




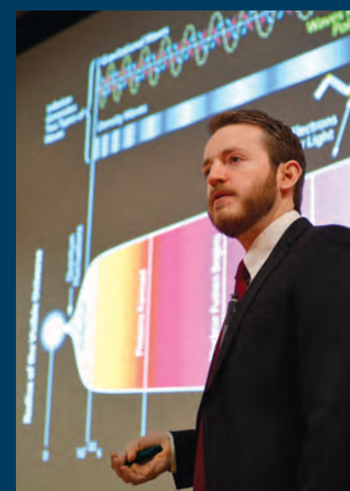

MIT Lincoln Laboratory

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

2014

ANNUAL REPORT

Massachusetts Institute of Technology

MIT Lincoln Laboratory

MIT LINCOLN LABORATORY 2014

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 63 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.

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MIT and Lincoln Laboratory Leadership

Massachusetts Institute of Technology

Dr. L. Rafael Reif
President

Dr. Martin A. Schmidt (left)
Provost

Dr. Maria T. Zuber
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

ORGANIZATIONAL CHANGES

Israel Soibelman

Assistant to the Director for Strategic Initiatives

Dr. Israel Soibelman was appointed Assistant to the Director for Strategic Initiatives. In this position, he is responsible for helping to establish Laboratory-level strategic plans, to develop external strategic relationships, and to lead strategic initiatives in targeted areas.

Melissa G. Choi

Division Head, Homeland Protection and Air Traffic Control

Dr. Melissa G. Choi was appointed head of the Homeland Protection and Air Traffic Control Division. She is responsible for research, development, and technology transfer of systems designed to help safeguard the homeland from terrorist activities and disasters, and to help ensure the safety of the national airspace.

Edward C. Wack

Assistant Division Head, Homeland Protection and Air Traffic Control

Edward C. Wack was named assistant head of the Homeland Protection and Air Traffic Control Division. Prior to this appointment, he served as the leader of the Bioengineering Systems and Technologies Group.

Justin J. Brooke

Division Head, Air and Missile Defense Technology

Dr. Justin J. Brooke was appointed head of the Air and Missile Defense Technology Division. He is responsible for the development and assessment of systems for defense against ballistic missiles, cruise missiles, and air vehicles.

Katherine A. Rink

Assistant Division Head, Air and Missile Defense Technology

Dr. Katherine A. Rink was named assistant head of the Air and Missile Defense Technology Division. Prior to this appointment, she served as the leader of the Advanced Concepts and Technologies Group.

Kevin P. Cohen

Assistant Division Head, Intelligence, Surveillance, and Reconnaissance and Tactical Systems

Dr. Kevin P. Cohen 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.

Joseph Dolan

Department Head, Facility Services

Joseph Dolan was named the head of the Facility Services Department, with responsibility for the operations and maintenance of the entire Lincoln Laboratory complex. He has had 18 years of experience in the department, including serving as its chief engineer and as the assistant department head.

Robert T-I. Shin

Director, MIT Lincoln Laboratory Beaver Works

Dr. Robert T-I. Shin was appointed the Director of MIT Lincoln Laboratory Beaver Works by the Dean of the MIT School of Engineering and the Director of Lincoln Laboratory. He was also named a member of the MIT School of Engineering Extended Engineering Council.

MIT Lincoln Laboratory Fellow

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

Richard P. Lippmann

Dr. Richard P. Lippmann has made key contributions to Lincoln Laboratory's programs in speech recognition and cyber security. He is an internationally recognized leader in neural networks and pattern classification and has pioneered innovative technology for cyber security.

He has authored or coauthored more than 100 papers, reports, or books. His article "An Introduction to Computing with Neural Nets" earned the first *IEEE Signal Processing Magazine* Best Paper Award and has been cited more than 6000 times. He is a 2011 recipient of an MIT Lincoln Laboratory Technical Excellence Award.

Letter from the Director

Lincoln Laboratory continues to work on large-scale hardware and software prototyping projects that incorporate advanced technology and new system architectures. To pull in the best ideas wherever we can find them, we continue to do projects that involve much collaboration inside and outside of the Laboratory. The speed of change for commercial and defense technology is increasing, and the emphasis on rapid development is spreading to many of our programs.

To adapt to current and future national security needs, we have created programs that cut across division lines; invested in laboratories that can be used in multiple domains; and upgraded facilities to promote the fabrication of new, state-of-the-art devices. The recent reorganization of our Advanced Technology Division into technology "product" areas will help us to provide advanced components and subcomponents to a wider range of applications. Our core, long-term work in space control, air and missile defense, and communication systems remains vital to our portfolio and benefits from the infusion of technology from areas such as cyber security and quantum information sciences.

This year we reached several important milestones. In 2014, the Microelectronics Laboratory marked its 20th year of operation, and the Haystack radar observed its 50th anniversary. Both facilities have supported outstanding research: the Microelectronics Laboratory has enabled advancements in semiconductor processes, charge-coupled-device technology, and optical projection lithography; and Haystack has contributed to the Laboratory's space surveillance activities and MIT's astronomy programs. The Haystack Ultrawideband Satellite Imaging Radar (HUSIR) is the latest upgrade to the facility, and the new radar is already demonstrating imaging resolution that will improve our knowledge of deep space.

While the list of accomplishments below represents only a small set of those featured in this annual report, the examples cover the range of our 2014 research and development activities:

- Lincoln Laboratory is working with the Federal Aviation Administration to develop the next-generation airborne collision avoidance system, ACAS X, which will support new flight procedures and aircraft classes.
- A secure, resilient cloud-computing test bed was established to evaluate technologies that could enable the broader use of cloud computing by the Department of Defense.
- A Laboratory-developed three-dimensional ladar, designed to uncover activity in heavily foliated areas, achieved high collection rates that were made possible by dual Geiger-mode avalanche photodiode arrays.
- New network- and transport-layer protocols enabled efficient transport of data over communications links degraded by outages caused by mobility or jamming.
- For a new solid-state S-band Air and Missile Defense Radar being developed by the Navy, the Laboratory prototyped and tested the radar's end-to-end ballistic missile defense discrimination architecture.
- The Laboratory achieved a new power record for coherently combined fiber laser systems. A first-ever coherent combining of quantum cascade lasers was also demonstrated.
- A novel photochemical process is expected to enable the additive manufacturing of three-dimensional siloxane-based microfluidic devices, thus widely expanding the capabilities of biological and biomedical lab-on-a-chip applications.

The Laboratory's community outreach programs continue to grow. We now have more than 30 science, technology, engineering, and mathematics (STEM) educational outreach programs, including the summer radar-building workshop for high-school seniors, Science on Saturday presentations, robotics team mentorship, and support to CyberPatriot teams of high-school "cyber scientists." Our community service programs continue to help many local charitable organizations.

We encourage you to read through this summary of our 2014 technical accomplishments, technology investments, and educational programs. We look forward to future breakthroughs as we continue to focus on technical excellence, integrity, and innovation.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

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

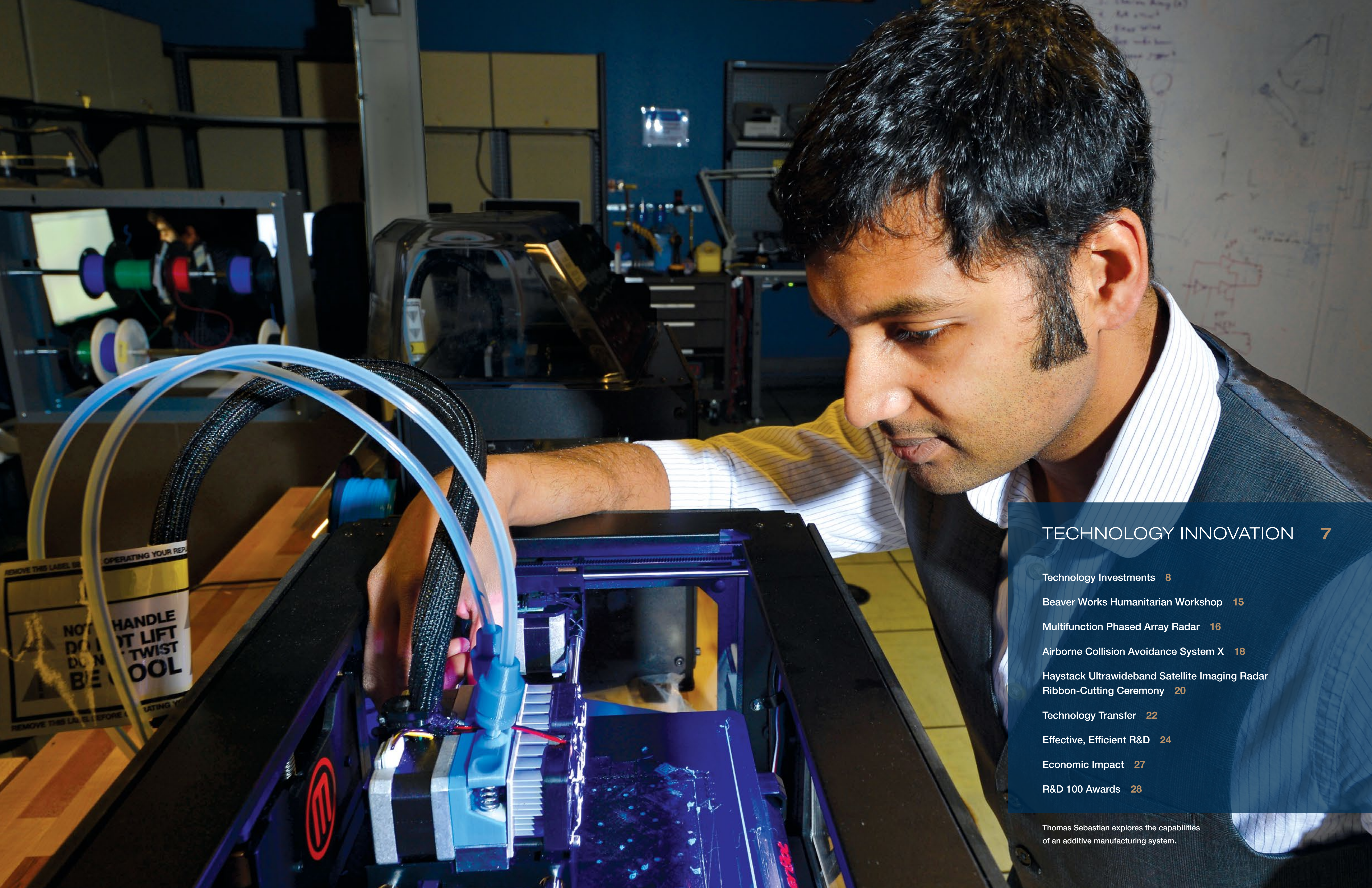
- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

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

Thomas Sebastian explores the capabilities of an additive manufacturing system.

Technology Investments

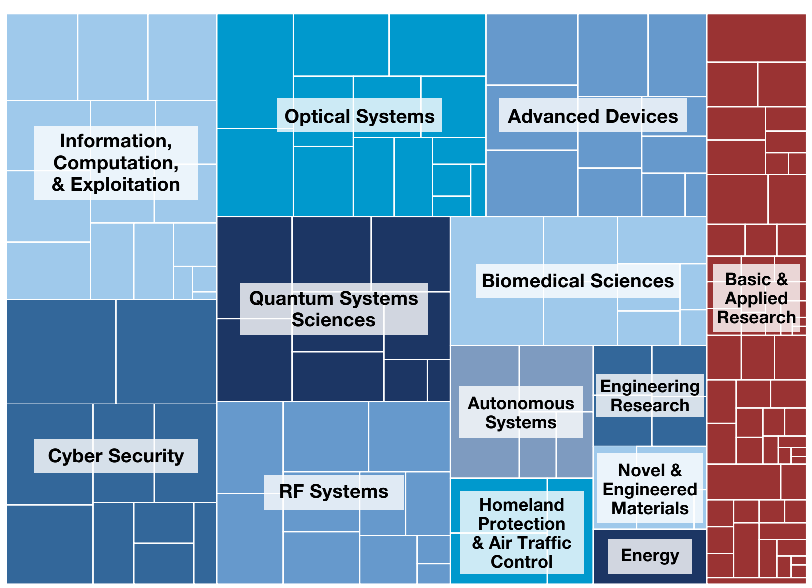
Lincoln Laboratory invests in the development of advanced technologies and capabilities to support the strategic needs of its missions and to promote research in emerging technology areas of relevance to national security.

The Technology Office is responsible for developing and directing strategic research at the Laboratory through focused investments in existing and emerging mission areas. The office seeks out capabilities to address critical problems that threaten national security and derives technology requirements from strategic assessments of the Laboratory's primary mission areas and from government sponsoring agencies. Members of the office interact regularly with the Assistant Secretary of Defense for Research and Engineering (ASD [R&E]) and other government agencies to maintain awareness of critical defense problems and to grow strategic technical relationships. The office also collaborates with and supports university researchers and, in doing so, aids in the translation of new technologies from laboratory-scale to end-user needs. The 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.

R&D Investment Portfolio

Internal research funding at Lincoln Laboratory derives primarily from Congressional appropriations administered by ASD(R&E). The focus of this funding is on long-term, high-impact research that is relevant to Department of Defense (DoD) needs. Additional funding is also available to support laboratory and engineering capability maintenance, to develop and operate broad-use test beds, and to support innovative research in basic and applied science areas. The internal R&D investment portfolio reflects this distribution and is strategically developed to address the critical technology needs of the Laboratory's existing mission areas and to provide the technical foundation to address emerging national security challenges.

LEADERSHIP
Dr. Bernadette Johnson, Chief Technology Officer
Dr. Eric Dauler, Associate Technology Officer (left)
Dr. Andy Vidan, Associate Technology Officer (right)



The Laboratory's internal R&D portfolio supports investments in technical infrastructure and targeted research thrusts across emerging and core Laboratory mission areas. This graphic displays the relative magnitude of 2014 internal funding across mission-critical technology (shaded blue) and basic and applied research (red). The smaller divisions within each block represent individual projects executed in that category.

» MISSION-CRITICAL TECHNOLOGY INVESTMENTS

The 2014 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 and Technology

Research into optical technology encompasses the development, analysis, and demonstration of novel concepts, technology, and systems to inform the next generation of optical systems for the nation's defense needs. Several technologies and capabilities are being pursued:

- High-power, medium-wavelength infrared and long-wavelength infrared lasers and sensor systems for infrared countermeasures and hyperspectral imaging
- Large-format imagers for low–size, weight, and power (SWaP) three-dimensional lidar systems
- Infrared persistent surveillance
- Atmospheric-compensated, long-baseline, high-resolution space and ground surveillance
- Large-area moving target indication and vibrometry

Cyber Security

The Laboratory's applied research on cyber security focuses on the development, evaluation, and deployment of prototype components and systems designed to improve the security of computer networks, hosts, and applications. The 2014 technologies listed below seek to assure the resilience of DoD missions against cyber attacks:

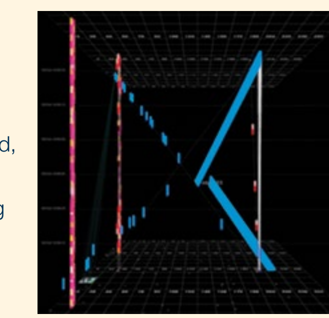
- Cyber situational awareness tools for effective analysis and visualization of high-volume cyber data
- Portfolio of analysis tools, packaged as the Platform for Architecture-Neutral Dynamic Software Analysis (PANDA), that dramatically improve the ability to rapidly perform low-level reverse engineering of software systems
- Functional encryption to enable practical, secure cloud computation

Technology Highlights

Lincoln Laboratory Secure and Resilient Cloud

Cloud computing is a low-cost, highly flexible solution for storing, managing, and deploying volumes of data. The DoD would like to use this computing model; however, current cloud technologies are focused on cost, availability, and scalability—not on DoD-level security.

The commercial cloud model is based on trusting cloud service providers, i.e., owners of massive server facilities that host computing resources. Client information is stored, processed, and communicated unencrypted inside the cloud, leaving users' data vulnerable to attacks that disrupt, deny access to, or steal the data. Therefore, resiliency, the ability to sustain operations during and after disruptions, is important for maintaining continuous access to critical resources.



This video snapshot shows a visualization of network traffic (normal streaming data in pink) collected during a distributed denial-of-service test attack (blue) conducted within the LLSRC test bed.

