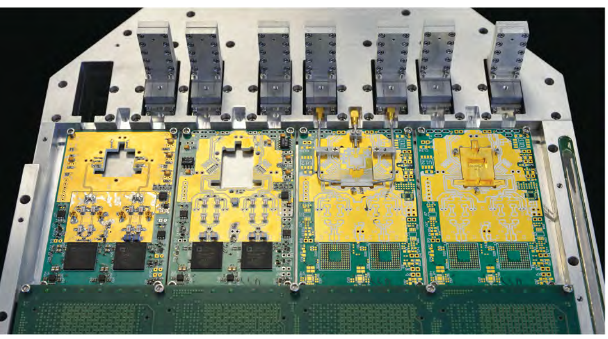
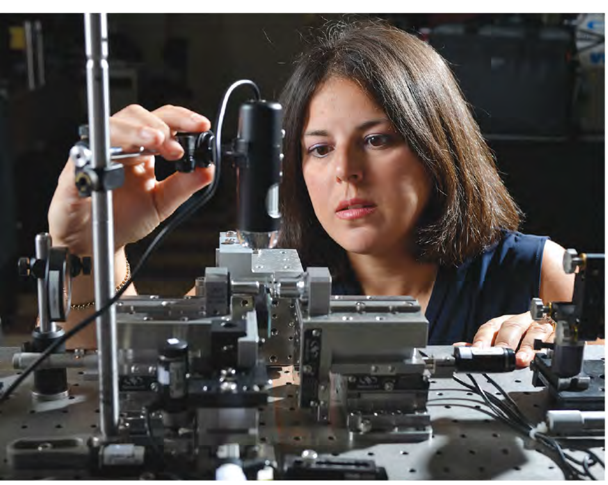
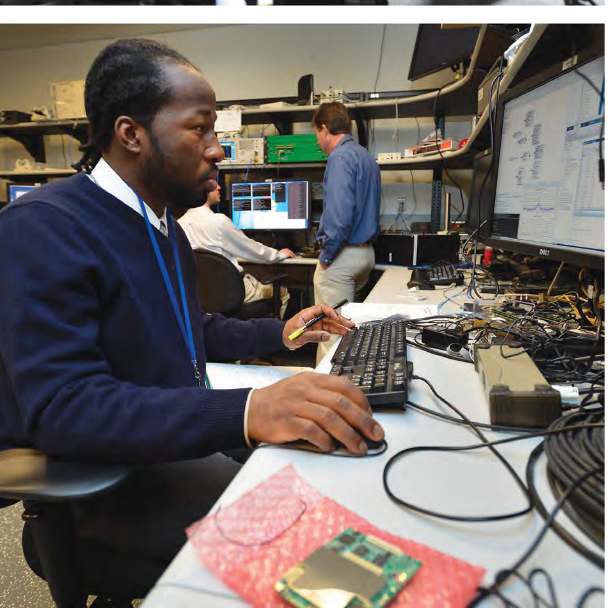
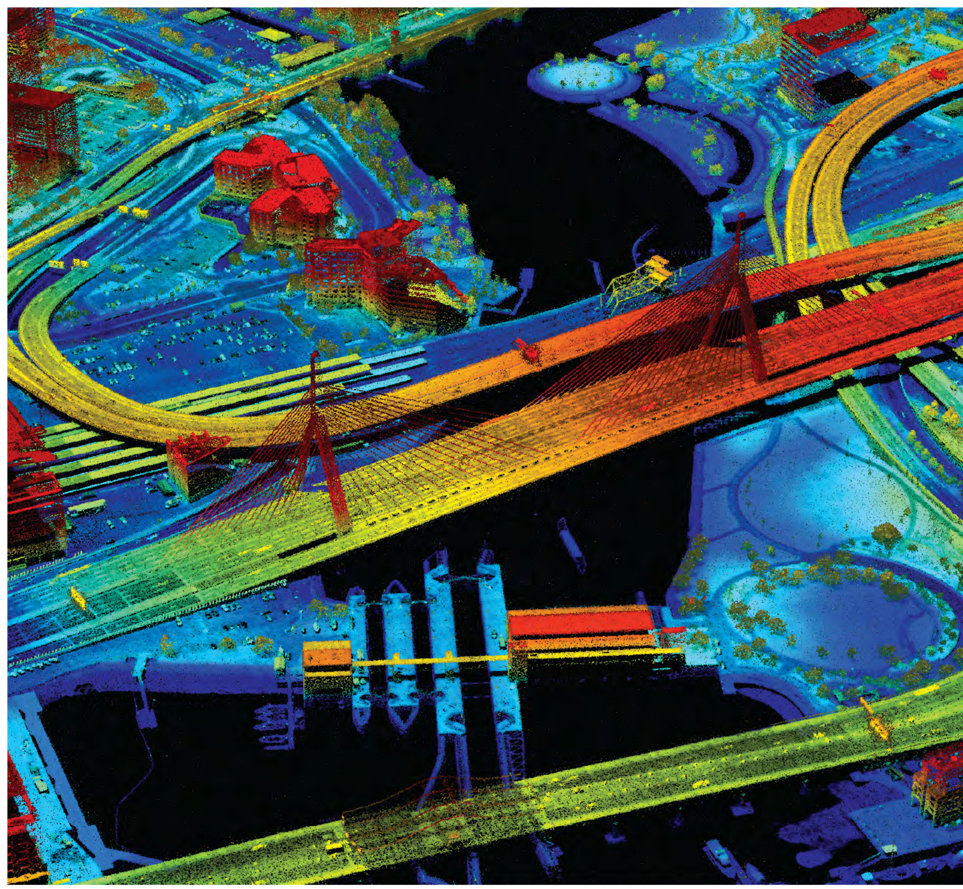






MIT Lincoln Laboratory

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY



ANNUAL REPORT 2015

Massachusetts Institute of Technology

Lincoln Space Surveillance Complex, Westford, Massachusetts

MIT Lincoln Laboratory

Reagan Test Site, Kwajalein Atoll, Marshall Islands

MIT LINCOLN LABORATORY 2015

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 Research and Development 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. Projects undertaken by Lincoln Laboratory focus 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. 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 64 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.

Table of Contents

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

MIT Lincoln Laboratory

Dr. Eric D. Evans
Director

Dr. Marc D. Bernstein (left)
Associate Director

Mr. C. Scott Anderson (right)
Assistant Director for Operations

LEADERSHIP CHANGES

Michael T. Languirand
Division Head, Engineering

Dr. Michael T. Languirand, formerly the assistant head of the Engineering Division, was appointed head of the division and a member of the Steering Committee. He brings extensive experience in overseeing large hardware projects to this management role.

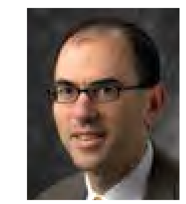
William D. Ross
Assistant Division Head, Engineering

Dr. William D. Ross was named assistant head of the Engineering Division. He was formerly the leader of the Advanced Electro-optical Systems Group (now the Integrated Systems and Concepts Group), served as the program lead for Lincoln Laboratory's Energy Initiative, and led the development of advanced imaging systems.

Marc N. Viera
Assistant Division Head, Intelligence, Surveillance, and Reconnaissance and Tactical Systems

Dr. Marc N. Viera was appointed assistant head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division. Prior to this appointment, he served as the leader of the Advanced Capabilities and Systems Group, directing Blue Team rapid prototyping and systems analysis efforts.

Eliahu H. Niewood
Appointment to Air Force Rapid Capabilities Office

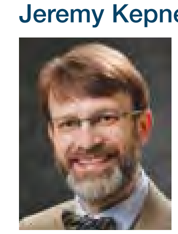


Dr. Eliahu H. Niewood, formerly the head of the Engineering Division, is serving on an Intergovernmental Personnel Act assignment at the U.S. Air Force Rapid Capabilities Office (RCO) in Washington, D.C. He will be helping to define the RCO's strategic directions and its contributions to the Department of Defense's new initiative promoting innovative technology development.

MIT Lincoln Laboratory Fellow

The Fellow position recognizes the Laboratory's strongest technical talent for their outstanding contributions over many years.

Jeremy Kepner



Dr. Jeremy Kepner has brought supercomputing to Lincoln Laboratory. He led the establishment of the LLGrid interactive, parallel computing system now used by hundreds of researchers across the Laboratory. His vision for a collaborative supercomputing facility guided the foundation of the Massachusetts Green High Performance Computing Center. He has developed innovative, advanced computing capabilities, such as the Parallel Matlab Toolbox, the Parallel Vector Tile Optimizing Library, and most recently the Dynamic Distributed Dimensional Data Model. He currently leads the Beaver Works Engaging Supercomputing research initiative.

Dr. Kepner is a prolific author, having published two textbooks and articles in many peer-reviewed journals. He has served as chair of the High Performance Extreme (formerly Embedded) Computing Conference for more than 10 years and is the recipient of a 2013 MIT Lincoln Laboratory Technical Excellence Award.

Letter from the Director

MIT Lincoln Laboratory has had another productive year prototyping systems and developing advanced technology in support of national security. Several large prototyping and long-term technology development programs are under way. We continue to transition many of the technologies resulting from such efforts either to industry or directly to the operational community, and we are increasingly working closely with high-technology startup companies from across the country.

Technology inside and outside of the Department of Defense (DoD) is evolving rapidly, and we continue to adapt the Laboratory's research and development activities to address current and future needs. This year, our Aerospace Division, renamed Space Systems and Technology, restructured its groups to undertake the development of resilient systems for space-based sensing and communication. Our Cyber Security and Information Sciences Division has been expanded to address heightened national needs for secure, resilient networks and effective management of big data. We believe that work in these areas will continue to grow.

New programs at the group level are covering a wide range of system and technology development for both national and global security. The recently established Humanitarian Assistance and Disaster Relief Systems Group is leveraging sensor, communication, and decision support technology within the DoD and from commercial companies to address critically important civilian needs around the world. Research performed by our new Energy Systems Group in collaboration with colleagues on campus at MIT is supporting DoD and civilian energy projects. We have also formed an Undersea Systems and Technology Group to specialize in undersea surveillance and communication systems. All of this work builds upon our past technology development experience.

Over the past year, we reached milestones in several areas:

- A prototype of a low-cost, multifunction phased array radar is expected to become the basis for upgrades to air traffic control and homeland protection radars across the country.
- We transitioned into operations the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), a three-dimensional ladar system designed to uncover hidden activity in heavily foliated areas. MACHETE has already been used in more than 160 sorties overseas.
- We demonstrated the first flight of a large number of self-organizing unmanned aerial vehicles for new defense system protection needs.
- A novel adaptive antenna array antenna will give aircraft an enhanced communications capability in highly contested electromagnetic environments.
- We demonstrated the largest short-wave-infrared focal plane array capable of detecting individual photons. This array will be used in new airborne and space-based sensor applications.
- A new space-based sensing capability will better protect U.S. systems.
- New techniques for secure and resilient cloud computing were developed and demonstrated.
- We exploited our high-density, three-dimensional wafer-scale integration technology to develop novel circuits that convert electrical signals into optical signals for rapid data distribution.
- Three of our technologies were recognized with R&D 100 Awards, given by *R&D Magazine* to the year's 100 most innovative technologies. Lincoln Laboratory has received 26 R&D 100 Awards over the last six years.

We encourage you to read through this report that summarizes accomplishments in all our mission areas and our ongoing involvement in educational and community outreach programs. We look forward to continuing our legacy of solving difficult national problems through technical excellence and integrity.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

To be the nation's premier laboratory that develops advanced technology and system prototypes for national security problems

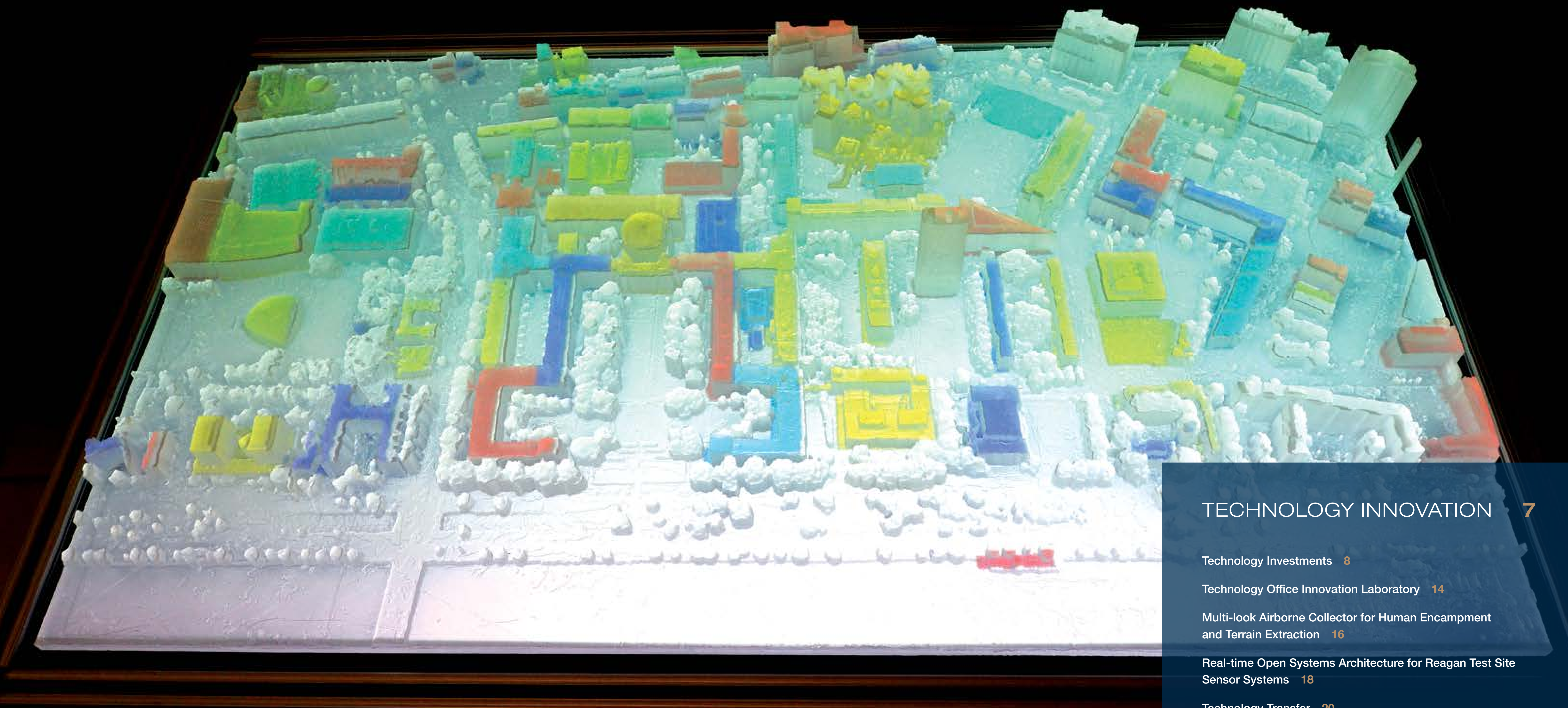
- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

VALUES

- **Technical Excellence:** The Laboratory is committed to technical excellence through the people it hires and through its system and technology development, prototyping, and transition.
- **Integrity:** The Laboratory strives to develop and present correct and complete technical results and recommendations, without real or perceived conflicts of interest.
- **Meritocracy:** The Laboratory bases career advancement on an individual's ability and achievements. A diverse and inclusive culture is critically important for a well-functioning meritocracy.
- **Service:** The Laboratory is committed to service to the nation, to the local community, and to its employees.

STRATEGIC DIRECTIONS

- Identify new mission areas, based on current and emerging national security needs
- Strengthen and evolve the current Laboratory mission areas
- Strengthen the core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition and user communities
- Increase outside connectivity and communications
- Improve Laboratory diversity and inclusion
- Expand community outreach and education
- Continue improving Laboratory administration and infrastructure



TECHNOLOGY INNOVATION 7

The model of MIT campus was 3D printed in the Technology Office Innovation Laboratory.

Technology Investments

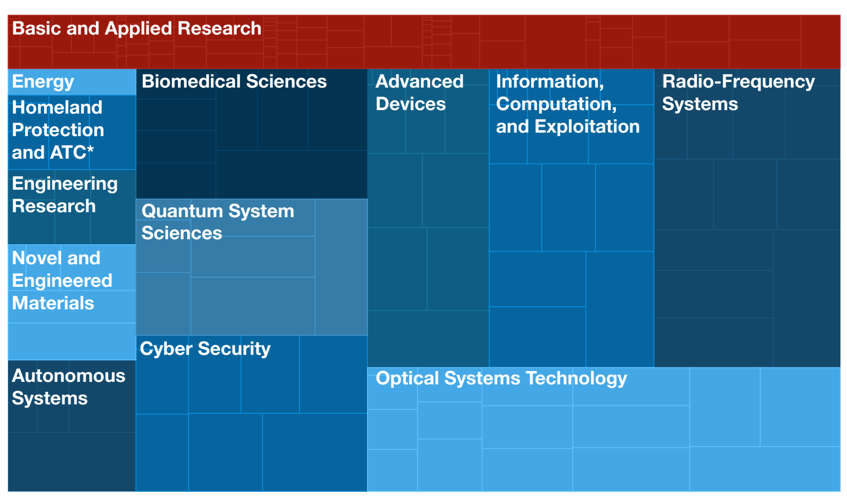
Lincoln Laboratory invests in applied research to develop new technologies and capabilities that support long-term needs in Laboratory mission areas. Research that is more speculative in nature is also supported, as it may lead to innovations that advance national security.

The Technology Office develops and directs strategic research at the Laboratory through focused investments in existing and emerging mission areas. Critical problems that threaten national security determine the Laboratory's research directions and push technology development accordingly. Anticipating challenges that could materialize within five to ten years, the office also supports research that may result in technology solutions for the future. To evaluate future technology needs, the office conducts internal assessments and considers the assessments of many government sponsoring agencies. Interactions with the Assistant Secretary of Defense for Research and Engineering (ASD [R&E]), the Defense Advanced Research Projects Agency, the Department of Homeland Security, and other agencies help the Laboratory maintain awareness of critical defense problems and grow strategic technical relationships. Collaborations with university researchers aid in the translation of new technologies from laboratory-scale to end-user needs.

LEADERSHIP
Dr. Bernadette Johnson, Chief Technology Officer
Dr. Beijia Zhang, Associate Technology Officer (left)
Dr. Peter A. Schulz, Associate Technology Officer (right)

R&D Investment Portfolio

Lincoln Laboratory's internal research and development (R&D) investment portfolio is developed through a number of mechanisms, including competitive solicitations, open calls for proposals in specific technical areas, focused infrastructure investments, and activities designed to promote innovative thinking and creative problem solving. Funding derives primarily from Congressional appropriations administered by ASD(R&E) and is utilized for long-term, high-impact research that is relevant to Department of Defense (DoD) needs. Additional funding is allocated to maintain engineering capabilities, to develop and operate broad-use test beds, and to support innovative research in basic and applied science.



*Air Traffic Control

The Laboratory's internal R&D portfolio supports investments in technical infrastructure and targeted research for emerging and core Laboratory technologies. This graphic displays the relative amounts of 2015 internal funding distributed across mission-critical technology (blue) and basic and applied research (red). The subdivisions within each block represent individual projects.

» MISSION-CRITICAL TECHNOLOGY INVESTMENTS

The 2015 investments are enabling the research and development of technologies that address the long-term challenges and the emerging issues within the Laboratory's core mission areas.

Optical Systems Technology

The development, analysis, and demonstration of novel concepts and technologies enable the next generation of optical systems. In 2015, investments are being made in

- Transmitter, receiver, and beam-pointing hardware for undersea laser communications over long distances
- Photothermal speckle modulation for remote sensing of chemicals and discrimination of remote objects
- Computational imaging sensors for search and track applications
- A focal plane array ladar that achieves two-dimensional (2D) coherent detection with high area coverage rates that support vibrometry and foliage-penetrating moving target detection
- Coherently combined sparse-aperture optical telescopes for deep-space imaging

Cyber Security

Focused on improving the security of computer networks, hosts, and applications, the Laboratory's applied research on cyber security includes the

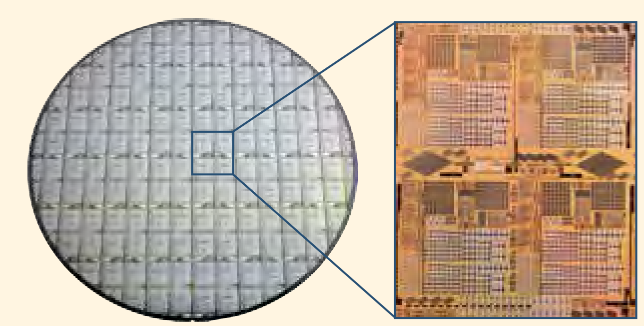
- Characterization and assessment of vulnerabilities created by programmable malicious integrated circuits
- Creation of new functional encryption definitions and protocols for secure cloud computing
- Automated reverse engineering of software systems and malware, including viruses and worms
- Development of a cloud processing architecture for just-in-time encryption (on-demand encryption that re-encrypts right after user decrypts data) of individual threads

Technology Highlight

Gallium Nitride on Silicon with Complementary Metal-Oxide Semiconductor Technology for Advanced Phased Arrays

High-power amplifiers (HPA) typically dominate a phased array radar or communication system's cost and power budget while constraining the transmitter's linearity. Increasing the efficiency of HPAs reduces the system's main power requirements, allowing a higher total output power, and decreases the system's size, weight, and cost. Creating amplifiers with high output power, high efficiency, wide bandwidth, and linearity requires state-of-the-art device technology and circuit techniques.

Lincoln Laboratory is developing a technology that combines gallium nitride (GaN) and silicon complementary metal-oxide semiconductor (Si CMOS) devices to enable more efficient HPAs and highly integrated transmitter/receiver (T/R) modules for advanced phased array systems. Because of GaN's wide bandgap, GaN devices grown on Si substrates provide high output power, high efficiency, and wide bandwidth. The use of CMOS devices enables the integration of additional high-density and power-efficient T/R hardware components, such as phase shifters, analog-to-digital and digital-to-analog converters, and digital controls. Integrating these components on a single integrated circuit greatly reduces the cost of the phased array system and enables circuit techniques, such as those for increasing power amplifier efficiency over wide bandwidths, that may not otherwise be possible.



Above is a 200 mm GaN-on-silicon wafer after it was processed in the Microelectronics Laboratory. Each die, or chip, on that wafer (callout) includes GaN transistors, passive components, and other test structures to help characterize the fabrication process and device properties.

>> *Technology Investments, cont.*

Radio-Frequency Systems

The investment in radio-frequency (RF) systems focuses on research, development, and evaluation of innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Projects being pursued in 2015 include the

- Development of an advanced Ku-band airborne test bed that employs open architectures and low-cost panel-array technology
- Use of adaptive multibeam antenna technology to provide robust communications for the contested airborne domain
- Design of novel ultrathin miniaturized RF receiver tags fabricated with silicon circuitry

Information, Computation, and Exploitation

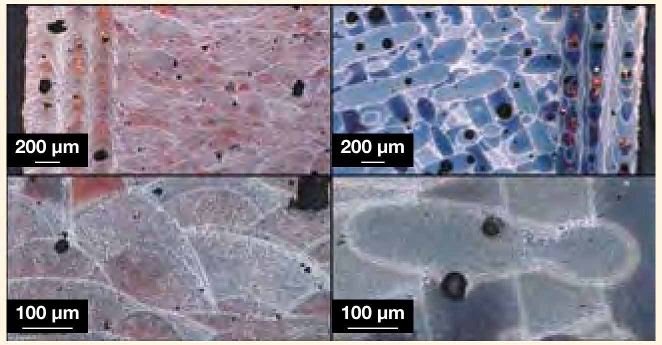
Challenges posed by the increasing growth in the volume and the variety of data available to the DoD and intelligence community are prompting innovation in several key areas, such as exploitation analytics, computation, processing, architectures, and data delivery. Currently, the Laboratory is leading advancements in

- Jointly mining time-aligned audio and visual data to facilitate content-based search and exploitation of large collections of unstructured, uncooperatively collected video
- Extending network-discovery algorithms to generate operationally relevant models of threat networks from potentially noisy multiple-intelligence data
- Assessing how cryogenic digital logic circuits could optimize the performance of future DoD computational architectures and providing recommendations for specific future applications

Technology Highlight

Mechanical Behavior of Three-Dimensionally Printed Metals

Lincoln Laboratory is increasingly employing three-dimensional (3D) printing, or additive manufacturing (AM), technologies to fabricate complex structural components for fielded prototype systems. Fused deposition modeling of polymer materials is typically used to print structures requiring low strength; direct metal laser sintering (DMLS) of metallic alloys is employed when components will be subjected to high operational loads. Though the mechanical properties of these alloys are purported to be comparable to those of conventional (wrought and machined) alloys, variations in the AM process parameters (laser power, travel rate) and in post-fabrication treatments (thermal stress relieving and hot isostatic pressing) potentially create differences in the alloys' mechanical behaviors.



