantum Systems Accelerator (QSA), a research coalition spanning 16 institutes that aims to bridge the gap between current error-prone quantum processors and future, more capable machines. Today, the three leading approaches to developing quantum computers each use a different base—trapped ions, superconductors, or neutral atoms—to serve as the quantum bits (qubits) of the system. Though each approach is widely unique, they all present a similar, enormous challenge: building hardware that can precisely control and measure the qubits before their fleeting coherence time (which limits how long they can be used to perform useful calculations) expires.

To guide this research, Mollie Schwartz is helping the QSA develop a technology roadmap that sets a shared direction to developing qubit control systems, the specifications of which vary by platform. An expert in superconducting qubits, Schwartz serves as a QSA thrust lead in this area. In 2021, she joined fellow thrust leads in organizing roadmapping exercises, which offered an opportunity for researchers spanning the QSA to share lessons learned about each approach and map out solutions together.

“Today’s roadmap is a mechanism for building a shared vision and highlighting areas where there can be closer collaboration across technology areas,” Schwartz said. “We don’t yet know which, if any, of these platforms is going to be the transistor of the quantum world, so we are pushing forward on all of them simultaneously.”
FIBER SENSOR ARRAY BUOY

In partnership with the Advanced Functional Fabrics of America (AFFOA), Lincoln Laboratory is leveraging its experience in fabricating fibers with embedded electronics to develop long-length sensor arrays that can operate in the ocean. Researchers are exploring how such fibers may enable a lightweight, low-cost system that can persistently monitor the undersea environment. Measurements of water temperature, salinity, and pressure collected by this system would improve researchers’ understanding of the ocean’s changing dynamics. This capability is also important for naval operators, who need real-time undersea environmental data to accurately interpret acoustic signals.

To realize this capability, Laboratory and AFFOA researchers are developing a novel approach to embedding an array of sensors into polymer fibers that would extend hundreds of meters underwater. The approach uses a fiber-drawing technique, performed in the Defense Fabric Discovery Center, in which a block of polymer is heated and pulled into a long fiber. During this draw process, copper wires are fed into the middle of the fiber, providing electrical connection for an array of tiny sensors and integrated circuits that are embedded into the fiber by using a customized soldering and encapsulation process. The sensors are integrated throughout the length of the fiber to capture data at various depths. Electronics at the surface of the water would transmit the data to aircraft, ships, or satellites. This technology has potential for addressing the needs of not only undersea monitoring but also ground and space-based applications.

Above, electronics are shown embedded in a fiber, where an encapsulant is used for protection from the water. At right, the resulting fiber has electronics and sensors integrated throughout its length. The Illuminated red light-emitting diodes are distributed throughout the fiber, along with the sensors and electronics.

The integrated circuit shown above has been embedded into a fiber to enable a low-cost, persistent undersea monitoring system. The penny is shown for scale.

Lincoln Laboratory military fellows gathered for a photo with U.S. Deputy Secretary of Defense Kathleen Hicks, center.

In July 2021, eight of the Laboratory’s military fellows had the opportunity to meet U.S. Deputy Secretary of Defense Kathleen Hicks at the Beaver Works Center in Cambridge, Massachusetts, for a discussion about current technology development focus areas and modernization efforts at the Laboratory and the Department of Defense (DoD).

“Deputy Secretary Hicks was very interested in learning about the fellows’ individual research areas in both their Lincoln Laboratory work and their studies on campus. I’m very glad that the Deputy Secretary was able to meet these talented officers and see how they are contributing to the Laboratory’s mission and our nation’s defense in the research and engineering domain,” said Executive Officer to the Director and Chief of Staff Robert Loynd.

The Beaver Works Center was one stop on a tour of New England the Deputy Secretary embarked on to assess current technologies being used by the military and its modernization efforts. During their discussion, the fellows shared with Deputy Secretary Hicks the projects they worked on at the Laboratory spanning a variety of areas, including machine learning for cybersecurity and defense technologies. Deputy Secretary Hicks then briefed the group on the DoD’s efforts to modernize its systems—especially through the use of artificial intelligence—and the challenges of modernization, including how to maximize the fuel efficiency of systems while minimizing their climate impacts.

“The most encouraging takeaway from our discussion with the Deputy Secretary of Defense is hearing that the DoD leadership’s priorities are aligning with the current assignments of the Lincoln Laboratory military fellows, whether they be hybrid warfare, cybersecurity, or hypersonics,” said U.S. Army Second Lieutenant Victor Kao, a military fellow. Kao works in the Systems and Architectures Group on research related to the Army’s Strategic Long-Range Cannon.

“It was exciting and invigorating to hear from Deputy Secretary Hicks about the priorities in today’s DoD to modernize the joint forces for near-term and long-term competition with peer adversaries and to better utilize the talents of the men and women working in the [defense] department,” said U.S. Air Force Second Lieutenant and military fellow Michael Geraghty, who works in the Laser Technology and Applications Group developing test setups for efficient testing of high-energy fiber-amplified lasers. He added, “It was clear that Dr. Hicks appreciated the Laboratory’s efforts toward these priorities.”
LAbORATORY INVOLVEMENT

WORKSHOPS AND SEMINARS

The workshops and seminars hosted by Lincoln Laboratory cover a wide range of topics. At these events, Laboratory experts and nationally prominent guest speakers share their research into emerging technologies.

Because of the coronavirus pandemic, the following on-site workshops were canceled or postponed in 2021: Cyber Endeavor, A2IA4 Systems and Technology Workshop, Counter-Human Trafficking Technology Workshop, Cyber Technology for National Security, Robustness of Artificial Intelligence System Assurance, Homeland Protection Workshop, Next Generation Identification and Awareness Technology Workshop, Human Language Technology and Applications Workshop, Space Control Conference, and the Technology and Applications Workshop, Human Language Technology and Applications Workshop, Space Control Conference, and the Technology and Applications Workshop.