The goals of the Lincoln Laboratory Secure and Resilient Cloud (LLSRC) program are (1) to extend a feasible computing capability to the DoD and the Laboratory for the three core services necessary in a cloud: communication, storage, and processing; and (2) to build a test bed to demonstrate security and resiliency for cloud computing.

Current research and development is focused on an advanced cryptographic technique based on multiparty computation (MPC). The technique enables a client to compute a function without revealing the variables to the cloud. A client's inputs are split into discrete pieces, or "secret shares," and are sent to different cloud nodes for computation. The outputs, or "result shares," are then sent back to the client who can securely recombine them to obtain the computational answer. To make these techniques practical for real applications, researchers are studying existing and novel algorithms to implement linear algebra kernels that exploit MPC.

>> Technology Investments, cont.

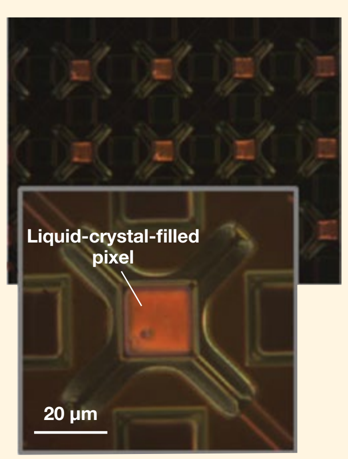
Technology Highlights

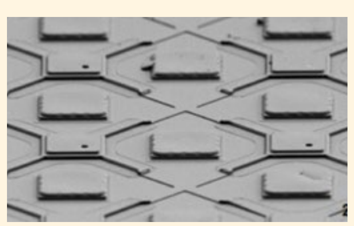
Liquid-Crystal Uncooled Thermal Imagers

Researchers at Lincoln Laboratory are developing a new type of liquid-crystal uncooled thermal imager for large-format (tens of megapixels) and sensitive focal plane arrays in the long-wavelength infrared (LWIR, 8–12 µm) spectral region. The imager uses sensitive liquid crystals to distinguish small changes in temperature created by an infrared image. Remote detection of polarized visible light by a solid-state imager changes the signal into a usable digital electronic output. The prototype imager has an optical readout that separates the LWIR-to-optical conversion process from the electronic readout. This decoupling simplifies the sensor architecture and enables independent optimization of components.

Uncooled thermal detectors have become an indispensable sensor technology for LWIR imaging applications, including tactical day and night imaging. The experimental liquid-crystal imager is a solution for the DoD's demand for a high-pixel-count LWIR detector that meets the size, weight, and power limitations of platforms such as tactical unmanned aerial vehicles. The imager addresses some of the problems associated with fabricating large-format uncooled LWIR arrays: scalability, increased signal noise with decreasing pixel size, and high fabrication costs. It may also enable new capabilities, for instance, jitter compensation, time-delay integration, and global shuttering.

The thermal imager initiative leverages the Laboratory's traditional strengths in silicon integrated-circuit fabrication, microelectromechanical systems, and microfluidics. The Liquid Crystal Institute at Kent State University is contributing to this program by researching liquid-crystal properties, such as photoalignment techniques and noise dependencies, important to the thermal imager.





An optical microscope picture of liquid crystals (left) and a scanning electron micrograph (above) show close-up views of an array of pixels. The 2 µm hole for filling the thermal pixel cavities with liquid crystals is apparent in some of the structures.

- Trusted and secure computing architecture that provides thread isolation through encryption integrated deep within the processor
- Secure cloud storage through algorithmic and cryptographic mechanisms
- Test bed and associated technologies for secure cloud computing centered around secure and resilient communications with provenance, storage, and processing

Advanced Devices

Advanced devices research focuses on developing unique and innovative components, subsystems, and sensing modalities that enable new system-level solutions to important national security problems. Current research is exploring a broad range of devices:

- Subthreshold microelectronics for low-power field-programmable gate arrays operating at ~0.3 V using custom transistors
- Mid-infrared integrated photonics, including passive waveguides to create arrays of quantum-cascade lasers
- Extended-wavelength Geiger-mode avalanche photodiodes for wavelengths >2 µm
- Integrated wavelength-division multiplexing laser communication (lasercom) transceivers utilizing integrated photonics to create flexible lasercom systems
- Active photonic integrated circuits with active and passive components in an indium phosphide–based platform
- Liquid-crystal, uncooled, multi-megapixel thermal imagers utilizing liquid-crystal transducers

Radio-Frequency Systems

Radio-frequency systems work focuses on research and development of innovative technologies for evolving DoD needs in radar, signals intelligence, communications, and electronic warfare. The 2014 projects include

- A Micro-sized Microwave Atmospheric Satellite as a low-cost, mission-flexible, rapidly deployable sensor for atmospheric sensing (launched in July 2014)
- Additive manufacturing of nonplanar RF antenna arrays
- Low-SWaP RF receivers for mobile or high-channel-count applications

Information, Computation, and Exploitation

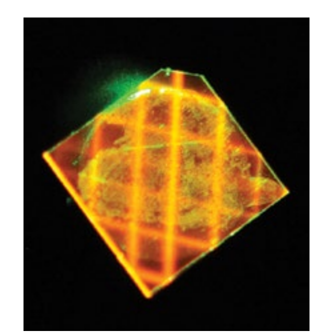
The information, computation, and exploitation initiative encompasses research and development in data processing, computation, exploitation, and visualization, with an emphasis on the emerging big data challenges posed by the enormous growth in the volume, variety, and collection rates of data available for DoD and intelligence community applications. Several technologies and capabilities are being pursued:

- High-throughput, low-power graph processor technology for computing complex graph algorithms on very large databases
- Customizable video analytics, utilizing user feedback during operations to automatically reconfigure an instance of the analytics' engine suited to the particular task
- Statistical models that capture the salient features of realistic threats or anomalous networks
- An application-specific integrated circuit demonstrating a split-fabrication configurable sparse fast Fourier transform kernel and a test bed for trusted operation of an embedded processor
- Effective exploitation of large, unstructured video archives through mining of audio and video data

Quantum System Sciences

Current research and development in quantum system sciences is focusing on systems that have sensing, communication, and/or processing power unachievable in classical systems. The 2014 portfolio covers a broad range of quantum information science technologies:

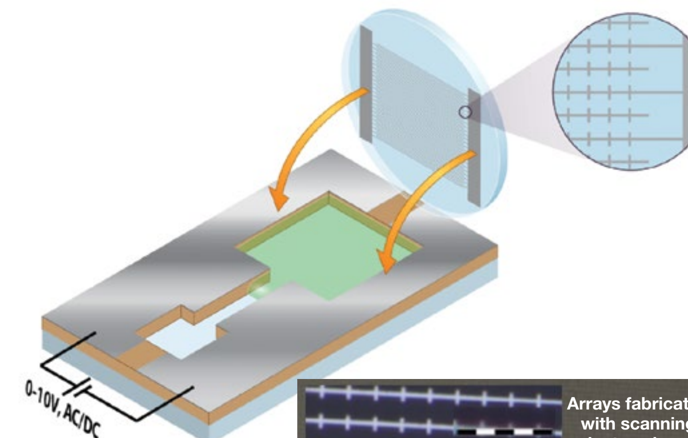
- Superconducting qubits with coherence times and control mechanisms that can be scaled up to demonstrations with 100s of qubits
- Trapped-ion quantum processing utilizing integrated photonics and other techniques for scaling to larger arrays of trapped ions
- A cryptographic framework, optimized architecture, and components to generate random numbers that can be verified by quantum mechanics, without component verification
- Individual quantum dots that emit, at low loss, infrared wavelengths
- Quantum sensing with nitrogen vacancies in diamond to develop highly sensitive magnetic-field sensors based on solid-state spins

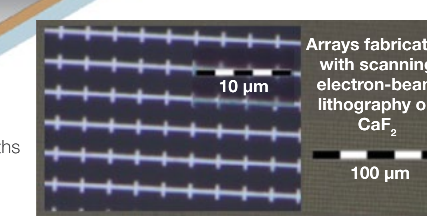


Fluorescence from nitrogen vacancies is pumped into a novel light-trapping diamond waveguide geometry as seen by the red Lissajous-like figure above.

Novel and Engineered Materials

Research and development is aimed at establishing world-class capabilities in engineered materials with properties that greatly enhance performance characteristics of devices and components. Current research is focused on low-loss and wide-bandwidth metamaterials using active elements for highly compact, high-performance antennas and graphene-plasmonic hybrids for optical-limiting applications, such as protecting focal planes from intense laser pulses.





Tunable filters for mid- and long-wave infrared wavelengths have been fabricated using liquid crystals and plasmonic frequency-selective surfaces.

Biomedical Sciences

The biomedical sciences initiative is developing technologies that increase human performance and prevent and predict injury through individualized biological monitoring, analysis, and interventions. The 2014 projects span a wide range of research areas:

- A field-deployable, noncontact optoacoustic imaging system to provide rapid ultrasonic images and diagnostic measurements
- A broad biomarker measurement and analysis framework to assess, understand, and improve human health and performance
- Tissue spectroscopy tools and analysis of epigenomic

>> Technology Investments, cont.

changes on skeletal muscle tissue to understand the phenomenology of musculoskeletal injury and healing

- Microfluidic expression modules that measure effects of a genetic code on essential genes

Homeland Protection and Air Traffic Control

Technical investments emphasize infrastructure development to support research and prototyping capabilities that solve critical national problems in transportation, land-border and maritime security, critical infrastructure protection, and disaster response. Research areas include advanced sensors, signal processing, data fusion, information exploitation, and decision support. The 2014 projects cover a range of technologies:

- Rapidly deployable test beds that are adaptable to diverse border and maritime threat environments
- Novel simulation capabilities for advancing new operational concepts for air traffic control
- Foundational big data, analytics, and serious-gaming techniques for air traffic flow management

Autonomous Systems

The Laboratory's applied research in autonomy and robotics enables unmanned systems to perform useful tasks in uncertain environments without continuous human-operator control. Several initiatives are being pursued:

- Development of a high-rate, high-resolution, low-SWaP optical sensor for obstacle detection
- Exploration of perception and planning algorithms for fast, near-ground flight of unmanned systems

Technology Highlights

Audio-Visual Mining of Uncooperatively Collected Video

The volume of video digitally produced and distributed today is greatly outpacing the development of content-based tools to help users sift through this unstructured data. For example, according to YouTube statistics, 100 hours of video are uploaded to their website every minute.

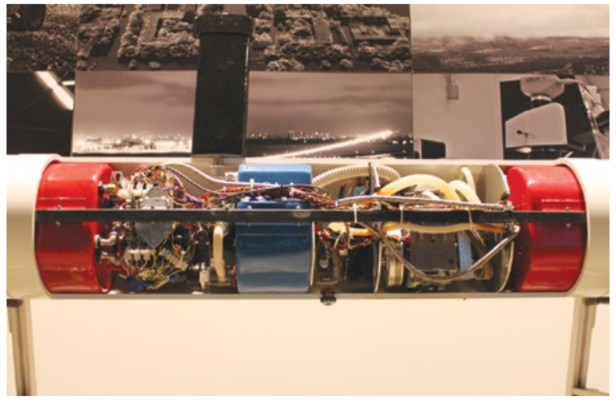
The Audio-Visual Mining of Uncooperatively Collected Video program is designed to bridge the gap between the exponentially growing volume of unstructured video data and the respectively insufficient number of analysts and available tools to extract meaning from those data. To offer better content-based search, summarization, and browsing of large collections of unstructured, uncooperatively collected video, researchers at Lincoln Laboratory are investigating new technologies for mining data from multiple formats (e.g., audio, video, and text).

By leveraging temporal alignment between audio and video channels, keywords spotted from an audio track can be correlated to visual models. This technique supports the semantic indexing of video content without explicit human labeling. Similar techniques combining facial recognition results with audio data can improve speaker recognition models.

Most current video analysis techniques are unimodal (e.g., audio only) and do not exploit information in other multimedia channels that could be useful in building algorithms to enhance the interpretation and exploitation of video data. The Laboratory's new approach is to jointly process time-aligned audio and visual information to improve visual object and person recognition, multimodal query-by-example searches, semantic search and recognition, and cross-modality (channel) search and data linking.

These capabilities will enable users to interactively search, explore, and summarize video content for semantically meaningful entities such as objects, identities, and scenes. Critical media-centric government applications that could benefit from an improved method for extracting information from video are analyses of seized media, social media forensics, and surveillance of foreign media.

An interdivisional Laboratory team with expertise in human language technology, computer vision, machine learning, text processing, and graph analytics is collaborating with James Glass, senior research scientist and head of the Spoken Language Systems Group at the MIT Computer Science and Artificial Intelligence Laboratory (CSAIL), to develop these new technologies.



The proof-of-concept fuel cell for an autonomous underwater vehicle (AUV) was developed through a collaboration between Laboratory researchers and students in an MIT mechanical engineering course. The current project is to design the fuel cell to fit in an actual AUV.

- Integration of an aluminum-water fuel cell into an autonomous underwater vehicle for enhanced-endurance operation
- Development of new capabilities for unmanned systems: autonomous decision making, dynamic retasking, and decentralized adaptive control

Engineering Research

Lincoln Laboratory is investing in the advancement of its technical engineering capabilities in order to facilitate the application of state-of-the-art engineering to the development of prototype systems. Research is focused in four areas: integrated modeling and analysis tools, advanced materials, optical capabilities, and process development.

Energy

Sustainable and secure energy systems are critically important to national security. Lincoln Laboratory supports DoD energy security as well as the national energy system's sustainability through three technical thrusts:

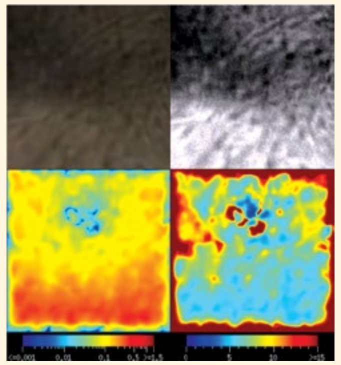
- System analysis and test-bed development of smart, cost-effective microgrid systems that ensure energy security at permanent installation sites and operational bases
- Targeted development of advanced energy technology prototypes to address critical gaps in current capabilities (a largely collaborative effort with MIT campus researchers)
- Proof-of-concept prototyping of soldier-scale systems that achieve long endurance and advanced capability at low SWaP

Technology Highlights

Autonomous Systems

Small and microscale unmanned aerial systems (UAS) are cost-effective and maneuverable, making them ideal platforms for remote sensing and surveillance. From detecting chemical agents to mapping wildfires, UAS can be deployed for a range of military and civilian applications in which direct human involvement is dangerous or not feasible. These aircraft can be remotely controlled by a pilot at a ground station or preprogrammed for autonomous flight.

Because of human error and signal processing latencies, the remote-controlled model is not well suited for low-altitude obstacle avoidance at high speeds. Furthermore, UAS dependencies on high-bandwidth communication restrict operation to within line of sight of a radio relay station. Overcoming these limitations requires increasing the level of onboard autonomy—the goal of the Fast Autonomous Low-Altitude Complex-Environment Optical Navigation for Small UAS (FALCONS) program. The Laboratory is developing sensing technologies and algorithms for autonomous operation to enable reliable high-speed, near-ground flight for small UAS in the absence of real-time, high-bandwidth communications.



The Digital Vision Sensor (DVS) was programmed to compute optical flow, i.e., the apparent motion of brightness in a scene at high frame rates. This image shows the optical flow processing (clockwise from upper left) for a simulated 3D scene: rendered scene image, simulated DVS image, computed optical flow magnitude (pixels/frame), and derived scene depth (meters).

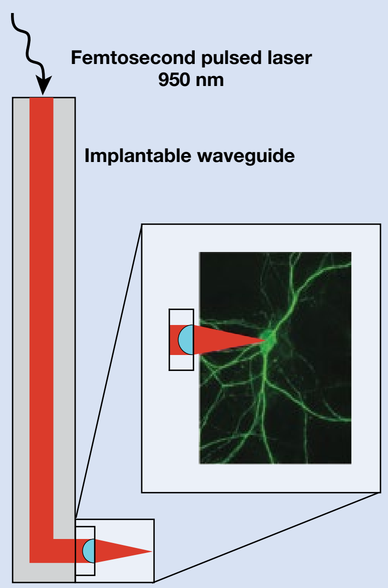
Sensing the environment is challenging for UAS because of fast scene dynamics, large variations in lighting, and significant SWaP constraints. To address these challenges, researchers are developing the Digital Vision Sensor (DVS), an optical imaging system that directly converts photons into digital frames. These frames are read into an on-chip, single-instruction multiple-data processor (i.e., a processor that performs the same operation on multiple data with one instruction, all on a single microchip), which can be programmed to perform complex computer vision tasks. This unique sensor-processor pairing provides the capabilities needed for UAS sensing: high sensitivity, high frame rate, low power, and flexibility.