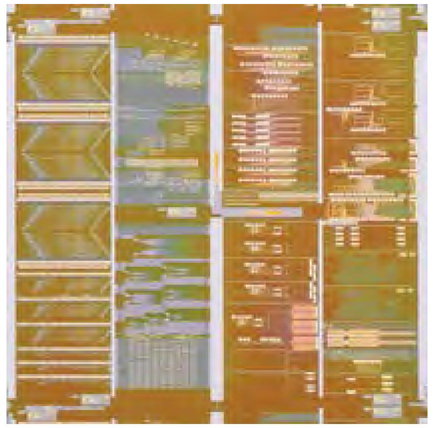
The laser fusion of alloyed aluminum powder (AlSi10Mg) results in segregated melt pools that rapidly cool to create the fine crystalline structure seen above: left, section perpendicular to build planes; right, section parallel to build planes. Surface layers are created perpendicular to the bulk (i.e., within the main volume of the material), and high porosity is evident.

To enable Laboratory engineers to use DMLS for the fabrication of reliable and increasingly complex aerospace system components (e.g., heat exchangers, spacecraft thruster nozzles, lightweight mirrors), researchers have been studying the mechanical properties of aluminum, titanium, and stainless steel DMLS alloys. Measurements of the stress-strain characteristics and cyclic fatigue behavior of these materials revealed that, while they demonstrate quasi-static stiffness and strength similar to the stiffness and strength of their conventional counterpart materials, they exhibit inferior strengths in response to dynamic loading. The very high surface roughness, porosity, and other intrinsic bulk defects (e.g., contaminant particles, microcracks, poorly fused or unmelted alloy powder) of the DMLS materials were shown to correlate directly with poor cyclic fatigue strengths. Laboratory researchers were able to improve the ductility and fatigue strength of the titanium alloy by post-processing it with hot isostatic pressure. Continued efforts are exploring thermal treatment of this alloy to produce a microstructure that will have fatigue strength approaching that of conventional material.

Advanced Devices

The development of unique, innovative components and subsystems enables new capabilities for electronics, optics, and sensing technologies. Several devices are being developed in 2015:

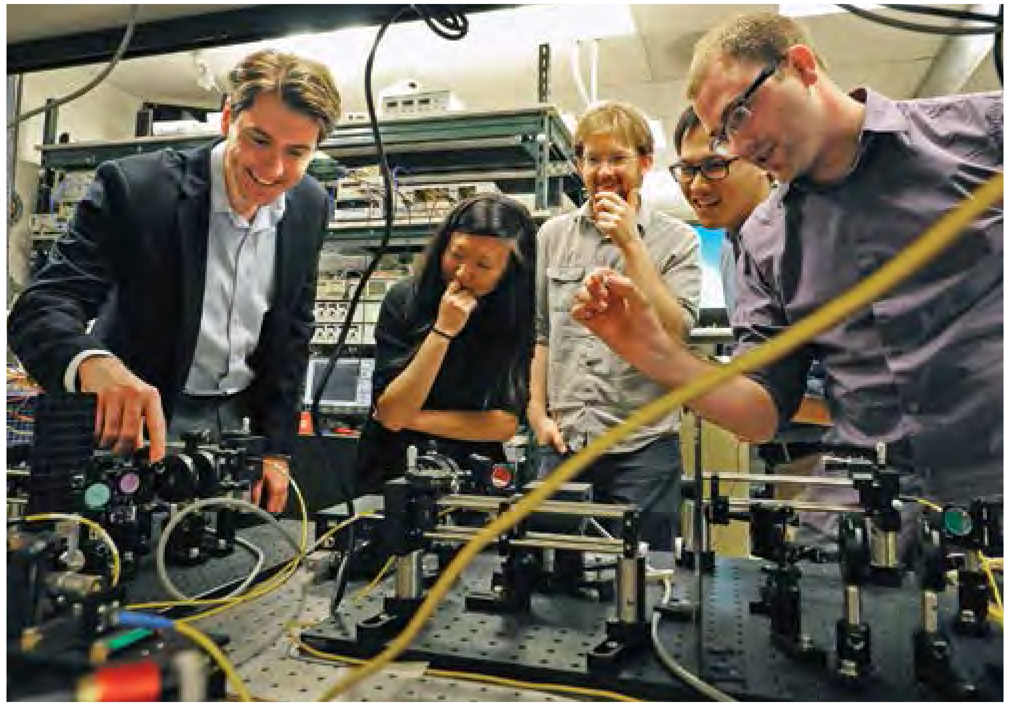
- Diamond transistors for use in extreme environments
- Digital on-chip processors for large visible imagers
- Large-format, short-wave infrared imagers for space surveillance and hyperspectral imaging
- Uncooled liquid-crystal megapixel thermal imagers for low–size, weight, and power applications
- Integrated wavelength-division multiplexing laser communication transceivers for different data rates and modulation formats
- Microhydraulic actuators for microrobotics



The photonic integrated circuit on this 22 × 22 mm silicon chip was fabricated in the Microelectronics Laboratory. The circuit is a reconfigurable eight-channel wavelength-division multiplexing optical receiver with more than 100 components.

Quantum System Sciences

Research and development in quantum system sciences focuses on systems that have sensing, communication, and processing power unachievable in classical systems. Researchers are exploring superconducting qubits with sufficiently long coherence times for quantum computing as well as quantum sensing with nitrogen vacancies in diamond for highly sensitive vector magnetic-field sensors. Another effort is to build a quantum computer on a chip by using integrated photonics and 2D trapping of two ion species.



P. Benjamin Dixon (left), a technical staff member at Lincoln Laboratory, discusses with MIT graduate students and postdoctoral associates how quantum illumination can be used for secure communication, potentially enabling much higher data rates than those possible with existing quantum secure communication protocols.

>> Technology Investments, cont.

Lincoln Laboratory researcher Todd Thorsen sets up a microfluidic device designed for high-throughput assembly and testing of genetic circuits.

Biomedical Sciences

The biomedical sciences initiative seeks to address national health-care needs and to enhance warfighter performance and resilience. Researchers are constructing a multimaterial three-dimensional (3D) printer that combines organic and inorganic materials to produce unique structures, such as complex scaffolds for cartilage tissue repair. A 3D-printed artificial gut in which microbial communities can be cultured and observed is being fabricated. To enhance the visualization and diagnosis of bone disease, traumatic brain injury, and internal bleeding, researchers are developing a noncontact ultrasonic imaging system.

Autonomous Systems

Autonomy and robotics research conducted at the Laboratory seeks to enable unmanned systems to perform useful tasks in complex air, ground, space, and maritime environments without continuous human control. Algorithms and sensing modalities are being developed to support autonomous navigation, object tracking and detection, real-time decision making, and vision-based obstacle avoidance.

Homeland Protection and Air Traffic Control

Investments support research and prototyping efforts that solve critical national problems in transportation safety, land-border and maritime security, critical infrastructure protection, and disaster response. The 2015 projects cover a range of technologies: a system that rapidly maps contaminated areas after a biological attack; decision support tools to address the integration of space launch and reentry vehicles into the National Airspace System; fast-time simulation tools that can be used in training air traffic controllers and testing newly developed air traffic management strategies; and an airborne sensor platform that performs wide-area monitoring in post-disaster zones and in heavily foliated environments.

Energy

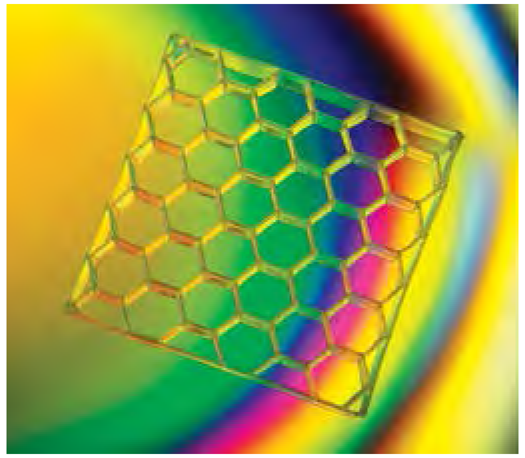
Lincoln Laboratory supports DoD energy security, the national energy system's sustainability, and energy generation in remote areas. Researchers are studying how the information and communications technologies used in DoD energy grids can be secured against cyber attacks. Technologies being developed to produce energy in remote locations include a miniature thermoacoustic engine, smart batteries, a portable power converter for generating alternating current from a photovoltaic source, and ultralightweight solar cells. A modular deployable multifunctional system that is being prototyped will provide water purification, power, communications, and cooling in disaster relief zones.

Engineering Research

The Laboratory's divisions depend on state-of-the-art engineering capabilities, which are explored and developed through investments in four areas of engineering research: integrated modeling and analysis tools, advanced materials, optical capabilities, and process development.

Novel and Engineered Materials

The Laboratory develops, manufactures, and tests novel materials whose properties can add new capabilities to systems and components, greatly enhancing their performance characteristics. Current research is focused on the development of materials for 3D printing of low-loss RF devices; the growth and characterization of 2D materials, such as transition metal dichalcogenides; and the demonstration of liquid-metal microfluidic devices for RF applications.



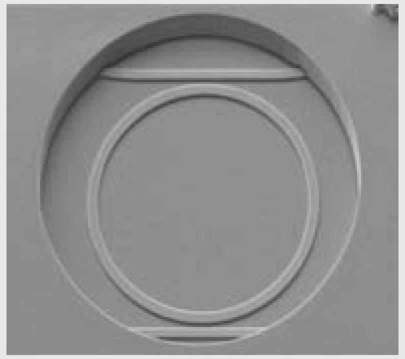
This hexagon test structure was 3D printed with a novel Lincoln Laboratory–developed low-loss RF dielectric material.

>> BASIC AND APPLIED RESEARCH

Basic and applied research projects focus on concept development. Funding is administered by the Technology Office and through committees that solicit and review proposals from Laboratory staff and MIT researchers. Investments in basic and applied research support many projects (see the infographic on page 8), two of which are highlighted below.

Permanent Refractive-Index Trimming for Integrated Optic Tuning

Integrated optics allows the monolithic integration of a large number of optical devices onto a single chip. One challenge with integrated optics, and silicon photonics in particular, is that the performance of some devices is critically dependent on the exact dimensions of the device. For example, the resonant frequency in an optical filter varies significantly with subangstrom dimensional changes. Because it is impossible to control such dimensional changes, the devices need to be tuned to the desired resonant frequency, typically by locally heating the optical structure—a suboptimal process because it requires control electronics and significant electrical power.



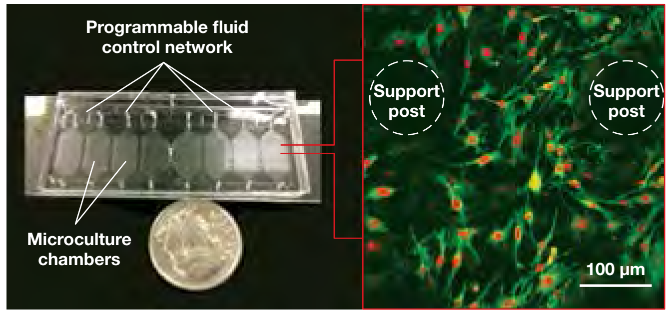
The cladding of this silicon ring resonator filter was selectively removed to allow application of a permanent refractive-index trimming material.

An alternative solution to active thermal tuning is to permanently trim the resonant frequency after fabrication by cladding the structure with a material having a refractive index that can be permanently changed through temporary local heating at high temperature (~500° C). This heating can be achieved by integrating resistive elements into the optical structure. The advantage of this method is that heat is only applied during the trimming phase. Lincoln Laboratory researchers are working to identify materials that will change index at high temperature and remain stable. To date, they have measured a suitable index change in several materials: hydrogen silsesquioxane, polymethyl glutarimide, and low temperature oxide. Future work will involve characterizing the stability of these materials and trimming filter devices. By eliminating the need for active control of individual filter elements, this technology can greatly simplify and lower the power requirements of optical systems, including those for free-space optical communications and for signal processing that uses RF photonics.

Regulation of Cellular Reprogramming via Microfluidics

Compared with other animals, such as salamanders and starfish, humans have a limited ability to repair and regenerate tissues and organs. One strategy to enable regeneration utilizes an individual's stem cells, which can divide and develop into almost any specialized cell type. Because stem cells from early embryos are scarce and the purification of adult stem cells only recapitulates specific tissues and organs, biologists have been developing methods to "reprogram" adult cells into induced pluripotent stem cells (IPSC) that can differentiate into any cell type. Yet generating IPSCs is highly inefficient (<0.1%).

To improve reprogramming efficiency, a team from Lincoln Laboratory, the Harvard Stem Cell Institute, and the Broad Institute of MIT and Harvard fabricated a novel microfluidic device that controls the microenvironment of cells during the reprogramming process. The device's fluidic control network permits the highly controlled introduction of spatial and temporal profiles of biochemical and mechanically induced reprogramming pressures on µm and nL scales; this network is connected to an array of chambers in which adult cells are captured, cultured, and microfluidically perturbed. Typically, reprogramming approaches use culture dishes and handheld pipettes, which are large (cm and mm scales) and require large populations of cells; as a result, cellular dynamics and signaling states that occur during the reprogramming process are obscured by cell surface markers or genes expressed only in pluripotent stem cells or from cell states of the most abundant type. The team's approach is the first to address these limitations, enabling dynamic analysis of the reprogramming process and increasing reprogramming efficiency to >5–10%.



The fabricated microfluidic device's programmable fluidic network is connected to miniature cell culture chambers. Inducible pluripotent cells that were cultured in the device are seen in the immunofluorescence image; a component of the cell's cytoskeleton, actin, is stained green and the nucleus is stained red.

The main area inside TOIL (above) features work benches and desk stations. TOIL's open layout facilitates collaboration. Inside the machine shop (right) are various tools, including a band saw, drill press, and milling machine. Staff must complete a general machine shop safety course and individualized training on each piece of equipment they wish to use.

Technology Office Innovation Laboratory

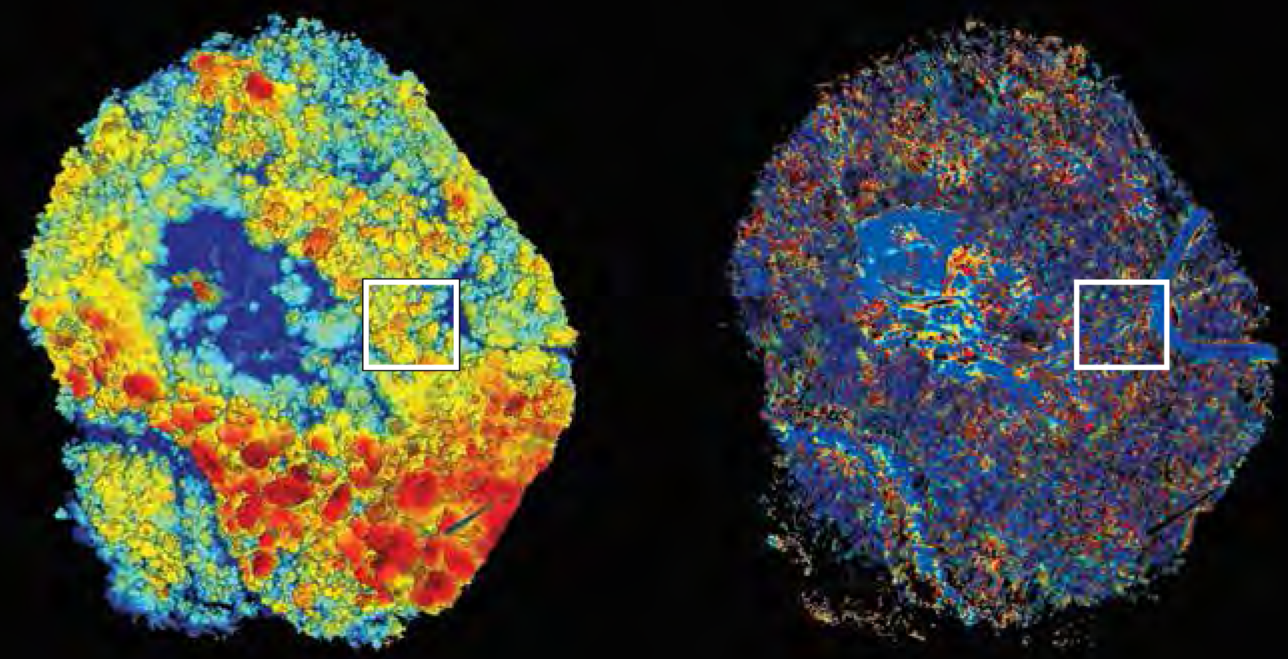
The Technology Office Innovation Laboratory (TOIL) is a do-it-yourself open space where Laboratory staff can validate preprogram ideas, pursue curiosity-driven prototyping, and work on internally funded programs that require experimentation and tinkering. Areas for rapid prototyping, electronics fabrication, machining, software engineering, and system development make TOIL a versatile "maker" space that can be used by technical staff from across the Laboratory. Each area is equipped with relevant tools—three-dimensional (3D) printers, manual and computer-controlled 3D machining equipment, electronics design and fabrication equipment, computer-aided design software—for which staff can receive hands-on training. This multidisciplinary setting encourages the cross-fertilization of ideas and skills, fostering innovation and creative problem solving.

PrintLab Challenge

Sponsored by the Technology Office, the PrintLab Challenge is an ongoing initiative to promote the Laboratory's collective understanding of the current capabilities and limitations of 3D printing. Staff members are encouraged to explore different printing concepts, methods, and materials. TOIL houses both industrial- and desktop-scale 3D printers.

Farshid Neylon-Azad (top right) adjusts a 3D-printer head in development for the Dynamic Build Volumes project to enable spatially unconfined 3D printing. Traditional 3D printers have fixed build volumes within which they can print high-resolution objects. David Scott (above), manager of TOIL, explains to members of Lincoln Laboratory's Technical Women's Network the various structures that can be fabricated by a 3D printer.

This pneumatic grabber is thought to be the first pneumatically actuated three-digit manipulator printed via fused deposition modeling (a 3D-printing technique), according to its maker, Thomas Sebastian. It requires minimal pressure to open, and its compliant structure allows it to grasp fragile objects.

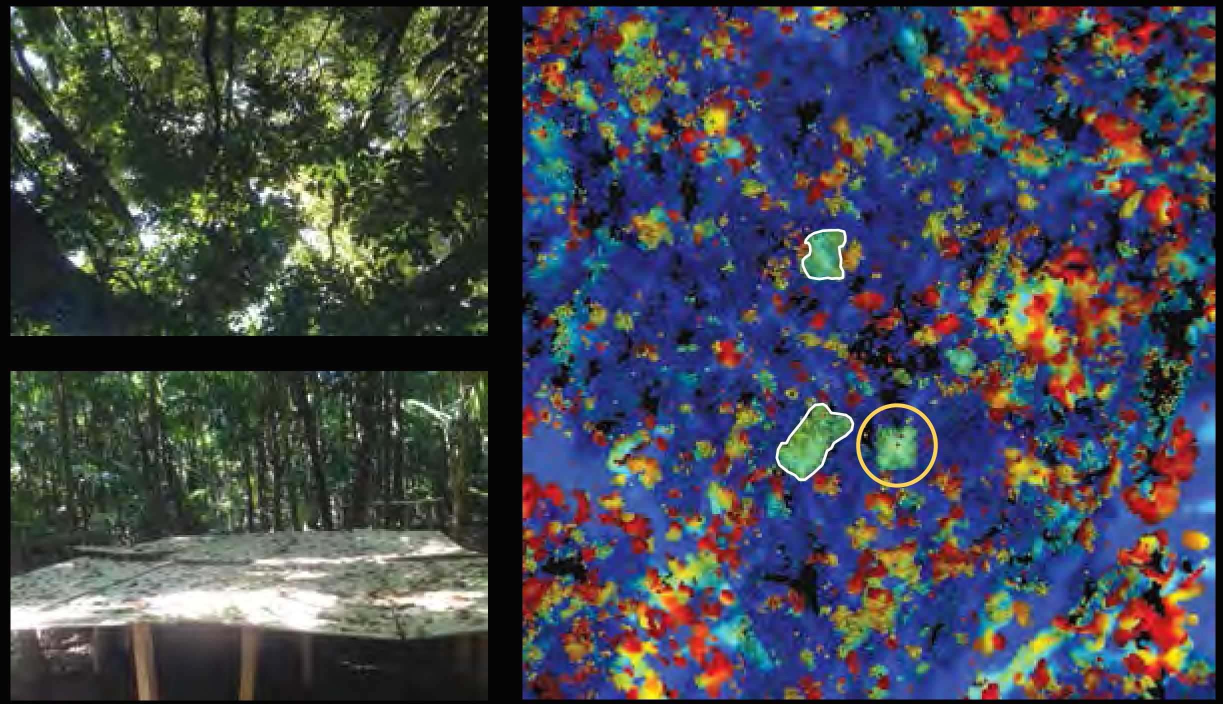


The Multi-look Airborne Collector for Human Encampment and Terrain Extraction imaged a 1 sq km diameter region of the El Yunque Rainforest in Puerto Rico. The blue-to-red color map (above left) is based on height above ground; blue corresponds to the ground level and red to the highest elevation above ground, i.e., the tallest treetops. The canopy can be digitally "defoliated" (above right) to reveal the structures, roads, and trails existing beneath it at any elevation. Several test structures were placed under heavy canopy in a 90 m × 90 m area, indicated by the corresponding white squares.

Multi-look Airborne Collector for Human Encampment and Terrain Extraction

In the aftermath of the 7.0-magnitude earthquake that struck Haiti in 2010, many roads and bridges were so badly damaged by and obstructed with rubble that vehicles were unable to navigate through them to conduct relief and recovery missions. At the request of the U.S. Southern Command (USSOUTHCOM), Lincoln Laboratory deployed its Airborne Ladar Imaging Research Testbed (ALIRT) to perform damage assessment and provide situational awareness. The ladar collected high-resolution, three-dimensional (3D) images of the earthquake-stricken capital Port-au-Prince. The products based on ALIRT's 3D imagery (e.g., digital elevation models, geometric change-detection maps) helped military commanders assess road and bridge trafficability, find helicopter landing zones, and quantify the mass migration of displaced persons so that relief distribution logistics could be appropriately planned.

The imagery produced by ALIRT in Haiti and later Afghanistan demonstrated the efficacy of using Geiger-mode avalanche photodiode (GMAPD) detector arrays in a ladar system to produce high-quality 3D imagery. Subsequently, USSOUTHCOM asked the Laboratory to develop an ALIRT-like system optimized with foliage-penetration capabilities. Called the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE), this system can peek through openings in dense canopy to form detailed images of natural and man-made structures existing at and near the ground level.



The above images correspond to the 90 m × 90 m region (shown in the figures on the facing page) in which test targets were placed under heavy canopy. A photograph taken from the ground level and looking up shows how much canopy cover was present (upper left). One of the targets is a 4.9 m × 4.9 m plywood structure, seen as photographed from the ground in the lower left. This target is called out in the yellow circle on a zoomed-in version of the digitally "defoliated" map (above right). Two other targets of different sizes and material composition are outlined in white. All test structures are placed at about the same height above ground, giving them a cyan color according to the blue-to-red color map. Because of their relatively clean edges and corners, they appear to be man-made rather than natural structures.

While flown on an airborne platform over a forested area, MACHETE performs multiple scans from different angles. During each scan, the ladar sends multiple high-energy, narrow laser pulses that illuminate the scene and scatter light in all directions. Some of the laser energy, or light, makes it through canopy openings to the ground and reflects back toward the system; this light is collected by a receiver telescope and focused onto two 16-kilopixel GMAPD detector arrays. At each pixel, a timing circuit measures the arrival time of the returning pulses. Because these pulses have distinct path lengths (based on the distance from the ground to MACHETE's airborne platform), their times of flight differ. This time-of-flight measurement is combined with pointing information of MACHETE's gimbaled scanning system and the position of the airborne platform to produce a geolocated 3D point-cloud image. The imagery is color-coded to indicate differences in scene elevation, with color brightness indicating the intensity of the reflected light.

Capable of collecting unobscured 3D imagery from an altitude of 25 kft and at an incredible area coverage rate ($400\ km^2$/hr at 25 cm resolution or $1200\ km^2$/hr at 50 cm resolution), MACHETE maps out city-scale areas in minutes. For a heavily forested area that has 90% canopy cover and is the size of New York City's Central Park ($3.4\ km^2$), MACHETE can provide detailed images of every building, footbridge, and walkway below the canopy at 25 cm resolution in about five minutes. Advanced onboard processing and analysis algorithms enable the classification of such features of interest. The canopy can be digitally "defoliated" to reveal the structures underneath at any selected height above ground. Compared to ALIRT and other airborne ladar systems, MACHETE produces a higher-resolution product from higher altitudes and at faster area collection rates.