2021 Schedule of Lincoln Laboratory Workshops

2021 Off-site Workshops

The Laboratory also coordinates off-site workshops with partnering organizations. Laboratory involvement may be co-chairmanship of events, technical leadership of sessions, or co-sponsorship.

IEEE High Performance Extreme Computing Conference (HPEC)

Twenty-five years ago, Lincoln Laboratory established this conference, then called High Performance Embedded Computing, to provide the research and sponsor communities with a forum for discussing advances in high-performance computing. It has grown into the largest computing conference in New England and the premier conference in the world on the convergence of high-performance and embedded computing. Its community is interested in computing hardware, software, systems, and applications for which performance matters. Presentations at each conference have focused on high-performance extreme computing technologies such as AI/machine learning (ML), cloud computing, field-programmable gate array advances, cyber analysis, big data, graph analytics, and quantum computing. Lincoln Laboratory still serves as the technical organizer for the conference; Jeremy Kepner served as the chairman, Robert Bond as the senior advisory board chair, and Albert Reuther as the technical chair for the 2021 conference. The technical committee for this conference included Lincoln Laboratory staff Masahiro Arakawa, Peter Boettcher, Chansup Byun, Vijay Gadepally, Karen Gettings, Saniye Mohindra, Paul Monticciolo, Julie Mufen, Darrell Ricks, Siddarth Samsi, and Michael Vai.

Graph Exploitation Symposium

The 2021 Graph Exploitation Symposium, hosted by MIT Lincoln Laboratory, brought together top network science researchers to share the latest advances and applications in the field. Network-based analysis continues to expand its reach and is applied to ever-more important areas of science, society, and defense with increasing impact. This virtual event focused on some of the year’s most relevant issues, such as analyzing disinformation on social media, modeling the pandemic’s spread, and using graph-based ML models to speed drug design. Several presentations at the symposium discussed the role of network science in analyzing influence operations, or organized attempts by state and/or non-state actors to spread disinformation narratives.
Diversity and Inclusion

A diverse workforce and an inclusive culture are more than just goals; they’re vital to Lincoln Laboratory’s technology mission. The Laboratory’s culture must reflect the diversity of the nation it serves, and solving the nation’s hardest problems takes the combined talents and unique views of many, sharing an environment where individuals are empowered to be their best. The Laboratory thrives when employees’ views, experiences, and knowledge combine to drive innovation, and the ability to rapidly develop technology is made possible by a work environment in which employees are embraced for what they can do and for who they are. Diversity and inclusion are the Laboratory community members’ responsibility to each other and to the nation they serve.

THE DIVERSITY AND INCLUSION OFFICE
In 2018, the Diversity and Inclusion (D&I) Office was established at Lincoln Laboratory. Its vision is to deliver a transformational competitive advantage to the Laboratory by becoming the national security industry exemplar in strategic D&I leadership and application. The D&I Office seeks to maximize individual and organizational performance and effectiveness by incorporating holistic D&I operations across people, business, and R&D systems and processes.

The D&I Office offers many resources and events for the Laboratory community, including seminars that cover a variety of topics such as racial bias in health; leadership development off-sites, where staff can learn how to lead effectively and inclusively; study groups; and Laboratory-wide educational and cultural initiatives.

Employee Resource Groups
Lincoln Laboratory’s employee resource groups (ERGs) provide opportunities for connection between employees and support to staff members during the transitions they make as they advance in their careers. From helping new staff acclimate to the Laboratory’s work environment, to encouraging professional development, to facilitating involvement in community outreach activities, the groups below help promote the retention and development of employees.

- **Lincoln Employees’ African American Network (LEAN)**
  LEAN addresses issues faced by current and prospective African American employees, and participates in recruiting, community outreach, professional development seminars, and external networking.

- **Lincoln Employees with Disabilities (LED)**
  LED supports employees with disabilities and helps to create an efficient and accessible workspace that is inclusive to all. LED also supports employees who have family members with disabilities.

- **Lincoln Laboratory Hispanic/Latinx Network (LLHLN)**
  LLHLN fosters awareness of Hispanic culture and promotes networking and professional development for its members.

- **Lincoln Laboratory New Employee Network (LLNEN)**
  LLNEN is a social networking group for new hires to help them transition into the Laboratory culture.

- **Lincoln Laboratory Out and Proud Network (LOPEN)**
  LOPEN provides a forum for the LGBTQ+ community at the Laboratory and strives to make an environment in which LGBTQ+ employees can thrive and feel comfortable.

- **Lincoln Laboratory Veterans’ Network (LLVETS)**
  LLVETS recognizes Laboratory employees who are U.S. veterans, supports veterans transitioning from the military, provides outreach to local active-duty troops and veterans, and informs members of activities and legislation affecting veterans.

- **Lincoln Laboratory Women’s Network (LLWN)**
  LLWN promotes the recruitment, retention, and achievement of women employees and provides a forum for them to share experiences, strategies for success, and resources.

- **Pan-Asian Laboratory Staff (PALS)**
  PALS promotes and builds awareness of the variety of Asian cultures present at the Laboratory and offers opportunities for its members to congregate and share experiences.