To enable autonomous UAS operation, researchers are developing algorithms that test possible flight paths and select the optimal trajectory (the route that avoids obstacles) on the basis of a three-dimensional (3D) map of the environment. The program is leveraging the DVS to explore the limits of high-level computer vision tasks, such as person detection, on SWaP-constrained platforms. A FALCONS flight test is expected in summer 2015.

>> Technology Investments, cont.

BASIC AND APPLIED RESEARCH

The basic and applied research projects focus on concept development that considers, but is not limited to, specific mission needs. Funding is administered directly from the Technology Office and through committees established to solicit and review proposals from the Laboratory staff as well as from MIT campus; awards are typically for one year and represent early-stage proof-of-concept research. The significant investment in basic and applied research supports many projects, as shown in the infographic on page 8; two unique projects are highlighted here.



This conceptual schematic shows a novel liquid-lens-coupled brain probe used for mapping neural activity at single-cell resolution.

Implantable Optics for Single-Cell Optogenetics Brain Imaging

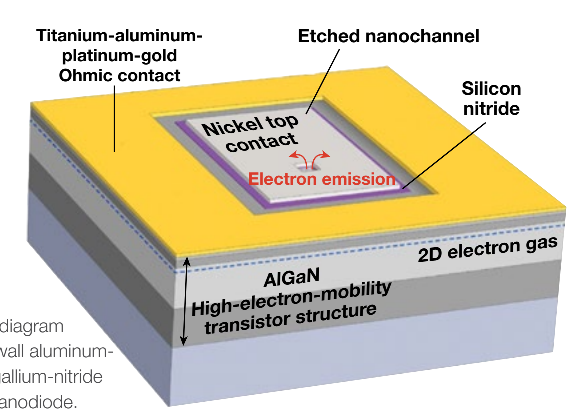
Over the past five years, many tools have emerged with the specific aim of increasing the mapping resolution of neural activation pathways in the brain by combining optical stimulation techniques with optogenetic transfection tools. Mapping brain activity to single-cell resolution has been globally recognized as a major initiative, with wide-ranging impacts in areas that include memory formation and retention, pathophysiology (e.g., behavioral disorders, neurodegenerative diseases), and sensory control.

In collaboration with MIT Professor Edward Boyden and his research group, Lincoln Laboratory researchers are actively involved in this initiative. The team is working to design, fabricate, and demonstrate implantable optofluidic components, consisting of micron-scale liquid lenses on the end of a waveguide. The optofluidic devices will bring light down into the brain, and, with electrically activated beam steering and focus capabilities, will attain unprecedented brain scanning at the single-cell level. The proposed work involves two technologies currently used in brain research—two-photon microscopy and optogenetics. The two-photon source enables millimeter-scale tissue penetration, while minimizing the problematic background noise of single-photon light sources. With optogenetics, proteins that function as light-activated electrical channels are expressed in neurons, enabling photonic simulation of networked neural tissue.

A New Approach to Vacuum Nanoelectronics

Electronics and electromagnetic sources that operate at higher frequencies, particularly in the terahertz (THz) range, can benefit from the high electron velocities achievable in free space. Miniaturized electronic tube devices can now be built smaller than the mean free path of air molecules. Consequently, for an electron operating in these devices, electron/air molecule scattering is suppressed, effectively describing a nanovacuum environment.

This effort seeks to extend previous silicon-based, vacuum-tube nanodiode and nanotriode concepts to the AlGaN material system in order to produce electron field emitters with the capability of THz modulation speeds. The sidewall device utilizes the high-electron-density inversion layer naturally created between AlGaN and GaN epitaxial layers to inject electrons into the nanovacuum. A free-electron travel distance of 60 nm is accomplished with a 40 nm silicon-nitride dielectric insulation layer between the AlGaN structure and the top metal collection anode. Initial experiments indicate that these vacuum nanoelectronic diodes show turn-on voltages ~10 times lower than previously reported devices that used metal as the emission cathode. The devices' field emission will undergo experimental verification. By providing a better understanding of the detailed physics of these novel field-emission diode structures, this effort could lead to improved high-current cathodes, nanoscale electron guns, and a new THz electronics platform.



This schematic diagram shows the sidewall aluminum-gallium-nitride/gallium-nitride field-emission nanodiode.

Researchers from Lincoln Laboratory, MIT, and the Harvard Humanitarian Initiative participated in the Beaver Works Humanitarian Workshop to identify opportunities for leveraging their respective expertise to improve humanitarian and disaster-relief efforts.

BEAVER WORKS HUMANITARIAN WORKSHOP

How can the effectiveness of humanitarian assistance and disaster-response efforts be improved with technology?

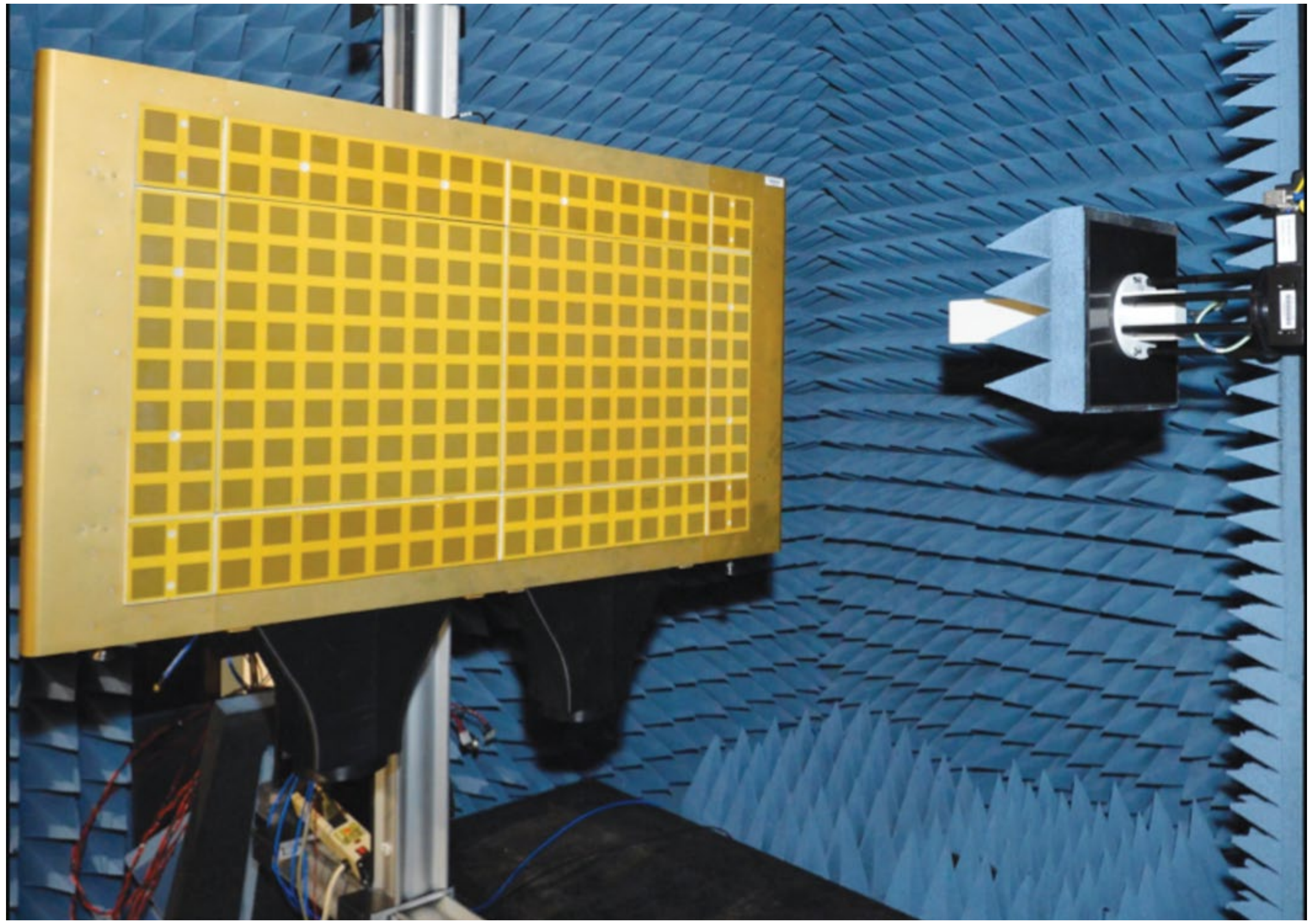
This question was the focus of the Beaver Works Humanitarian Workshop, organized by Lincoln Laboratory and the Harvard Humanitarian Initiative (HHI) and held on 20 and 21 February at the MIT Lincoln Laboratory Beaver Works Center in Technology Square, Cambridge, Massachusetts.

Twenty-five attendees, primarily from various divisions at MIT campus, Lincoln Laboratory, and the HHI, began a discussion about how advanced technologies could aid in strengthening responses to humanitarian crises and environmental disasters. This initial meeting was a chance for HHI professionals in medicine, social policy, and public health management to share their experience in promoting researched practices for humanitarian aid with scientists and engineers interested in applying advanced systems to problems encountered in relief missions.

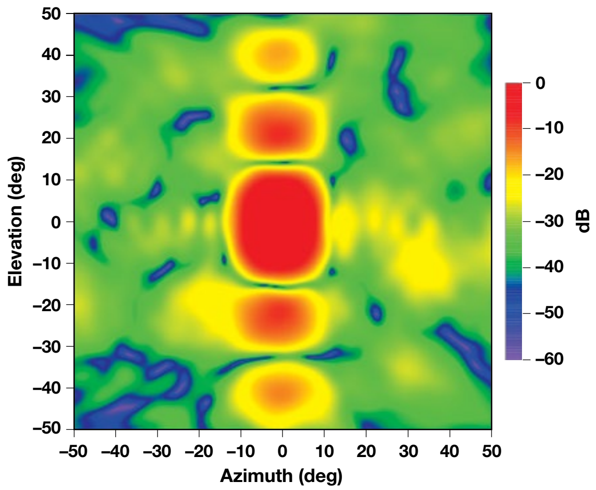
Lincoln Laboratory participants presented the Laboratory's recent experiences in integrating technology into humanitarian and disaster-response projects:

- After the 2010 earthquake that devastated Haiti, a Laboratory-developed imaging system provided near-real-time mapping support to U.S. agencies managing relief efforts.
- Staff from Lincoln Laboratory also worked in Haiti with humanitarian-aid professionals to provide an assessment tool and data analysis to help managers of the U.S. post-earthquake relief effort coordinate and evaluate the interagency aid activities.
- The California Department of Forestry and Fire Protection (CAL FIRE) has widely deployed the Laboratory-developed command-and-control software suite, Next-Generation Incident Command System, to improve situational awareness during wildfires.

The Beaver Works Humanitarian Workshop started the dialog. In June, a follow-up workshop on disaster-response techniques was held at the center. Continued engagement in a humanitarian program will involve assessing the potential uses of Laboratory-developed technology in relief operations and creating a long-term plan.



Multifunction Phased Array Radar

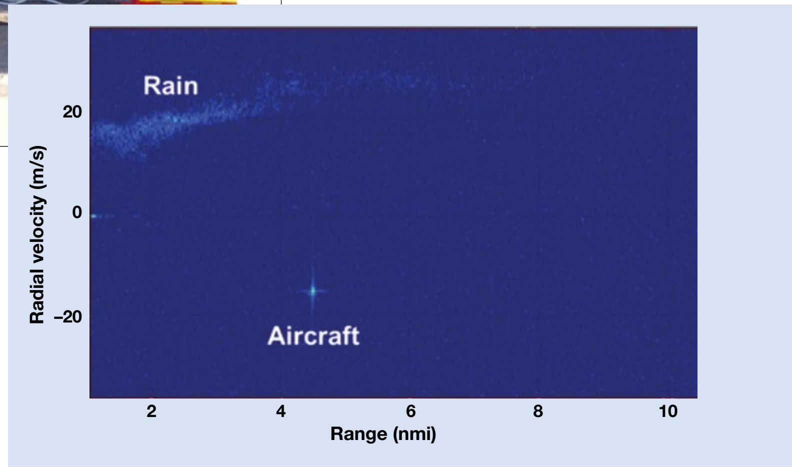


The far-field patterns of the prototype, two-panel, Multifunction Phased Array Radar were measured in Lincoln Laboratory's near-field antenna test facility (top). The measured two-dimensional beam-intensity plot (above) shows excellent symmetry and power levels.

Today's U.S. weather and aircraft surveillance radar systems are from 10 to more than 40 years old. Ongoing technical refreshes and service-life-extension programs can keep these radars operating in the near term, but they will eventually need to be replaced. These legacy systems will have difficulty meeting the future observational demands of the weather and aviation communities. Modern active phased array radars could provide desired heightened capabilities, such as faster volume scans of severe weather events and three-dimensional (3D) tracking of noncooperative aircraft. In addition, a multifunction phased array radar (MPAR) could fulfill all of the missions now performed by several distinct radar systems, reduce the total number of government weather and aircraft surveillance radars in the country, and unify them into one streamlined platform and network.

For the past several years, Lincoln Laboratory has been at the forefront of the research and development effort to turn the MPAR concept into a viable option for the next-generation national airspace-surveillance system. In the past, phased array radars were largely limited to military use because of their high cost. If MPAR is to be affordable for the civil sector, the hardware cost for the antenna array must be dramatically reduced.

The two-panel prototype MPAR array (left) is used at Hanscom Field to collect observations of aircraft and weather in the vicinity. The range-Doppler plot below is of the weather and aircraft observed by this prototype array.



Under sponsorship of the Federal Aviation Administration (FAA), National Oceanic and Atmospheric Administration (NOAA), and the Air Force, and in partnership with a Massachusetts-based company (MACOM), the Laboratory developed a prototype dual-polarized MPAR antenna array with overlapped subarrays. This radar is expected to be at least an order of magnitude cheaper (in large quantity) than a comparable unit produced for the military today.

The Laboratory is using the prototype MPAR antenna panel to troubleshoot and then mitigate technical risks. As investment decisions loom ahead for stakeholder agencies, it must be shown that performance targets can be met by an MPAR system, and legacy system requirements developed for rotating antennas need to be redefined to reflect the capabilities of active electronically steered antennas. As a first step in tackling these tasks, the development team built a two-panel array. Beam-pattern measurements made in the Laboratory's indoor antenna test range showed excellent agreement with theoretical results. The array was then taken to nearby Hanscom Field, where simultaneous observations of aircraft and weather were successfully conducted.

As a next step, the Laboratory is constructing a 10-panel array that will be mounted on a rotatable pedestal carried by a relocatable trailer. Then, the array will be connected to a controller and signal processing system, also housed in the trailer, to allow real-time data display and full, raw-data recording for field experiments. This scaled-aperture MPAR demonstrator will be located at NOAA's National Severe Storms Laboratory in Norman, Oklahoma, in order to evaluate the system under the extreme weather conditions there and to take advantage of the plethora of preexisting weather and aircraft surveillance radars nearby for comparison purposes. Particularly, the performance of the array's dual-polarization measurement and calibration will be assessed because such capabilities are critical for weather observation and are still a high-risk area for phased array radar. In addition, multi-mission scan strategies will be implemented, and the capability to digitally form multiple simultaneous reception beams for rapid volume scanning and 3D tracking will be demonstrated.

ACAS X (above) alerts pilots to nearby traffic and issues actions to avoid midair collision. The ACAS X flight-test team (left) gathers outside an experimental aircraft at the William J. Hughes Technical Center, the Federal Aviation Administration's national scientific test base and the primary facility supporting NextGen testing.