Following an initial capability demonstration in Puerto Rico's El Yunque Rainforest, MACHETE was deployed in May 2014 to USSOUTHCOM's area of responsibility, a region comprising 31 countries and 15 areas of special sovereignty in Central and South America and the Caribbean. The ladar has since been successfully conducting sorties outside the continental United States in support of USSOUTHCOM missions. Lincoln Laboratory continues to monitor and analyze system performance and upgrade MACHETE's sensing and processing capabilities.

ALCOR, at left, and TRADEX radar

ALTAIR

A Super RADOT sensor

Real-time Open Systems Architecture for Reagan Test Site Sensor Systems

Lincoln Laboratory, under the sponsorship of the U.S. Army Space and Missile Defense Command, designed, developed, and implemented a new Real-time Open Systems Architecture (ROSA II) technology that is improving the efficient operation of the radar and optical sensors at the Reagan Test Site (RTS) on the Kwajalein Atoll in the Marshall Islands. This technology decomposes the real-time control program and data processing chain into individually defined functional software components that are housed atop a common, flexible, real-time communications substrate. Because this architecture offers a level of real-time data accessibility and system control that has not been achieved previously, it allows for netcentric operation at the sensor and provides an ability to rapidly implement new software functions or to substitute existing functions from other systems built with ROSA II.

ROSA II has been successfully implemented on the test site's radar sensors: the Millimeter Wave system (MMW), the ARPA-Lincoln C-band Observables Radar (ALCOR), two MPS-36 tracking radar systems, the Target Resolution and Discrimination Experiment (TRADEX), and the ARPA Long-Range Tracking and Instrumentation Radar (ALTAIR). The Super Recording Automatic Digital Optical Tracker (Super-RADOT) optical sensors at RTS are also utilizing ROSA II.

MMW radar system

While the Radar Open Systems Architecture (ROSA), the first-generation architecture that Lincoln Laboratory developed, was designed primarily for use on dish radar systems, this second-generation ROSA II extends the open concept to all sensor and control system software. The ROSA II control program and back-end processing for optical, radar, and telemetry systems use a layered software architecture that isolates sensor applications from underlying hardware and software elements, such as operating systems, middleware, communication fabrics, and computer platforms. Key to this approach is the ROSA Thin Communications Layer, a novel application program interface developed by the Laboratory to unify the data and information transfer interface and to isolate the application component layer from the details of middlewares and other data-transport mechanisms. Because ROSA II enables the interoperability of diverse hardware and software components, systems are not constrained to only one operating platform or only system-specific components.

For Department of Defense acquisitions, systems utilizing open architectures, such as ROSA II, offer significant advantages:

- New systems can be rapidly developed and fielded because software development and unit testing is efficient.
- System functionality can be updated more effectively than in the past because only software modules key to the specific upgrade need to be replaced or modified.
- System maintenance costs are reduced because hardware and software can be reused or can be purchased from commercial vendors through competitive third-party bidding.

Technology Transfer

Lincoln Laboratory's research and development activities help strengthen the nation's technology base.

The transfer of the Laboratory's new capabilities and enabling technologies helps ensure that advanced technology is available to the U.S. military services and government agencies, and that U.S. industry is at the forefront of technical innovation.

2015 TECHNOLOGY TRANSITIONS

Advanced Technology

A world-leading superconducting microelectronic process was made available to industry performers.

Air Traffic Control

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

Decision support tools are being transferred into the Federal Aviation Administration's (FAA) Traffic Flow Management System through 2020. These tools provide 0–2-hour forecasts of convective weather impact on terminal arrival routes and use wind, ceiling, and visibility forecasts and airport-specific operating procedures to aid in setting airport arrival rate targets.

Communication Systems

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

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

Intelligence, Surveillance, and Reconnaissance Systems and Technology

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

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

Tactical Systems

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

Selected Patents 2014–2015

Patterned Nonreciprocal Optical Resonator
Lionel C. Kimerling, Caroline A. Ross, Lei Bi, Peng Jiang, Juejun Hu, Dong Hun Kim, and Gerald F. Dionne
U.S. Patent no.: 8,837,877

Time-Interleaved Multi-modulus Frequency Divider
Matthew C. Guyton
U.S. Patent no.: 8,847,637

Method and Apparatus for Measuring a Position of a Particle in a Flow
Thomas H. Jeys, Antonio Sanchez-Rubio, Ronald H. Hoffeld, Jonathan Z. Lin, Nicholas M.F. Judson, George S. Haldeman, and Vincenzo Daneu
U.S. Patent no.: 8,867,046

Filter-Based DPSK Communications System
David O. Caplan and Mark L. Stevens
U.S. Patent no.: 8,886,049

Digital Readout Method and Apparatus
Michael Kelly, Daniel Mooney, Curtis Colonero, Robert Berger, and Lawrence Candell
U.S. Patent no.: 8,933,832

Method and Kit for Stand-off Detection of Explosives
Charles M. Wynn, Robert W. Haupt, Sumanth Kaushik, and Stephen T. Palmacci
U.S. Patent no.: 8,935,960

Patterning of Nanostructures
Joseph M. Jacobson, David Kong, Vikas Anant, Ashley Salomon, Saul Griffith, Will DelHagen, and Vikrant Agnihotri
U.S. Patent no.: 8,937,001

Vehicle Localization Using Surface Penetrating Radar
Byron M. Stanley, Matthew T. Cornick, Charles M. Coldwell, Jeffrey C. Koechling, and Beijia Zhang
U.S. Patent no.: 8,949,024

Asymmetric Multilevel Outphasing Architecture for RF Amplifiers
Joel L. Dawson, David J. Perreault, SungWon Chung, Philip Godoy, and Everest Huang
U.S. Patent no.: 8,957,727

Method and Apparatus for Sparse Polynomial Equalization of RF Receiver Chains
Andrew Bolstad, Benjamin A. Miller, Karen Gettings, Merlin Green, Helen Kim, and Joel Goodman
U.S. Patent no.: 8,958,470

Methods of Achieving Optimal Communications Performance
David O. Caplan and Walid A. Atia
U.S. Patent no.: 8,958,666

Apparatus and Method for Aerosol Collection and Fluid Analysis
John P. D'Angelo
U.S. Patent no.: 8,955,368

Analog/Digital Co-design Methodology to Achieve High Linearity and Low Power Dissipation in a Radio Frequency (RF) Receiver
Helen Kim, Merlin Green, Andrew Bolstad, Daniel D. Santiago, Michael N. Ericson, Karen Gettings, and Benjamin A. Miller
U.S. Patent no.: 8,964,901

Coatings
Nuerxiati Nueraji, Albert J. Swiston, Michael F. Rubner, and Robert E. Cohen
U.S. Patent no.: 8,986,848

Optoelectronic Detection System
James D. Harper, Richard H. Mathews, Bernadette Johnson, Martha S. Petrovick, Ann Rundell, Frances E. Nargi, Timothy Stephens, Linda M. Mendenhall, Mark A. Hollis, Albert M. Young, Todd H. Rider, Eric D. Schwoebel, and Trina R. Vian
U.S. Patent no.: 9,005,989

Imaging Systems and Methods for Immersive Surveillance
Daniel B. Chuang, Lawrence M. Candell, William D. Ross, Mark E. Beattie, Cindy Y. Fang, Bobby Ren, Jonathan P. Blanchard, Gary M. Long Jr., Lauren L. White, Svetlana V. Panasyuk, and Mark Bury
U.S. Patent no.: 9,007,432

Spark-Induced Breakdown Spectroscopy Electrode Assembly
Shane M. Tysk, John P. D'Angelo, and William D. Herzog
U.S. Patent no.: 9,030,659

Efficient Pulse Doppler Radar with No Blind Ranges, Range Ambiguities, Blind Speeds, or Doppler Ambiguities
William S. Song
U.S. Patent no.: 9,075,138

Assisted Video Surveillance of Persons of Interest
Jason R. Thornton, Daniel J. Butler, and Jeanette T. Baran-Gale
U.S. Patent no.: 9,111,147

Thulium Laser
Tso Yee Fan
U.S. Patent no.: 9,112,329

Architecture for Content and Host-Centric Information Dissemination in Delay-Tolerant MANETs
Praveen Sharma, Jason Biddle, Aaron Daubman, Evan Fiore, Timothy Gallagher, Jeremy Mineweaser, Santiago Paredes, Daniel Souza, Heather Zwahlen, Maximillian Merfield, and Larry Robinson
U.S. Patent no.: 9,110,226

Methods, Systems, and Apparatus for Coherent Beam Combining
Steven J. Augst, Juan C. Montoya, Tso Yee Fan, and Antonio Sanchez-Rubio
U.S. Patent no.: 9,134,538

High Peak Power Optical Amplifier
Bien Chann, Tso Yee Fan, Antonio Sanchez-Rubio, and Steven J. Augst
U.S. Patent no.: 9,136,667

Method and Apparatus for Making Optimal Use of an Asymmetric Interference Channel in Wireless Communication Systems
Rachel Learned
U.S. Patent no.: 9,148,804

>> *Technology Transfer, cont.*

Homeland Protection: NICS Reaches Australia

The Department of Homeland Security Science and Technology Directorate (DHS S&T) and Lincoln Laboratory have entered into a partnership with Emergency Management Victoria (Australia) to collaborate on the development of future advancements to the Next-Generation Incident Command System (NICS) that was developed by the Laboratory under DHS S&T sponsorship. Emergency Management Victoria, which had already begun to implement the NICS decision support software to help manage responses to disasters, has been training 1000s of its first responders to use the system.

Through the establishment of this partnership, any improvements and modifications made to NICS will be shared and incorporated into a standards-based open-source system that is expected to be released to the global community by 2016. One strength of NICS is its ability to integrate data from multiple sources. "Oftentimes, systems used to manage disasters are not interoperable, making collaboration difficult and resource management take longer than it needs to. In a disaster, wasting time can cost lives and property," says Gregory Hogan, leader of the Laboratory's Humanitarian Assistance and Disaster Relief Systems Group and program manager for NICS.

In addition to enhancing the current tools for providing situational awareness during disaster responses, the partner organizations will be exploring mobile applications of the system and ways for NICS to operate in rural environments whose network connectivity is limited or in areas whose communications infrastructure has been damaged by a disaster.

Melissa Choi (far left), Head, Homeland Protection and Air Traffic Control Division, Lincoln Laboratory, and Reginald Brothers (center), Under Secretary for Science and Technology, Department of Homeland Security, met with representatives from the Australian Parliament and the Emergency Management Victoria to establish a collaboration to further develop the Next-Generation Incident Command System.

New Lincoln Laboratory Field Office

Lincoln Laboratory Director Eric Evans (center), assisted by (left to right) Christopher Putko, Jeffrey Gottschalk, Stephen Rejto, and William Semancik, cut the ribbon to open a field site in Annapolis Junction, Maryland, on 30 April 2015. The field site will support research and development efforts sponsored by the National Security Agency, U.S. Cyber Command, the Defense Information Systems Agency, and other DoD and intelligence community organizations.

Helping Achieve Dominant U.S. Capabilities

MIT Lincoln Laboratory's research and development, technology transfer activities, and management and operations support the Department of Defense's Better Buying Power initiative.

In April 2015, the Department of Defense (DoD) released its third iteration of Better Buying Power (BBP). Developed and implemented in 2010, BBP is a continuous effort to improve productivity, efficiency, and effectiveness in the defense acquisition system. The 2015 version, known as BBP 3.0, adds a strong emphasis on the criticality of maintaining U.S. technological superiority.

The central theme in BBP 3.0 is "achieving dominant capabilities through technical excellence and innovation." As a DoD Research and Development (R&D) Laboratory, Lincoln Laboratory supports the BBP objectives by addressing three key areas:

- *Maintaining technological superiority.* Lincoln Laboratory focuses its R&D on developing innovative technology to solve the most difficult national security problems. Directing its efforts to areas of strategic importance to current and emerging DoD missions, the Laboratory is building and demonstrating novel systems, applications, components, and prototypes. These cutting-edge technologies can be rapidly fielded or integrated into existing systems to enhance the capabilities of the U.S. warfighter.

  To assure that its workforce remains at the forefront in science and engineering, the Laboratory emphasizes technical education, supporting initiatives such as the Lincoln Scholars program that funds study toward advanced degrees and both onsite and distance learning courses that cover a broad range of fields.

  Throughout the 2015 Annual Report are highlights of the work the Laboratory is performing to provide the DoD with advanced technical solutions to DoD needs. Unique work in new technologies is showcased in the preceding Technology Investments and Technology Transfer sections.

- *Influencing the affordability of future government acquisition programs.* By analyzing the efficacy of program requirements, the Laboratory optimizes the process and schedule for system development, thus reducing the costs of and technical risks to programs. Through transferring intellectual property and prototypes to government agencies and industry and by developing systems that use commercially available components, the Laboratory enables the government to take advantage of competitive bidding for the procurement of new systems.

- *Ensuring effective and cost-efficient operations.* The Laboratory embraces its fiduciary responsibility to be a good steward of taxpayer dollars. A variety of mechanisms to reduce costs and increase operational efficiency are maximizing sponsors' investments. For example, the Laboratory leverages the purchasing power of MIT through its eCAT system, which allows buyers to obtain volume discounts and which streamlines the purchasing process for commercial off-the-shelf items.

DEPARTMENT OF DEFENSE · UNITED STATES OF AMERICA

"Potential adversaries are challenging the U.S. lead in conventional military capability in ways not seen since the Cold War. Our technological superiority is based on the effectiveness of our research and development efforts."

— Frank Kendall,
Under Secretary of Defense for Acquisition, Technology and Logistics, in formally issuing BBP 3.0

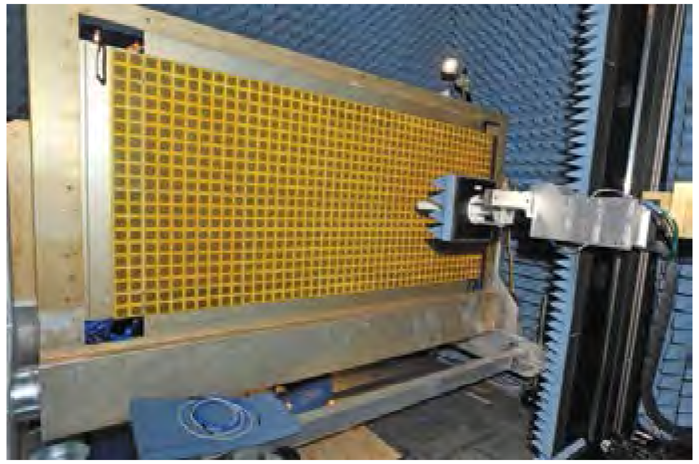
>> Helping Achieve, cont.

Better Buying Power in Action

The following examples are a small sample of the ways Lincoln Laboratory actively supports BBP 3.0.

Effective Innovation

Lincoln Laboratory is developing the Multifunction Phased Array Radar (MPAR) to provide faster scanning and higher-quality observations of aircraft and weather than can be achieved by current radar systems. Because MPAR can simultaneously perform aircraft and weather surveillance, an MPAR network could reduce the total number of radars needed for these functions by approximately one-third, potentially saving the government billions of dollars over the lifetime of the radars. In addition, since 2006, Lincoln Laboratory personnel have been developing low-cost active phased array radar to increase the affordability of this technology that is now standard equipment for many defense applications but has not been adopted by civilian agencies, such as the Federal Aviation Administration (FAA) and the National Weather Service (NWS), because of its high costs. This May, the Laboratory demonstrated a low-cost, dual-polarized 10-panel MPAR system that supports the FAA and NWS missions.



Measurements of far-field antenna patterns were taken with this Multifunction Phased Array Radar prototype in Lincoln Laboratory's antenna test facility. Measurements showed excellent symmetry and power levels.

Under the SensorSat program, the Laboratory is working to demonstrate a new approach for providing space situational awareness of the geosynchronous Earth orbit; this approach is aimed at improving satellites' capability to frequently search portions of the sky. Researchers are developing a 100 kg–class microsatellite with a 10 cm aperture telescope. By utilizing commercial vendors and off-the-shelf components, the SensorSat team expects to build the system in approximately 36 months for less than $64 million, as compared to previous system developments, such as for the Space-Based Space Surveillance System, which took 72 months to design and build at a cost of more than $1 billion.

U.S. Air Force Renews Lincoln Laboratory's Contract

On 28 April, MIT and the U.S. Air Force signed a contract renewal to continue the operation of Lincoln Laboratory as a Federally Funded Research and Development Center. At the signing were (front row) Mark Johnson, Procurement Contracting Officer, Air Force Life Cycle Management Center, Enterprise Acquisition Division, Hanscom Air Force Base; and Michelle Christy, Director, MIT Office of Sponsored Programs; (back row) Scott Kiser, Director of Contracting, Air Force Life Cycle Management Center, Hanscom Air Force Base; Scott Anderson, Assistant Director for Operations, Lincoln Laboratory; Maria Zuber, Vice President for Research, MIT; Richard Lombardi, Principal Deputy Assistant Secretary of the Air Force (Acquisition); Alan Shaffer, Principal Deputy Assistant Secretary of Defense for Research and Engineering; and Eric Evans, Director, Lincoln Laboratory.

Efficient Processes

The Laboratory is employing modular open-system architectures (OSA) in many of its development programs because these architectures enable developers to create or modify embedded systems without expensive design work to accommodate the specific needs of the new systems. For example, by integrating OSA in the Advanced Airborne Radar, a test bed used in developing radar concepts and demonstrating advanced radio-frequency (RF) technology, the Laboratory will be able to easily and quickly tailor the radar to meet various test requirements and will save the expense and time of obtaining a test capability from external vendors. The use of OSAs also allows for greater industry participation in the development process and for efficient, effective transition of prototype systems to industry production.

The Laboratory, a major supporter of small business, is partnering with these businesses to transfer intellectual property and prototypes. For example, as part of an effort that is developing advanced border surveillance technologies for the Department of Homeland Security Science and Technology Directorate, Lincoln Laboratory will work with the sponsor to transition these technologies to a small business.

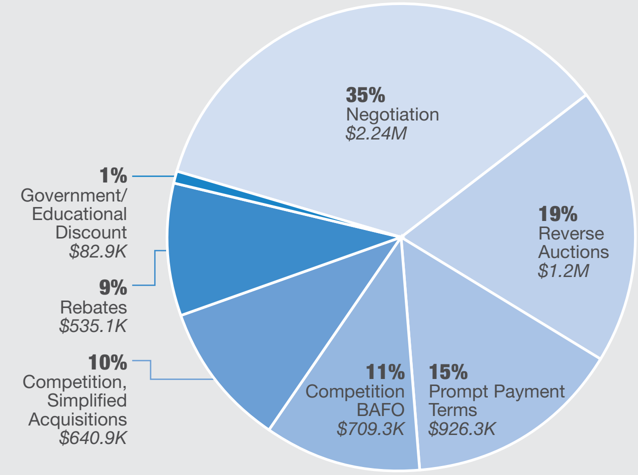
Lincoln Laboratory is developing an online system that automatically generates the government-required classification and control markings on products (e.g., documents, software, videos) containing technical information. The system is expected to save Laboratory staff significant time in identifying the appropriate classifications and determining the proper set of markings and to improve the protection and control of technical data.

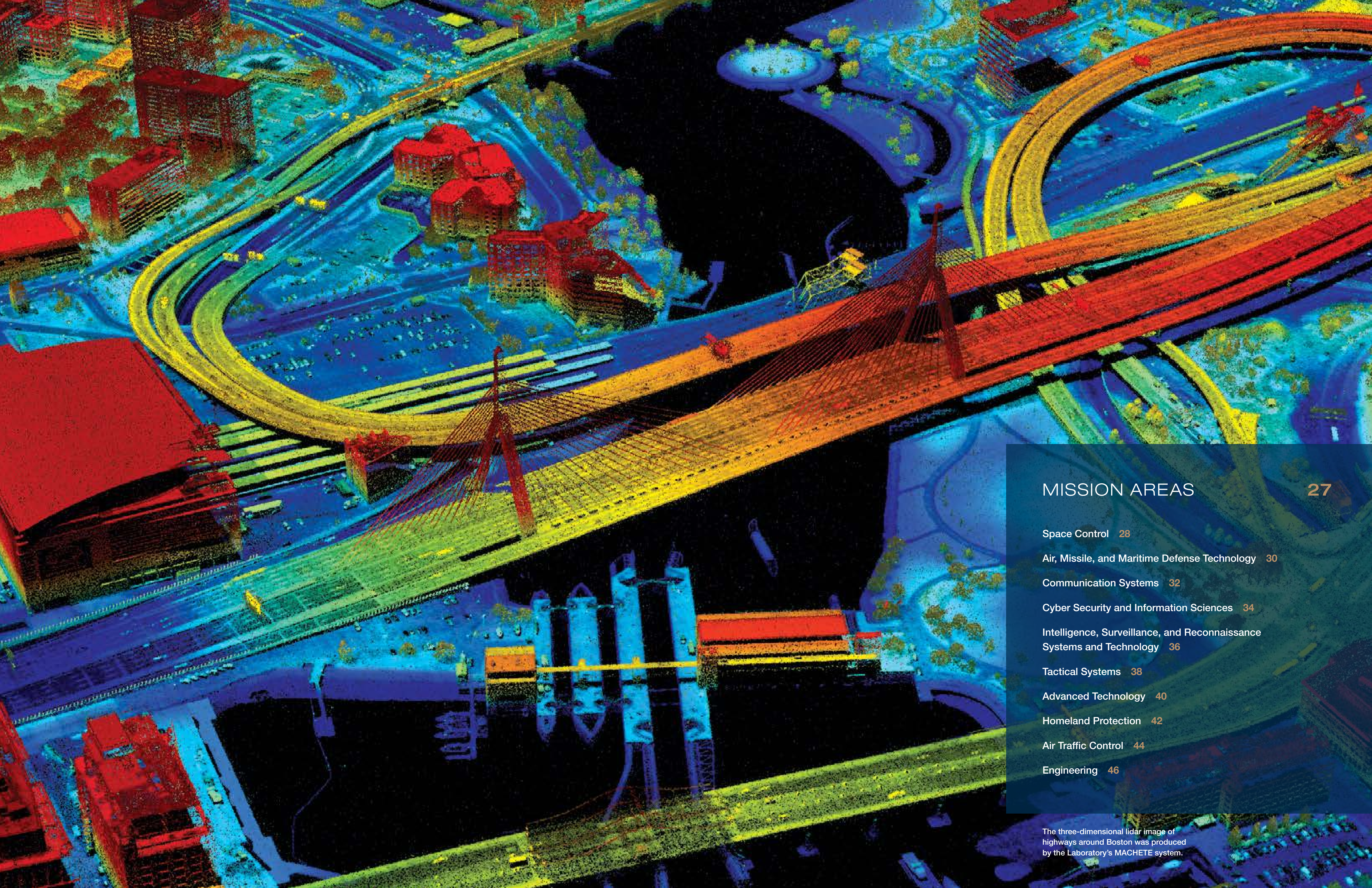
Contracting for Better Buying Power

To realize more than $6.3 million in savings in subcontract awards, Lincoln Laboratory's Contracting Services Department has employed strategies that support the following BBP 3.0 goals: (1) improve methods for sourcing goods and services, (2) eliminate unproductive, superfluous procurement processes and documentation, (3) promote effective competition for goods and services, and (4) develop a highly qualified staff of contracting professionals.

The chart below presents the breakdown of the savings accrued by applying the following contracting techniques:

- Requesting that subcontractors submit bids that reflect a best and final offer (BAFO) has promoted a competitive bid process, reduced time-consuming negotiations, and thus lowered the Laboratory's costs for goods and services.
- Simplifying the acquisition procedures has encouraged companies to seek and compete for Laboratory business and has also saved processing costs associated with procurement documentation.
- Using reverse auctions by which subcontractors compete to obtain business helps ensure that the Laboratory pays reasonable prices for goods and services.
- Utilizing government and educational discounts and manufacturer rebates for purchases saves 100s and 1000s of dollars each year.
- Negotiating better terms for large purchases and for prompt payments results in significant savings.
- Offering an in-house leadership development program in government contracting is creating a team of professional specialists who employ best practices to coordinate effective contracts.



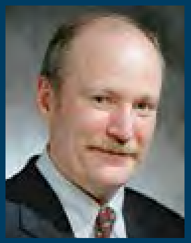


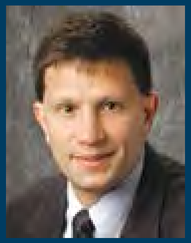
MISSION AREAS

The three-dimensional lidar image of highways around Boston was produced by the Laboratory's MACHETE system.