- **Recent College Graduates (RCG)**
  RCG is a networking group for new employees transitioning from college life. Activities include social networking events and trips, community involvement, and peer-to-peer technical presentations.
D&I: IT TAKES ENGAGED AND ACCOUNTABLE LEADERSHIP
Achieving a workplace commitment to diversity, inclusion, and equity takes the proactive support of management and the involvement of thought leaders from across the organization. Lincoln Laboratory is fortunate to have such a team of individuals dedicated to D&I goals:

- The Executive Diversity and Inclusion Council is cochaired by Lincoln Laboratory Director Eric Evans and Chief Diversity and Inclusion Officer Chevy Cleaves. The council represents a best practice designed to provide strategic oversight of, organizational support for, and accountability regarding D&I transformation while establishing and solidifying the Laboratory’s position as an employer and partner of choice. The council is composed of 14 representatives across divisions, departments, offices, and levels.
- Fifteen members make up the Diversity & Inclusion Champions, one representing each division and department. This best practice supports coordination, strategic communications flow, alignment, and transformation through select senior leaders in each department and division.
- Each of the nine members of the Cross-Cultural Executive Sponsors for ERGs shares experience as a leader, strategist, and innovator with an ERG, helping advise and shape pathways that foster an inclusive, welcoming environment across the Laboratory.

Advancing Leadership in D&I
Over the last year, Lincoln Laboratory sponsored 32 individuals to participate in and benefit from the Diverse Leadership Development Collaborative program. Seeking to develop internal high-potential talent, the Laboratory teamed with two local organizations that help companies build a diverse pool of executive talent:

- The Partnership Inc. has evolved from its original focus on the advancement of African Americans in corporate Boston to an organization that supports multicultural professionals at all levels in an increasingly diverse and global workforce. The Partnership makes corporations and institutions more competitive in a global economy by helping them attract, develop, and retain talented multicultural professionals at all levels of leadership, and creating a corporate climate that encourages diversity and helps multicultural professionals thrive. The Partnership Inc. offers leadership development programs that help individuals at all stages of their careers define and reach their professional goals.
- Conexión’s initial impetus was the growing corporate demand for Hispanic/Latinx talent. Conexión seeks to identify and fast-track the professionals who are ready to challenge the next level of increasing responsibilities. Through their leadership programs, Conexión helps prepare Hispanic/Latinx leaders to accept increasing responsibilities to ensure that not only Hispanic/Latinx communities and organizations but also the country thrive and prosper in the future.

A series of two-day D&I Leadership Off-sites encouraged Lincoln Laboratory managers to examine their personal and leadership styles, understand emotional and intercultural intelligence, evaluate their strengths and weaknesses, and explore ways to adapt their abilities to meet the requirements of an increasingly diverse workforce. The meetings discussed how leaders can foster successful team performance by better understanding how to leverage the impact of these skills in the context of current and future challenges and opportunities. These off-sites also prompted the creation of Communities of Practice with, and for, Laboratory leaders who serve as ERG Executive Sponsors and D&I Champions from each business unit. The feedback from participants in these off-sites has been overwhelmingly positive.

Conferences
An understanding of the ways individuals can both support and inclusively lead an increasingly diverse workforce is critical to an organization’s ability to sustain a work environment that encourages teamwork, innovation, and success. Through a number of conferences, leaders and staff gained important insights into fostering D&I in the workplace and shared ideas on successful D&I initiatives.

The 2021 Simmons Leadership Conference, sponsored for the 42nd consecutive year by the Simmons University Institute for Inclusive Leadership, was attended by 230 people from Lincoln Laboratory. This record Laboratory attendance was not only because the conference’s virtual format allowed for a wide audience but also because the D&I Office and the Lincoln Laboratory Women’s Network coordinated awareness of and admission to the event. In line with the theme of “authenticity and resiliency,” the 2021 conference sought to empower women to become leaders who adapt to change and new challenges while retaining their principles and individuality.

The conference features lively panel discussions, signature dialogues, and skill-building workshops on topics ranging from business strategy and innovation to career management.

The Massachusetts Conference for Women features workshops and seminars on relevant issues, such as business and entrepreneurship, health, and work/life balance. Since the first conference in 2005, this event has grown to attract more than 10,000 attendees annually. (In prepandemic years, all seats were sold out within minutes.) Staff from Lincoln Laboratory continue to enjoy this conference’s opportunities for business networking, professional development, and personal growth.

The Women’s Business Leadership Conference sponsored by Diversity Woman Media attracts women business leaders of all races, cultures, and backgrounds from the world’s largest corporations and entrepreneurs from successful women-owned businesses. Recognized as the premier women’s leadership conference for racial, ethnic, and gender diversity, the event gives attendees the chance to hear and learn from some of the most influential thought leaders and executives across the nation and world.

The EmERGe Leadership Summit is the only biennial conference designed specifically for members of ERGs and diversity councils. Attendees learn and share creative strategies for improving diversity, inclusion, and equity in the workplace. The 2021 event, again held virtually, explored how ERGs and diversity councils can better align themselves to their organizations’ goals and business.
LABORATORY INVOLVEMENT

GEM FELLOWSHIP PROGRAM

After taking a break last year because of the COVID-19 pandemic, the GEM program resumed in 2021 with 22 fellows joining the Laboratory for the summer. GEM is a network of leading corporations, laboratories, and research institutions that enables qualified students from underrepresented communities to pursue graduate education in science and engineering.

GEM fellows work as summer interns while completing their studies and receive financial support that is often the deciding factor in their pursuing graduate education. The internship process also allows companies to access and recruit talented candidates that they may not find otherwise. GEM fellowships at the Laboratory offer the students numerous returns, from networking opportunities to high-level research experience.

GEM fellow Miles Smith worked in the Energy Systems Group to develop some state-of-health measurement techniques for a novel battery architecture that his supervisor is developing. About his fellowship experience, Smith said, “I have had a very positive experience and have found the support at Lincoln Lab to help me feel connected within the Lab community.”

LABORATORY D&I EVENTS AND INITIATIVES

RE2AcT Study Groups

RE²AcT (Research. Educate. Empathize. Act. Transform) is an ongoing initiative at the Laboratory that was developed by the D&I Office in summer 2020 to help members and leaders of the Laboratory community develop the foundation necessary to strategically respond to the challenge of systemic racism while building a more diverse and inclusive organization.