Airborne Collision Avoidance System X

Since the 1970s, Lincoln Laboratory has participated in the development and refinement of an onboard collision avoidance system on behalf of the Federal Aviation Administration (FAA). In its current manifestation, the Traffic Alert and Collision Avoidance System II (TCAS II), mandated worldwide on all large commercial aircraft, has significantly improved the safety of air travel. Major transformations to the airspace that are being implemented over the next decade through the FAA's Next-Generation Air Transportation System (NextGen) render TCAS II unsustainable for current and future aviation. Because of TCAS II's rule-based collision avoidance logic, even small modifications to the existing system to meet NextGen requirements would be difficult.

In response, Lincoln Laboratory has been developing and maturing the Airborne Collision Avoidance System X (ACAS X). This airborne avionics safety system pioneers the application of decision theory and computer optimization to collision avoidance logic. Probabilistic models are used to represent various sources of uncertainty such as pilot nonresponse, while computer optimization considers safety and operational objectives as defined by system experts and operational users to determine if alerts should be sent to the cockpit. The system issues two types of alerts: traffic advisories that assist pilots in seeing threat aircraft and resolution advisories that direct pilots to increase or maintain their separation from detected threat aircraft. These instructions are announced to pilots aurally and shown visually on their flight-deck display.

ACAS X logic is implemented in the Honeywell International Inc. prototype used in the 2013 proof-of-concept flight test.

Studies of operational suitability show that ACAS X reduces midair collision risk by 59%, unnecessary disruptive alerts by 25%, and design-cycle time by at least 50% when compared to TCAS II. These safety and operational benefits are achieved while complying with evolving NextGen airspace procedures and technologies. ACAS X is fully compatible with reduced en route separation standards, closely spaced parallel runway operations, and other new precision arrival procedures that will bring flying aircraft closer together to increase arrival rates at airports. The system's flexible surveillance architecture supports the use of the NextGen-adopted Automatic Dependent Surveillance–Broadcast satellite-based positioning system and electro-optical and infrared sensors, which enable unmanned aircraft to detect the position and velocity of other aircraft. Because ACAS X logic can be tailored to meet specific performance requirements, unmanned aircraft will be equipped with collision avoidance protection and be granted unrestricted access to the National Airspace System for the very first time. These capabilities contribute to NextGen's goals of making air travel more safe, efficient, and environmentally friendly.

Following a successful proof-of-concept flight test in August 2013, development of the international Minimum Operational Performance Standards began. After these standards are published in 2018, flight evaluations will be conducted. It is expected that ACAS X will subsequently be installed in more than 30,000 transport-category passenger and cargo aircraft worldwide.

At the ribbon-cutting ceremony, Gen William Shelton delivered the keynote address to guests assembled in HUSIR's impressive radome.

Haystack Ultrawideband Satellite Imaging Radar Ribbon-Cutting Ceremony

On 11 February 2014 during a ceremony at the Lincoln Space Surveillance Complex in Westford, Massachusetts, Dr. Eric Evans, Director, Lincoln Laboratory; General William L. Shelton, Commander, Air Force Space Command; and Lieutenant General Ellen M. Pawlikowski, Commander, Space and Missile Systems Center, Air Force Space Command, cut the ribbon to welcome the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) to the U.S. Space Surveillance Network (SSN).

Left to right, Lt Gen Ellen Pawlikowski, Gen William Shelton, and Dr. Eric Evans performed the honors at the HUSIR ribbon-cutting ceremony.

HUSIR, the highest-resolution space-object imaging radar of the SSN, is the latest development in the technological evolution of high-performance microwave systems. Its predecessors were the 1964 Haystack radar facility and the 1978 upgrade, the X-band Haystack Long-Range Imaging Radar (LRIR). When the 2000s-era proliferation of very capable small satellites demanded a major advance in space-object characterization capabilities, the Laboratory proposed that significantly improved image quality could be achieved with the Haystack antenna by adding a wideband transmitter and processing system to enable dual-band operation in both X and W bands.

"HUSIR's imagery has already proven to be of great value for the Joint Space Operations Center's space situational awareness mission."

Colonel John Wagner, Commander, 614th Air and Space Operations Center, and Director, Joint Space Operations Center

Over the ten years of HUSIR's development, the program advanced the state of the art in radar systems to meet HUSIR's challenging requirements: adding W-band imaging without degrading any of the existing X-band performance, and attaining the sensitivity to enable excellent imaging of all near-Earth objects. To achieve HUSIR's enhanced capability, Lincoln Laboratory personnel realized a number of engineering accomplishments:

- Designing the antenna to track a satellite with 0.5-millidegree accuracy
- Removing and replacing the cap of the 150-foot-diameter radome
- Ensuring the surface of the new dish was accurate to 100-micron root mean square over its 120-foot diameter
- Upgrading the hydrostatic azimuth bearing to support the weight of the new antenna
- Building a gyrotron traveling-wave tube (gyroTWT) with sufficient power to track and image satellites in low Earth orbit
- Developing new signal processing techniques to compensate for the effects of W-band electromagnetic wave propagation through the troposphere

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.

2014 TECHNOLOGY TRANSITIONS

Communication Systems

The Advanced Extremely High-Frequency (EHF) Interim Command and Control (IC2) terminals were transitioned to operation by subcontractors and will be transferred to military operators.

The Laboratory continues to transfer design elements of the compact airborne laser communications terminal to industry.

Homeland Protection

The Next-Generation Incident Command System, developed with the California Department of Forestry and Fire Protection (CAL FIRE) and sponsored by the Department of Homeland Security (DHS) Science and Technology (S&T) Directorate, was deployed to more than 400 first-responder organizations.

Advanced Technology

A GPS-based tracking device was transitioned to industry for fabrication of production-level quantities and for additional follow-on improvements.

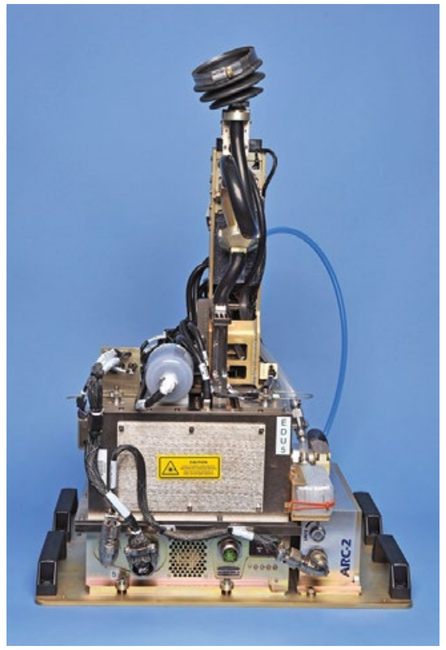
Air Traffic Control

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

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

Engineering

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



The Rapid Agent Aerosol Detector (RAAD) is a fluorescence- and elemental-composition-based bioaerosol detector with a unique single-particle discrimination capability.

Selected Patents 2013–2014

High Peak Power Optical Amplifier
Bien Chann, Tso Yee Fan, Antonio Sanchez-Rubio, and Steven J. August
U.S. Patent no.: 8,531,761

External-Cavity One-Dimensional Multi-wavelength Beam Combining of Two-Dimensional Laser Elements
Bien Chann, Tso Yee Fan, and Antonio Sanchez-Rubio
U.S. Patent no.: 8,531,772

Electronic Shutter with Photogenerated Charge Extinguishment Capability for Back-Illuminated Image Sensors
Barry E. Burke
U.S. Patent no.: 8,536,625

Directed Material Assembly
Theodore H. Fedynyshyn and Richard Kingsborough
U.S. Patent no.: 8,551,566

High-Efficiency Slab-Coupled Optical Waveguide Laser and Amplifier
Robin K. Huang, Reuel P. Swint, and Joseph P. Donnelly
U.S. Patent no.: 8,571,080

Wide Band and Radio Frequency Waveguide and Hybrid Integration in a Silicon Package
Carl O. Bozler, Jeremy Muldavin, Peter W. Wyatt, Craig L. Keast, and Steven Rabe
U.S. Patent no.: 8,587,106

Gas Detector for Atmospheric Species Detection
Eric R. Statz, Alan E. DeCew Jr., and Jonathan B. Ashcom
U.S. Patent no.: 8,599,381

Methods and Apparatus for In-Pixel Filtering in Focal Plane Arrays
Kenneth I. Schultz, Brian Tyrrell, Michael W. Kelly, Curtis Colonero, Lawrence M. Candell, and Daniel Mooney
U.S. Patent no.: 8,605,853

Two-Dimensional Wavelength-Beam-Combining of Lasers Using First-Order Grating Stack
Bien Chann, Tso Yee Fan, and Antonio Sanchez-Rubio
U.S. Patent no.: 8,614,853

Method and Apparatus for Generating a Forecast Weather Image
Srinivas Ravela, William J. Dupree, Timothy R. Langlois, Marilyn M. Wolfson, and Christopher M. Yang
U.S. Patent no.: 8,625,840

Modulator for Frequency-Shift Keying of Optical Signals
Bryan S. Robinson, Don M. Boroson, Scott A. Hamilton, and Shelby J. Savage
U.S. Patent no.: 8,625,999

Multidimensional Associative Array Database
Jeremy Kepner
U.S. Patent no.: 8,631,031

Digital Compensation of a Nonlinear System
Helen H. Kim, Merlin R. Green, Benjamin A. Miller, Andrew K. Bolstad, Andrew R. Chen, and Daniel D. Santiago
U.S. Patent no.: 8,644,437

Mission Planning Interface for Accessing Vehicle Resources
Roger Khazan, Adam S. Petcher, and Daniil M. Utin
U.S. Patent no.: 8,644,512

Rate Adaptive Nonbinary LDPC Codes with Low Encoding Complexity
Nicholas B. Chang
U.S. Patent no.: 8,656,244

Asymmetric Multilevel Outphasing Architecture for RF Amplifiers
Joel L. Dawson, David J. Perreault, SungWon Chung, Philip Godoy, and Everest Huang
U.S. Patent no.: 8,659,353

Focal Plane Array Processing Method and Apparatus
Michael Kelly, Brian Tyrrell, Curtis Colonero, Robert Berger, Kenneth Schultz, James Wey, Daniel Mooney, and Lawrence Candell
U.S. Patent no.: 8,692,176

Efficient High-Harmonic-Generation-Based EUV Source Driven by Short Wavelength Light
Franz X. Kaertner, Edilson L. Falcao-Filho, Chien-Jen Lai, Kyung-Han Hong, and Tso Yee Fan
U.S. Patent no.: 8,704,198

Mechanical Memory Transistor
Carl O. Bozler
U.S. Patent no.: 8,704,314

Method and Apparatus for Complex In-Phase/Quadrature Polyphase Nonlinear Equalization
Joel I. Goodman, Benjamin A. Miller, Matthew A. Herman, and James E. Vian
U.S. Patent no.: 8,705,604

Single-Electron Detection Method and Apparatus for Solid-State Intensity Image Sensors with a Charge Splitting Device
David C. Shaver, Bernard B. Kosicki, Robert K. Reich, Dennis D. Rathman, Daniel R. Schuette, and Brian F. Aull
U.S. Patent no.: 8,710,424

Simultaneous Transmit and Receive Antenna System
Alan J. Fenn, Peter T. Hurst, Jeffrey S. Herd, Kenneth E. Kolodziej, Leonard I. Parad, and Hans Steyskal
U.S. Patent no.: 8,749,441

On-Chip Miniature Optical Isolator
Juan C. Montoya, Steven J. Spector, Reuel Swint, and Caroline A. Ross
U.S. Patent no.: 8,749,871

Processor for Large Graph Algorithm Computations and Matrix Operations
William S. Song
U.S. Patent no.: 8,751,556

Mobile Coherent Change Detection Ground Penetrating Radar
Robert G. Atkins, Justin J. Brooke, Matthew T. Cornick, and Beijia Zhang
U.S. Patent no.: 8,786,485

Photonically Enabled In-Flight Data Reorganization
David J. Whelihan, Scott M. Sawyer, and Jeffrey J. Hughes
U.S. Patent no.: 8,792,786

Method and Apparatus for Modulation Using a Conductive Waveguide
Matthew E. Grein, Theodore M. Lyszczarz, Michael W. Geis, Steven J. Spector, Donna M. Lennon, and Yoon Jung
U.S. Patent no.: 8,818,150

Multiprocessor Communication Networks
William S. Song
U.S. Patent no.: 8,819,272

Effective, Efficient R&D

MIT Lincoln Laboratory's research and development and its technology transfer activities support the government's Better Buying Power initiative.

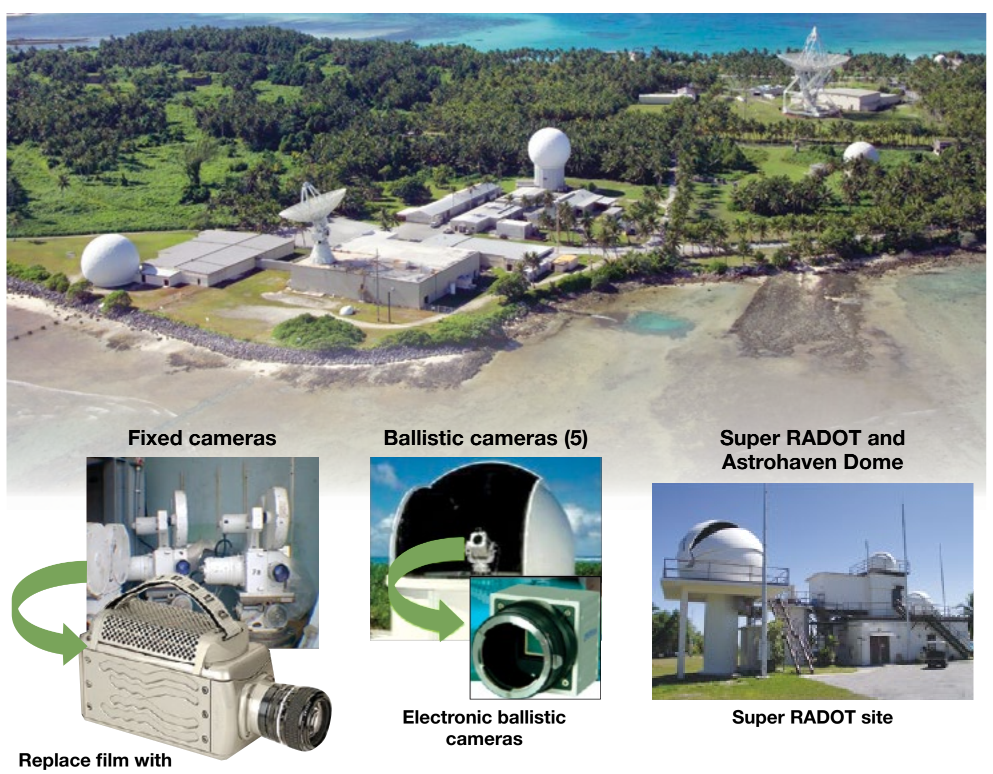
As a Department of Defense (DoD) Research and Development (R&D) Laboratory, Lincoln Laboratory is committed to being an effective partner in the DoD's acquisition process. In its program activities, the Laboratory is applying the Better Buying Power (BBP) strategy developed under the leadership of the Under Secretary of Defense for Acquisition, Technology and Logistics Frank Kendall to "achieve greater efficiency and productivity in defense spending." The BBP principles are aligned to three overarching objectives:

- Providing better administration of tax dollars spent on technology while minimizing technical risks in programs and delivering needed capabilities to the DoD
- Improving the efficiency and the effectiveness of the government's acquisition process
- Increasing business competition and innovative R&D in industry and government

Achieving Effectiveness for Government Sponsors

Lincoln Laboratory's programmatic efforts have significant impacts on the DoD's realization of the BBP goals.

- The Laboratory's deep experience in R&D offers the government insight into new technologies or proposed systems to inform DoD acquisition decisions. By optimizing its program resources and implementing efficient processes, the Laboratory reduces development costs for both the government and its contractors. For example, the Laboratory is advising the Air Force on requirements for a system architecture that will simplify the integration of components and allow the cost-effective implementation of future upgrades.
- Through the dissemination of enabling technologies, multiple programs exploit the initial R&D effort, increasing opportunities for competition not only in the acquisition phase but also during upgrade stages in a system's life cycle. For example, several system development projects executed by the Laboratory and contractors have relied on the Laboratory's Radar Open Systems Architecture (ROSA, and its second-generation version, the Real-Time OSA) software suite, which is interoperable with diverse hardware and software products. These projects have realized millions of dollars' worth of savings in development and maintenance costs that would have accrued if software customized for each unique system had been used.
- Prototype systems and their enabling technologies that the Laboratory delivers to sponsors and transitions to industry help foster innovation and dynamic competition in the defense industry. For example, a multiyear development process with substantial industry involvement improved the performance of a mobile antenna positioner that mechanically steers the antenna dish to maintain pointing at a communications satellite and reduced the prototype cost per unit from more than $1 million to approximately $150,000.