Space Control

Leadership

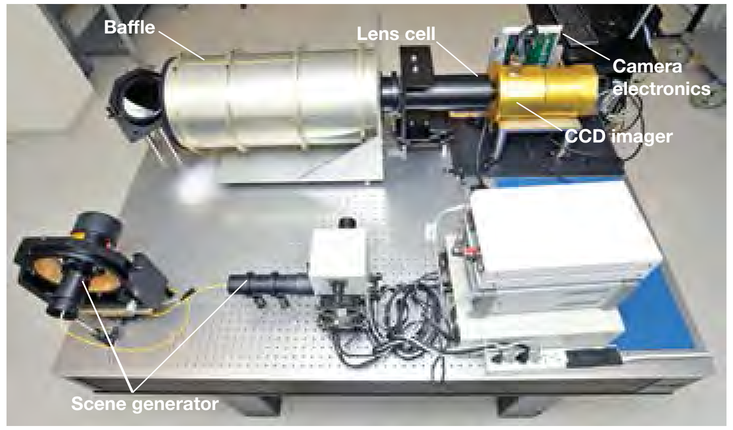

Dr. Grant H. Stokes


Mr. Lawrence M. Candell

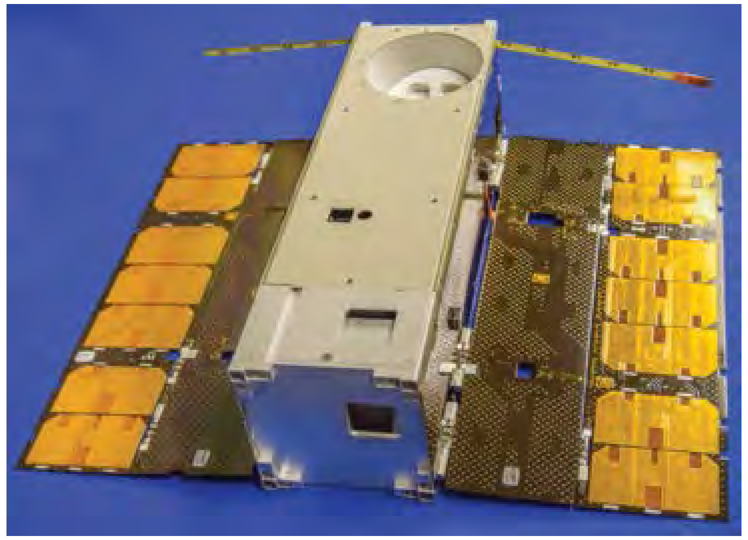

Dr. William J. Donnelly III

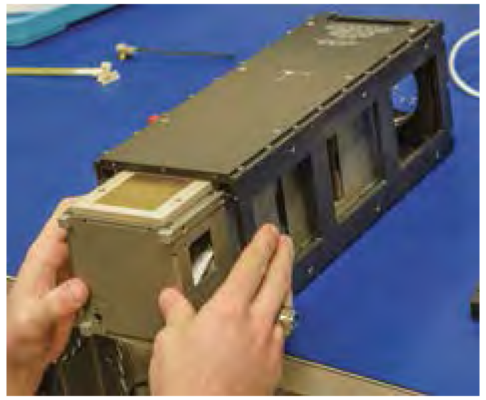

Mr. Craig E. Perini

Lincoln Laboratory develops technology that enables the nation to meet the challenges of an increasingly congested and contested space environment. The Laboratory develops and utilizes systems to detect, track, and identify man-made satellites; collects orbital-debris detection data to support space-flight safety; performs satellite mission and payload assessment; and investigates technology to improve monitoring of the space environment, including space weather and atmospheric and ionospheric effects. The technology emphasis is the application of new components and algorithms to enable sensors with greatly enhanced capabilities and to support the development of net-centric processing and decision support systems.



Flight-like hardware subsystems for SensorSat were integrated and tested as part of a system capability demonstration. Seen here is the imaging system, which consists of a Lincoln Laboratory–developed charge-coupled-device (CCD) imager, camera electronics, a custom lens cell, and a state-of-the-art lightweight baffle.





The development of the Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat is quickly progressing. Mass mockups of the deployed solar panels/ultrahigh-frequency antennas (left) and prelaunch configuration deployer during a fit check of the satellite (above) have been completed.

Principal 2015 Accomplishments

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

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

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

- Detailed design and testing of key flight hardware components of the Microwave Radiometer Technology Acceleration (MiRaTA) satellite have been completed. This joint effort between Lincoln Laboratory and MIT Space Systems Laboratory is a follow-on mission to MicroMAS-1 that will use a tri-band radiometer and global-positioning-system radio occultation technology in a 30 × 10 × 10 cm CubeSat to provide calibrated observations of atmospheric temperature, water vapor, and cloud ice.

- Lincoln Laboratory continued to support the development and testing of the U.S. Air Force Space Fence radar system. In March 2015, the system completed its critical design review. The system's capabilities were successfully demonstrated in a Laboratory-developed modeling and simulation environment. A plan for using test equipment to emulate space objects will enable early testing of the fully functional scaled prototype of the system.

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

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

Future Outlook

- SensorSat will proceed through detailed design, flight hardware fabrication, and vehicle integration and test with delivery scheduled for 2017. The SensorSat design and technologies will be transferred to industry for possible use as the Air Force procures the follow-on to the current Space-Based Space Surveillance satellite.

- The Laboratory will continue to design and analyze simulation scenarios and drive algorithm development for the Space Fence.

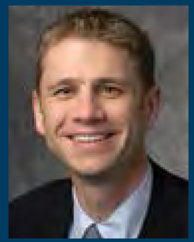
- The MicroMAS-2 and MiRaTA satellites will complete integration and testing in support of launches planned for late 2016.

- The Laboratory will continue to analyze, prototype, and demonstrate new sensor, processing, and operations capabilities to inform U.S. government architectures and concepts of operations for space superiority.

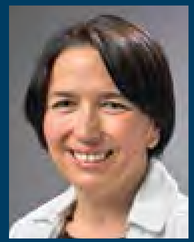
- Automated techniques and algorithms for tactical space command and control, including high-value-asset surveillance and persistent-threat monitoring, will be refined. Efforts to significantly improve radar sensitivity and search rates are planned.

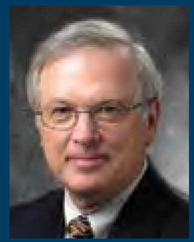
Air, Missile, and Maritime Defense Technology

Leadership


Dr. Justin J. Brooke


Dr. Kevin P. Cohen


Dr. Katherine A. Rink


Mr. Dennis J. Keane

Lincoln Laboratory develops and assesses integrated systems for defense against threats posed by ballistic missiles, cruise missiles, and air and maritime platforms in tactical, regional, and homeland defense applications. Activities in this mission area include the investigation of system architectures, development of advanced sensor and decision support technologies, development of pathfinder prototype systems, extensive field measurements and data analysis, and the verification and assessment of deployed system capabilities. A strong emphasis is on developing innovative solutions, maturing technologies, rapid prototyping of systems, and transitioning new capabilities for operational systems to the government and government contractors.

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

The Laboratory developed and deployed a seeker radar test bed (left) to participate in numerous exercises and data collection events. The custom-built radar integrated onto a Navy P-3 aircraft (above) was used to collect data on target and clutter phenomenology and to characterize the anticipated performance of several system concepts. Results generated from the collected data influenced government assessments of and decisions on new defense capabilities.

Principal 2015 Accomplishments

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

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

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

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

- A multipurpose radar test bed is being developed to advance techniques for the next-generation of airborne radars. The test bed will become operational in 2016 and will initially be used to study the performance of arbitrarily flexible waveforms.

- To support the Missile Defense Agency's initiatives to improve homeland defense capabilities, the Laboratory is developing improvements in the Ballistic Missile Defense (BMD) System that will provide a basis for future algorithm development.

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

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

Future Outlook

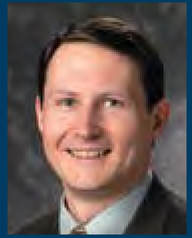
- Development, testing, and deployment of credible counters to the ballistic missile threat will continue to be a significant national priority. The Laboratory's efforts will focus on new capabilities for homeland BMD, including a new RKV, an improved Ground-Based Interceptor, upgraded radar and optical sensors, and enhanced discrimination technologies. In addition, the Laboratory will work to evolve capabilities to defend against regional threats; these capabilities include advancements to the Aegis, Terminal High-Altitude Area Defense (THAAD), and Patriot systems, as well as new sensor and interceptor alternatives.

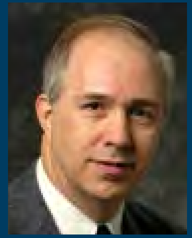
- Defense of land and sea bases against increasingly capable and long-range threats remains a high priority for the Department of Defense. A significant focus for the Laboratory will be the development and test of layered defenses, such as left-of-launch and counter-C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) capabilities, and of kinetic and electronic defenses in all phases of flight. Particularly important will be developing, testing, and fielding electronic attack capabilities to counter advanced cruise and ballistic missile threats.

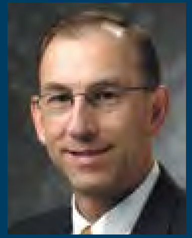
- Lincoln Laboratory will grow its portfolio of submarine and antisubmarine warfare technology and systems to address advancing and proliferating threats in the undersea domain.

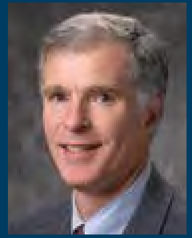
Communication Systems

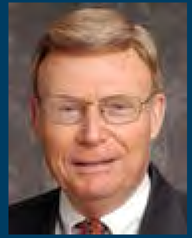
Leadership


Dr. J. Scott Stadler


Dr. Roy S. Bondurant

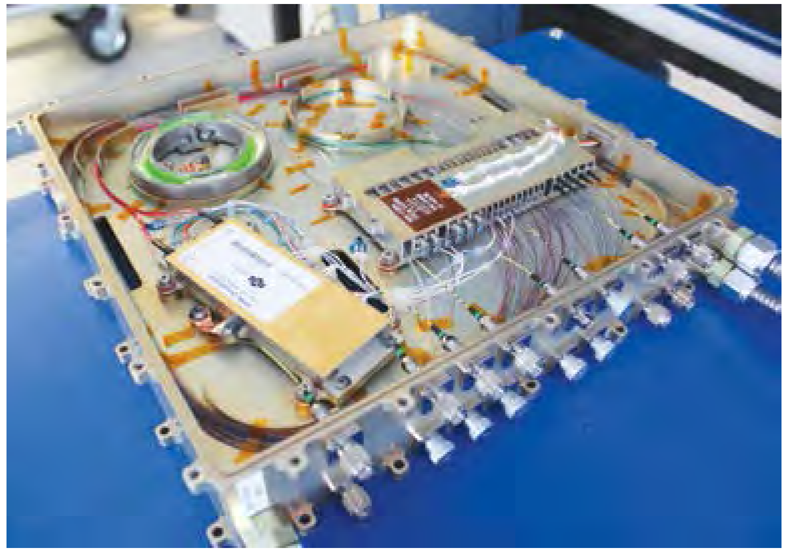

Dr. James Ward


Dr. Don M. Boroson


Dr. David R. McElroy

Lincoln Laboratory is working to enhance and protect the capabilities of the nation's global defense networks. Emphasis is placed on synthesizing communication system architectures, developing component technologies, building and demonstrating end-to-end system prototypes, and then transferring this technology to industry for deployment in operational systems. Current efforts focus on radio-frequency military satellite communications, free-space laser communications, tactical network radios, quantum systems, and spectrum operations.


During the Pacific Command–sponsored Northern Edge exercise in Alaska, the Lincoln Laboratory team (above) tested a high-fidelity data-collection and demonstration system designed and developed for airborne platforms. The technology provides improved interference mitigation for deployed and emerging airborne communication systems while supporting the rapid transition of capabilities into existing tactical communication networks.


The differential phase-shift keying modem built and environmentally tested by Lincoln Laboratory will be transitioned to industry. This modem provides near-quantum-limited communication performance over a very wide dynamic range of received input power and data rates.


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

Principal 2015 Accomplishments

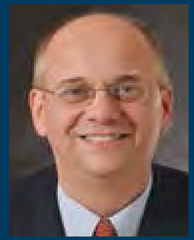
- The Lincoln Laboratory Ka-band Test Terminal was upgraded with enhanced Ka-band instrumentation and will be utilized for post-launch on-orbit characterization of the Wideband Global System Flight 7 through 10 satellites.
- A real-time network test bed developed by the Laboratory was deployed at Aberdeen Proving Grounds, Maryland. The test bed, which is operated by U.S. Army personnel, is being used to evaluate the performance of vendor equipment and to optimize the configuration of tactical networks.
- A novel adaptive array antenna design will give fighter aircraft an enhanced communications capability in a highly contested electromagnetic environment.
- The Protected Tactical Waveform was demonstrated over the air. This test confirmed the viability of providing jamming resistance when the waveform is operating over existing military and commercial transponders.
- The Laboratory is transitioning operations of the Interim Command and Control Terminals to the U.S. Air Force. These terminals are used to operate the nation's protected military satellite communications (MILSATCOM) constellation.
- Flight tests using the Laboratory's Boeing 707 airborne networking test bed aircraft were completed to support the development phase of the Air Force Family of Advanced Beyond-Line-of-Sight Terminals.
- A full network and waveform model of an advanced airborne waveform was developed and demonstrated. The waveform is designed to provide increased robustness and capacity while still being able to coexist with the military standard Link 16 tactical data link.
- The Laboratory designed, implemented, and extensively tested a new Group Centric Networking protocol, which promises to provide improvements in scalability and resilience over traditional mobile ad hoc networking protocols.
- The final design of a prototype airborne laser communications terminal was completed. This terminal operates over a wide field of regard through a conformal interface.
- A command-and-control terminal for the Enhanced Polar System was delivered to Clear Air Force Station, Alaska, to support initial terminal checkout.
- Lincoln Laboratory developed an algorithm that enables tactical radios to synchronize timing without reliance on GPS. Future work will implement this algorithm as a protocol that can be run in software-defined radio platforms.
- Using a custom-developed high-performance capacity-achieving forward error correction code, the Laboratory demonstrated world-record binary phase-shift keying communication performance of <1.5 photons-per-bit at a 2.88 Gbps data rate.

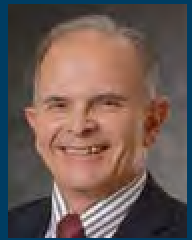
Future Outlook

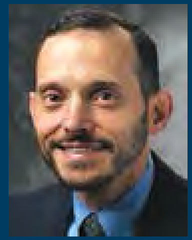
- In response to the increased use of autonomous vehicles in Department of Defense applications, Lincoln Laboratory will develop theoretical limits and practical implementations of communication and networking protocols to support large swarms of autonomous vehicles in highly contested environments.
- The Laboratory will investigate technologies and architectures that can unify communications, radar, electronic warfare, and signals intelligence.
- Components and architectures will be developed for quantum communications, networking, and sensing.
- The use of airborne satellite surrogates developed by the Laboratory will be demonstrated with existing military terminals; the surrogates may augment or replace existing capabilities.
- The Laboratory will develop novel technologies for improving the capacity and overall performance of airborne tactical networks that will be used in current and next-generation fighter aircraft, unmanned vehicles, and weapon systems.
- The Laboratory's implementation of the next-generation combat aircrew training network will integrate virtual and constructive targets and entities into the live aircrew training environment.

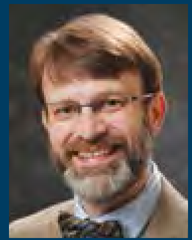
Cyber Security and Information Sciences

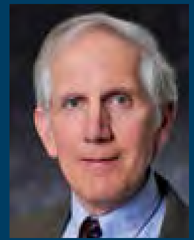
Leadership


Mr. Stephen B. Rejto


Mr. David R. Martinez

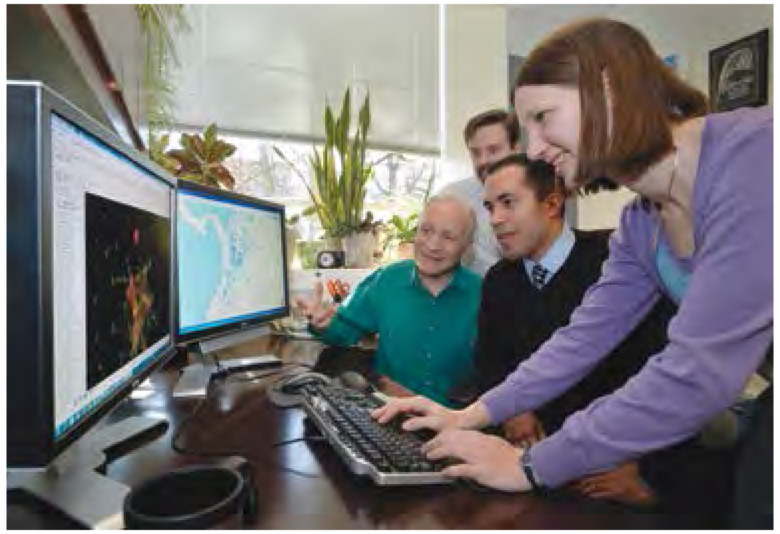

Dr. Marc A. Zissman


Dr. Jeremy Kepner


Dr. Richard P. Lippmann

Lincoln Laboratory conducts research, development, evaluation, and deployment of cyber-resilient components and systems designed to ensure that national security missions can be accomplished successfully despite cyber attacks. Work in cyber security includes research; cyber analysis; architecture engineering; development and assessment of prototypes that demonstrate the practicality and value of new cyber protection, detection, and reaction techniques; and, where appropriate, deployment of prototype technology into operations. The Laboratory plays a major role in the design, development, and operation of large-scale cyber ranges and cyber exercises. In addition, the Laboratory develops advanced hardware, software, and algorithms for processing large, high-dimensional datasets from a wide range of sources, including speech, imagery, text, and network traffic. To facilitate this development, researchers employ high-performance computing architectures, machine learning for advanced analytics, and relevant metrics and realistic data sets.


Patrick Cable upgrades storage in the Lincoln Laboratory Secure and Resilient Cloud test bed. Researchers use this test bed to develop and test next-generation cloud security technologies, such as encrypted databases that allow the intelligence community to conduct counterterrorism missions while protecting privacy.


From front to back, Kara Greenfield, Joel Acevedo-Aviles, Daniel Halbert, and William Campbell explore extracted information using VizLinc, an open-source software system developed by Lincoln Laboratory to integrate information extraction, search, graphical analysis, and geolocation for the Department of Defense and the intelligence community.


Matthew Alt monitors signal traces to analyze the startup behavior of an automotive engine management unit as part of an effort to re-host the engine software in a virtual machine. The re-hosted software allows testing of cyber resiliency techniques to protect automobiles from malicious attacks.

Principal 2015 Accomplishments

- Lincoln Laboratory led the design of a highly resilient key-management architecture for the next-generation Protected Tactical Satellite Communications Service.
- The Laboratory developed and demonstrated a next-generation secure processor that has advanced key management, hardware-accelerated cryptography, and intrinsic support for volume protection.
- Several large experiments were conducted in support of the Department of Defense's (DoD) Director of Operational Test and Evaluation and the U.S. Cyber Command's (USCYBERCOM) Project C. The experiments focused on the performance of USCYBERCOM Cyber Protection Teams.
- The Laboratory completed in-depth cyber vulnerability assessments of multiple U.S. tactical platforms.
- Data integrity capabilities were developed for use in a key U.S. Navy information processing system.
- In conjunction with operational users from across cyber centers at multiple combatant commands, Lincoln Laboratory tested cyber behavioral and temporal anomaly detection analytics.
- A tactical edge cyber-electromagnetic environment emulation was developed to support U.S. Marine Corps (USMC) training and exercises.
- In partnership with potential USMC users, the Laboratory demonstrated the utility of its prototype wearable augmented-reality displays for a tactical urban setting.
- The MIT SuperCloud is the first cloud environment that delivers big data, database, supercomputing, and enterprise clouds on the same hardware without compromising performance. Lincoln Laboratory developed the SuperCloud in collaboration with the Engaging Supercomputing Research Projects at Beaver Works.
- The Laboratory's new hidden Markov model techniques allow the recognition of time-varying patterns of behavior in transactional data, including potentially fraudulent financial transactions.
- Deep neural network recognition techniques were successfully applied to language and speaker recognition and demonstrated significant performance improvements over previous state-of-the-art systems.
- At an international competition in machine translation, Lincoln Laboratory scored highest in several tracks, including those for Arabic-to-English, Farsi-to-English, and Russian-to-English translation.
- The VOCALinc speaker-comparison software tool was transitioned to the Federal Bureau of Investigation (FBI). VOCALinc is the first automated speaker-recognition system to be adopted and included in an FBI forensic standard operating procedure.

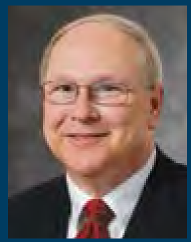
Future Outlook

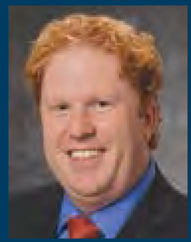
- Lincoln Laboratory will continue to use unconventional sensors and human language technology to explore cyber analysis and threat discovery.
- Leveraging foundational security metrics work performed for the Department of Homeland Security, the Laboratory will develop cyber risk-quantification methods for DoD missions.
- The Cyber System Assessments Group will continue cyber vulnerability assessments of U.S. tactical systems and architectures.
- The Laboratory's expanding role with U.S. Transportation Command will include helping the command define its future vision for cyber situational awareness and resiliency.
- Cyber technology assessments will expand to government entities, including Assistant Secretary of Defense for Research and Engineering, Office of Cost Assessment and Program Evaluation, and Defense Advanced Research Projects Agency.
- To support the Air Force Research Laboratory's development of a secure, resilient embedded system architecture for airborne and other platforms, the Laboratory is contributing technology for key management, resilient design, and resilience assessment.
- The Laboratory will develop, test, and evaluate novel cyber inference and prediction algorithms in support of intelligence community missions.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Leadership


Dr. Robert T-I. Shin

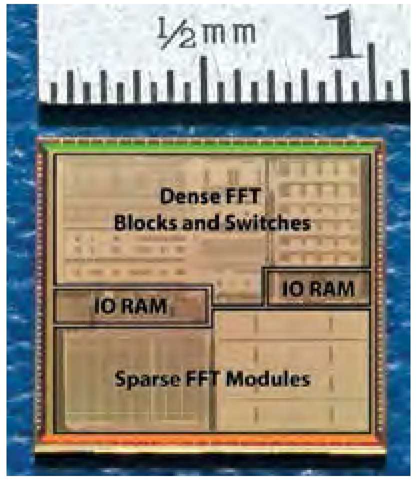

Mr. Robert A. Bond


Dr. Marc N. Viera

To expand intelligence, surveillance, and reconnaissance (ISR) capabilities, Lincoln Laboratory conducts research and development in advanced sensing, signal and image processing, automatic target classification, decision support, and high-performance computing. By leveraging these disciplines, the Laboratory produces novel ISR system concepts for surface and undersea applications. Sensor technology for ISR includes passive and active electro-optical systems, surface surveillance radar, radio-frequency (RF) geolocation, and undersea acoustic surveillance. Increasingly, the work extends from sensors and sensor platforms to include the processing, exploitation, and dissemination technologies that transform sensor data into the information and situational awareness needed by operational users. Prototype ISR systems developed from successful concepts are then transitioned to industry and the user community.

The Lincoln Laboratory Multi-Aperture Sparse Imager Video System (MASIVS) sensor, which collects and analyzes wide-area motion imagery, is fully integrated onto the U.S. Army Constant Hawk aircraft.

The MACHETE ladar and processing subsystems were installed on a DHC-8 aircraft.



The photograph shows a novel, reconfigurable, high-performance signal processing chip that implements a new sparse fast Fourier transform invented by MIT.

Principal 2015 Accomplishments

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

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

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

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

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

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

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

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

Future Outlook

- Lincoln Laboratory is continuing significant efforts to support the DoD and the intelligence community with architecture engineering, systems analysis, technology development, and advanced capability prototyping.

- Enhanced activities in electronic warfare and U.S. Navy maritime and undersea surveillance are expected as part of the national shift to meeting security challenges in the Asia-Pacific region.

- The importance of ISR data exploitation will grow as new wide-area sensing capabilities are fielded. Automation techniques to address the increasing analyst workload will emphasize improved fusion and statistical inferencing that use multisource and nontraditional sensor data sources.

- The Laboratory will continue to help the government develop, prototype, and employ open-system architecture paradigms for sensors, avionics payloads, and ground-control stations.

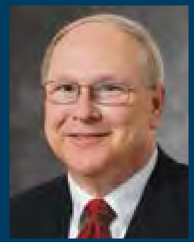
- Laser-based sensing will expand into new applications as the technology for optical waveforms and coherent laser-based sensing improves.

- Airborne radar systems will evolve to support new unmanned and manned platforms, while exploiting advances in antennas and processing techniques.