In fall 2020, the D&I Office launched the RE²AcT study groups, which allow Laboratory employees to read and discuss various books about social issues in America. The goal of the study groups is to create an inclusive and safe atmosphere for small group learning and discussion while identifying additional areas for research, learning, and development.

In 2021, study group members read and discussed the following books: Just Mercy by Bryan Stevenson; Supreme Inequality by Adam Cohen; In the Shadow of Statues by Mitch Landrieu; The Soul of America by Jon Meacham; Biased by Jennifer Eberhardt; Stamped from the Beginning by Ibram Kendi; The Negro’s Civil War by James McPherson; Whistling Vivaldi by Claude Steele; and How to be an Antiracist by Ibram Kendi.

Lincoln Laboratory Featured in Savoy Magazine

The Laboratory was featured in an article about corporate diversity in the Spring 2021 Issue of Savoy magazine, a leading African American lifestyle and business magazine. The article highlighted how the Laboratory, alongside other national and global organizations, is transforming culture in the national security sector by drawing on the strengths and perspectives of a diverse and inclusive workforce. “At the Laboratory, a diverse workforce and an inclusive culture are more than just goals; they’re vital to our mission,” Chevy Cleaves, Lincoln Laboratory Chief Diversity and Inclusion Officer, said in the article. “Innovation thrives at the nexus of inclusion and diversity, and we are committed to leveraging talent from all across the nation to help us identify and solve some of the world’s most challenging problems.”

Shown at left is a graphic printed alongside Lincoln Laboratory’s featured article in the Spring 2021 Issue of Savoy magazine.
Dr. Martin Luther King Jr. Celebration
On February 4, the Lincoln Employees’ African American Network (LEAN) sponsored their eighth Annual MLK Celebration, which was inspired by Dr. Martin Luther King Jr.’s “I Have a Dream” speech. The theme of the event was “Fulfilling the Dream with Courage and Hope.” The event opened with a video montage that asked several Laboratory employees about what Black History Month means to them. Karl Reid, Executive Director of the National Society of Black Engineers, delivered the event’s keynote address. Reid began his keynote, titled “Towards Inclusive Excellence: Fulfilling the Dream with Courage and Hope,” by asking what Dr. King’s dream would look like if it were to be brought forward into contemporary times. Reid’s answer, laid out throughout his keynote, was that “diversity and equity are a means to an end, and the end is inclusive excellence—it’s creating an inclusive environment where everyone can play a role and feel a part of an organization.”

Cultivating Leadership, Achievement, and Success Symposium

The Laboratory held its fourth annual Cultivating Leadership, Achievement, and Success (CLAS) Symposium in March 2021. The Lincoln Laboratory Women’s Network launched the symposium in 2018 with the goal of furthering cultural development in the workplace, providing training opportunities for leadership skills, and highlighting people who make the Laboratory a better place to work. General David Thompson, the first Vice Chief of Space Operations for the United States Space Force, gave the keynote address. In his keynote, Thompson spoke about the importance of selecting the right leadership, effectively leveraging talent, and leading an organization through big changes. The symposium also included two panel discussions about leadership for the Laboratory of the future and a course about best practices for building strong virtual teams. The event concluded with an awards ceremony recognizing employees for their positive impacts on Laboratory culture, excellence in mentorship, and contributions to Laboratory events and initiatives.

Asian Pacific American Heritage Month

Throughout the month of May, communities at the Laboratory and across the country observed Asian Pacific American Heritage Month—a period of paying tribute to the generations of Asian and Pacific Islanders who have enriched America’s history and are instrumental in its future success. The Pan-Asian Laboratory Staff (PALS) hosted a series of events in May that included a discussion with Adrienne Sui, a poet and the author of Peach State; a trivia event about Asian American and Pacific Islander history, activism, and entertainment; and a historical overview of Asian Americans given by MIT Professor of Asian Civilizations Emma Teng.

Celebrating Juneteenth
On June 17, the same day President Joseph Biden signed a bill to designate Juneteenth as a new national holiday, members of LEAN and the Laboratory community came together for a virtual event that consisted of a moderated panel discussion and open discussion about the significance of Juneteenth. Prior to the event, participants were asked to view two videos that give context to the history and meaning of Juneteenth. Nearly 400 people attended the discussions to share their reflections, questions, and comments regarding the videos and Juneteenth. On June 18, the Laboratory observed Juneteenth as a federal holiday for the first time.

Hispanic Heritage Month
From September to October 2021, the Laboratory’s Hispanic/Latina Network hosted virtual events to celebrate national Hispanic Heritage Month. The month’s events included a technical presentation about a data-driven method being used to monitor the COVID-19 pandemic in Puerto Rico, a technical and inclusivity talk from an integration and test manager at NASA, a presentation from an infectious disease specialist on the effects of the pandemic on minority and underrepresented groups, and other virtual events that celebrate Hispanic culture.

Members of the Our Voices, Our Vote (OVOV) team accepted their Strength in Unity awards. The OVOV team organized events in 2021 to recognize the centennial anniversary of the 19th Amendment, which guaranteed American women the right to vote.
Awards and Recognition

2020 MIT Lincoln Laboratory Technical Excellence Awards

David R. Crompton, for excellence in building complex hardware systems that are critical to the development of space systems, optical payloads, and precision mechanisms, and for expertise in structural analysis and testing that enable innovative engineering solutions for ground, sea, air, and space prototype systems.

Dr. Alan J. Fenn, for innovation in developing antennas and adaptive arrays that provide revolutionary capabilities for ground-, air-, and space-based radar, electronic warfare, communications, and sensing systems, and for leadership in building a world-class facility for simulating, prototyping, and testing novel antenna and electromagnetic systems at Lincoln Laboratory.