The optical sensors at the Reagan Test Site (RTS) (lower images) are being modernized. By utilizing the Radar Open Systems Architecture (ROSA) modular, net-centric design, the development effort provided deployable systems with unified control and data recording. The use of ROSA, which is employed in all the radar systems at RTS (top photo), sped up the development schedule, lowered development costs, and decreased the time and expense spent on system maintenance.

The table below illustrates the success of several transitions of technology to sponsoring agencies or industry partners.

The five-axis machining equipment rapidly and efficiently produces components for prototype systems, resulting in savings in energy, manpower, and time.

Achieving Efficiencies

The Laboratory utilizes a variety of mechanisms to effect cost savings and increase operational efficiency. These initiatives support internal applications of the BBP model and maximize sponsors' investments.

- The Laboratory is implementing efficient processes: upgrading videoteleconferencing capabilities in order to reduce the need for costly travel; automating business procedures, such as invoicing; and developing new techniques for fabricating components less expensively.

Example Impacts on Acquisitions		
Deliverable	**Use/Impact**	**Benefit**
A government-reference, high-fidelity laser communications test bed	The test bed is used to validate communications terminals built by vendors	The test bed saves the sponsor the cost of funding separate test beds for each vendor
Corridor Integrated Weather System (CIWS) development and operation	CIWS data informs decisions that reduce air traffic delays by an accumulated 100,000 hours annually	CIWS saves an estimated $100M/year in airline operating expenses and $200M/year in passenger value time
Prototype design of a multifunction phased array radar	Units of this cost-effective, multiuse system could replace the collection of aging single-purpose radars now employed by the Federal Aviation Administration (FAA) in the nation's airspace system	By utilizing one radar design instead of multiple designs customized for each radar system, the FAA would achieve significant cost reductions in both initial replacement (fabrication) and ensuing maintenance
A bioagent detector that uses an ultraviolet laser and easily replaceable subsystems	The sensor is capable of rapid detection, exhibits a a very low false-alarm rate, and has a higher probability of biological threat detection than previous systems	This new system decreases user costs because fewer false alarms must be followed up with lab assessments and the design requires less maintenance. The system is estimated to reduce operating costs by $50M/year if 500 U.S. government biodetection systems were replaced

>> Effective, Efficient R&D, cont.

- By cross-sharing services and goods, the Laboratory maximizes resources: partnering with MIT campus's contracting services to leverage online catalog volume pricing, and investing in lab spaces and equipment shared by multiple sponsored programs.
- The Laboratory's Contracting Services Department has established "smart" buying practices: negotiating blanket purchase agreements with vendors, centralizing software purchase agreements, and employing the FedBid reverse auction (competitive bidding).
- Improvements in facilities and operations realize long-term savings: upgrading facility systems decreases maintenance costs; reducing nonessential electricity usage during peak-load periods lowers energy bills; and acquiring state-of-the-art machining technology capable of faster throughput results in savings in both fabrication costs and operator time.

Over the past five years, 96 initiatives resulted in internal savings of more than $120 million. The table at right highlights some of these projects.

Example Efficiencies

Action	Impact	Savings
Built a customized shock testing table for $75K	Allows in-house vibration/shock testing	Outside shock testing = $8K/day; savings for one program have already been $35K
Implemented 3rd shift for the Microelectronics Lab	Reduces startup/shutdown procedures from 5 cycles/week to 1 cycle/week	11.5% decrease in operational costs
Negotiated 21 fiscal-year 2013 blanket purchase agreements at fiscal-year 2012 rates	Reduces program costs	Saved $2.8M for the year
Implemented a comprehensive deferred-maintenance program to prioritize and address facility needs	Reduces maintenance expenditures through the installation of state-of-the-art facility systems and proactive approach	Maintenance costs over the 5 years of this program have decreased 45%

CASE STUDY

Achieving Better Buying Power for the Space Fence

The goal of the U.S. Air Force Space Fence program is to deploy advanced ground-based S-band radar systems that will enable the tracking of more and smaller low-Earth-orbit objects than U.S. space surveillance systems currently can track. The enhanced detection, tracking, and measurement capabilities of the new Space Fence will support more accurate warnings of space-object threats and improve safety of flight for manned space missions.

The original Space Fence program requirements specified three radars located in the continental United States (CONUS). Lincoln Laboratory, under the sponsorship of the Air Force Life-Cycle Management Center, was tasked with reviewing the Space Fence design. Systems analysis completed at the Laboratory helped recast the requirements in mission capability terms rather than radar design terms. After extensive analysis, modeling, and simulation, reinforced by S-band data collections, the Laboratory researchers demonstrated that a prime near-equatorial outside-CONUS surveillance radar, plus a second smaller radar, could cost-effectively meet the Space Fence mission needs. Each radar would consist of a receive array with multiple simultaneous beams along with a collocated transmit array with a fan-like beam. This modification of system requirements would reduce life-cycle costs by giving contractors flexibility in the radar architecture and promoting energy efficiency.

Lincoln Laboratory also developed a low-risk and affordable reference radar design utilizing commercial components; this design served as a basis for evaluating contractor designs during the competitive procurement process. In addition, a Laboratory-built performance assessment system directly interfaces with the contractors' radar models to support testing of the system designs.

The Space Fence program office conducted a successful contract award in June 2014 and selected Lockheed Martin to develop the Space Fence. Through the efforts described above, the Laboratory helped the Air Force reduce the acquisition and life-cycle costs of the system to less than one-third the original $6 billion and $14 billion estimates, respectively.

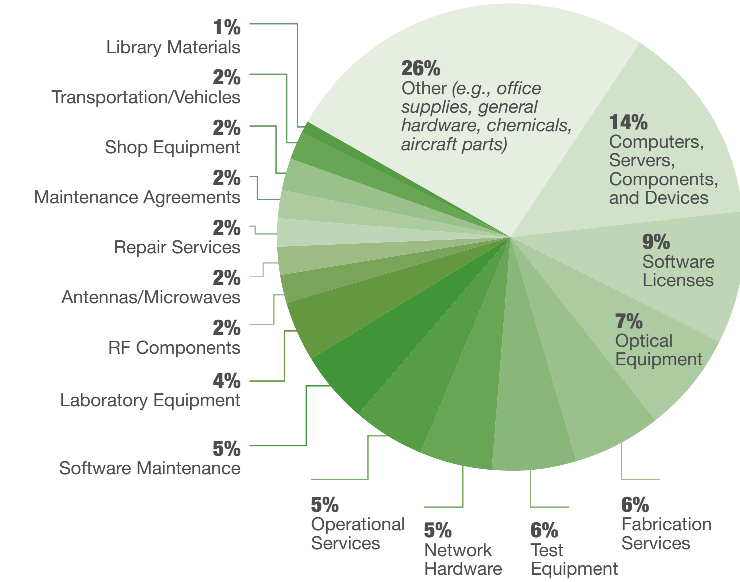
Economic Impact

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

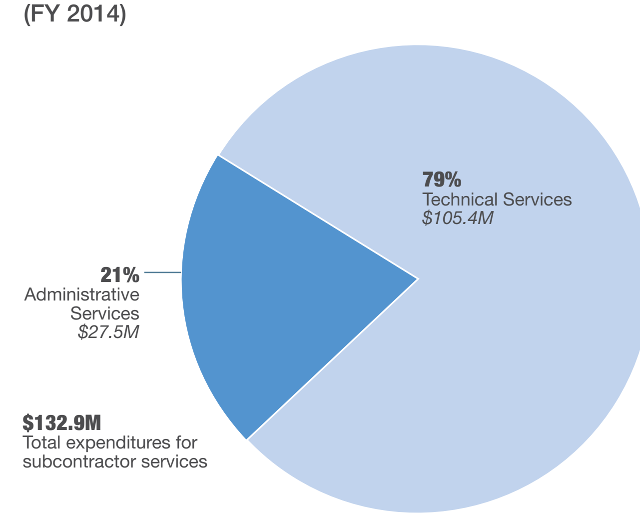
During fiscal year 2014, the Laboratory issued subcontracts with a value that exceeded $363 million. The Laboratory, which typically awards subcontracts to businesses in all 50 states, purchased more than $220 million in goods and services from New England companies in 2014, with Massachusetts businesses receiving approximately $185 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 2014, 50% 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.

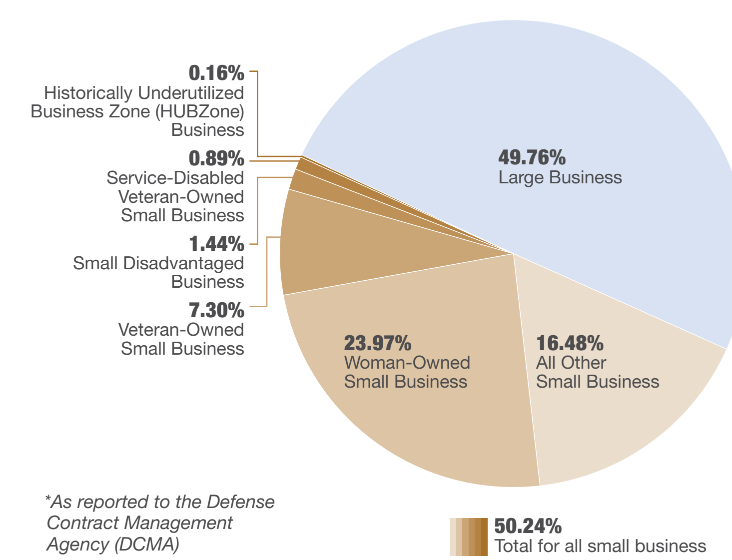
Commercial hardware and materials contracted to businesses (FY 2014)



Subcontractor services (FY 2014)



Contract awards by category of businesses (FY 2014)*



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

R&D 100 Awards

Six technologies developed at MIT Lincoln Laboratory were named 2014 recipients of R&D 100 Awards. Given annually by *R&D Magazine*, a publication for research scientists and engineers, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. Recipients of R&D 100 Awards are chosen from hundreds of nominations by a panel of independent evaluators and editors of *R&D Magazine*. The winning innovations represent a broad range of technologies developed in industry, government laboratories, and university research facilities worldwide.

Representatives from the teams that developed the six Lincoln Laboratory technologies that won 2014 R&D 100 Awards accept commemorative plaques at the awards banquet and ceremony held on 7 November in Las Vegas, Nevada.

Airborne Sense-and-Avoid Radar Panel

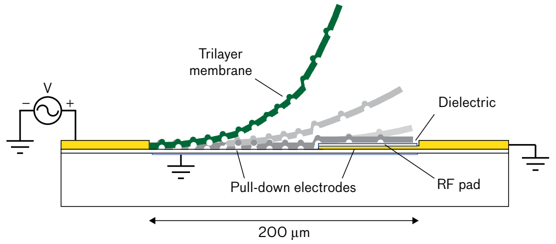
This compact stepped-notch antenna array, designed for sense-and-avoid systems for unmanned aerial vehicles, supports aircraft and weather detection in a single multi-function aperture.

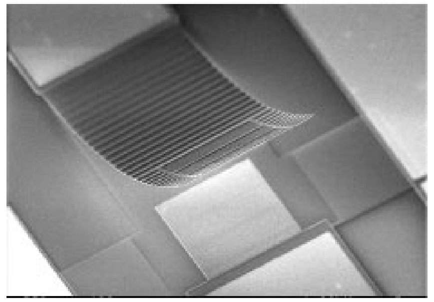
DEVELOPMENT TEAM: Dr. Sean Duffy, Dr. Patrick Bell, David Bragdon, Glenn Brigham, Dr. Rodney Cole, Matthew Edwards, Thomas Ferguson, H. David Goldfein, Dr. Jeffrey Herd, Edward Martin, Kevin Newman, Dr. Michael Owen, Daniel Santiago, and Sean Tobin

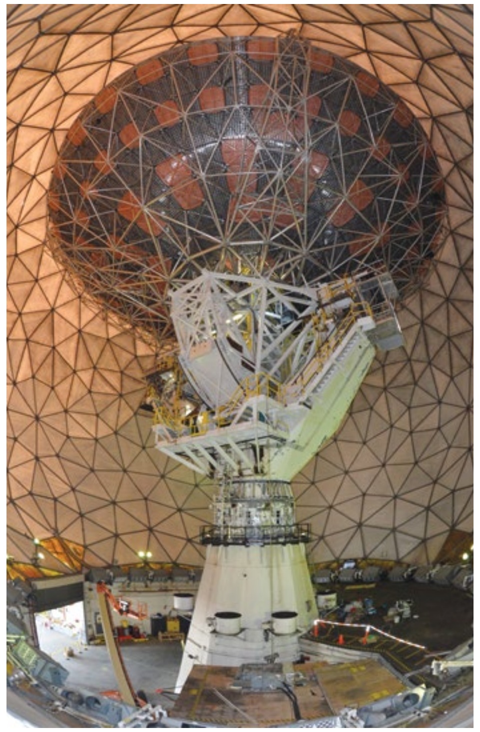
Curled Microelectromechanical Switch

This compact, low-loss, reliable radio-frequency switch eliminates most sticking and contamination problems inherent in traditional microelectromechanical switches.

DEVELOPMENT TEAM: Dr. Carl Bozler, Dr. Craig Keast, Dr. Jeremy Muldavin, Steven Rabe, and Dr. Peter Wyatt. Innovative Micro Technology provided the manufacturing design.







Haystack Ultrawideband Satellite Imaging Radar

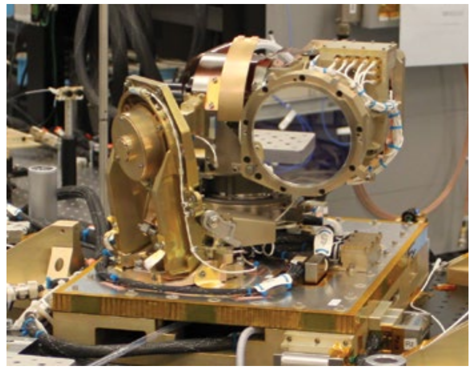
This ground-based, dual X- and W-band sensor that produces very-high-resolution images of space objects is the highest-resolution, long-range satellite characterization sensor in the world.

DEVELOPMENT TEAM: Dr. Joseph Usoff, Dr. Mark Czerwinski, Michael Clarke, David Crompton, Dr. James Eshbaugh, Dr. Michael Glynn, Raid Habayeb, Dr. George Haldeman, Timothy Hiett, Dr. Weber Hoen, Gerard Languirand, Dr. Michael Languirand, Dr. Michael MacDonald, Dr. Robert Morrison, Dr. Todd Mower, Dr. Mark Silver, and Nikolas Waggener, and a team of more than 100 individuals from the Aerospace and Engineering Divisions, as well as employees of consulting subcontractors Simpson, Gumpertz, and Heger, and Communications and Power Industries

Localizing Ground-Penetrating Radar

This sensor provides autonomous ground vehicles with real-time global-position localization by using very-high-frequency radar measurements to match relatively static below-the-ground features to previously mapped ones.

DEVELOPMENT TEAM: Dr. Matthew Cornick, Byron Stanley, Dr. Charles Coldwell, Will Bartlett, Birol Bekirov, William Brown, Robert Bucknam, Phillip Davis, Paul Doucette, Dr. Alan Fenn, Edward Froehlich, Dr. Jeffrey Koechling, Edwin LeFave, Dr. Janusz Majewski, George Middleton, Matthew Pineau, Larry Retherford, Trina Vian, Dr. Beijia Zhang, and Julius Zolotarevsky



Lunar Laser Communication System

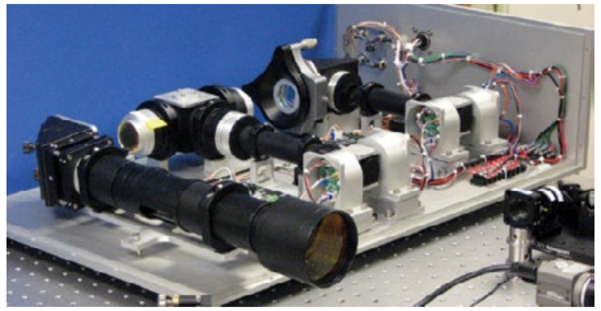
This system used a pulsed laser beam to transmit data at a record-breaking download speed from a lunar-orbiting space terminal to a ground terminal in New Mexico, and demonstrated an uplink rate 5000 times that of any lunar-orbiting radio system. This technology was also the winner of an R&D Editor's Choice Award, which is given to the three R&D 100 Award winners that the magazine's editors believe are the most innovative and impactful.