Tactical Systems

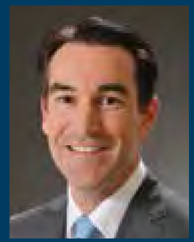
Leadership

Dr. Robert T-I. Shin



Mr. Robert A. Bond

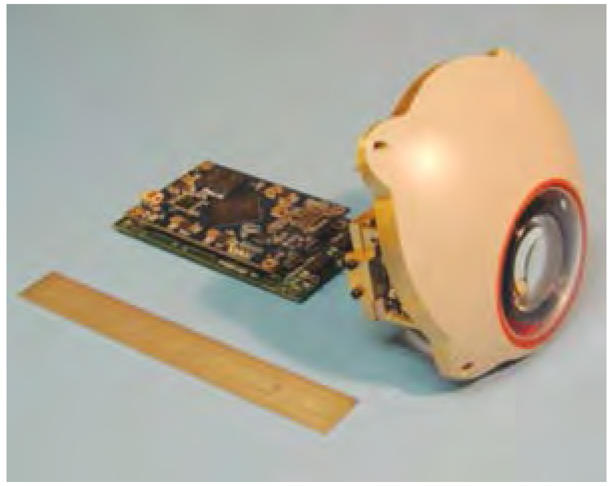
Dr. Marc N. Viera



Dr. Christopher A.D. Roeser

Lincoln Laboratory assists the Department of Defense (DoD) in improving the development and employment of various tactical air and counterterrorism systems through a range of activities that includes systems analysis to assess technology impact on operationally relevant scenarios, detailed and realistic instrumented tests, and rapid prototype development of U.S. and representative threat systems. A tight coupling between the Laboratory's efforts and DoD sponsors and warfighters ensures that these analyses and prototype systems are relevant and beneficial to the warfighter.

The Lincoln Laboratory team transitioned to Army Special Forces an airborne sensor as a field-replaceable modular kit on a small unmanned aerial vehicle.



A novel sensor prototype with a custom electro-optical camera and onboard processing was developed to characterize advanced real-time vision-aided navigation algorithms through instrumented flight tests.

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

Principal 2015 Accomplishments

- Lincoln Laboratory completed a study of U.S. Air Force fighter aircraft performance and limitations versus current and anticipated future foreign-threat fighters. This assessment included systems analysis, backed by laboratory and flight testing, of advanced infrared and radio-frequency sensor kill chains, electronic attack and electronic protection, and missile systems. Findings have been briefed to senior DoD leadership to inform their decision-making process for future system capabilities and technology investments.

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

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

- Overarching assessments of the Air Force's Family of Systems (FoS) architecture were performed. Systems analysis focused on protected communications; integrated intelligence, surveillance, and reconnaissance (ISR); strike capabilities; mission effectiveness; and survivability. Results briefed to DoD leadership are being used to develop a future acquisition strategy and concepts of operation for the FoS.

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

- Advanced architectures and technologies are being developed for use in next-generation counter–improvised explosive device (C-IED) electronic attack systems. The Laboratory is conducting field demonstrations and technology transition of advanced capabilities for future Counter Radio-Controlled IED Electronic Warfare (CREW) systems.

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

Future Outlook

- Lincoln Laboratory will continue to assess, develop, and demonstrate innovative concepts for enhancing the survivability of U.S. air vehicles. This work will inform new capability development and future technology road maps.

- The Laboratory will be supporting the tactical community through systems analysis, advanced capability prototyping, and measurement campaigns. These efforts will address a broad spectrum of needs, with an emphasis on the evolving security challenges in the Pacific region.

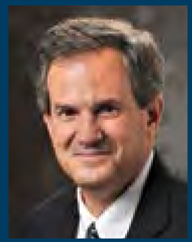
- Ongoing efforts will provide innovative concepts and prototype systems to counter terrorism and to enable operations in contested environments. The emphasis for new programs will be on developing solutions to emerging global-protection problems.

- Continued growth in electronic warfare technology for the DoD and intelligence community is expected, predominantly in the areas of electronic protection for tactical aircraft and ground vehicles, and electronic support measures for airborne signals intelligence (SIGINT) capabilities.

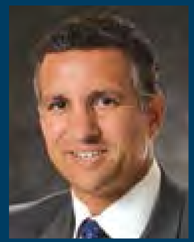
Advanced Technology

Leadership

Dr. Robert G. Atkins



Dr. Craig L. Keast

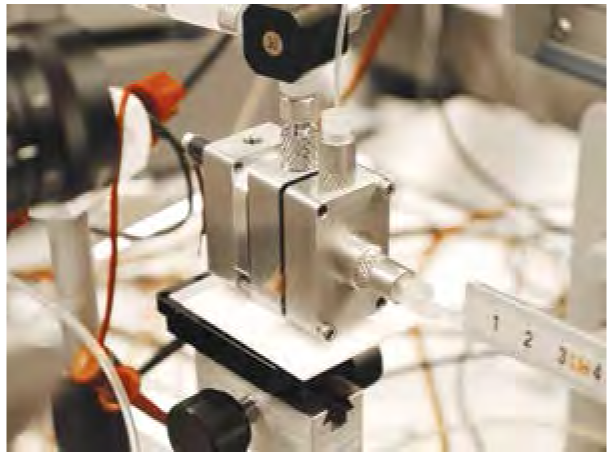


Dr. Simon Verghese

Dr. Richard W. Ralston

The Advanced Technology mission supports national security by identifying new phenomenology that can be exploited in novel system applications and by then developing revolutionary advances in subsystem and component technologies that enable key, new system capabilities. These goals are accomplished by a community of dedicated employees with deep technical expertise, collectively knowledgeable across a wide range of relevant disciplines and working in unique, world-class facilities. This highly multidisciplinary work leverages solid-state electronic and electro-optical technologies, innovative chemistry, materials science, advanced radio-frequency (RF) technology, and quantum information science.

Jonilyn Yoder prepares a 200-millimeter-diameter silicon wafer patterned with superconducting single-flux-quantum circuits for automated evaluation of more than 25,000 room-temperature test structures.



The Laboratory developed a prototype of a microhydraulic actuator that uses electrowetting inside an array of microcapillaries to convert electrical power into hydraulic power. This actuator could potentially be used to harvest energy and to replace small motors and piezoelectrics in microrobots.

Staff members (left to right) Andrew Benedick, Juan Montoya, Niyom Lue, and Franklin Jose discuss implementation details of optical phased array technology. The agile beam-steering capability provided by such an array could benefit lidar and remote-sensing applications.

Principal 2015 Accomplishments

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

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

- Lincoln Laboratory demonstrated the largest short-wave infrared focal plane array capable of time stamping single photons. The array is two times larger than that used in previous demonstrations and utilizes a Laboratory-fabricated 256 × 128 Geiger-mode avalanche photodiode array hybridized with a custom complementary metal-oxide semiconductor (CMOS) digital readout integrated circuit.

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

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

- The Laboratory completed the first wafer-scale demonstration of heterogeneous integration of electronic and photonic components. Utilizing 90 nm CMOS electronics and silicon photonic wafers, the Laboratory exploited its high-density, three-dimensional wafer-scale integration technology to realize circuits that convert electrical signals into optical signals that can be routed off a chip to other components.

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

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

Future Outlook

- The need to perform worldwide monitoring of threats and to search for increasingly small signatures representative of emerging terrorism or weapons of mass destruction will motivate the development of new sensor capabilities. New sensor component technologies will be explored to enable these capabilities.

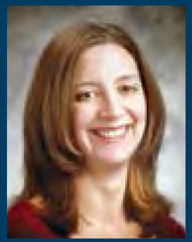
- Advanced computation activity will continue to increase with the pursuit of quantum information systems, cryogenic CMOS, ultralow-power CMOS, and other technologies for efficient specialized computation.

- Low-cost RF phased array panel technology will begin to transition into Department of Defense systems, such as search and track radars. This work builds on technology being developed for air traffic control and weather radars.

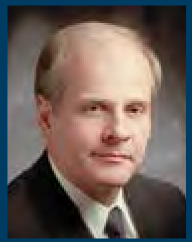
- High-energy lasers and supporting sensor systems will be developed for future fielded applications of national interest, including homeland defense against adversary missiles and unmanned aerial vehicles.

Homeland Protection

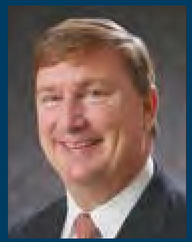
Leadership



Dr. Melissa G. Choi



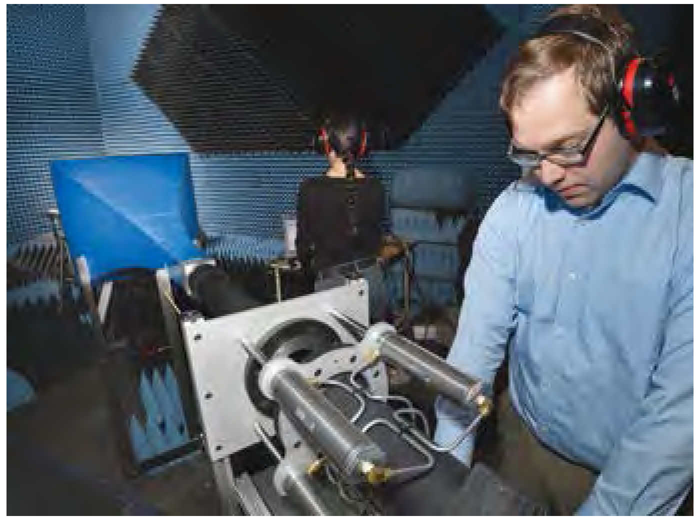
Mr. James M. Flavin



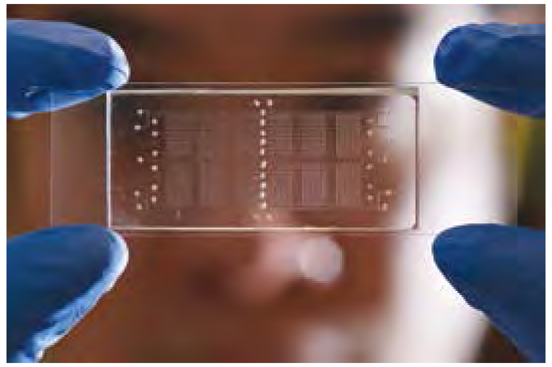
Mr. Edward C. Wack

Dr. Timothy J. Dasey

The Homeland Protection mission supports the nation's security by innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from either man-made or natural disasters. The broad sponsorship for the mission area spans the Department of Defense (DoD), the Department of Homeland Security (DHS), and other federal, state, and local entities. Recent efforts include architecture studies for the defense of civilians and facilities, new microfluidic technologies for DNA assembly and transformation and for gene synthesis, improvement of the Enhanced Regional Situation Awareness system for the National Capital Region, the assessment of technologies for border and maritime security, and the development of architectures and systems for disaster response.



Christopher Smalt (foreground) and Johanna Bobrow operate a shock tube in an anechoic chamber to quantify blast-wave propagation effects on instrumented headforms as part of the Laboratory's traumatic brain injury and auditory health research.



David Kong holds a microfluidic device that performs 96 parallel biochemical reactions with volumes one thousand times smaller than those required by conventional methods. The Laboratory is developing highly parallelized microfluidic devices to support its synthetic biology efforts in the rapid prototyping of novel genomic designs.

A capability for reliably detecting and tracking unmanned aerial vehicles (UAV) is needed to safely integrate them into U.S. airspace. In collaboration with the DHS Science and Technology Directorate, Lincoln Laboratory is working to develop such a capability. Above, the acoustic signature of a commercial UAV is measured in an urban environment.

Principal 2015 Accomplishments

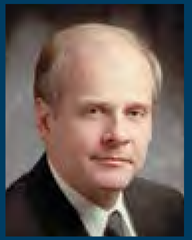
- The Laboratory continues to lead the development of technology and architectures for countering a broad range of weapons of mass destruction. Activities include measurement-based threat phenomenology studies, technology assessments, critical infrastructure remediation, and improvised explosive device forensics development.
- Partnering with the U.S. Army Research Institute of Environmental Medicine, the Laboratory successfully demonstrated the first phase of ultralow-power wearable physiological monitoring systems that use an open architecture and can operate securely in tactical environments.
- Next-generation video-analysis capabilities for law enforcement, mass transit security, and border patrol are being developed with emphases on accelerating video review by humans and cueing operators to unusual targets.
- The Laboratory, in collaboration with the Joint Program Executive Office for Chemical and Biological Defense and its international partners, conducted a series of measurements to improve understanding of chemical and biological threat agents and to enable the development of technologies needed to counter such threats.
- Laboratory-developed prototypes are advancing capabilities for humanitarian assistance and disaster response operations. Funded by the DHS Science and Technology Directorate's (S&T) First Responders Group, the Next-Generation Incident Command System, a command-and-control software platform, is improving situational awareness for firefighters in California and emergency managers in Victoria, Australia. Other decision support tools are enabling better preparation for and responses to coastal hurricanes.
- A prototype forensic DNA measurement and analysis technique utilizes next-generation DNA sequencing to reliably identify a suspect's DNA in complex, multiple-contributor sample mixtures.
- In partnership with the DHS S&T Homeland Security Advanced Research Projects Agency, Lincoln Laboratory is assessing and developing unmanned aerial vehicle detection architectures and technologies to help protect critical infrastructures and special-event sites.
- For the second year in a row, the Laboratory's neurocognitive team won an international competition for their estimation of depression severity from audio and video recordings. The recognition highlighted the efficacy of the Laboratory's speech processing techniques for psychological health assessments based on phoneme-dependent speaking rate and incoordination of vocal tract articulators.
- A multimodal immersive laboratory is being built for use in noninvasive cognitive and physiological monitoring research. A 27-foot virtual-reality dome features 360-degree visualization and motion-capture capabilities and a dual-belt, force-plate treadmill on a six-degrees-of-freedom actuator.

Future Outlook

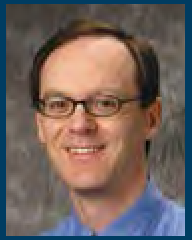
- Integrated air, land, and maritime architectures are needed to advance border and critical infrastructure security. The Laboratory will leverage its expertise in sensors, cyber security, information processing, decision support, and open systems to develop these architectures.
- Information-sharing architectures, novel sensors, and analytics for data mining and collaborative decision making will be developed to improve the ability of the DoD, DHS, and other organizations to efficiently and rapidly provide humanitarian assistance and respond to natural and man-made disasters.
- The Laboratory will continue to lead the development, analysis, and testing of advanced architectures for chemical and biological defense, including biometrics and forensic technologies for theater and homeland protection. Key areas include sensors, rapid DNA sequencing and identification techniques, test beds, and data-fusion algorithms that provide early warning of human exposure to hazardous agents.
- The DoD's biomedical research goals of protecting the health and performance of soldiers in both training and operational environments will require miniaturized sensors for physiological monitoring, traumatic brain injury assessments, novel genetic sensing and analysis, and noninvasive musculoskeletal imaging.

Air Traffic Control

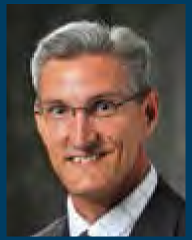
Leadership



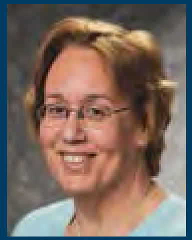
Mr. James M. Flavin



Dr. James K. Kuchar



Dr. Gregg A. Shoults



Dr. Marilyn M. Wolfson

Since 1971, Lincoln Laboratory has supported the Federal Aviation Administration (FAA) in the development of new technology for air traffic control. This work initially focused on aircraft surveillance and weather sensing, collision avoidance, and air-ground data link communication. The program has evolved to include safety applications, decision support services, and air traffic management automation tools. The current program is supporting the FAA's Next Generation Air Transportation System (NextGen). Key activities include development of the next-generation airborne collision avoidance system; refinement and technology transfer of NextGen weather architectures, including cloud processing and netcentric data distribution; and development of standards and technology supporting unmanned aerial systems' integration into civil airspace.

Lincoln Laboratory staff provide training and elicit user requirements in the field for new technologies, such as the Route Availability Planning Tool (RAPT) shown above. The tool is now operational as part of the Federal Aviation Administration's Traffic Flow Management System in New York, Chicago, Philadelphia, and Washington, D.C.

Seen on its trailer, the 10-panel Multifunction Phased Array Radar (MPAR) prototype was delivered to NOAA's National Severe Storms Laboratory in Norman, Oklahoma, where its weather and aircraft surveillance performance is being evaluated under a variety of environmental conditions.

The Offshore Precipitation Capability provides a real-time depiction of weather beyond the range of radars, filling in key coverage gaps in the Gulf of Mexico, the Caribbean, and other regions. The technology is undergoing laboratory performance evaluation prior to operational field tests.

Principal 2015 Accomplishments

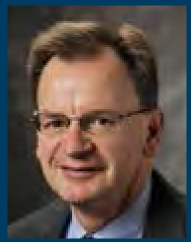
- System studies and antenna panel development continued for the Multifunction Phased Array Radar (MPAR). The Laboratory constructed a mobile 10-panel prototype array that will be used to refine system requirements and to quantify dual-polarization performance for weather observations. Results from this analysis will be used to refine the design of a full-scale 76-panel advanced technology demonstrator array. The Laboratory plans to build this array in partnership with the FAA and the National Oceanic and Atmospheric Administration (NOAA).
- An effort was initiated to build a prototype Small Airport Secondary Surveillance sensor that has the potential to provide low-cost terminal-area surveillance. A prototype aperture has been developed to demonstrate real-time surveillance performance.
- Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a global radar-like view of convective weather beyond the coverage of radars. In the upcoming year, NOAA and the FAA will assess the quality and operational suitability of OPC information.
- Lincoln Laboratory is playing a key role in developing the NextGen Airborne Collision Avoidance System X (ACAS X), which will support new flight procedures and aircraft classes. Using the National Aeronautics and Space Administration's (NASA) Ikhana aircraft, a flight test conducted by the Laboratory, FAA, and NASA successfully demonstrated an ACAS X variant for unmanned aircraft systems (UAS). Standards development for ACAS X has been initiated, and plans to conduct a full system test with the FAA are under way.
- Standards and algorithms are being developed for UAS sense-and-avoid (SAA) capabilities for the Department of Defense, Department of Homeland Security, and FAA. The Laboratory worked with the SAA Science and Research Panel to publish a "well clear" separation standard for UAS.
- Analyses are being conducted to guide the FAA on wind information needs for a range of NextGen applications, including four-dimensional trajectory-based operations and interval management procedures. These analyses are guiding the establishment of performance requirements and standards for enabling concepts of operation, technologies, and information sources.
- Operational improvements are being developed to reduce fuel burn and to mitigate the environmental impacts of aviation. For airport surface operations, the Laboratory has developed and assessed decision support tools that reduce taxiway congestion and efficiently balance queues of aircraft at departure runways. Methods to save fuel and reduce emissions, including modified procedures to optimize the cruise altitude and speed of aircraft and to delay their deceleration as they approach the runway for landing, are being explored with a range of stakeholders.

Future Outlook

- Lincoln Laboratory will apply its expertise in surveillance processing, data management, algorithms, and human systems integration to increase its role in developing future NextGen concepts, including trajectory-based operations, interval management, Automatic Dependent Surveillance–Broadcast (ADS-B) applications, environmental impact mitigation, and surface operations management.
- Requirements definition, prototyping, and technology transfer support for next-generation weather capabilities will be ongoing. These capabilities include improvements in sensing technology, data dissemination architectures, decision support tools for managing air traffic at congested airports during severe weather, and algorithms for estimating airspace capacity reductions caused by thunderstorms.
- Support of current and future FAA safety systems will be focused on preparations for additional flight testing of ACAS X variants for UAS. The Laboratory will also provide support to a new surveillance architecture that fully exploits the benefits of ADS-B.
- The Laboratory's key role in national and international efforts to integrate UAS into civil airspace will be primarily in the area of conflict avoidance with manned aircraft. The Laboratory will continue to develop standards and requirements, safety evaluation methods, and threat detection and maneuver algorithms; to develop and deploy real-time prototypes; and to transfer technology to industry.

Engineering

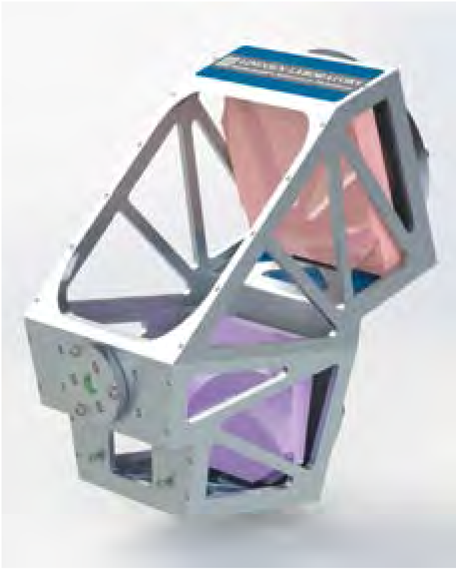
Leadership


Dr. Michael T. Languirand


Dr. William R. Davis


Dr. William D. Ross

Fundamental to the success of Lincoln Laboratory is the ability to build hardware systems incorporating advanced technology. These systems are used as platforms for testing new concepts, as prototypes for demonstrating new capabilities, and as operational systems for addressing warfighter needs. To develop the variety of systems used in programs across all mission areas, the Laboratory relies on its extensive capabilities in mechanical design and analysis, optical system design and analysis, aerodynamic analysis, mechanical fabrication, electronics design and assembly, autonomous and control systems design and analysis, energy systems design and analysis, system integration, and environmental testing. These capabilities are centered in the Laboratory's Engineering Division, which is an important contributor to many of the Laboratory's most successful efforts.



Optical design technology developed by the Engineering Division has, for the very first time, made optical prescriptions of nonsymmetrical surfaces possible. These so-called freeform optics, fabricated by diamond turning, are being used to build a high-performance, three-mirror aluminum telescope. The telescope's larger mirrors, seen in pink and purple in the rendering at left, are about 15 cm in diameter.

The Lincoln Laboratory Interactive Virtual Environment enables researchers to play out mission scenarios with human actors and robots and to test advanced sensing capabilities and autonomy algorithms developed to streamline human-robot teaming. This work is motivated by the Department of Defense's growing interest in utilizing autonomous systems to enhance warfighter situational awareness.

The Department of Homeland Security is leveraging Laboratory–developed microgrid systems at standalone border patrol facilities along the U.S. southern border (above). These systems are also being used at Department of Defense domestic installations and overseas forward operating bases to enhance national energy security, resiliency, and efficiency.

Principal 2015 Accomplishments

- A newly formed Energy Systems Group is focusing on the development of microgrid systems, advanced energy technology, and portable, energy-efficient capabilities for soldiers. Collaborations with the Advanced Technology Division and MIT campus concentrate on improving photovoltaic, battery, electronics, and control technologies.
- Design and analysis tools for freeform optics (i.e., optical elements with arbitrary surfaces), used in conjunction with the Laboratory's diamond-turning machine, are supporting the development of optical systems that can achieve higher imaging resolution than that possible with conventionally designed systems of the same size and weight.
- A direct metal laser sintering machine is enabling the rapid fabrication of parts with complex geometries.
- Integrated modeling software tools for coupling structural, thermal, fluids, optical, and control simulations were utilized on a number of programs to optimize system design variables while maintaining system performance.
- A laser scanning digital microscope, flash diffusivity instrument, rheometer, X-ray photoelectron and auger electron spectrometer, tabletop universal test system, digital-image-correlation software, and other materials testing tools are enhancing the development and evaluation of advanced materials.
- Researchers are exploring and evaluating methods of human-robot interaction in the recently completed Lincoln Laboratory Interactive Virtual Environment, a three-dimensional motion-capture theater.
- Novel sensing, vision processing, and autonomy algorithms are guiding small unmanned aerial vehicles (UAV) operating at very low altitudes. Integration of photon-to-digital imaging with tightly coupled planning algorithms enabled the UAVs to perform high-speed obstacle avoidance in complex environments. Scene depth derived from stereo cameras was used to alter a multirotor's Global Positioning System (GPS) trajectory.
- Military and commercial interest in the Localizing Ground-Penetrating Radar (LGPR) has grown since it was chosen for an R&D 100 Award, patented, and selected as the topic of an article in the *Journal of Field Robotics*. The Laboratory is currently investigating the use of LGPR in GPS-denied localization and is collaborating with the U.S. Military Academy at West Point to design a vehicle mount that automatically moves LGPR out of the way of obstacles during off-road operations.
- Sessions of the fifth annual Mechanical Engineering Technology Symposium, held in September 2015, focused on advanced materials, additive manufacturing, vibration testing, mechanical-thermal technologies, optical technology, and control systems.

Future Outlook

- Over the past year, the Laboratory began developing the next generation of weather-sensing CubeSats and worked on multiple efforts to develop deployable aperture systems for small satellites. As a result of these and other technology developments, the Laboratory expects to see significant growth in its small satellite, CubeSat, and micro-satellite work in the near future.
- New technology investments will be focused on developing a model-based engineering approach to improve the speed of program execution; adding chip-scale packages and chip-on-board assemblies to existing surface-mount circuit board assembly capabilities; and developing hierarchical, multifunctional, and thermal materials for reduced size, weight, and power (SWaP) and higher-performance payloads than those built with conventional materials.
- The Energy Systems Group's portfolio will be expanded to include the development of more energy-efficient, portable equipment for soldiers. Integrated systems and concepts will be needed to reduce SWaP requirements and extend the energy endurance of existing devices such as batteries. Efforts across the group will involve increased collaborations with MIT campus and support to Department of Energy sponsors.
- The Laboratory will move forward with the development of detailed design plans for the construction of a new engineering and prototyping facility.