2020 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Nicholas D. Hardy, for system analysis expertise and technical insights that have enabled his major contributions to critical challenges in modern optical communications technology, including the demonstration of entanglement-based quantum communications over fiber and free-space channels and of high-rate undersea laser communications.

Dr. Meghan E. Ramsey, for demonstrating excellent technical capabilities and leadership in multi-agency programs that are addressing the threats from emerging pathogens, the pathology of infectious diseases, the development of countermeasures, research in aerosol science, and biodefense response and recovery.

2020 MIT Lincoln Laboratory Best Paper Award


2020 MIT Lincoln Laboratory Best Invention Award

Dr. Melissa A. Smith, Donna-Ruth Yost, Noah Siegel, Dr. Daniel Freeman, and Dr. Paulo Lozano, for the invention of Electrospray Device and Fabrication Methods.

2021 Election to the National Academy of Engineering

Dr. Marija Ilic was named a member of the National Academy of Engineering (NAE) for her contributions to electric power system analysis and control. The NAE is a private, nonprofit institution that brings eminent engineers together to provide independent advice to the federal government on engineering and technology.

2021 IEEE Fellow

Dr. Robert T-I. Shih, for leadership in electromagnetic modeling of radar systems and in microwave remote sensing. The IEEE is the world’s largest technical professional organization and annually confers the rank of Fellow on senior members whose body of work has advanced innovation in their respective fields.

2021 FLC Northeast Regional Award for Excellence in Technology Transfer

The Federal Laboratory Consortium for Technology Transfer (FLC) selected Lincoln Laboratory as the Northeast region’s winner of its award for outstanding achievement in technology transfer. The award recognizes two Laboratory technologies: Forensic Video Exploitation and Analysis, a suite of analytic tools to help investigators review surveillance video footage; and Keyline, a software architecture that increases the security and privacy of data and services in the cloud.

2021 Fellow of the Society for Industrial and Applied Mathematics

Dr. Jeremy Kepner, for contributions to interactive parallel computing, matrix-based graph algorithms, green supercomputing, and big data. The Society for Industrial and Applied Mathematics helps build cooperation between mathematics and the fields of science and technology to solve real-world problems.

2020 IEEE Boston Section Distinguished Service Award

Dr. Albert I. Reuther, for his dedicated support of the IEEE Boston Section’s 2020 High Performance Extreme Computing Conference (HPEC) and his efforts to virtualize the conference in response to the COVID-19 pandemic. Reuther serves as the technical chair of the IEEE HPEC conference.

AIAA Associate Fellows

Above left to right, Dr. William J. Blackwell, James R. McIntyre, and Dr. Mark J. Silver were selected to the 2021 class of Associate Fellows of the American Institute of Aeronautics and Astronautics (AIAA).

2021 MassTLC Mosaic Award

Awarded to Chevalier “Chevy” Cleaves by the Mass Technology Leadership Council (MassTLC) for his work in creating access and opportunity for future leaders. Cleaves received the award for his work at the Laboratory as well as his past work as the first Chief Diversity Officer at the U.S. Air Force and first Vice President of Global Diversity and Inclusion at Boston Scientific.

Inclusion in the Massachusetts HERstory

Yari Golden-Castano, one of 91 women, was one of 91 women, from pioneer days to today, with ties to Massachusetts who have been selected by Massachusetts Senate President Karen Spilka to be featured in the second edition of the 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.

Support category: Kathleen L. Cable, above left, for her excellent efforts as the Division Administrative Assistant of the Homeland Protection and Air Traffic Control Division, and her support to special events and committees at the Laboratory; Steve B. Salsbury, above right, for his sustained, exceptional leadership of the operations of Lincoln Laboratory’s chilled water plant.
2021 ICAO Walter Baginhi Award
The International Civil Aviation Organization (ICAO) presented this award to Dr. Vincent A. Orlando for his sustained and significant contributions to international aviation.

2021 Gold HIRE Vets Medallion Award
Awarded to Lincoln Laboratory for the second consecutive year in recognition of efforts to recruit, hire, develop, and retain veteran employees. The Laboratory was one of 849 employers awarded a medallion across the nation.

2021 Award for Excellence in Diversity and Inclusion
At the North American HR Executive Summit, a gathering hosted by Executive Platforms for human resources (HR) executives, Lincoln Laboratory was honored with this award, which is given to industry-leading organizations that have made exceptional efforts to build equality and openness into the fabric of their workforce culture.

2021 James A. Cogswell Award
Awarded to the Huntsville Field Site by the Defense Counterintelligence and Security Agency for outstanding industrial security. This award is given to facilities that have established and maintained a security program that exceeds basic National Industrial Security Program requirements.

2020 Superior Security Rating
Awarded to Lincoln Laboratory by the U.S. Air Force for the 15th consecutive year. The rating represents the Laboratory’s commitment to safeguarding sensitive and classified information.

2020 Department of the Air Force-MIT Artificial Intelligence Accelerator (AIA) Awards
Awarded to two teams involving Lincoln Laboratory staff. One team received the Director’s Award, which highlights “excellence and impact with a focus on collaboration across the AIA and with stakeholders,” for their efforts on the Earth Intelligence Engine to build weather and climate resiliency. Dr. Mark Veillette led this team, which included Dr. Allison Chang and Esther Wolf. The other team received the Challenge Award for designing and implementing two challenges—competitions that engage academia, industry, and the public in solving a common problem—focused on optimizing Puckboard, a web-based software application for scheduling aircrews to mission and training flights. This team was led by Michael Snyder, and the other members included Dr. Amy Alexander, Kandrick Cancio, Dr. Jeremy Kepner, and Jessamyn Liu.