DEVELOPMENT TEAM: Dr. Don Boroson, Dr. Bryan Robinson, Dr. Dennis Burianek, Dr. Farzana Khatri, Dr. Daniel Murphy, and Paul Sasson led the team of approximately 150 members. Dr. Donald Cornwell of NASA's Goddard Space Flight Center and John Rush of NASA's Space Communications and Navigation Program Office supported this development effort.

Wide-Area Chemical Sensor

This self-referencing spectrometer that measures concentrations of specified target particulates in the atmosphere allows the wide-area detection of chemical releases because it can operate at long range and with great sensitivity.

DEVELOPMENT TEAM: Dr. Eric Statz, Dr. Jonathan Ashcom, Rosalie Bucci, Alan DeCew, Robert Freehart, David Ireland, Dr. Sumanth Kaushik, Dr. Jae Kyung, Dr. Jane Luu, Brian Player, Patrick Quinn, David Schue, Dr. Tina Shih, Alexander Wilson, Dr. Samuel Wong, and Dr. John Zayhowski



The 120-foot-diameter dish of the Haystack Ultrawideband Satellite Imaging Radar resides in a space-frame radome.

MISSION AREAS 31

Space Control

Leadership


Dr. Grant H. Stokes


Mr. Lawrence M. Candell

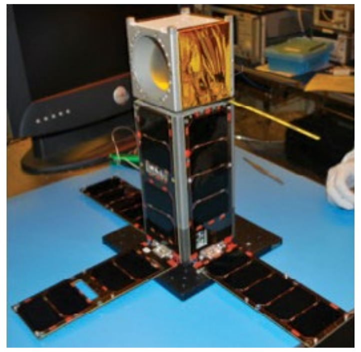

Dr. William J. Donnelly III


Mr. Craig E. Perini

Lincoln Laboratory develops technology that enables the nation's space surveillance system to meet the challenges of space situational awareness. The Laboratory works with 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 systems for the nation's Space Surveillance Network.


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

Image courtesy of NASA


An Orbital Sciences Cygnus cargo spacecraft delivered the Micro-sized Microwave Atmospheric Satellite (MicroMAS) CubeSat, shown above with its solar arrays opened, to the International Space Station (ISS) on 13 July 2014 as part of the Orb-2 cargo resupply mission launched from the Mid-Atlantic Regional Spaceport in Virginia. The NanoRocks CubeSat Deployer, shown in the left photo, will be used to put MicroMAS into position for space-based terrestrial weather sensing.

Principal 2014 Accomplishments

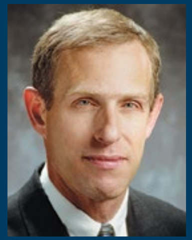
- The 3.5-meter Space Surveillance Telescope (SST) has been providing data on the deep-space debris environment. SST recently completed a Military Unit Assessment for the U.S. Air Force. Efforts are under way to develop a data-reduction pipeline for the National Aeronautics and Space Administration's (NASA) asteroid and minor-planet discovery missions.
- Integration and testing of the Haystack Ultrawideband Satellite Imaging Radar (HUSIR) were completed. After a successful Air Force Space Command operational trial period, HUSIR became the most recent addition to the U.S. Space Surveillance Network (SSN). With its new 8 GHz bandwidth and 3 mm wavelength W-band capability, HUSIR is now the highest-resolution imaging radar in the SSN, supporting the U.S. Strategic Command's space situational awareness (SSA) mission.
- Initial steps were taken to transfer technologies and concepts developed under the tactical SSA initiative to the Joint Space Operations Center (JSpOC) of the Joint Forces Combatant Command. This initiative integrates operational space surveillance sensors and the Laboratory's sensor technology programs in a net-centric, multisensor fusion, foundational architecture as a prototype tactical space command-and-control system. Tactical handoffs from optical search sensors to radars and tactical custody of high-interest space objects are routinely demonstrated as part of the initiative.
- In support of NASA's orbital debris measurement program, two of the Lincoln Space Surveillance Complex radars—the HUSIR X-band radar and the Haystack Auxiliary (HAX) Ku-band radar—provided high-precision metric data on very small (5 mm–10 cm) debris in a large number of orbital regimes. More than 1000 hours of data collected from HAX were used to update the orbital debris size distribution model. Data collected from HUSIR were transferred to NASA's Orbital Debris Office at Johnson Space Center for validation and application.
- Lincoln Laboratory continued to transition technology and to provide technical expertise to the JSpOC Mission System acquisition program, which is delivering a modernized, net-centric command-and-control system to enable multiple JSpOC missions in support of the U.S. Strategic Command and its Combatant Commanders.
- Lincoln Laboratory, jointly with the MIT Space Systems Laboratory, developed, tested, and delivered for flight a 30 × 10 × 10 cm CubeSat carrying a nine-channel passive microwave radiometer. This CubeSat, the Micro-sized Microwave Atmospheric Satellite (MicroMAS), is a compact, low-cost, low-power system that will be deployed from the International Space Station for a 90-day demonstration flight in 2015.

Future Outlook

- SST will continue to support SSA and minor-planet discovery during 2014 and will be relocated to Australia in 2015 to provide enhanced SSA capability in that region.
- Future HUSIR efforts will focus on developing new operational concepts for high-resolution imaging and techniques for advanced data exploitation. Data from the HUSIR X-band and HAX radars will continue to be sent to NASA.
- As part of its tactical SSA initiative, the Laboratory will define concepts of operation to respond to identified tactical space challenges and will develop applications to provide warning and decision support to the warfighter.
- Micro-sized Microwave Atmospheric Satellite (MicroMAS) technologies will be leveraged in new systems for the collection of critical data for future weather forecasting. The next flight demonstration will be the Microwave Radiometer Technology Acceleration Cubesat in 2015.
- The Laboratory will continue to work with the JSpOC Mission System (JMS) program office to compose the Increment 3 effort and transfer Laboratory-developed services into JMS.

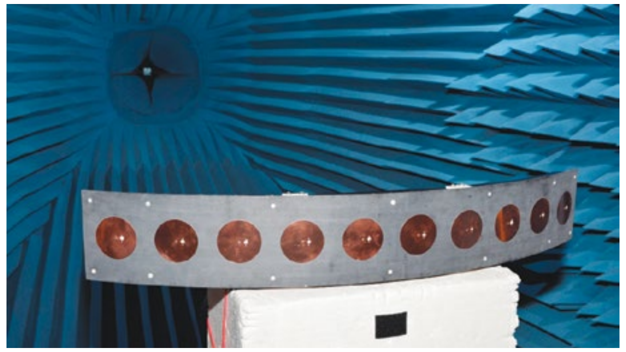
Air and Missile Defense Technology

Leadership

Dr. Justin J. Brooke Dr. Andrew D. Gerber Dr. Katherine A. Rink Mr. Dennis J. Keane

Lincoln Laboratory develops and assesses integrated systems for defense against ballistic missiles, cruise missiles, and air vehicles in tactical, regional, and homeland defense applications. Activities include the investigation of system architectures, development of advanced sensor and decision support technologies, development of flight-test hardware, extensive field measurements and data analysis, and the verification and assessment of deployed system capabilities. A strong emphasis is on rapidly prototyping sensor and system concepts and algorithms, and on transferring resulting technologies to government contractors responsible for developing operational systems.



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

Lincoln Laboratory is working with the Missile Defense Agency to develop optical sensors for ballistic missile defense. At left, an optical sensor is being tested at the Laboratory. Above, another sensor is emplaced on Makaha Ridge at the Pacific Missile Range Facility in Kauai, Hawaii.

Principal 2014 Accomplishments

- As Aegis Ballistic Missile Defense (BMD) Advanced Technology Development Agent, the Laboratory continues to work within the government team to help establish Aegis BMD system requirements and technology needs for future combat systems. The Laboratory is utilizing the digital-pixel focal plane array in its development of an integrated dewar cooler assembly for potential use in future missile seekers.
- In leading the architecture engineering and analysis efforts for the command, control, battle management, and communications (C2BMC) system requirements review, the Laboratory addressed the areas of track processing, sensor resource management, weapons coordination, and planning.
- Under the optics modernization project for the Reagan Test Site (RTS), the improvements at two of the optical sites were completed; four of the five sites are now fully upgraded. The RTS Automation and Decision Support project and the Telemetry Modernization effort both underwent successful system requirements and preliminary design reviews.
- The Laboratory continued to extend the capabilities of a test asset used by the Navy to serve as a surrogate for a threat missile seeker. The asset, integrated onto a Navy P-3 aircraft, is being used to support tests on new capabilities for countering antiship missile threats. The asset was used to collect data on multiple test campaigns conducted through the year. In addition, a new seeker front-end will be used in an assessment of capabilities for countering a land-attack missile.
- The Laboratory's role in risk-reduction activities for a new solid-state S-band Air and Missile Defense Radar (AMDR) being developed by the Navy included prototyping and testing the radar's end-to-end ballistic missile defense discrimination architecture.
- The Laboratory continued to assist the Navy in the checkout of the new E-2D Advanced Hawkeye airborne early-warning system and played a key role in the diagnosis and remediation of several problems discovered in data collections from the system design and development aircraft. The Laboratory is working with the contractor on modifications to address the problems and with the Navy on a set of future capabilities for the E-2D system.
- A set of assessments related to the anti-access/area denial (A2/AD) problem were conducted for the Office of the Assistant Secretary of Defense for Research and Engineering. These assessments included studies of options for defense of land bases, for ship defense, and for countermeasures to adversary capabilities.

Future Outlook

- As part of its test program, the Missile Defense Agency performs ground and flight tests of the Ballistic Missile Defense System. Lincoln Laboratory will continue to have a large role in test planning, test range and instrumentation improvements, and capability assessment.
- Engineering analysis of threats based on sound technical intelligence is needed to achieve the best possible capability for the Ballistic Missile Defense System. Lincoln Laboratory continues to help optimize intelligence sensor mission planning, extract key insights from collected data, and develop advanced concepts and technologies for improving technical intelligence in the future.
- The Navy is focusing on a set of sophisticated antiship missile threats and is assessing how these threats may impact future Fleet operations and influence the need for improved air and missile defense capabilities. The Laboratory will continue to assess the impact of these threats and to develop and demonstrate near-term modifications to existing systems, as well as longer-term advanced capabilities, to respond to these emerging threats.
- Next-generation national assets, as well as emerging threats, are driving performance enhancements to the Reagan Test Site offensive and defense missile testing and space operations. Lincoln Laboratory will lead the development of next-generation sensor systems and advanced algorithms for signal processing, automation, and decision support.

Communication Systems

Leadership

Dr. J. Scott Stadler

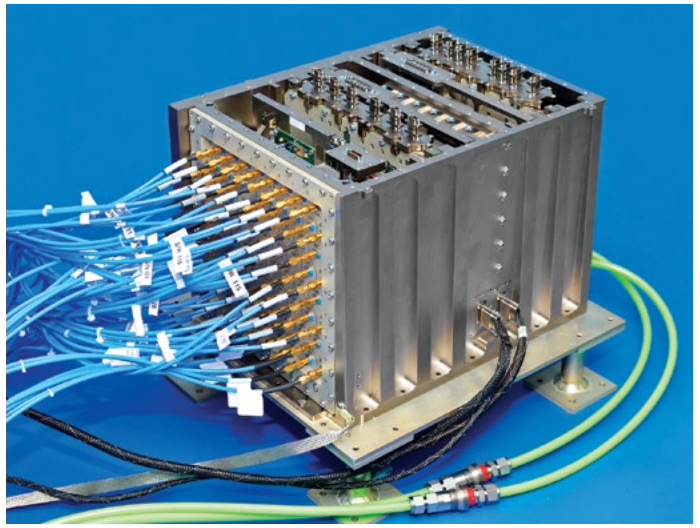
Dr. Roy S. Bondurant

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.



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

The Over-the-Air Ka-band Test Terminal (far left) and the Protected Tactical System Advanced Test Set (left) will be utilized together to test the new Protected Tactical Waveform. The Lincoln Laboratory–built implementation of the waveform will be used in lab and over-the-air tests to validate the capabilities of vendor implementations of the waveform.

Principal 2014 Accomplishments

- The Lunar Laser Communication Demonstration successfully achieved reliable communications between a satellite in lunar orbit and Earth. The link represents the longest laser communication link (385,000 km) and the highest-rate link (622 Mbps) achieved by a system flown to the Moon. All objectives were satisfied during the mission, validating Lincoln Laboratory's overall laser communications, system engineering, communications, and pointing/acquisition/tracking methodology.
- New network- and transport-layer protocols enabled efficient transport of data over communications links degraded by outages caused by mobility or jamming. The protocols increase throughput by a factor of 10 while maintaining the reliability of traditional networking protocols.
- A flight demonstration showed the possibility of adapting emerging commercial satellite communications services to suit the needs of the Very Important Person Special Air Mission fleet while drastically reducing cost. The system enables rapid switching between military and commercial satellites without interrupting the user applications.
- The Laboratory-developed prototype implementation of a dynamic-link adaptation capability for the Advanced Extremely High-Frequency terminals demonstrated significant benefits in throughput and robustness.
- A series of flight tests characterized radio-frequency (RF) propagation over water at low elevation angles for airborne satellite surrogates and demonstrated viable operating ranges for this architecture.
- Extensive performance measurements and functional testing of the Air Force Family of Advanced Beyond-Line-of-Sight Terminals on the 707 airborne test bed were conducted.
- The Laboratory worked with the Defense Advanced Research Projects Agency to prototype an airborne-communications radio architecture designed to enable the rapid insertion of new technology into future air-dominance applications.
- The demonstration of active frequency control of distributed feedback laser diodes to better than +/–20 MHz (root mean square) is helping enable the simplified design of high-sensitivity optical receivers.
- A high-fidelity laser communication terminal test bed that emulates free-space channel propagation effects and local platform disturbances will be used to verify link interface compliance and functional requirements in optical performance, acquisition, tracking, and communication.
- A world-record 2-photon-per-bit sensitivity was demonstrated in an optically preamplified, coherent laboratory modem operating at 10 and 20 Gbps.

Future Outlook

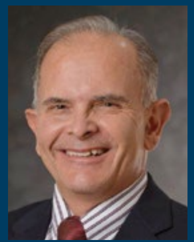
- Lincoln Laboratory will transition technology to the National Aeronautics and Space Administration's (NASA) Laser Communications Relay Demonstration satellite and will develop a low-Earth-orbit terminal for the International Space Station.
- A recently developed capacity-based undersea optical communications performance model that quantifies microscale channel effects over a global range will be used to synthesize high-rate undersea terminals.
- The Advanced Extremely High-Frequency (AEHF) Calibration Facility developed by the Laboratory will be used to complete the checkout and calibration of future AEHF satellites, and the Enhanced Polar System Interim Command and Control terminal will be deployed to Clear Air Force Station in Alaska.
- The Laboratory will develop devices and algorithms to optimize communications, electronic warfare, and sensing.
- Technology for photon-counting detectors will continue to be matured and used to enable advanced systems concepts.

Cyber Security and Information Sciences

Leadership

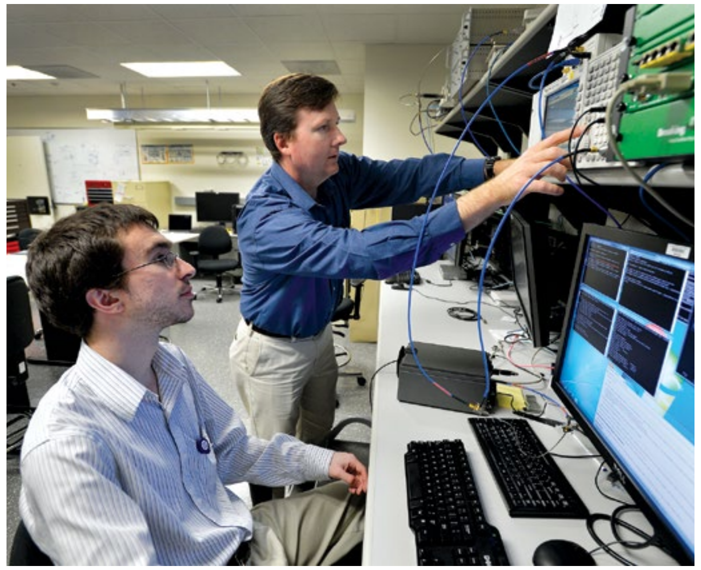

Mr. Stephen B. Rejto


Dr. Marc A. Zissman


Mr. David R. Martinez


Dr. Richard P. Lippman

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. Efforts include 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. The Laboratory also 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. Emphasis is placed on high-performance computing architectures, machine learning for advanced analytics, and the use of relevant metrics and realistic datasets.