LABORATORY INVOLVEMENT

Officers from all branches of the Services are working at Lincoln Laboratory under the Military Fellows program.

Technical Education

Lincoln Laboratory invests in developing and sharing the knowledge that will drive future technological advances and inform the next generation of engineers.

EDUCATIONAL COLLABORATIONS WITH MIT

Students and instructors in the RACECAR workshop offered during the Independent Activities Period (IAP) are seen here after the workshop finale, a competition for their autonomous cars to navigate through tunnels beneath MIT campus buildings.

Independent Activities Period at MIT

Lincoln Laboratory technical staff led activities offered during MIT's Independent Activity Period (IAP), a four-week term from 5 to 30 January 2015. Under the IAP program, for-credit classes are available for registered MIT students, and noncredit activities, which may span the full four weeks or a limited number of days, are open to all members of the MIT community. IAP offerings range from academic classes to hands-on engineering projects to artistic pursuits.

During the 2015 intersession, David Kong taught a for-credit course offered by the MIT Department of Biological Engineering. This year's course, *Fluidics for Synthetic Biology: Prototyping Microbial Communities*, introduces students to the use of digital fabrication tools, with an emphasis on 3D printing, for the manufacture of fluidic devices for culturing microbial communities. Lincoln Laboratory technical staff members Todd Thorsen and Peter Carr gave guest lectures during the course, which was held jointly at the MIT Lincoln Laboratory Beaver Works facility and wet labs at MIT campus.

Students in the Introduction to Lasercom IAP course align optics to transmit music across the room by using a laser beam.

Lincoln Laboratory expanded the number of noncredit courses organized and led by its technical staff members to seven activities:

- Lincoln Laboratory staff reprised the two popular build-a-radar sessions: *Build a Small Radar System*, conducted by Patrick Bell (team lead), Bradley Perry, Shakti Davis, Alan Fenn, Kenneth Kolodziej, and John Meklenburg; and *Build a Small Phased Array Radar System*, directed by Todd Levy (team lead), Patrick Bell, Jeffrey Herd, Kenneth Kolodziej, and Nicholas O'Donoughue.
- Robert Freking, with assistance from Gregory Balonek and Joseph Vornehm, again conducted the *Hands-on Holography* activity in which students learn how holographic phenomena can be used in real-world sensing applications.
- A new offering this year was the *Innovation Tournament*, a four-day exploration of techniques for generating and presenting innovative ideas. Robert Atkins, Kevin Cohen, Matthew Cornick, Robert Galejs, and Kenneth Gregson developed the curriculum on the Laboratory's blue-teaming model and directed the interactive sessions.
- In the new *Introduction to Lasercom: Build Your Own Laser Audio Transmitter* activity, David Caplan, Gavin Lund, John Moores, and Jade Wang introduced students to the principles of laser communications and led them through the process of designing and building a basic laser audio communication system.
- Another first-time offering was *RACECAR* (for Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot), a workshop in which student teams were challenged to develop software that would enable a converted radio-controlled car equipped with lidar, camera, inertial sensors, and embedded processing to race around a large course. Michael Boulet, Owen Guldner, and Michael Park collaborated with Sertac Karaman of the MIT Department of Aeronautics and Astronautics to mentor the teams whose autonomous cars would ultimately compete to navigate an MIT tunnel network.
- Scott Pudlewski and Thomas Royster led *Software Radio*, a course in which two-person teams used a combination of MATLAB and a software-defined radio platform to build wireless GPS receivers.

For the assembly of a small radar system, a student in an IAP build-a-radar course drills holes in a plywood mount for the radar's components (top) and another student solders components onto a circuit board.

Many of this year's IAP noncredit activities were held at Beaver Works. The *RACECAR*, *Software Radio*, *Introduction to Lasercom*, and the two build-a-radar workshops conducted lectures in the classroom area, utilized the 3D-printing capabilities, and made ample use of the prototyping shop at the facility.

MIT Professional Education—Short Programs

Lincoln Laboratory collaborates with MIT faculty to offer courses through MIT's Professional Education Short Programs. Short Programs typically run during the summer and bring participants from industry, government, and business to MIT's campus for intensive, three- to five-day courses designed to expand participants' familiarity with emerging technologies.

In summer 2015, two courses included members of the Laboratory's technical staff among the lecturers:

Patrick Bell, Alan Fenn, Kenneth Kolodziej, John Meklenburg, Nicholas O'Donoughue, and Bradley Perry joined Michael

>> *Technical Education, cont.*

Watts, a professor in MIT's Department of Electrical Engineering and Computer Science, to present *Build a Small Radar System*.

Michael Boulet, Mark Donahue, and Kenneth Cole collaborated with H. Harry Asada of MIT's Department of Mechanical Engineering and Matthew Walter of the Toyota Technological Institute at Chicago to conduct *Rapid Robotics: Autonomous Systems with Open Source Software*.

VI-A Master of Engineering Thesis Program

Students in MIT's VI-A Master of Engineering Thesis Program spend two summers as paid interns at Lincoln Laboratory, contributing in projects related to their courses of study. Then, the students work as research assistants while developing their master of engineering theses under the supervision of both Laboratory engineers and MIT faculty. In 2015, five VI-A students are participating in the program, gaining experience in testing, design, development, research, and programming.

Research Assistantships

Lincoln Laboratory employs a limited number of research assistants from MIT. Working with engineers and scientists, these students contribute to sponsored programs while investigating the questions that evolve into their doctoral theses. The facilities, the research thrusts, and the reputations of staff members are prime inducements behind the graduate students' decision to spend three to five years as research assistants in a technical group.

Undergraduate Research Opportunities and Practice Opportunities Programs

Lincoln Laboratory is one of the research sites that partner with MIT's Undergraduate Research Opportunities Program (UROP) and Undergraduate Practice Opportunities Program (UPOP). Students undertaking a UROP or UPOP assignment may choose to do a research project for course credit or accept a paid internship.

Most participants at the Laboratory are interns working under the direct supervision of technical staff members. The students engage in every aspect of onsite research—developing research proposals, performing experiments, analyzing data, and presenting research results. In summer 2015, 12 undergraduates were hired as UROP interns and 7 as UPOP interns.

Advanced Concepts Committee

The Advanced Concepts Committee (ACC) provides funding and technical support for researchers who are investigating novel concepts that address high-priority national problems. Each year, the committee reviews proposals for short-term projects and then selects ones that explore innovative technology developments that may enable new systems or promote significant improvements in current practices. The ACC encourages collaborative projects with MIT faculty and also funds a limited number of studies and projects conducted by MIT researchers in areas pertinent to Lincoln Laboratory's programs.

BEAVER WORKS

Beaver Works, a joint initiative between Lincoln Laboratory and the MIT School of Engineering, serves as an engine for innovative research and a mechanism for expanding project-based learning opportunities for students. By leveraging the expertise of MIT faculty, students and researchers, and Lincoln Laboratory staff, Beaver Works is strengthening research and educational partnerships to find solutions to pressing global problems.

CAPSTONE COURSE

The signature Beaver Works collaboration is the capstone course, an MIT engineering class at the center of which is a project to develop technology that solves a real-world problem identified by Lincoln Laboratory researchers. Capstone courses usually span two semesters—the first to conceptualize and design a system that addresses a need, and the second to then fabricate a prototype system. Students draw from the foundational knowledge of their instructors and the field experience of Laboratory mentors to achieve a workable solution.

In fall 2014 and spring 2015, MIT ran two capstone courses:

- *Mobile Tactical Power Systems*, offered by the Department of Mechanical Engineering. The course challenge is to develop novel energy options that reduce or eliminate a logistics burden faced by deployed military units: the transport of diesel fuel to power generators at forward bases.
- *Environmental Awareness in the Maritime Domain*, for credit in either the Department of Aeronautics and Astronautics or Department of Mechanical Engineering. This cross-department project is to design, build, and demonstrate an autonomous seaplane along with a buoy system that recharges batteries and exchanges data. This buoy will enable the seaplane to accomplish long-endurance surveillance operations in marine environments.

The prototype seaplane developed by students in a capstone course is shown here taxiing on the water during an initial test in Stow, Massachusetts.

UNIVERSITY ACTIVITIES

The Beaver Works center, located just off the MIT campus in Cambridge, has become a popular venue used by many MIT classes and programs.

- The fabrication areas offer ready access to tools and high-tech equipment, such as 3D printers and a laser cutter, that support hands-on construction of prototypes by students from not only the engineering departments but also groups such as the MIT Robotics Club and the MIT UAV Club.
- In January, IAP activities led by Lincoln Laboratory staff were conducted at Beaver Works. The flexible spaces adapted well to both lecture-style classes and prototyping workshops.
- On 28 February, approximately 70 MIT undergraduate and graduate students participated in the Assistive Technologies Hackathon (ATHack) at Beaver Works. Teams of students, who had in the weeks preceding ATHack met with local people who live with disabilities, prototyped engineering solutions to problems faced by their "clients," creating such devices as a voice-activated cane and a hands-free walker.

MIT students hacked a printer to create the mechanical page turner seen above. By moving his head, their client, a conductor with cerebral palsy, can command the device to turn pages of sheet music.

MEETINGS

Because of its open, flexible floor plan, Beaver Works accommodates meetings of all sizes. Since 2014, two dozen groups have booked the center for their meetings. Above are participants in the Humanitarian Assistance and Disaster Response (HADR) Workshop that discussed ways advanced technology could help relief agencies respond to crises.

K–12 EDUCATIONAL OUTREACH

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

>> Technical Education, cont.

UNIVERSITY PROGRAMS

Summer Research Program

In 2015, 236 undergraduate graduate students from 79 different schools participated in the Summer Research Program, which offers students from top universities across the country internships in technical groups. The students gained hands-on experience in a foremost research environment while contributing to projects that complement their courses of study. The Laboratory also provided short research assignments for 50 cadets and midshipmen from the U.S. military academies.

University Cooperative Education Students

Technical groups at Lincoln Laboratory employ students from area colleges as cooperative education interns working full time with mentors during the summer or work/study semesters and part time during academic terms. Highly qualified students selected for the program become significant contributors to technical project teams, building prototypes, analyzing data, and testing applications in the field. In 2015, 60 cooperative education students worked at the Laboratory.

SPOTLIGHT

Lincoln Laboratory's Radar Course Travels to New Mexico

For five years, Lincoln Laboratory has offered build-a-small-radar courses during MIT's three-week intersemester Independent Activities Period. On 7 February 2015, an abbreviated version of the radar course became an Aggie Engineering Challenge at New Mexico State University (NMSU). These student challenges are one of the programs held at the Aggie Innovation Space, a facility in which NMSU students (Aggies) have access to resources and mentors that can help them conceptualize and build innovative technologies.

New Mexico State University students use laptop-driven small radar systems to measure the speed and range of moving objects encountered outdoors.

Shakti Davis, a member of the technical staff in the Airborne Radar Systems and Techniques Group who has been an instructor for the radar workshops and who is an alumna of NMSU, worked with Patricia Sullivan, associate dean of the NMSU College of Engineering, and Muhammad Dawood, associate professor in the Klipsch School of Electrical and Computer Engineering, to organize a one-day syllabus that gives students both an introduction to the basics of radar systems and a hands-on experience taking actual radar measurements. The date of the workshop was chosen to coincide with Davis's recruiting visit to the campus.

The radar challenge was devised as a competition. During the morning session of the Saturday workshop, 26 students attended lectures on the history, uses, and fundamentals of radar systems. They learned about detection and ranging, and ran MATLAB simulations to step through key functions of a radar system. Split into teams of four or five, the students were quizzed on the lectures, and teams were awarded points for correct answers.

In the afternoon, the students moved outside to perform experiments with the small laptop-operated radar systems built by participants in Lincoln Laboratory's radar workshops. The teams used these radars to measure the speed of passing cars, to gauge the range of objects, and to study the Doppler signatures of everyday moving objects, such as a person walking or a spinning bicycle wheel.

"The students had a chance to see everyday objects 'through the eyes of the radar,'" says Davis. The teams gained points for completing experiments. At the end of the workshop, the three teams that had accrued the most points earned Lincoln Laboratory t-shirts and gift cards to Barnes and Noble bookstores.

"This was a chance for students to work with radar—something they've heard about but not actively played around with," says Davis. "Initially for them, the systems were sort of mysterious 'black boxes.' We took some of the mystery out."

The workshop was a successful outreach venture on two fronts. "The students were really excited and interactive, asking lots of questions," says Davis. Additionally, NMSU faculty are interested in developing spin-off programs that are modeled on Lincoln Laboratory's radar workshop: a four-hour radar course for teachers seeking ideas for hands-on science projects and a one- to two-week workshop for students in grades 7 to 12.

MILITARY FELLOWS PROGRAM

Each year, MIT Lincoln Laboratory awards fellowships to support the educational pursuits of active-duty military officers from all of the Service branches. This partnership acquaints military officers with the process of developing technologies that directly impact national security while providing the Laboratory with constructive insights of the officers.

- Officers enrolled in a Senior Service School work in research programs at the Laboratory and take national security management courses at MIT campus.
- Senior officers participating in the Army's Training with Industry Program are assigned full time to a Laboratory technical group.
- Fellows pursuing graduate degrees work on Laboratory-sponsored programs that complement their thesis research.

In addition, the Laboratory employs military liaisons, and cadets and midshipmen from the U.S. Service academies.

SPOTLIGHT

Colonel Brian Lieb, U.S. Army

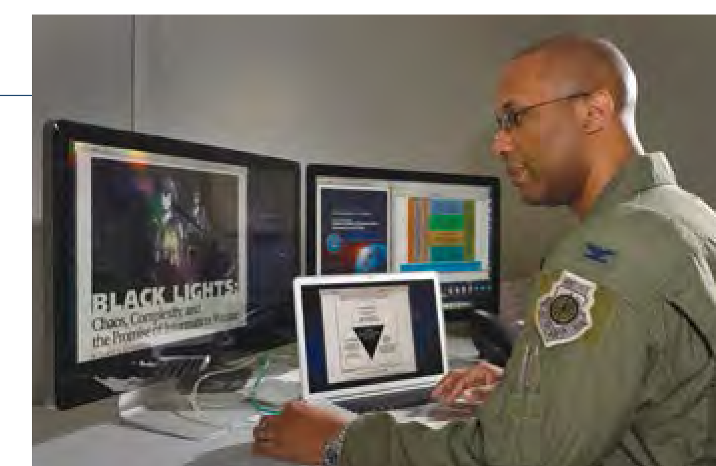
COL Lieb discusses with colleagues Joseph Shultz (left) and Matthew Karas (right) the idea of mounting a small, lightweight, multi-aperture sensor on a quadcopter to provide wide-area motion imagery (WAMI) in support of tactical U.S. Army force protection needs. The background screen shows an example of WAMI as captured by the Laboratory-developed Multi-Aperture Sparse Imager Video System.

In August 2014, after returning from a deployment to Afghanistan, Colonel Brian Lieb began a new kind of assignment: serving a two-year tour as the U.S. Army Office of the Deputy Chief of Staff for Intelligence liaison to Lincoln Laboratory. An Army War College graduate with 21 years of Army experience, including six deployments, COL Lieb provides operational perspectives to the technical groups with whom he works. In turn, he sees the range of Laboratory-developed technologies that could be transitioned to the military. Currently, he is involved in several projects—an aerial intelligence, surveillance, and reconnaissance program; an effort to improve shared situational awareness among dismounted soldiers; and technical feasibility studies for the U.S. Army intelligence enterprise. Reflecting on his experience at the Laboratory thus far, COL Lieb says, "I have gained an appreciation for the Laboratory's capabilities, an understanding of how the Laboratory supports national defense, and knowledge of the technology acquisition process."

SPOTLIGHT

Colonel William E. Young, Jr., U.S. Air Force

"Working with a talented team of engineers and researchers to tackle some of the nation's most pressing cyberspace challenges has been one of the most personally and professionally rewarding experiences of my career," says Colonel William E. Young, Jr. An MIT doctoral degree candidate in engineering systems and an Air Force liaison to the Laboratory's Cyber System Assessments Group, Col Young is applying system-theoretic approaches to improve systems engineering, operational design, red teaming, and campaign-level mission assurance in the cyberspace domain. His research, coupled with his 23 years of operational experience, helps mission owners and commanders identify the key cyber terrain that must be defended to effectively accomplish a mission.



Col Young applies sociotechnical principles to cyber warfare theory to identify engineering requirements for secure and resilient cyber systems. "Something as simple as translating abstract engineering terms into concrete operational terms that a sponsor can understand helps eliminate cyber vulnerabilities at the concept stage," says Col Young.

>> *Technical Education, cont.*

WORKSHOPS AND SEMINARS

LINCOLN LABORATORY WORKSHOPS

The list of workshops and seminars hosted by Lincoln Laboratory shows the range of research that the Laboratory shares with the technical and defense communities. The workshops address technology developments in longstanding program areas, such as air vehicle survivability and air and missile defense, and in newer areas of research, such as homeland protection and cyber security.

The workshops bring in guest speakers from the defense community, industry, and academia to add their perspectives on the application of advanced technology to their fields. These events provide valuable exchanges of ideas and insights into the directions for future research. Most workshops run for two to three days. The exception is the Defense Technology Seminar, a week-long program of seminars and tours offered to approximately 50 to 75 invited guests from the military and government agencies.

2015 Schedule of Onsite Workshops

APRIL

7–9 Air and Missile Defense Technology Workshop
13–17 Defense Technology Seminar

MAY

5–7 Space Control Conference
12–14 Air Vehicle Survivability Workshop
19–20 Lincoln Laboratory Communications Workshop
27–28 Advanced Technology for National Security Workshop

JUNE

2–4 Intelligence, Surveillance, and Reconnaissance (ISR) Systems and Technology Workshop
15–17 Cyber and Netcentric Workshop

JULY

16–17 Graph Exploitation Symposium

SEPTEMBER

29–30 Mechanical Engineering Technology Symposium

NOVEMBER

3–5 Anti-access and Area Denial (A2/AD) Systems and Technology Workshop

Offsite Workshops

The Laboratory also coordinates offsite workshops with partnering organizations. Laboratory involvement may be cochairmanship of events, technical leadership of sessions, or cosponsorship of workshops.

2015 schedule of offsite workshops

- IEEE International Symposium on Technologies for Homeland Security, **14–16 April** in Waltham, Massachusetts
- IEEE High Performance Extreme Computing Conference, **15–17 September** in Waltham, Massachusetts
- IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference, **5–8 October** in Rohnert Park, California
- Air Traffic Control Workshop coordinated with the Federal Aviation Administration (FAA) and held in **November** at the FAA Headquarters in Washington, D.C.

COURSES

Hosted at Lincoln Laboratory

Lincoln Laboratory also hosts a number of multiday courses for user communities with which the Laboratory interacts. Courses for invited military officers and Department of Defense civilians enhance understanding of current research and the systems developed at the Laboratory, and are part of the Laboratory's mission to extend scientific knowledge.

David Mooradd demonstrated the concepts of gain and beamwidth during a session of the Introduction to Radar Systems course.

2015 Defense Technology Seminar

The 2015 Defense Technology Seminar was held at Lincoln Laboratory in April. Forty-seven military officers and Department of Defense civilian employees (above) attended the weeklong event that focused on evolving military challenges. Technical staff from the Laboratory and nationally prominent guest speakers presented seminars on national security and current geopolitical issues. A one-day Defense Technology Seminar was held on 3 April for cadets of the U.S. Military Academy.

2015 schedule of onsite courses

- Introduction to Radar Systems, **16–18 June**
- Networking and Communications, **15–16 September**

Offsite courses at the Naval War College

Technical staff present courses at the Naval War College, Newport, Rhode Island; each semester, one course is scheduled, and the topics vary to address the college's needs. The courses scheduled in the past few years have been in cyber security, ballistic missile defense, and space technology.

Technical Seminar Series

Members of the technical staff at Lincoln Laboratory present technical seminars to interested college and university groups. The 2015 slate of 57 available seminars covers a wide range of topics in radar technology, air traffic control, advanced electronics, cyber security, human language technology, and communication systems.

Robert Work, Deputy Secretary of Defense, center, who toured MIT Lincoln Laboratory in May, also addressed attendees at the 37th Air Vehicle Survivability Workshop. He is seen here with, left to right, Robert Shin, Head, ISR and Tactical Systems Division, Lincoln Laboratory; Maria Zuber, Vice President for Research, MIT; Eric Evans, Director, Lincoln Laboratory; William LaPlante, Assistant Secretary of the Air Force for Acquisition; Thomas Ehrhard, Special Assistant to the Deputy Secretary of Defense; and Randall Walden, Director, Air Force Rapid Capabilities Office.

>> Technical Education, cont.

PROFESSIONAL DEVELOPMENT

Lincoln Laboratory's extensive research and development accomplishments are enabled by the strength of its staff. The variety of educational opportunities and technical training available to staff help ensure continuing excellence.

Lincoln Scholars Program

Technical staff members interested in pursuing degrees at either the master's or doctoral level can apply to the competitive Lincoln Scholars Program, which supports full-time graduate study at Boston-area universities. During the academic year, the scholars attend on-campus courses and continue to contribute to Laboratory programs on a weekly basis under terms arranged with the Graduate Education Committee; in between semesters and after receiving their degrees, they work at the Laboratory full time. Each scholar is paired with a mentor who oversees his or her academic progress and ongoing contributions to the Laboratory. Currently, 24 staff members are Lincoln Scholars.

Part-Time Graduate Studies Program

The Part-Time Graduate Studies Program enables staff to work full time at the Laboratory while pursuing part-time technical and nontechnical graduate studies via distance learning or at local universities. As of the fall 2015 term, 16 staff members are participating in the program.

Boston University Program

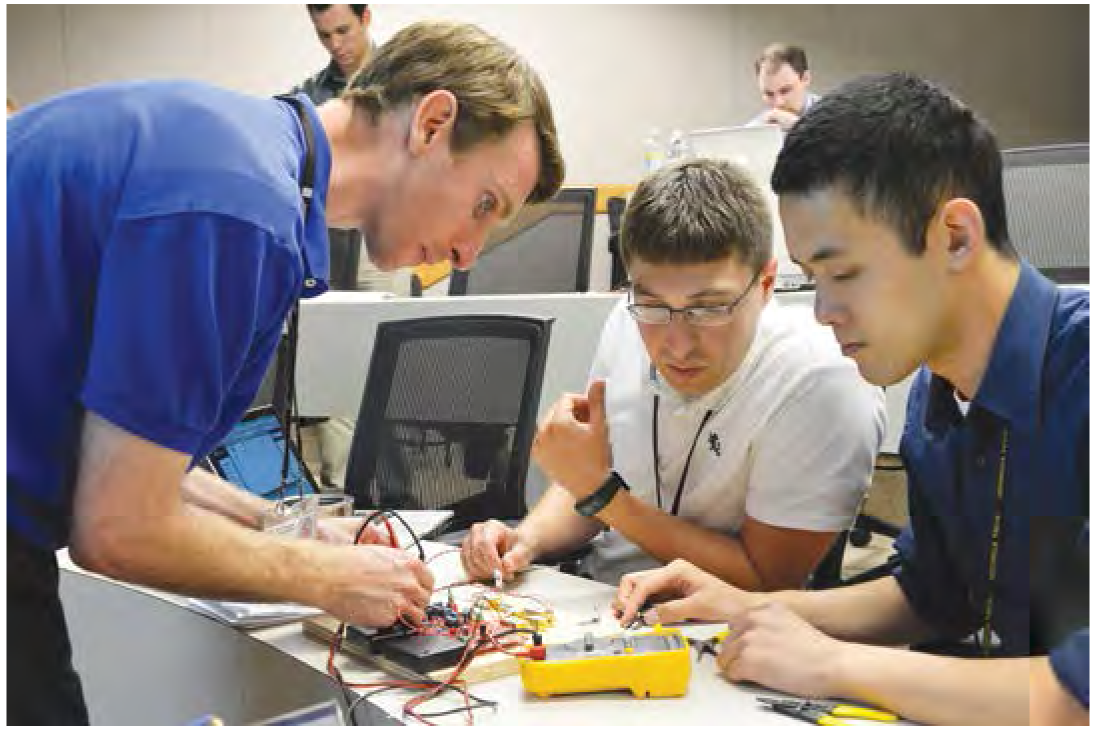
Core and elective courses from Boston University's (BU) master's program in computer science (MSCS) are being offered onsite at Hanscom Air Force Base. These courses, which have included Computer Networks, Cryptography, and Software Engineering, can be taken independently or as part of a certificate or master's degree program through BU. More than 100 staff members have enrolled in the MSCS program since it started three years ago.

Lincoln Laboratory Overview for New Employees

During this three-day orientation, technical and administrative staff are briefed by division and department leadership; tour onsite and offsite Laboratory facilities; and network with colleagues.