2021 MIT Excellence Awards
Bringing out the Best category:
- Dr. Martine M. Kalke
- Dr. Jonathan D. Pitts

Embracing Diversity, Equity, and Inclusion category:
- Alice Lee

Serving Our Community category:
- Zachary Sweet

Outstanding Contributor category:
- Dr. Rajan S. Gurjar
- David F. Johnson

2021 Cultivating Leadership, Achievement, and Success Awards
- Employee Recognition Group Excellence Award: Alice Lee
- Equity Award: Dr. Bonita J. Burke
- Outstanding Mentor Award: Dr. Bryan Ward
- Leadership Award for Advancing Organizational Culture: Dr. Martine M. Kalke and Heather E. Rogers
- Peer Award for Cultural Impact: Ngaire K. Underhill
- Emeritus Award: Gerald C. Auger

Our Voices, Our Vote category:
- Julie A. Arltor-Mehta
- Christine M. Carlino
- Stephanie B. Darga
- Marie L. Dow
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Economic Impact
Lincoln Laboratory serves as an economic engine for the region and the nation through its procurement of equipment and technical services. During fiscal year 2021, the Laboratory issued subcontracts with a value of $472.7 million to businesses in all 50 states, Washington, D.C., and Puerto Rico. The Laboratory purchased $232.4 million in goods and services from New England companies, with $178.2 million in contracts awarded to Massachusetts businesses. The Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.
This year’s Beaver Works Summer Institute was held in a virtual format, enabling the program to include more students and more courses. The course offerings were increased from 9 to 13 classes, and a record 351 students were accepted, compared to last year’s 178 students.
EDUCATIONAL AND COMMUNITY OUTREACH

Educational Outreach

LINCOLN CODERS
The first Lincoln Coders educational outreach program for sixth and seventh grade students from middle schools in nearby Lincoln, Massachusetts, and Hanscom Air Force Base took place in the spring. Thirteen program facilitators from the Laboratory’s Recent College Graduates employee resource group worked with 17 students for seven weeks to teach them how to code. Each student chose to work in Scratch, JavaScript, or Python. With the help of the facilitators, students built their own unique chatbots, fighting games, and chess game in Python; meteor-catching games in JavaScript; and animations and interactive games in Scratch.

Olivia Brown and Victoria Helus gave a brief presentation on artificial intelligence and machine learning, after which the students worked on their coding projects and then presented the progress they had made at the end of the class. The goal of the program was to teach the students to be brave, resilient, creative, and purposeful through coding.

After seven weeks of hard work, Hanscom and Lincoln Middle School students in Lincoln Coders presented final projects, like this chess game code. Mentoring of students by Laboratory staff was key to the success of this new program.

“I didn’t learn how to code until college. Having this experience at that age would have been awesome,” said Adam Gjersvik, a Lincoln Coders facilitator. “I loved being able to give students that opportunity, especially given the growing importance of knowing how to code in society today.”

LINCOLN LABORATORY CIPHER
For seven years, Lincoln Laboratory has offered students interested in mathematics and cryptography a weeklong summer workshop called Lincoln Laboratory Cipher (LLCipher). In August 2021, the program was held virtually for 30 high school students from across the country eager to learn advanced mathematics. Laboratory staff volunteered as primary instructors and assisted students in understanding modern theoretical cryptography.

After learning the basics of cryptography, students learned how to build a secure encryption scheme and digital signature. Typically, the workshop curriculum includes hands-on demonstrations and activities that reinforce basic lessons of classical and modern cryptography; however, this year, these activities were introduced online. Aspects of abstract algebra, number theory, and complexity theory were included in the curriculum, as well as topics of active research interest in cryptography, such as zero-knowledge proofs and multiparty computation.

This year and learned course material from Laboratory technical staff.

G.I.R.L. ARTIFICIAL INTELLIGENCE/MACHINE LEARNING (AI/ML) WORKSHOPS

G.I.R.L. AI/ML Workshop: Lynn

On December 30, 2020, Laboratory staff members hosted a Girls’ Innovation Research Lab (G.I.R.L.) workshop in which they partnered with Girls Inc. of Lynn, Massachusetts, to teach middle and high school girls the basics of artificial intelligence (AI) and machine learning (ML).

For this virtual workshop on AI, Victoria Helus and Olivia Brown led the planning for the 20 attendees. Riley Martell, Amy Chen, and Bich Vu explained how AI and ML differ from standard computer programming, how to tell if a technology is using AI, and how AI algorithms are designed.

“One unique aspect of our workshop is that it did not involve any computer programming,” said Brown. “Because the workshop was code free, the girls could focus on learning the high-level concepts behind AI, rather than spending their time trying to get code to run.”

The girls used candy to explore an algorithm design technique called a decision tree. The girls were tasked with sorting the candy by asking progressively more specific questions—such as, is the wrapper brown, does the candy contain chocolate, and does the candy contain nuts? The girls were encouraged to be creative and decide for themselves what features were important in organizing their “data.” Staff hope that these events will give girls confidence by disrupting the notion that only certain people belong in the AI/ML field.

G.I.R.L. AI/ML Workshop: Lowell

As proof of the success and popularity of the AI/ML Workshop in December, the same workshop was requested by Girls Inc. of Lowell, Massachusetts, in April. Victoria Helus and Olivia Brown led the workshop, while Riley Martell and Yari Golden-Castano assisted with presentations. These volunteers shared their personal stories with the almost 20 girls, detailing what inspired them to follow a technical career path, what their current jobs entail, and why they love working in the AI/ML field.

G.I.R.L. AI/ML Workshop: Hanscom

A third workshop on AI/ML was held in June for seventh grade students in Hanscom Middle School. The 63 students learned what constitutes AI and practiced building decision trees. A timely addition was a discussion about biases in ML and why it’s important to be conscious of bias.