In the mobile device laboratory, Mark Smith (in background) and Evan Fiore of the Cyber Systems and Operations Group investigate the cyber-electromagnetic environment for handheld devices and wireless communication.


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


Eric Evans (center left), Director of Lincoln Laboratory, and Jeremy Kepner (center right), senior staff in the Computing and Analytics Group and lead of the data center project, cut the ribbon to inaugurate the newly deployed EcoPod, which houses the Laboratory's SuperCloud research supercomputer. In the background are members of the team that has developed the Laboratory's interactive cluster computing capability, LLGrid.

Principal 2014 Accomplishments

- The Cyber Analytical Station was deployed to multiple Department of Defense (DoD) Combatant Command Joint Cyber Centers. The technology provides operators with the ability to proactively identify and locate network threats, and increases the timeliness of the information while decreasing the number of analysts needed.
- Lincoln Laboratory supported and hosted a series of realistic cyber offense and defense exercises to quantify the performance of newly formed Cyber Protection Teams and National Mission Forces.
- A new cyber range tool suite released to the cyber testing and training community significantly improves the ability to rapidly instantiate realistic range environments extending from enterprise to tactical levels.
- The Laboratory improved cyber security by accrediting the first-ever high-to-low multilevel security system based on data provenance.
- The annual cyber Capture-the-Flag game held on the MIT campus expanded to 170 students representing 25 teams and 9 universities, giving local-area college students the opportunity to learn about cyber security and cutting-edge research. This year's competition included defensive technology from the Defense Advanced Research Projects Agency's (DARPA) Clean-Slate Design of Resilient, Adaptive, Secure Hosts (CRASH) program.
- A secure and resilient cloud test bed was established to measure and quantify technologies that can lead to secure cloud computing.
- The Global Pattern Search at Scale unstructured-data discovery tool was transitioned to the National Geospatial-Intelligence Agency. This tool enables analysts to discover events, causal factors, and sentiment trends without prior detailed knowledge of data content.
- Lincoln Laboratory researchers presented a week-long class on big data analytics and high-performance computing to analysts from the intelligence community. The class covered the fundamentals of handling large datasets, including methods for ingesting, validating, and optimizing the processing of large volumes of data.
- The new Lincoln Laboratory SuperCloud, a "green" computing center installed at Holyoke, Massachusetts, near a hydroelectric power station, is enabling world-class computing capabilities while providing economies in power consumption and cost.
- The Laboratory developed the VizLinc system, an open-source software suite that integrates automatic information extraction, search, graph analysis, and geolocation for interactive visualization and exploration of large datasets, which include text, speech, video, and data. VizLinc has been submitted to and included in the DARPA open-source software catalog for big data.

Future Outlook

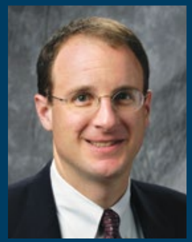
- Lincoln Laboratory will continue to strengthen the coupling between its cyber security activities and its other mission areas to secure mission systems. Specifically, initiatives are under way to broaden the role of cyber security in missile defense, air traffic control, space control, and homeland security.
- The Laboratory will continue to broaden its role and support to cyber range capabilities. Cyber red/blue exercises are expected to expand to include kinetic mission areas (ballistic missile defense; intelligence, surveillance, and reconnaissance; and space control), and the tempo of the exercises will increase.
- The Lincoln Laboratory Secure and Resilient Cloud test bed will expand its capabilities to permit the evaluation of numerous secure cloud technologies.
- Novel analytics, visualization, and systems will continually be developed and transitioned to help protect DoD systems from cyber attacks.
- The Laboratory will advance capabilities in modeling, analytics, anticipatory computing, and human-machine interaction tools to allow faster time to insight in the presence of a data deluge.
- Work on language-based analytics will be extended in order to develop multisource analytics, including network analysis and anomaly detection on both structured and unstructured financial data.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Leadership

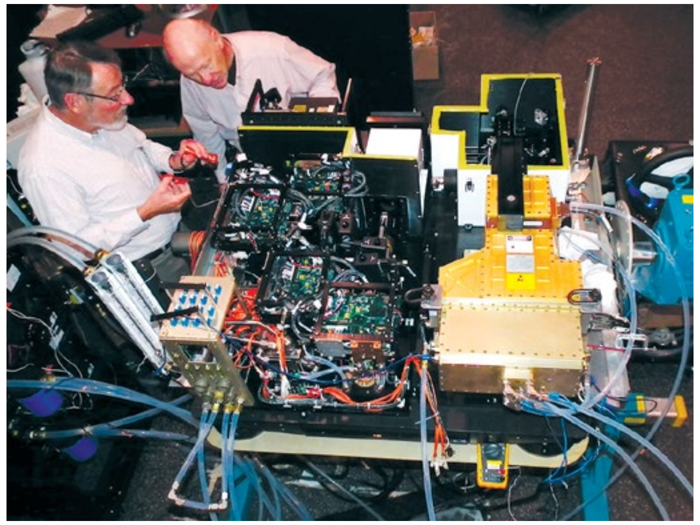

Dr. Robert T-I. Shin


Mr. Robert A. Bond


Dr. Kevin P. Cohen


Dr. William D. Ross

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 MACHETE ladar sensor is successfully integrated onto a DHC-8 aircraft.

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

Principal 2014 Accomplishments

- The Wide-Area Infrared System for Persistent Surveillance (WISP) was deployed for airborne counterterrorism; ground- and ship-based systems were further developed for force protection. The Multi-Aperture Sparse Imager Video System (MASIVS) for collecting wide-area motion imagery was augmented with improved onboard processing and reach-in exploitation tools to support active deployments. An immersive imaging capability was developed and deployed to support the Boston Police Department's event protection activities.
- The Laboratory developed the Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) three-dimensional ladar, designed to uncover clandestine activity in heavily foliated areas. The system's high area collection rates are enabled by dual 64 × 256 Geiger-mode avalanche photodiode arrays. MACHETE was integrated on a DHC-8 aircraft and underwent field tests before its transition to operations. The Laboratory developed the onboard and ground processing, including algorithms to facilitate timely exploitation of imagery.
- Working with the Defense Advanced Research Projects Agency (DARPA), the Laboratory supported the development of a distributed multiple-input, multiple-output (MIMO) radio for high-data-rate, low-probability-of-exploitation RF communications. The Laboratory led work on an application-specific integrated circuit (ASIC) for a small-form-factor implementation of the radio. The ASIC should achieve world-class performance for communications applications, delivering more than 1.7 trillion operations per watt.
- Alternative approaches to radar target detection and classification are improving detection probability and correct classification while lowering false-alarm rates. Electronic protection techniques were developed to improve radar detection, tracking, and imaging of surface objects.
- The Laboratory developed automation and sonar signal processing algorithms for operational submarine, surface ship, and distributed undersea surveillance systems. Advanced tracking, association, and localization approaches improve operator situational awareness and effectiveness in high-clutter conditions.
- An unprecedented 128 dB spur-free dynamic range was achieved for an analog-to-digital converter (ADC) that uses digital linearization techniques. The system injects a special waveform into the input of the ADC to remove high-order nonlinearities, and then employs digital nonlinear equalization to remove the remaining low-order nonlinearities.
- An area-search mode for the Air Force's pod-based, open-architecture Dismount Detection Radar was integrated into the contractor-developed system for flight testing.
- Working with the intelligence community, Marine Corps, Army, and Air Force, the Laboratory developed advanced processing, exploitation, and dissemination software tools and open architectures. Red/blue exercises assessed software operational effectiveness, and architectures for distributed common ground systems were prototyped and evaluated.

Future Outlook

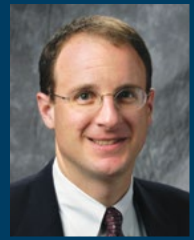
- Lincoln Laboratory anticipates continuing its efforts to support the Department of Defense and intelligence community with architecture engineering, systems analysis, technology development, and advanced capability prototyping.
- Enhanced activities in electronic warfare and Navy maritime and undersea surveillance are expected as part of the national shift to security challenges in the Asia-Pacific region.
- Emphasis on 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 using multisource and nontraditional sensor data sources.
- The Laboratory will continue to help the government develop, prototype, and employ open-systems 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

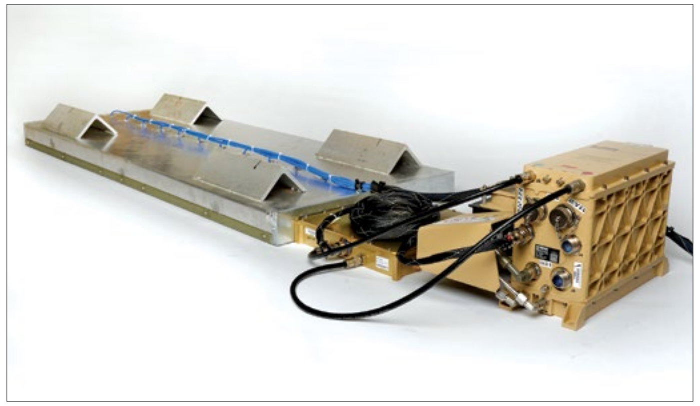

Mr. Robert A. Bond


Dr. Kevin P. Cohen


Dr. Christopher A.D. Roeser


Dr. Marc N. Viera

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. capabilities 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.


Lincoln Laboratory's robust localization sensor, the Localizing Ground-Penetrating Radar (LGPR), provides real-time global-position estimates for autonomous vehicles even under adverse weather or road conditions. This technology won a 2014 R&D 100 Award as one of the year's 100 most significant technological developments. Seen here is the 5-foot-wide LGPR antenna array (left-hand silver object). Attached on the right are the switch and the hardened chassis containing the radar electronics and computer.


The Lincoln Laboratory team that is supporting instrumented flight testing on an F-22A aircraft is seen at a recent flight test at Nellis Air Force Base, Nevada.


This Puma unmanned aerial vehicle is equipped with the vector sensor that the Laboratory developed to provide a tactical geolocation capability. The Puma's first flight occurred at the Camp Edwards air field in Massachusetts.

Principal 2014 Accomplishments

- Lincoln 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 assessment includes systems analysis of proposed options, development of detailed models and fielded prototypes of threat radars and their electronic protection systems, and testing of various electronic attack systems.
- Technical assessments of the impact of exporting advanced military systems were performed for the Office of the Undersecretary of Defense for Acquisition, Technology and Logistics and Congress to help inform the decision-making process for major export programs.
- The Laboratory continued a detailed analysis of the impact of digital radio-frequency memory-based electronic attack on air-to-air weapon system performance. Results from flight testing, systems analysis, and hardware-in-the-loop laboratories have been used to improve U.S. electronic protection systems and to inform senior DoD leadership's decision making for future system capabilities and technology investments.
- Overarching system assessments of the Air Force's Family of Systems architecture focused on protected communications; integrated intelligence, surveillance, and reconnaissance, and strike capabilities; and mission effectiveness and survivability. Results of these studies were used in a series of way-ahead briefings provided to senior DoD leadership, who are using the information to develop the future acquisition strategy and concepts of operation.
- The Laboratory continues to rapidly prototype advanced sensors and systems to counter insurgency operations. A vector sensor developed to provide tactical geolocation capability from a man-portable, unmanned aircraft system (UAS) successfully completed local testing and is transitioning to the operational community for evaluation outside the continental United States in FY14. Also, a prototype low-frequency magnetic gradient sensor was integrated on multiple platforms for field-test evaluation, and a miniature, low-cost sensor system was flight tested for the U.S. Army on a Shadow UAS.
- The Laboratory is developing advanced architectures and technologies for use in next-generation counter-improvised-explosive-device (C-IED) electronic attack systems. This year's activities culminated in field demonstrations and technology transition of a significantly advanced capability intended for use in future Counter Radio-Controlled IED Electronic Warfare (CREW) systems.
- Two novel airborne signals intelligence capabilities were developed and demonstrated, and an existing capability was upgraded. Robust prototypes for all three efforts were transitioned to operational use, and the technologies are being transitioned to industry.

Future Outlook

- Lincoln Laboratory will continue to assess, develop, and demonstrate innovative concepts for enhancing the survivability of U.S. air vehicles in challenging environments. This work will inform new capability developments and technology road maps, leading to advanced countermeasures, sensors, and system architectures.
- Through rigorous trade studies based on measured data and detailed systems analysis, the Laboratory will inform senior U.S. Air Force and DoD leadership on future Family-of-Systems architectures.
- Under several new programs, innovative concepts and novel prototype systems for counterterrorism applications and for asymmetric countermeasures will be provided on rapid timelines.
- Lincoln Laboratory will grow its portfolio of submarine and antisubmarine warfare technology and systems to address advancing and proliferating threats in the undersea domain.
- Further growth in electronic warfare for the DoD and intelligence community is expected, predominantly in the areas of electronic protection for tactical aircraft and ground vehicles, electronic support measures for airborne signals intelligence capabilities, and enhanced geolocation systems for addressing the evolution of radio-frequency systems.

Advanced Technology

Leadership

Dr. Robert G. Atkins

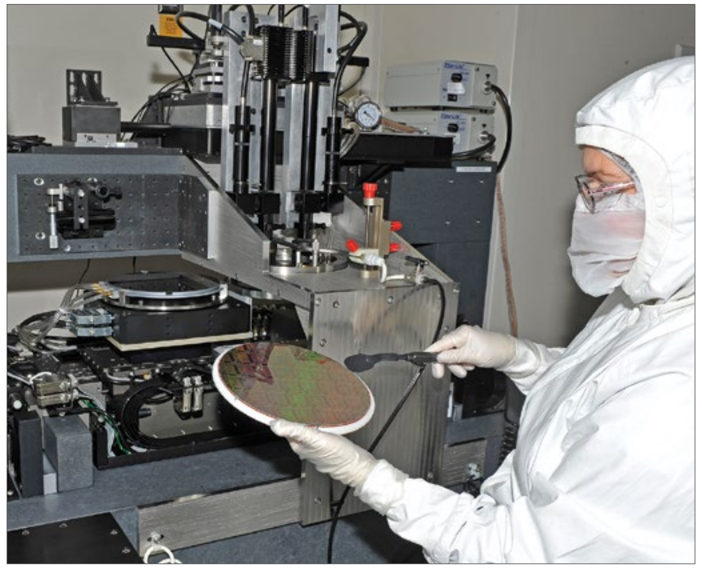
Dr. Craig L. Keast

Dr. Simon Verghese

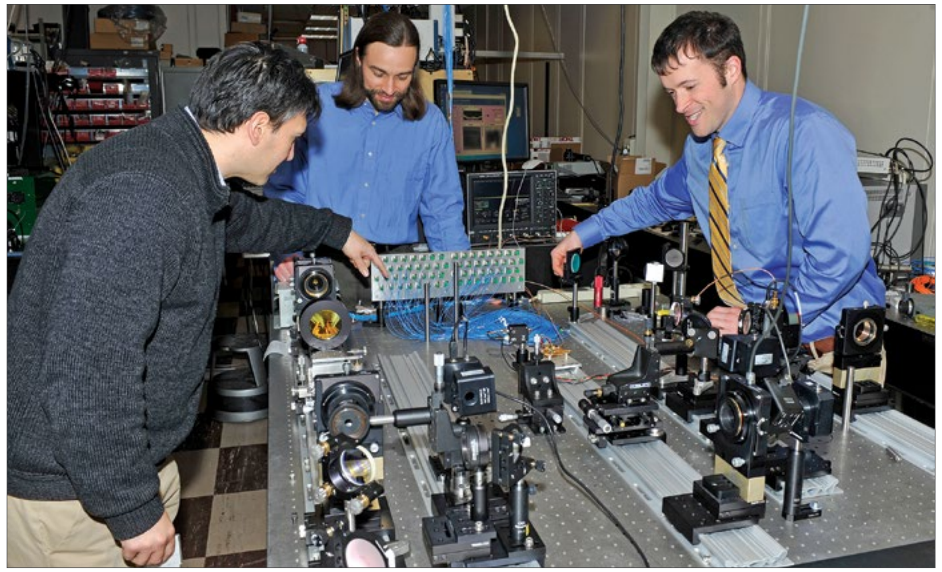
Dr. Barry E. Burke

Dr. Richard W. Ralston

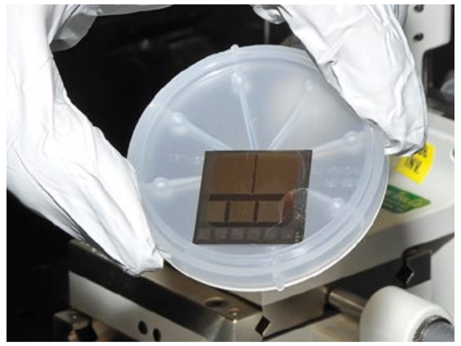
The Advanced Technology mission supports national security by identifying new phenomenology that can be exploited in novel system applications and by then developing revolutionary advances in subsystem and component technologies that enable key, new system capabilities. These goals are accomplished by 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.