Technical Education Program Onsite Courses

A range of technical, programming, and software application courses are taught by either Laboratory experts or outside instructors. Technical courses are typically multisession and cover topics such as robotics, radar, serious games, signal processing, cyber security, machine learning, and communications. Classes on programming languages and interactive computing environments and certification courses for various operating systems and network devices are offered regularly.



Kenneth Kolodziej (standing), co-organizer of the "Build a Radar" technical education course, checks the different voltages on the students' signal processing board for their radar system.

Diversity and Inclusion

A commitment to fostering an inclusive workplace helps ensure that Lincoln Laboratory maintains an excellent, diverse staff, thereby strengthening its ability to develop innovative solutions to problems.

Members of the MLK, Jr.'s Breakfast Planning Committee gather with the keynote speakers and Lincoln Laboratory Director at the conclusion of the event.

Second Annual Martin Luther King, Jr. Breakfast

"What does Dr. King's life and legacy mean to you?" This question was the focus of the second annual Martin Luther King, Jr. Breakfast, organized by the Lincoln Employees' African American Network and held on 18 February at the Minuteman Commons Community Center on Hanscom Air Force Base. Personal reflections were offered by three keynote speakers: Edmund W. Bertschinger, Institute Community and Equity Officer at MIT; Shannon Roberts, a technical staff member in the Laboratory's Cyber Analytics and Decision Systems Group; and Alyce Johnson, Manager of Staff Diversity and Inclusion at MIT.
In the context of their experiences and the recent tragedies that have sparked widespread racial tension, the speakers quoted many of King's writings, including the book *Why We Can't Wait*, and the speeches "Facing the Challenge of a New Age" and "The American Dream." The selected excerpts and the speakers' reflections touched upon themes such as individual rights, human dignity, and equal access to education. This year's approximately 200 attendees included distinguished guests Colonel Christopher Faux and Lieutenant Colonel Thatcher Kezer, both of the Massachusetts Air National Guard, and Raheem Beyah, a professor at the Georgia Institute of Technology.

> *"The Laboratory has a rich history. The Laboratory is famous for its technical excellence. It is famous for the technical depth of its staff. But we should not rest until the Laboratory is also famous for its diverse and inclusive culture, for the care and respect that we have for each other, and for the recognition that we need to lead. Dr. King would expect nothing less."*
>
> **Director Eric D. Evans, opening remarks**

>> *Diversity and Inclusion, cont.*

Laboratory Director Eric Evans (far right) and William Kindred (far left), manager of the Laboratory's diversity and inclusion programs, are photographed with nine of the ten GEM fellows who interned at the Laboratory over the summer.

The National GEM Consortium

As an employer member of the National GEM Consortium, Lincoln Laboratory offers paid summer internships to students from underrepresented minorities who are pursuing graduate study in science, technology, engineering, and mathematics (STEM) through the GEM Fellowship Program. The goal of the program is to increase the number of STEM students nationwide. Ten GEM fellows performed research at the Laboratory in summer 2015.

Austin Murdock, a second-year GEM fellow attending the University of California, Berkeley, focused his research on computer security and network intrusion-detection and intrusion-prevention systems. "Being a GEM fellow was a great way to be paired with a good mentor, have access to the right tools, and get hands-on experience in the cybersecurity field," says Murdock.

Ranysha Ware, a Laboratory technical staff member and GEM fellow alumna who completed two summer internships at the Laboratory as a University of Massachusetts, Amherst, graduate student, credits the GEM program for supporting her professional development: "As a black woman in computer science, I sometimes feel that I don't belong or that I'm an imposter in a field dominated by people who don't look like me. The GEM program connected me with other underrepresented STEM students and helped me form a support network of mentors from UMass Amherst and Lincoln Laboratory."

As part of its participation in GEM, the Laboratory sends representatives to the Annual GEM Board Meeting and

Leslie Watkins (back) mentors first-year GEM fellow Marissa Garcia, who interned at Lincoln Laboratory in summer 2015. Here, Garcia investigates small propeller motors used in a micro–unmanned aerial vehicle platform. Her project for the summer was to miniaturize a camera payload for this platform.

Conference. Eric Evans, director of Lincoln Laboratory and president of the GEM Executive Committee, and William Kindred, manager of the Laboratory's diversity and inclusion programs, attended the 2015 event held from 5 to 7 August at the John F. Kennedy Presidential Library and Museum in Boston, Massachusetts. The Laboratory sponsored an Executive Committee meeting and a tour of its Lexington, Massachusetts, facility and cosponsored the opening reception, at which Evans delivered a welcome address.

Mentorship Programs

Recognizing that strong mentorships enhance an inclusive workplace, Lincoln Laboratory conducts four formal mentoring programs:

- New Employee Guides acquaint newly hired staff members with their groups, divisions, or departments.
- Career Mentoring is a six-month, one-on-one mentorship that helps technical and administrative professionals with career development.
- Circle Mentoring small discussion groups, led by experienced employees, address diverse topics relevant to professional development and career growth.
- Assistant Group Leader Mentoring partners a newly promoted assistant group leader with an experienced group leader to help with the transition into new responsibilities.

A new cycle of Career Mentoring began in 2015 with 47 mentors and 47 mentees. Carrying over from 2014 are the 20 mentors and 132 mentees participating in Circle Mentoring and the six mentor-mentee pairs participating in Assistant Group Leader Mentoring.

During one of five monthly mentoring sessions, William Streilein (left), a group leader, provides advice to Mark Silver, a technical staff member, on how to advance his career at the Laboratory. "This kind of discussion does not come up in everyday work settings," says Silver. According to Streilein, who has participated in multiple mentoring programs as both a mentor and a mentee, the experience benefits him too: "Because I work in the cyber division and Mark in engineering, I get a different view on how the Laboratory operates."

Presentations for 2015

February

In honor of Black History Month, the Laboratory's African American Network and the Office of Diversity and Inclusion hosted two seminars:

"What Do Science, Technology, and Innovation Mean from Africa?" Clapperton Mavhunga, MIT, discussed how Africans rely on traditional knowledge to acquire technology and make their own.

"Password Security, Measurement, and Correlation Quantification." Raheem Beyah, Georgia Institute of Technology, presented a prototype system that provides a platform for password research.

March

The Women's History Month technical speaker was Niaja Farve, a PhD candidate and researcher in the Fluid Interfaces Group at MIT Media Lab. Her presentation, "Wearable Applications for Improved Well-Being," provided examples of wearable devices positively affecting people's behaviors and habits.

April

"Parenting LGBT (Lesbian, Gay, Bisexual, Transgender) Kids." Morganne Ray, program director at Justice Resource Institute, provided advice to parents unsure of how to respond to their children's coming out to them.

June

"Diversity and Mindful Leadership." This talk by Renée Richardson Gosline, MIT Sloan School of Management, was broadcast at the Laboratory. The talk, recorded at the MIT Diversity Summit, explored how individuals can become effective leaders in a diverse world.

Employee Resource Groups

The Laboratory's resource groups provide support to staff members 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 following groups help promote the retention and achievement of employees:

>> *Diversity and Inclusion, cont.*

"The concerts give the Laboratory community a respite that is fun, inspiring, restorative, and perhaps informative in introducing new genres and musical concepts."

Leanne McNally,
member of the concert committee and a key event organizer

During this year's Music Technology Seminar on 31 March, world-renowned stringed-instrument bow maker Benoit Rolland (at podium) explained the art of bow making and presented his most recent innovation: the Galliane frog. A fundamental evolution in classical bow design, the Galliane frog sets the bow hair at an ergonomic angle to follow a musician's natural arm movement. Violinist In Mo Yang (inset) then played his violin using a traditional bow and one featuring a Galliane frog to demonstrate the difference in sound quality. Cellist Haden McKay also took to the stage.

Noontime Concerts

The Lincoln Laboratory Noontime Concert series features music from a variety of genres. Offerings range from classical European to American jazz to Latino dance to Celtic music. Last year, the annual Music Technology Seminar was established to integrate elements of music technology and craftsmanship with musical performance.

- New Employee Network
- Technical Women's Network
- Hispanic/Latino Network
- Out Professional Employee Network
- African American Network
- Veterans Network
- Employees with Disabilities Network

Highlights

In January, the Technical Women's Network gathered to watch and discuss Anne-Marie Slaughter's TED talk, "Can we [women] have it all?" Sponsored by TED, a nonprofit dedicated to spreading ideas through short, powerful videos, this talk explores why shifts in work culture, public policy, and social norms can lead to more equality for men and women.

In February, the Veterans Network handed out valentines and balloons to veterans at the Edith Nourse Rogers Memorial Veterans Hospital as part of the Department of Veterans Affairs National Salute to Veteran Patients.

Several activities were held in June as part of LGBT Pride Month, including an ice cream social, a seminar on LGBT families, and a Boston Pride Parade march.

Prof. Rafael Bras, provost and executive vice president for academic affairs at the Georgia Institute of Technology, was the guest speaker at the third annual Hispanic Heritage Month Celebration, hosted by the Hispanic/Latino Network in October.

Awards and Recognition

The commitment to excellence that characterizes our staff has enabled the Laboratory's 64 years of achievements and its sustained reputation for innovation.

Member of the National Academy of Engineering

Dr. Eric D. Evans, for contributions to engineering. Election to the National Academy of Engineering, a nonprofit organization providing technical expertise to the U.S. government, is one of the highest distinctions accorded to American engineers.

2015 Fellow of the American Institute of Aeronautics and Astronautics

Dr. Eric D. Evans, "for sustained and outstanding technical leadership in the application of advanced technology and system architectures to critical national security problems."

2015 Associate Fellow of the American Institute of Aeronautics and Astronautics

Dr. Marc D. Bernstein, for contributions to the science or technology of aeronautics.

2016 Associate Fellows of the American Institute of Aeronautics and Astronautics

Dr. Steven R. Bussolari and **Dr. Eliahu H. Niewood**, for contributions to the science or technology of aeronautics.

2015 Fellow of the Institute of Electrical and Electronics Engineers

Dr. William S. Song, for "contributions in high-performance low-power embedded processors."

2015 Edwin H. Land Medal

Dr. Mordechai Rothschild and **Dr. David C. Shaver** shared this award with Dr. Joseph Mangano of the Defense Advanced Research Projects Agency. The award recognizes their contributions to the development of the argon fluoride excimer laser and modern, deep-ultraviolet photolithography for the semiconductor industry.

2014 MIT Lincoln Laboratory Technical Excellence Awards

Dr. David O. Caplan, for "his outstanding technical contributions to optical communications; leadership in developing advanced high-sensitivity optical transceivers for terrestrial and space-based applications; and innovations in multi-rate signaling formats and flexible free-space laser communication architectures."

Dr. Vyshnavi Suntharalingam, for "her deep technical knowledge of and contributions to the field of advanced imaging technology; creativity in developing silicon-based imagers, innovative charge-coupled devices, and active pixel sensors; and leadership of projects in imager design and fabrication that have had significant impact on Laboratory systems."

2014 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Matthew T. Cornick, for "his work in the development and operational support of a novel ground-penetrating radar; stellar analysis and project leadership skills in fast-paced assessment and rapid prototyping programs; and contributions to the characterization of low-frequency RF, very high-frequency, and ultrahigh-frequency phenomenology for various applications."

Dr. Hamed Okhravi, for "his development of a critical road map and associated analytical tools for cyber resiliency analyses of moving target systems; technical leadership in developing and analyzing secure applications; and substantial contributions to the literature on cyber security."

2014 MIT Lincoln Laboratory Best Paper Award

Dr. William J. Blackwell and **Dr. Adam B. Milstein**, for "A Neural Network Retrieval Technique for High-Resolution Profiling of Cloudy Atmospheres," published in the *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 7, no. 4, April 2014.

2014 MIT Lincoln Laboratory Best Invention Award

Dr. Mark S. Veillette, **Dr. Haig Iskenderian**, **Dr. Marilyn M. Wolfson**, **Christopher J. Mattioli**, **Earle R. Williams**, **Eric P. Hassey**, and **Patrick M. Lamey**, for *Offshore Precipitation Capability*, for which a patent was filed in May 2014.

>> *Awards and Recognition, cont.*

Recipients of 2015 MIT Lincoln Laboratory Administrative and Support Excellence Awards are, left to right, John Bilodeau, Eric Carrera, Heather Wilcox, and Allison MacDonald.

2015 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative Category: **Allison J. MacDonald**, for "leading efforts that have positively impacted service delivery, information management, and data availability within the Environmental, Health, and Safety Office;" and **John E. Bilodeau**, for "routinely going above and beyond his division-level job duties to fulfill information technology needs across the Laboratory."

Support Category: **Heather A. Wilcox**, for "applying strong leadership and collaboration skills in support of a department office and the Laboratory;" and **Eric P. Carrera**, for "supporting the prototyping and testing of RF systems through his work as a technician."

2015 SPIE Technology Achievement Award

Dr. Keith B. Doyle, in recognition of "outstanding contributions to integrated analysis of optical systems, incorporating into this analysis elements of optical, thermal, and structural engineering." SPIE is an international society for optics and photonics.

2015 Nelson P. Jackson Aerospace Award

Presented by the National Space Club to the **Lunar Laser Communications Demonstration Team**, composed of members from NASA Goddard Space Flight Center and MIT Lincoln Laboratory. The award recognizes the team for "record-breaking achievement using broadband lasers for space communications."

2015 Massachusetts ECO Award

MIT Lincoln Laboratory received a 2015 Excellence in Commuter Options (ECO) Award at the Pinnacle level for its strong program that facilitates employees' usage of alternatives to single-occupancy automobile commuting. The Pinnacle level is the highest ECO Award ranking, recognizing institutions and businesses that provide extensive services to commuters.

Best Paper Award, 2015 Spring Simulation Multiconference

Dr. Neal Wagner, **Dr. Richard P. Lippmann**, **Dr. Michael L. Winterrose**, **Dr. James F. Riordan**, **Tamara H. Yu**, and **Dr. William W. Streilein** coauthored "Agent-based Simulation for Assessing Network Security Risk Due to Unauthorized Hardware," which was named the best paper in the Agent-Directed Simulation Symposium at the 2015 Spring Simulation Multiconference.

SOLIDWORKS Women in Engineering Honoree

Kristen E. Railey, chosen as the May 2015 honoree of SOLIDWORKS Corporation's Women in Engineering program, which monthly recognizes a woman for her leadership and innovation in an engineering field. She has developed open courseware to interest and instruct young women in engineering principles.

Honorable Mention in National Security Agency's Best Scientific Cybersecurity Paper Competition

Dr. Hamed Okhravi, **Dr. James Riordan**, and **Dr. Kevin Carter** were recognized with one of two honorable mentions in the National Security Agency's (NSA) annual Best Scientific Cybersecurity Paper Competition, a component of the NSA's Science of Security Initiative that promotes pioneering research in cybersecurity.

2015 Fred W. Ellersick MILCOM Award for Best Paper

Eric R. Tollefson and **Bruce R. Jordan Jr.**, for the paper "Out-Phased Array Linearized Signaling (OPALS): A Practical Approach to Physical Layer Encryption," entered in the Unclassified Technical Program at MILCOM (IEEE Military Communications Conference) 2015.

2015 Luis de Florez Award

Michael L. Stern received the MIT Department of Mechanical Engineering's 2015 Luis de Florez Graduate Design Award that is given for a research project that shows outstanding ingenuity and creativity.

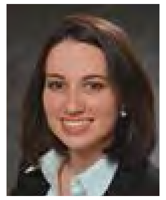
Chair of the IEEE Cybersecurity Initiative

Dr. Robert K. Cunningham will chair the steering committee for the IEEE's Cybersecurity Initiative, a project to focus attention on designing software that better protects systems and networks from cyber attack.

2015 Tufts University Mentoring Award

Dr. Daniel V. Rabinkin was selected by Tufts University's Class of 2015 electrical and computer engineering majors as the industry mentor of the year for his work with the senior design course students on their capstone project.

Selection for 2015 U.S. Frontiers of Engineering Symposium



Dr. Mabel D. Ramirez was selected to participate in the National Academy of Engineering's U.S. Frontiers of Engineering Symposium, a multiday event that brings the nation's most innovative young engineers together to discuss the application of technology to challenging global problems.

2015 Bay State Bike Week Challenge Award

The Lincoln Laboratory team pedaled 11,160 miles to earn a first-place award in the MassCommute challenge to bicycle instead of driving to destinations during Bike Week, 9–17 May. The team, which was first in its division of businesses with 3000–4999 employees, also logged the most miles of any size team registered in the challenge.

First Place—2014 Audio/Visual Emotion Challenge

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

2014 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) Award

A training simulation developed by a Lincoln Laboratory and Office of Naval Research team was selected the best government entry in the Serious Games Showcase and Challenge at I/ITSEC. The interactive program was designed to improve Navy personnel's tactical responses to cruise missile threats.

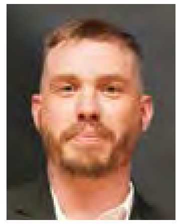
2015 MIT Excellence Awards

Bringing Out the Best Award
Dr. Robert K. Cunningham

Serving the Client Award
Joseph N. Masello

Unsung Hero Award

Chiamaka O. Agbasi-Porter



Richard C. Gervin

Dr. Marc A. Zissman

Innovative Solutions Award

Gulfstream GII APU Root Cause Investigation Team, Kenneth L. Burkett, Richard Coveno, Brandon J. Dilworth, Todd R. Lardy, Robert J. Longton, Robert L. Maynard, Kenneth S. McKenna, Christopher P. McNeil, Lance F. Michael, Todd M. Mower, Robert A. Murray, and Melissa S. Nelson

Lincoln Laboratory Prime Contract Team, Susan Dawson, Michael Greenidge, Daniel R. Kay Jr., Stephen P. Kent, Stephanie Leonardi, Kristin N. Lorenze, Patricia M. O'Riordan, Frank D. Schimmoller, David A. Shumsky, David Suski, and Steven Tran

>> *Awards and Recognition, cont.*

R&D 100 Awards

Three technologies developed at MIT Lincoln Laboratory were named 2015 recipients of R&D 100 Awards. Given annually by *R&D Magazine*, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. A panel of independent evaluators and editors of *R&D Magazine* choose the recipients from hundreds of nominated candidates that represent a broad range of technologies developed in industry, government laboratories, and university research facilities.

Representatives of Lincoln Laboratory attended the 2015 R&D 100 Awards banquet on 13 November in Las Vegas, Nevada. Seen here (left to right) are Timothy Dasey, Albert Swiston, Ronald Duarte, Kenneth Kolodziej, Dana Sinno, Marc Bernstein, and Beijia Zhang.

Self-Defense Distributed Engagement Coordinator

A decision support tool that automatically evaluates the potential responses to anti-ship threats and recommends defensive actions

DEVELOPMENT TEAM: Nicholas Hatch, Dana Sinno, Sung-Hyun Son, Geordi Borsari, Reed Jensen, Michael Molignano, Anu Myne, Timothy Navien, Mabel Ramirez, Katherine Rink, Stephen Uftring, Lincoln Laboratory; Joel Cofield, Daniel Finkel, Erica Heffer, Daniel Hogan, Stacey Morin, Jessica Stigile, and Jacob Wasserman, formerly of Lincoln Laboratory; Adrian Becker and Dimitris Bertsimas, MIT

Video Content Summarization Tool

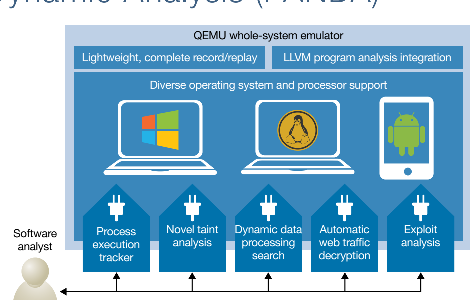
Software that creates summary views of long-duration surveillance videos to allow analysts to quickly identify activities of interest

DEVELOPMENT TEAM: Jason Thornton, Marianne DeAngelus, Ronald Duarte, Zach Elko, Kim Lasko, and Timothy Schreiner, Lincoln Laboratory; Nicholas Gallo, Christine Russ, and Aaron Yahr, formerly of Lincoln Laboratory

Platform for Architecture-Neutral Dynamic Analysis (PANDA)

An extensible, plug-in software framework that enables computer engineers to identify system vulnerabilities by dynamically analyzing program code

DEVELOPMENT TEAM: Joshua Hodosh, Patrick Hulin, Timothy Leek, and Ryan Whelan, Lincoln Laboratory; Brendan Dolan-Gavitt, New York University's Tandon School of Engineering; Wenke Lee, Georgia Institute of Technology; David Kaeli, Northeastern University



2015 R&D 100 Award Finalists

Eight technologies developed at Lincoln Laboratory were selected by *R&D Magazine* as 2015 finalists:

- Composable Analytics
- Dynamic Photoacoustic Spectroscopy
- Instantaneous Direction-Finding Vector Sensor
- Laser Ultrasound for Medical Imaging
- Lincoln Adaptable Real-Time Information Assurance Test bed
- Rare-Earth Microbarcodes
- Simultaneous Transmit/Receive on the Move
- Vocal and Facial Biomarkers of Depression Based on Motor Coordination and Timing

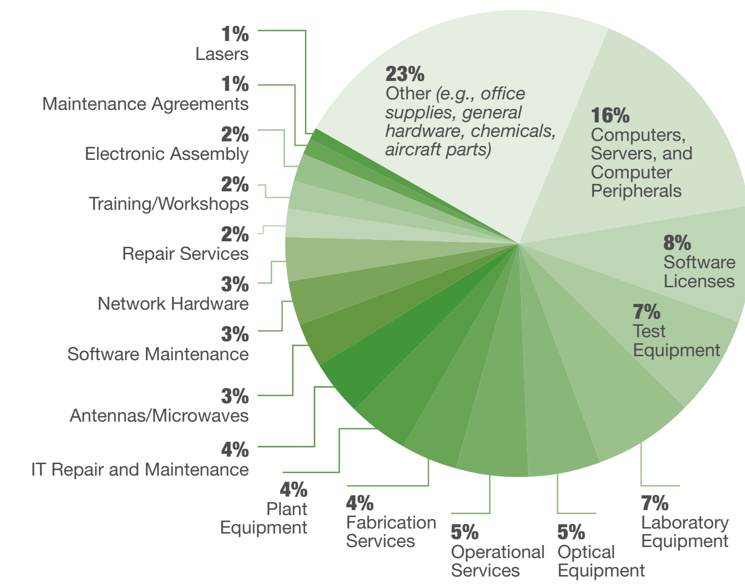
Economic Impact

Lincoln Laboratory serves as an economic engine for the region and the nation through its procurement of equipment and technical services.

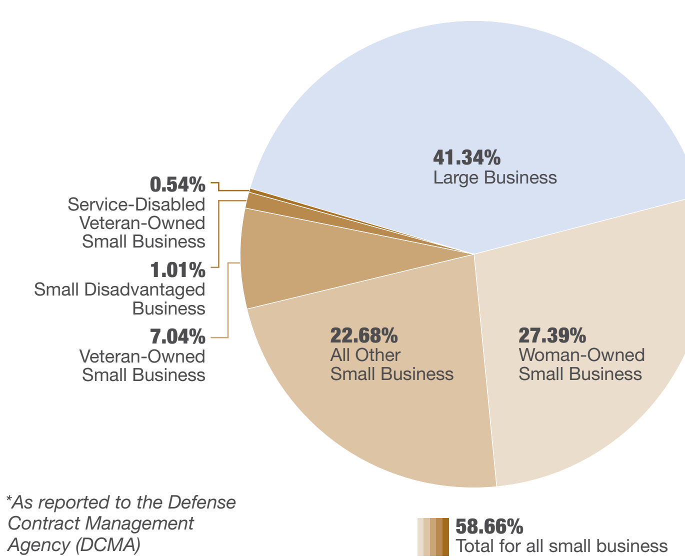
During fiscal year 2015, the Laboratory issued subcontracts with a value of approximately $600 million. The Laboratory awarded subcontracts to businesses in all 50 states and purchased more than $351 million in goods and services from New England companies in 2015, with Massachusetts businesses receiving approximately $293 million. States as distant as California and Texas also realized significant benefits to their economies.

Small businesses—which supply construction, maintenance, fabrication, and professional technical services in addition to commercial equipment and material—are primary beneficiaries of the Laboratory's outside procurement program. In 2015, more than 58% of subcontracts were awarded to small businesses of all types (as reported to the Defense Contract Management Agency). The Laboratory's Small Business Office is committed to an aggressive program designed to afford small business concerns the maximum opportunity to compete for purchase orders. In addition, the Laboratory contracts with universities outside of MIT for basic and applied research. These research subcontracts include expert consulting, analysis, and technical support.