The lead presenters were Victoria Helus and Olivia Brown. The event was organized by Yari Golden-Castano, who was assisted by volunteers Amy Chen, Cassian Corey, Peijun Shao, Adam Kern, Nathan Vaska, and Andrew Schoer.

Hanscom Middle School educators were grateful for the presentation and indicated that several of the students said it was the best thing they’ve done all year.
LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS (LLRISE)

The tenth Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), a two-week program for 31 rising high school seniors, was held in July 2021. The program was offered in a virtual format, just as in 2020, and explained the basics of radar systems and three different radar modes: Doppler radar, pulsed coherent radar, and synthetic aperture radar. Laboratory staff volunteering their time to prepare and host the lectures included Ryan Bohler, David Brigada, Mark Jones, Aryk Ledet, David Maurer, David Scott, George Pantazis, and Andrew Volpe.

The students in the program came from a wide variety of backgrounds that are typically not well represented in STEM fields. The 2021 class included students who will be first-generation college students, are from low-income backgrounds, and whose race is underrepresented in STEM.

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Prior to the course, the students were shipped a radar kit that they could use for building their own experiments with the help of mentors and teaching assistants via Zoom. The participants were provided with radar code but also learned basic coding in Python so that they could develop their own experiments and simulations using their kits. Many of the experiments involved using the radars to measure the distance or movement of objects. For example, one group of students measured how a ball moved traveling down a staircase, and another measured how fast a dog’s tail wagged as different people the dog knew came home.

At the end of the program, students presented their final group projects to Laboratory personnel as well as families, friends, and peers to showcase what they had learned.

LLRISE participants listened as Louie Lopez, Director of DoD STEM (top left), provided an overview of DoD STEM opportunities and scholarships that can further the academic careers of students or help prepare them for careers in the DoD.

In March, Lincoln Laboratory Outreach partnered with the Texas Alliance for Minorities in Engineering (TAME) to provide the LLRISE course in a virtual setting for high school students from Texas during their spring break week.

The organization offers age-specific programs to spark and support student interest in the sciences and technological careers, and provides professional development and curriculum ideas for teachers to educate families about opportunities in STEM.

The students completing this shortened one-week workshop were encouraged to apply for the full two-week radar summer workshop, as well as the one-week cryptography program.

In October, J. Brent Parham’s Space Weather talk explained how plasma and radiation emissions from the Sun can hamper satellites, communications, and electrical grids. Parham further described how and why NOAA tracks the weather in space. Participants were intrigued to see evidence of the Sun’s coronal eruptions and the ways they can drastically affect systems on earth.

The Space Weather Science on Saturday presentation by J. Brent Parham showed children how solar wind variations and geomagnetic storms can penetrate our atmosphere and disrupt Earth’s magnetic field, temporarily threatening spacecraft, navigation systems, and power grids.

EDUCATIONAL AND COMMUNITY OUTREACH

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At the end of the program, students presented their final group projects to Laboratory personnel as well as families, friends, and peers to showcase what they had learned.

LLRISE participants listened as Louie Lopez, Director of DoD STEM (top left), provided an overview of DoD STEM opportunities and scholarships that can further the academic careers of students or help prepare them for careers in the DoD.

In March, Lincoln Laboratory Outreach partnered with the Texas Alliance for Minorities in Engineering (TAME) to provide the LLRISE course in a virtual setting for high school students from Texas during their spring break week.

The organization offers age-specific programs to spark and support student interest in the sciences and technological careers, and provides professional development and curriculum ideas for teachers to educate families about opportunities in STEM.

The students completing this shortened one-week workshop were encouraged to apply for the full two-week radar summer workshop, as well as the one-week cryptography program.

In October, J. Brent Parham’s Space Weather talk explained how plasma and radiation emissions from the Sun can hamper satellites, communications, and electrical grids. Parham further described how and why NOAA tracks the weather in space. Participants were intrigued to see evidence of the Sun’s coronal eruptions and the ways they can drastically affect systems on earth.

The Space Weather Science on Saturday presentation by J. Brent Parham showed children how solar wind variations and geomagnetic storms can penetrate our atmosphere and disrupt Earth’s magnetic field, temporarily threatening spacecraft, navigation systems, and power grids.
BEAVER WORKS SUMMER INSTITUTE
This year’s Beaver Works Summer Institute (BWSI) was held in a virtual format, enabling the program to include more students and more courses. Thirteen courses were offered for 301 students. The classes presented this year were Autonomous RACECAR, Autonomous Air Vehicle Racing, Autonomous Underwater Vehicle Racing Challenge, Autonomous Cognitive Assistant, Unmanned Air System—Synthetic Aperture Radar, Data Science for Health and Medicine, Build a CubeSat, Embedded Security and Hardware Hacking, Remote Sensing, Serious Game Design and Development with AI, and new classes on Cyber Security for Software Intensive Systems, Quantum Software, and Assistive Technology.

All students received either prebuilt hardware or a kit of parts so that all courses still incorporated a strong hands-on engineering experience. “Bringing the BWSI program online has helped make the course materials available to many more people than we initially imagined,” said Joel Grimm, Beaver Works manager. “We have increased the number of online prerequisite courses available and created asynchronous courses for learners. It is so much more accessible than we ever thought possible.”