Commercial hardware and materials contracted to businesses (FY 2015)

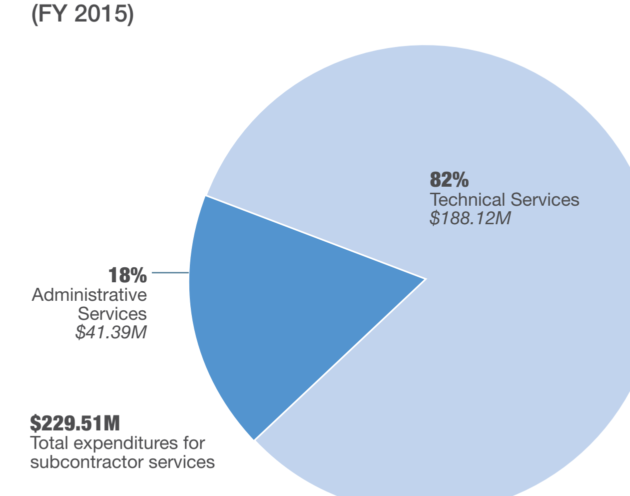


Contract awards by category of businesses (FY 2015)*



*As reported to the Defense Contract Management Agency (DCMA)

Subcontractor services (FY 2015)



EDUCATIONAL AND COMMUNITY OUTREACH 69

Attendees at the 2015 Sons Day watch Lincoln Laboratory's pendulum track Earth's rotation.

Educational Outreach

Community outreach programs are an important component of the Laboratory's mission. Outreach initiatives are inspired by employees' desires to help people in need and to motivate student interest in science, technology, engineering, and mathematics (STEM).

Lincoln Laboratory Community Outreach

At the Electricity, Ions, and Chemistry presentation, Jude Kelley shows children how to find ions in red cabbage.

Science on Saturday

How can we see colors in the visible light spectrum? How can a computer verify identity via retinal scans? What can real robots do? How can we find ions in foods like pickles? These questions were the focus of demonstrations given by Laboratory scientists and engineers at this year's Science on Saturday events. More than 3500 local K–12 students, their parents, and teachers attend these free onsite events during the school year. This year marks the tenth anniversary of Lincoln Laboratory's Science on Saturday demonstrations.

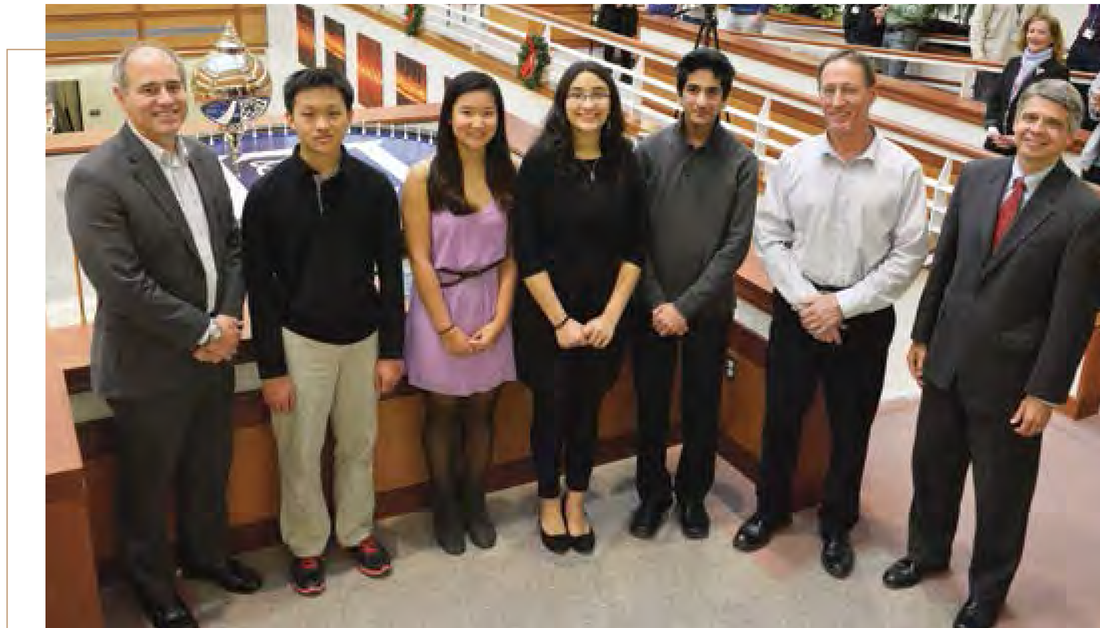
LLRISE Workshop at Beaver Works

In February, Lincoln Laboratory hosted a one-day radar workshop based on its popular two-week Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) program. Held at Beaver Works, the workshop was a chance for local students to learn about the principles of radar.

Lectures delivered in the two-week program (history of radar, radar hardware, radar basics, ranging, MATLAB intro, Doppler) were presented in condensed form.

Mentors and volunteers included Raoul Ouedraogo, Alexis Prasov, Wingyan Beverly Lykins, Christ Richmond, Crystal Jackson, John Nwagbaraocha, Loren Wood, Shakti Davis, David Granchelli, and Eric Phelps. Each student group gave a three-minute presentation of what they learned. Program coordinator Chiamaka Agbasi-Porter says, "This one-day workshop was successful. I think we can further tailor the course, currently designed for rising seniors, for lower grade levels."

Eric Phelps (right) assists two students in testing the voltage of their radar.



At the December event to unveil the pendulum exhibit, the four Lexington High School students who helped with the project—(left to right) Jerrick Chen, May Zhou, Mia Kobs, and Videh Seksaria—were photographed with Frank Robey, project lead (far left), David Scott, manager of the Technology Office Innovation Laboratory (second from right), and Eric Evans, director, Lincoln Laboratory. Below, the tiny radar system is one of two that provide real-time returns of the pendulum's motion. These radar measurements are displayed on one of the screens of the interactive computer interface installed nearby.

SPOTLIGHT

Foucault's Pendulum at Lincoln Laboratory

On 15 December 2014, a pendulum installed in Lincoln Laboratory's East Atrium was released for its inaugural "swing." The Laboratory's pendulum daily replicates the experiment that French scientist Jean Bernard Léon Foucault performed at the Panthéon during the 1851 Paris Exhibition. His pendulum swung over a circular plot of sand on the floor while the audience watched as a stylus attached to the pendulum's ball traced a series of lines in the sand, each slightly clockwise to the previous one. Because a pendulum does not change its plane of motion, the explanation for this drawing must be that the floor is moving—that is, Earth is rotating about its axis. As with many modern pendulum exhibits, the Laboratory's pendulum reenvisions Foucault's sand tracings with the sequential tumbling of pegs circularly arranged at the limits of the pendulum's arc.

The installation of the pendulum was a collaborative project that enlisted a multidisciplinary team from the Laboratory and four physics students from nearby Lexington High School to develop a museum-quality display about Foucault's experiment and the science governing the pendulum's motion. The dual goals of this educational outreach activity were to involve students in an engineering activity and to create an attraction that would engage the curiosity of the many middle- and high-school students who come to Lincoln Laboratory for outreach programs.

The final exhibit comprises not only the pendulum but also an interactive touchscreen presentation that summarizes Foucault's experiment, discusses the physics of the pendulum's movement, and highlights some current scientific explorations in which the Laboratory is involved. In addition, the exhibit includes a new twist—radar tracking of the pendulum's movements, supplied by two small radar units set up at corners of the base.

The students contributed to various aspects of the project. Videh Seksaria, Mia Kobs, and May Zhou designed sample 3D-printed components for the display, working with David Scott in the Technology Office Innovation Laboratory to learn the SOLIDWORKS software used to create the drawings from which the components are fabricated. The three helped craft the storyline for the interactive display; later, their feedback on the touchscreens' sequence, graphics, and language prompted adjustments to improve the display's audience appeal.

Jerrick Chen took measurements that the engineering team used to assess the performance of the little radars and assisted with the coding employed in the computer-driven touchscreens.

The project met its goals: the exhibit provides an arresting learning experience, and the development of it inspired the students, who agreed with May: "This experience solidified my interest in becoming an engineer."

>> *Educational Outreach, cont.*

Above, the 2015 LLRISE students, shown with Lincoln Laboratory mentors, prepare for two weeks of college-level courses and hands-on engineering activities. Below, LLRISE students test their radars' ability to measure the movement of a balloon pendulum.

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

LLRISE
LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Out of 222 applicants from across the United States, 18 rising high-school seniors were chosen for the fourth Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) Workshop, held July 12–25.

With the help of Lincoln Laboratory scientists and engineers, the participants built their own Doppler and range radars. In addition to learning about radar systems and the history of radar, the students were instructed in computer-aided design, 3D printing, circuit board assembly, electromagnetics, pulse compression, signal processing, antennas, MATLAB programming, electronics, and the principles of physics. In past years, the students tested their radar designs through instructor-designed experiments, but this year, the students creatively designed their own experiments.

"LLRISE pushed me in the best possible way, both socially and academically. I am extremely satisfied with and grateful for my experience in LLRISE."

Participants resided on MIT campus, where they received practical advice on the college admissions process. In between instructional lectures and engineering activities, the students toured the Laboratory's Flight Test and RF System Test Facility, and the MIT Haystack Observatory in Westford, Massachusetts.

The LLRISE coordinator, Chiamaka Agbasi-Porter, was supported by nine technical staff members who taught various portions of the workshop and assisted the students with assembling their radars and debugging their electronics.

Turing Machine Exhibit

A team of Lincoln Laboratory scientists helped two high-school seniors from the Community Charter School of Cambridge, Massachusetts, build a version of a Turing machine, a theoretical computing system proposed by Alan Turing as a means to mathematically calculate anything. This project helped the students satisfy an internship requirement.

Chad Spensky, Benjamin Nahill, Stuart Baker, Timothy Greer, and Jack Lepird served as mentors, teaching Trevon Bennett and Kyania Burke about basic electrical engineering, mathematical concepts, and product development. Bennett appreciated the guidance from his mentors: "While we had never built one of these machines, the mentors were able to use their experience to come up with ideas and direct us through the process. Kyania and I were able to add our ideas as well."

At the Community Charter School of Cambridge Senior Internship Exhibition Night held at Google in Cambridge, Massachusetts, students Kyania Burke and Trevon Bennett (second and third from the left) explain the process used to build the Turing machine replica. Their Lincoln Laboratory mentors, Timothy Greer (left), Chad Spensky (right), and Benjamin Nahill (far right), attended the event.

The students learned how to work with the Python programming language, Raspberry Pi single-board computers, the Arduino electronic prototyping platform, and machine tools. They also developed the embedded microcontrollers, numerous motors and sensors, and code to control the machine.

The Laboratory staff plan to continue working to deploy a polished machine at Lincoln Laboratory as a long-term exhibit.

LLCipher

In August, Lincoln Laboratory held a new outreach program, LLCipher. Offered at Beaver Works, this one-week workshop provides an introduction to modern cryptography—a math-based, theoretical approach to securing data.

Lessons in abstract algebra, number theory, and complexity theory provided students with the foundational knowledge needed to understand theoretical cryptography. Students built on that knowledge to construct provably secure encryption and digital signature schemes. On the last day, students learned about zero-knowledge proofs (proving a statement is true without revealing any information beyond the truth of the statement) and multiparty computation (computing a function over multiple parties' inputs while keeping the inputs private).

Workshop designer and lead instructor Sophia Yakoubov (standing) makes her way through the classroom as the students work on a physical secret communication challenge.

The idea for the course came from Bradley Orchard. Sophia Yakoubov developed the course and served as the lead instructor, with the help of Emily Shen and David Wilson.

According to Orchard, "Sophia did a superb job designing the course, as evidenced by the enthusiasm and participation of the students. The students were engaged, asking questions and demonstrating that they understood the material, and, most importantly, having fun."

Yakoubov says that the first LLCipher workshop was clearly a success: "The most common suggestion among students was to extend the length of the program, so we plan to add more activities into next year's workshop."

>> *Educational Outreach, cont.*

SPOTLIGHT

"Make Your Own Wearables" Workshop

"Close your eyes and picture an engineer," said mechanical engineer Kristen Railey to the group of 50 high-school girls gathered at Lincoln Laboratory on 13 December 2014 for an engineering workshop. "Okay, open your eyes and raise your hand if you imagined Mark Zuckerberg, a car mechanic, or characters from The Big Bang Theory." Dozens of hands immediately flew up. "Now," she directed, "raise your hand if you imagined someone like me." Fewer than five hands shot up in the air.

"I want girls to realize that engineers look like me and them," says Railey, who organized and led the full-day workshop designed to introduce girls to engineering by having them make their own wearables—apparel and accessories that incorporate computer and electronic technologies. The girls not only left the workshop with 3D-printed bracelets but also with basic skills in computer-aided design (CAD), computer programming, and circuitry. As a former MIT mechanical engineering undergraduate with no precollege exposure to engineering, Railey knows all too well how a lack of such skills can deter girls from the field.

The FLORA (a wearable electronics platform) circuit board, positioned on the ankle area of the girls' boots, measures the resistance from a pressure-sensitive conductive sheet placed in the heel of the insole. A battery pack, which is tucked into the shoelaces, is connected to the FLORA. When the girls walk, the resistance of the sheet drops, triggering the red lights seen above.

The girls learned about the applications of 3D printers and various machine shop tools; attended a session on SOLIDWORKS CAD software; created 3D models of bracelets; and programmed light-emitting diodes for a shoe-wearable electronic circuit that they built. Presenting some of the real-world applications of wearable technology were two guest speakers: a prosthetic foot designer and the co-inventor of Wristify, a thermoelectric bracelet. "I learned a lot about different areas of engineering that I didn't even know existed," said one girl.

The one-day workshop will be offered again next year. In the meantime, Railey is engaging this year's participants through social media and on her Girls Who Build website. "The conversation does not end here with the workshop. I want to create a community that connects girls to local engineering workshops and summer camps, female role models, and educators," states Railey.

"I want girls to realize that engineers look like me and them."

**Kristen Railey,
mechanical engineer and workshop organizer**

David Scott, manager of the Technology Office Innovation Laboratory, explains to the girls how a MakerBot 3D printer functions and what kind of parts it can make. On the bench, 3D-printed parts of various shapes, sizes, and complexities are displayed.

Wow! That's Engineering!

In June, 100 girls in sixth through eighth grade attended a Wow! That's Engineering! workshop cohosted by the Boston chapter of the Society of Women Engineers and Lincoln Laboratory's Technical Women's Network. The workshop's goal was to "wow" girls by showing them what they can accomplish as engineers and what it is like to be an engineer. "Girls in middle school often lose their enthusiasm for science. The workshop presents engineering as an exciting career choice," says Yari Rodriguez, event coordinator.

The girls practiced hands-on engineering and interacted with female scientists and engineers. They reverse engineered (took apart) appliances, made a light-emitting diode (LED) flashlight, designed a balloon-powered car, and examined DNA samples from their saliva.

AFCEA Internships

In summer 2015, two local Massachusetts graduating high-school seniors worked at the Laboratory under an internship program arranged by the Lexington-Concord chapter of the Armed Forces Communications and Electronics Association (AFCEA). Mentored by Derrick Feld, Chi Chi Nwodoh of Bedford assisted in the mechanical construction of satellite terminal prototypes for a newly developed satellite system. Nahom Ghile of Malden, who helped Josh Erling and Andrew Daigle develop software to control and configure a system to record and measure radio-frequency (RF) data, participated in open-air testing of the system to characterize the noise levels present in the RF spectral band.

CyberPatriot

In the fall, Lincoln Laboratory sponsored three teams in CyberPatriot, a national competition for high-school students learning defensive computer security. The 14 students (four of whom were new to CyberPatriot) were mentored by Kevin Bauer, Jorge Coll, and John Wilkinson. After learning how to identify malware, "clean" a computer system, and establish a secure network, the teams competed in the statewide competition. One team advanced to the Northeast regional competition.

Robotics Outreach

Robotics teams meet weekly during the fall to design and program a robot to accomplish tasks as required by the challenge set forth by For Inspiration and Recognition of Science and Technology (FIRST).

FIRST Technical Challenge

Grades 7–12
24 students, 2 teams

Mentored by Jacob Huang and Jenifer Evans

iiMITless

Mightybots (MITibots) – competed at the State Finals

Jr. FIRST Lego League

Grades K–3
18 students, 3 teams

Mentored by Beverly Lykins, Hemonth Rao, and Stephen Valentine

Lego League Explorers

Tech Titans

Storm

FIRST Lego League

Grades 4–8
95 students, 11 teams

Mentored by Loretta Bessette, Jacob Huang, Curtis Heisey, and Carol Chiang

Legosaurus

Bot Vaderz

Flaming Ninja Waffles

Mindstrosity – competed at the State Finals

Anonymous Rulers

RoboOwls

The Crazy 8s

Titanium Lego Dudes

Zero Gravity

EV3s

EV4s

Jacob Huang and Loretta Bessette organized and hosted the Massachusetts FIRST Technical Challenge State Championship in February, with the assistance of James Streitman, Nancy List, Joseph Usoff, Peter Klein, David Blocher, and Nicholas Stanisha among others.

Community Giving

Lincoln Laboratory employees engage in many activities supporting worthy causes that contribute to the overall quality of life within and outside their communities.

WALK TO END ALZHEIMER'S

50
members raised $35,000, ranking the team the 2nd-highest fundraiser in the Boston walk

Boston Food Bank

5797
meals were assembled for needy families by volunteers from the Lincoln Employees' African American Network

JIMMY FUND WALK

87
miles were walked by a 3-member team who raised $2700

Troop Support

174 soldiers received care packages from Lincoln Laboratory since fall 2014

LLVETS DISC GOLF TOURNAMENT

26 people raised $300 to support the Wounded Warrior Project

WOUNDED WARRIOR SOLDIER RIDE

2102
dollars were raised by 9 team members in this rehabilitative cycling event for injured service members

AUTUMN ESCAPE BIKE TREK

3915
dollars were raised by 5 riders for the American Lung Association

BIKE & HIKE THE BERKSHIRES

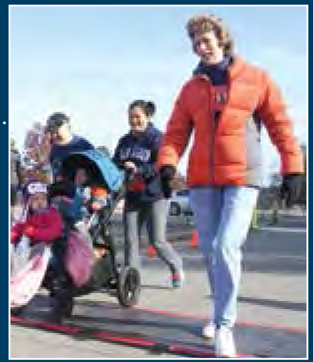
2980
dollars were raised by the Bike & Hike Team to help strike out multiple sclerosis

HEART WALK

4864
dollars were raised by 8 team members to help raise awareness about heart disease

Veterans' Day Fun Run

28
Laboratory veterans ran to support deployed soldiers from Massachusetts



LL Pi

252
pies were sold, raising $7050 for Community Servings, which delivers meals to AIDS patients

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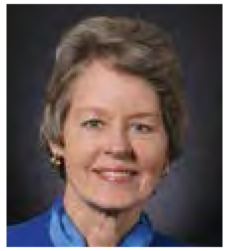

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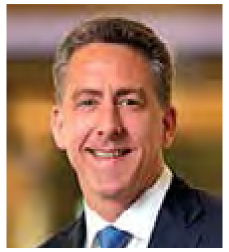

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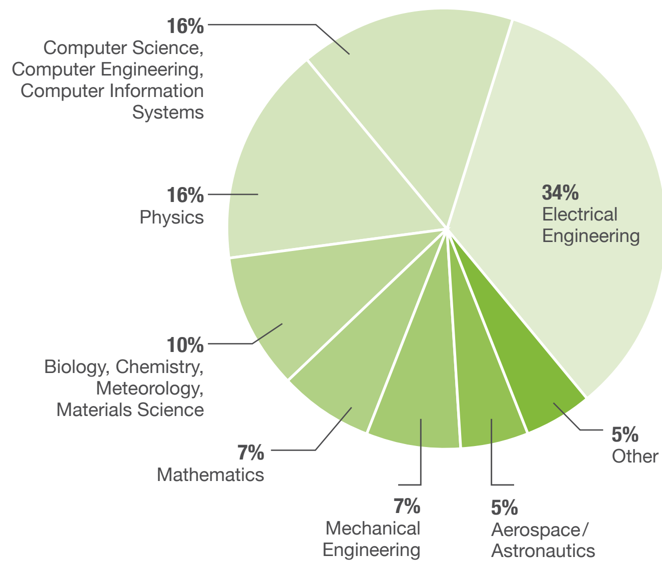
Staff and Laboratory Programs

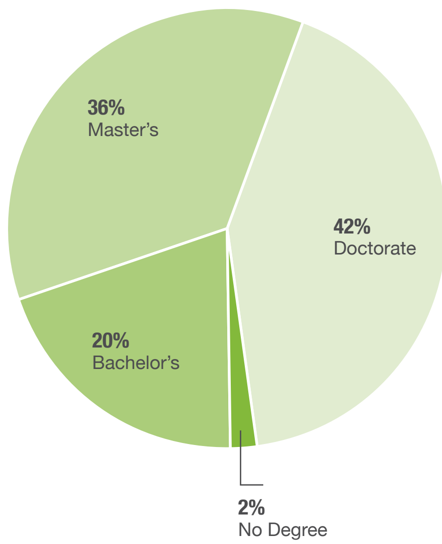
1779	Professional Technical Staff
1079	Support Personnel
460	Technical Support
529	Subcontractors
3847	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

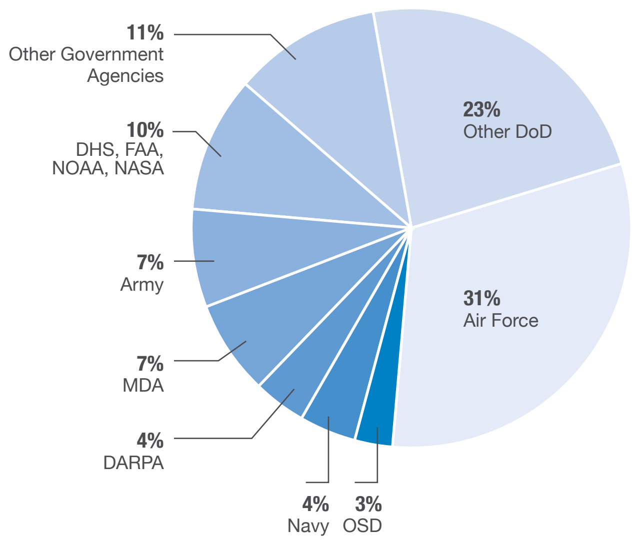


Academic Degree

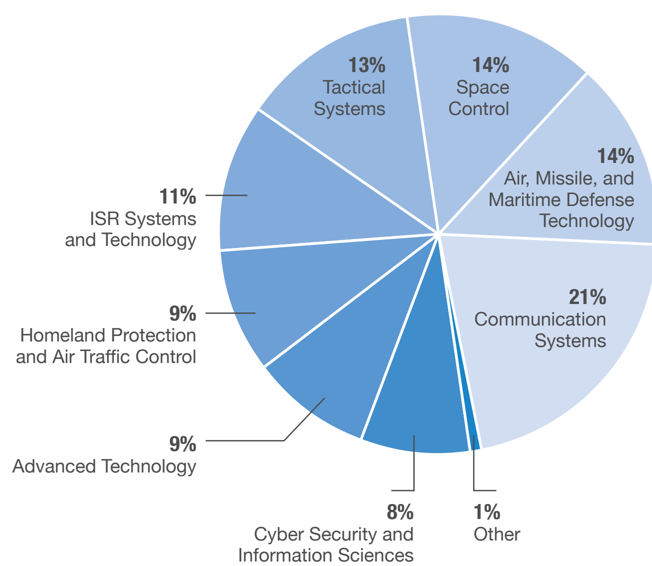


Breakdown of Laboratory Program Funding

Sponsor



Mission Area



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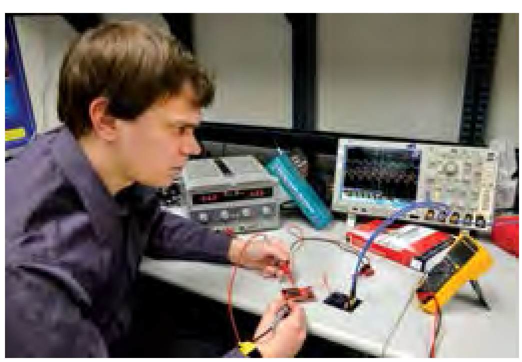

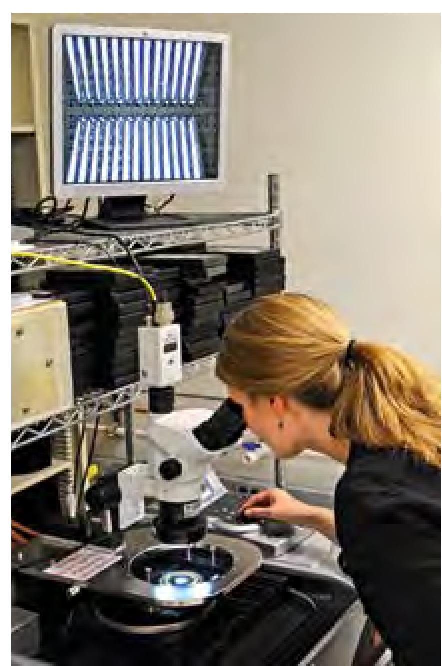

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

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