BWSI: RACECAR IN HUNTSVILLE
For the first time, staff at the Laboratory’s field site in Huntsville, Alabama, offered a summer BWSI RACECAR program for six high school students. This program came about through the efforts of primary instructors Patrick O’Shea, Sarah Crews, and Justin Kizer, with assistance from Tom Schwab and Kim Shepard of MITRE Corporation. Throughout this four-week course, students gained experience programming in Python, working with lidar and stereoscopic depth cameras, and solving navigation and identification problems in order to teach an autonomous mini-car to respond to specific directives. In addition to learning how autonomous technology works, the students visited Aerobotix, a robotics technology company, and viewed the launch of the Blue Origin Shepard Rocket at the U.S. Space and Rocket Center. The field site teamed up with MITRE to build a racetrack to test the students’ skills navigating autonomously around a challenging course. The program culminated with student presentations. Keith Henderlong, Huntsville Field Site lead, said, “I have no doubt this STEM outreach program inspired and transformed the future for local Huntsville-area students.”

Students assemble components of their autonomous mini-car prior to programming it in the Huntsville BWSI RACECAR program.

BWSI: RACECAR IN KWAJALEIN ATOLL
BWSI sailed to the Laboratory’s Kwajalein Field site in the Marshall Islands. After a month of lessons, Kwajalein high school students learned how to create code, develop algorithms, and use software to teach a mini-car navigation, mapping, and object detection. Lincoln Laboratory program instructors helped the students understand the material while Ranny Rani translated into Marshallese. The students learned to build and program small remote-controlled vehicles to move, avoid obstacles, navigate using a visual sensor, detect objects, and maneuver through obstacles on a racetrack in an event that was well attended by teachers, parents, and children from the community, and leadership from the Marshall Islands, U.S. Army Garrison-Kwajalein Atoll, and the Ronald Reagan Ballistic Missile Defense Test Site. “RACECAR provided opportunities for students to develop prototyping skills while exploring autonomous machine learning,” said Willis. “Plus, it’s just fun driving mini-cars around.”

High school students review program code before the final competition event that was attended by leadership from the Marshall Islands and the U.S. Army Garrison-Kwajalein Atoll.

Community Giving

DONATION DRIVES

Bedford Veterans Affairs Medical Center
Santo Lucente created a year-round clothing donation drive for local veterans residing at the Bedford Veterans Affairs Medical Center. Lucente, a member of the Lincoln Laboratory Veterans’ Network, said, “The Bedford Center has facilities for homeless veterans, who need all the basic necessities when they arrive. As a veteran myself, I want to do my part in helping them get what they need.”

Santo Lucente and Marilyn Rosado donate boxes of new clothing for veterans to personnel from the Bedford Veterans Affairs Medical Center in Bedford, Massachusetts.

BEDFORD VETERANS AFFAIRS MEDICAL CENTER

Boston Medical Center
Christopher Gibbons started a clothing and toy drive in October to benefit Boston Medical Center’s clothing bank and their Child Life program. Donations to the clothing bank are given to patients in need, while the Child Life program collects small toys for in-patient kids. This in-kind donation program at Boston Medical Center is an efficient way to distribute the generosity of the Laboratory community to those most in need of support.

ALZHEIMER’S AWARENESS AND OUTREACH

Walk to End Alzheimer’s
This year, Lincoln Laboratory celebrated its 13th anniversary of participating in the Walk to End Alzheimer’s. The walk took place in a virtual setting on September 26. The 11 team members walked individually on sidewalks, tracks, and trails to participate in this year’s walk and raised $24,770 of their $30,000 goal.

Santo Lucente and Marilyn Rosado donate boxes of new clothing for veterans to personnel from the Bedford Veterans Affairs Medical Center in Bedford, Massachusetts.

Ride to End Alzheimer’s
For the tenth year, the Alzheimer’s Support Community invited cyclists to join the 2021 Ride to End Alzheimer’s in Rye, New Hampshire. This year’s team raised $22,605, surpassing their goal of $20,000 and ranking them the fourth-highest fundraising team in the region.

GAINING GROUND FARM
The Health & Wellness subcommittee organized two volunteer work sessions at Gaining Ground Farm this year: one on June 5 and another on September 11. Laboratory volunteers harvested 3,000 pounds of squash and cleared a field for a cover crop. They also received a grant from the MIT Community Giving Fund, enabling them to give a $500 donation to Gaining Ground Farm, which grows food for organizations that assist those experiencing food insecurity.

STOP HATE COMMUNITY BAKE SALE
Victoria Helus organized a series of bake sales to combat hate against minorities. While most bake sales disappeared during the pandemic, Helus cleverly produced a menu of bakery items to pre-order, baked the requested items, and offered touch-free delivery/pick-up. She raised $1,030 in June 2020 and donated it equally among the American Civil Liberties Union, the Innocence Project, and Black Women’s Blueprint. In March 2021, she repeated the effort and raised $1,200, splitting the proceeds equally between Stop Asian American Pacific Islander Hate, the Asian American Legal Defense Fund, and the Asian Pacific Fund.

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Composition of Professional Technical Staff

**Academic Discipline**
- 19% Physics
- 33% Electrical Engineering
- 17% Computer Science, Engineering
- 8% Biology, Chemistry, Meteorology, Materials Science
- 8% Mechanical Engineering
- 6% Mathematics
- 6% Aerospace, Astronautics
- 3% Other

**Academic Degree**
- 36% Master’s
- 42% Doctorate
- 18% Bachelor’s
- 4% No Degree

Breakdown of Laboratory Program Funding

**Sponsor**
- 90% Department of Defense
- 10% Non-Department of Defense

**Mission Area**
- 15% Air, Missile, and Maritime Defense Technology
- 12% Tactical Systems
- 11% Advanced Technology
- 18% Space Systems and Technology
- 20% Communication Systems
- 6% Cyber Security and Information Sciences
- 4% ISR Systems and Technology
- 4% Advanced Research Portfolio
- 2% Air Traffic Control

1,806 Professional Technical Staff
1,300 Support Personnel
536 Technical Support Personnel
486 Subcontractors

4,128 Total Employees