Donna-Ruth Yost of the Quantum Information and Integrated Nanosystems Group prepares for a wafer-scale bonding of 8-inch-diameter optical photonic and complementary metal-oxide semiconductor (CMOS) wafers.



Juan Montoya, Andrew Benedick, and Scot Shaw use prototype technology to demonstrate a new optical phased array beam-combining approach developed at Lincoln Laboratory with support from the Defense Advanced Research Projects Agency (DARPA).



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

Principal 2014 Accomplishments

- Methods for real-time detection of vapors at concentrations <1 part per trillion have been developed and are being used to understand chemical-agent releases and to improve canine training in the detection of trace chemicals.
- Lincoln Laboratory developed a novel photochemical process that is expected to enable the additive manufacturing of three-dimensional siloxane-based microfluidic devices, thus widely expanding the capabilities of biological and biomedical lab-on-a-chip applications.
- A new power record for coherently combined fiber laser systems was attained. A first-ever coherent combining of quantum-cascade lasers was also demonstrated.
- Several engineering development units of the Rapid Agent Aerosol Detector (RAAD) were completed. RAAD may provide an upgrade to the Joint Biological Point Detection System, enabling improved performance and reduced maintenance in comparison to other bioaerosol triggers.
- Initial operation of the Multifunction Phased Array Radar (MPAR) was successfully demonstrated. MPAR is a prototype system for the next-generation Federal Aviation Administration and National Oceanic and Atmospheric Administration's integrated air traffic control and weather radar.
- A simultaneous transmit and receive (STAR) system for look-through electronic attack was developed and demonstrated. The system provides more than 85 dB of transmit-to-receive isolation on a moving ground vehicle by employing a high-isolation antenna and adaptive RF and digital cancellation techniques.
- First-generation, high-pixel-count, InP-based Geiger-mode avalanche-photodiode arrays were successfully fabricated with sizes of 256 × 128 (50 μm pitch) and 256 × 256 (25 μm pitch) pixels. This technology will enable wide-field-of-view system applications. A new micro-fuse technology was also developed and demonstrated on 256 × 256–pixel devices. Fuses integrated at the pixel level will provide chip-level robustness and enhance overall system reliability.
- A coherent, two-channel microwave-photonic receiver was developed to downconvert microwave signals from X band to an intermediate frequency with a bandwidth of 1.1 GHz. The spur-free dynamic range of the microwave-photonic downconversion process was shown to be 20–30 dB better than that of a high-quality microwave electronic mixer.
- The Laboratory fabricated superconducting qubits and achieved state-of-the-art performance in coherence times for both two-dimensional (35 microseconds) and three-dimensional (140 microseconds) transmon qubits.

Future Outlook

- The growing need to perform worldwide monitoring will motivate the development of new sensor capabilities in a variety of areas, including ladar, passive imaging, and radar.
- Defending the global commons will require advanced capabilities designed for contested environments, prompting component developments in RF electronics, lasers, imagers, computation, and microsystems.
- A need for highly scaled computation systems for exploiting large datasets acquired from new sensing modalities will drive the exploration of low-power computing approaches.
- The increasing importance of sensing chemical, radiological, and explosives threats will prompt the development of new detection systems.
- Continuing concerns with irregular warfare will motivate the scaling of sensor capabilities to a more distributed battlefield, enabling advanced sensing at lower echelons.
- The proliferation of autonomous systems will trigger the development of additional capabilities for vision, navigation, power, and communications.
- Space control and astronomy science applications will drive the continued development and advancement of sensitive, large-format focal planes.

Homeland Protection

Leadership

Dr. Melissa G. Choi

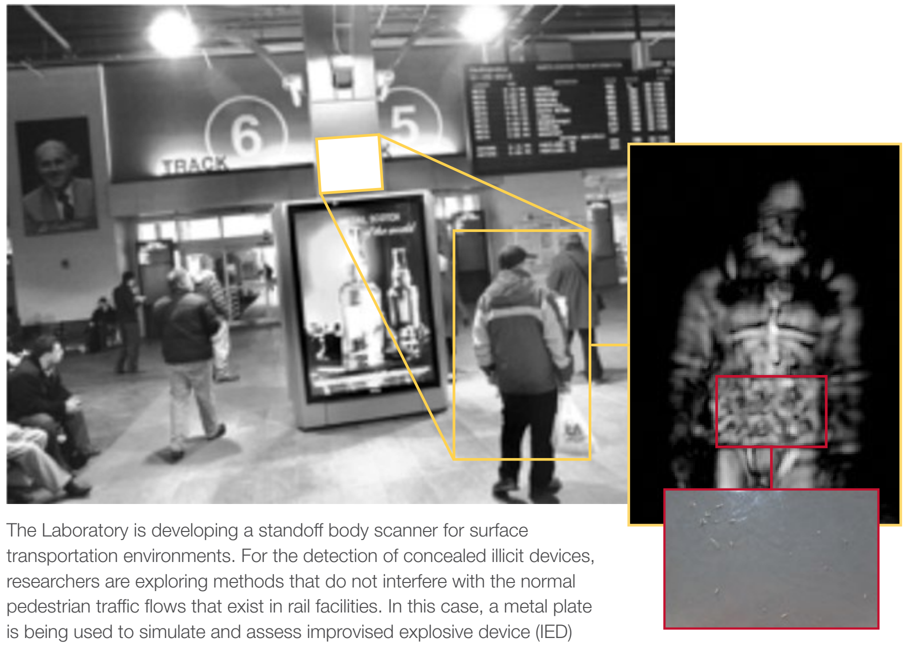
Mr. James M. Flavin

Dr. 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 this 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.

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



The Laboratory is developing a standoff body scanner for surface transportation environments. For the detection of concealed illicit devices, researchers are exploring methods that do not interfere with the normal pedestrian traffic flows that exist in rail facilities. In this case, a metal plate is being used to simulate and assess improvised explosive device (IED) detection performance through heavy clothing.

The near-field measurement range at the RF System Test Facility is used to characterize millimeter-wave imaging through common materials and to investigate sparse aperture sampling. Shown above are the near-field probes used for transmitting and receiving millimeter test signals.

Principal 2014 Accomplishments

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

- Working with the U.S. Army Research Institute of Environmental Medicine (USARIEM), the Laboratory is developing advanced physiological monitoring sensors, signal processing algorithms, and open architectures that will reduce heat casualties, noise-induced hearing loss, and musculoskeletal load injuries in service members.

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

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

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

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

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

- In partnership with USARIEM, the Laboratory successfully demonstrated the first phase of ultra-low-power, wearable physiological monitoring systems, including signal processing algorithms and tactical communications.

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

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

Future Outlook

- Securing and defending U.S. borders and critical infrastructures will motivate studies to define an integrated air, land, and maritime architecture. Solutions will leverage the Laboratory's strengths in advanced sensors, cyber security, data fusion, and decision support.

- The need for improved disaster response will prompt Laboratory development of information-sharing architectures, storm-surge sensor capabilities, analytics for data mining and collaborative decision making, and technologies for dynamic preparedness exercises.

- 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.

- The DoD's biomedical research goals of protecting the health and performance of warfighters in both training and operational environments will require miniaturized sensors for physiological monitoring, novel genetic sensing and analysis, fieldable musculoskeletal imaging, noninvasive neurocognitive assessments, and tactical body area networks.

Air Traffic Control

Leadership

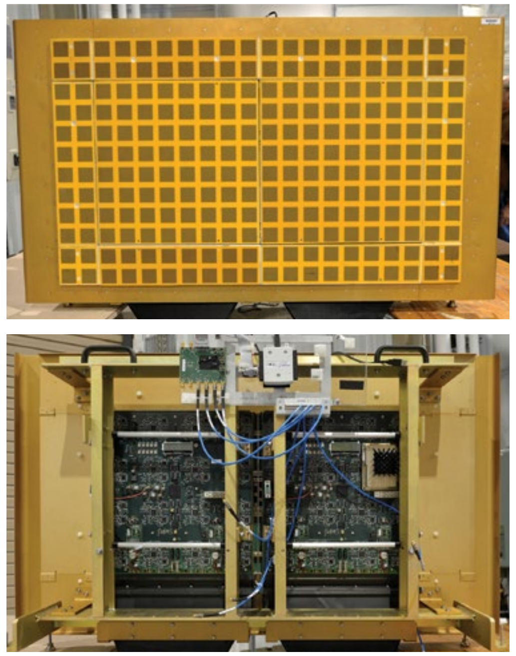

Mr. James M. Flavin


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 net-centric data distribution; and development of standards and technology supporting unmanned aerial systems' integration into civil airspace.


These photos show the front (top) and back (bottom) views of the 128-element dual-polarization Multifunction Phased Array Radar (MPAR). The Laboratory is currently building a mobile demonstration radar with a 640-element array that will be deployed for field testing.


Lincoln Laboratory's air traffic control simulation facilities are used to design and evaluate new technologies for airport traffic management and integration of unmanned aircraft into civil airspace.

Principal 2014 Accomplishments

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

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

- The NextGen Weather Processor (NWP) consolidates multiple legacy FAA weather processing platforms and introduces new functionality, such as 0–8-hour thunderstorm-forecasting technology developed by Lincoln Laboratory. The Laboratory is leading efforts to define requirements for NWP, to develop a reference technical architecture, and to provide technical evaluations of industry proposals. This year, core acquisition documentation was delivered in support of the source-selection process.

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

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

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

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

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, 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 continue. 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 the capacity reductions caused by thunderstorms.

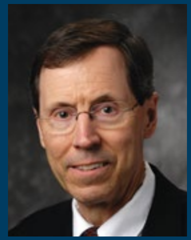
- Support for current and future FAA safety systems will continue. Efforts will focus on preparing for two flight tests in FY15: one with an ACAS X variant for UASs and the other with a new surveillance architecture that fully exploits the benefits of ADS-B.

- The Laboratory's key role in national and international efforts to integrate UASs into civil airspace will be primarily in the area of conflict avoidance with manned aircraft. The Laboratory will continue developing standards and requirements, safety evaluation methods, threat detection and maneuver algorithms; developing and deploying real-time prototypes; and transferring technology to industry.

Engineering

Leadership


Dr. Eliahu H. Niewood


Dr. William R. Davis


Dr. Michael T. Languirand

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 construct 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 system development, 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.

MIT graduate students conduct a final verification of attitude-determination sensors for the Micro-sized Microwave Atmospheric Satellite (MicroMAS) in Lincoln Laboratory's Environmental Test Laboratory. The MicroMAS project was a collaboration between technical groups within the Laboratory's Engineering and Space Control mission areas and researchers at MIT's Space Systems Laboratory to design and build a low-cost nanosatellite capable of providing observations of storm dynamics.

The Laboratory's new ground vehicle test bed is supporting current and future unmanned autonomous systems work in localization, perception, and mapping. A novel Lincoln Laboratory–designed localizing ground-penetrating radar positioned underneath the vehicle enables 3-centimeter-level real-time localization to a prior map at travel speeds up to 60 mph. A lidar mapping sensor, camera, and dual differential global positioning systems were also integrated into the mobile test bed to provide accurate mapping and localization capabilities.

Two Lincoln Laboratory researchers received a distinguished paper award from the Society of Manufacturing Engineers (SME) for their paper on the 3D-printed, extendable-wing Variable Airspeed Telescoping Additive Unmanned Air Vehicle (pictured above). This award, presented at SME's annual Rapid Prototyping Conference, recognizes a paper that has had a significant impact on rapid prototyping or additive manufacturing.

Principal 2014 Accomplishments

- In partnership with the MIT Kavli Institute for Astrophysics and Space Research, Lincoln Laboratory began the flight hardware development phase of the Transiting Exoplanet Survey Satellite (TESS), selected for launch in 2017 by the National Aeronautics and Space Administration (NASA). The Laboratory is building the four telescopes and focal planes for TESS, which will map out the entire sky in search for exoplanets.
- Work began on developing rapid perception and planning solutions for a novel low–size, weight, and power (SWaP), high-speed sensor for small unmanned aerial vehicles flying in crowded environments at low altitude. In addition, a new ground vehicle test bed was built with several state-of-the-art sensors, including a novel localizing ground-penetrating radar.
- Continuing to support the development and demonstration of intelligent power management for future tactical microgrids, the Laboratory designed and built prototype microgrid power distribution hardware that will be integrated into its forward operating base microgrid test bed. The test bed, which was expanded to include applications for tactical energy storage, will be used to demonstrate power-management architectures that increase energy security and efficiency on the battlefield.
- The Laboratory's work with the MIT Department of Aeronautics and Astronautics on developing the Micro-sized Microwave Atmospheric Satellite (MicroMAS) included testing and integration of the satellite, which was delivered to the International Space Station in July 2014.
- The use of additive manufacturing was expanded to applications for numerous programs, including airborne and space payload developments. One development was the Variable Airspeed Telescoping Additive Unmanned Air Vehicle, constructed almost entirely with three-dimensionally printed parts.
- The Laboratory continued to invest in cutting-edge fabrication and electronic assembly tools, including a fatigue-testing machine for characterizing advanced materials, diamond turning tools for the fabrication of precision mechanical and optical parts, an automated pick-and-place machine for creating circuit boards, and an advanced X-ray inspection tool.
- The fourth annual Mechanical Engineering Technology Symposium was held at Lincoln Laboratory in September 2014. Sessions focused on advanced materials, additive manufacturing, integrated engineering analysis, environmental testing, and microsatellite mechanical design. Laboratory presentations described work performed under the engineering technology initiative on topics such as integrated optomechanical analysis, pyrotechnic shock testing, laser vibrometry, and the mechanical behavior of additive metals.

Future Outlook

- Significant emphasis will be placed on advancing the engineering technology used to field robust prototypes of Laboratory sensors and systems. A variety of technologies in the materials, optics, environmental testing and analysis, and fabrication areas have been identified as technologies for the Laboratory to adopt, adapt, or develop.
- Investment in new technology will be focused on adapting advanced materials for Laboratory applications and developing advanced design tools for additive manufacturing.
- Plans for the construction of a new engineering and prototyping facility will move forward, with completion of the detailed design expected during the coming year.

LABORATORY INVOLVEMENT

University of Massachusetts–Lowell students in the Air Force Reserve Officer Training Corps tour the Flight Test Facility.

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

Eric Evans (standing far left), Lincoln Laboratory's Director, and Robert Atkins (standing second from left), head of the Laboratory's Advanced Technology Division, meet with the students and instructors of the radar-building courses offered by Laboratory technical staff at MIT during the Independent Activities Period. The students are seen here with the small radar systems and the phased array radars they constructed and tested.

Independent Activities Period at MIT

Lincoln Laboratory technical staff continue to lead activities offered during MIT's Independent Activity Period (IAP), a four-week term spanning the January semester break. Under the IAP program, for-credit classes are available for registered MIT students, and non-credit activities are open to all members of the MIT community. The IAP offerings range from academic seminars to hands-on engineering projects to artistic pursuits.

During the 2014 IAP, Dr. David Kong conducted a for-credit graduate-level course, *Open-Source Microfluidics for Synthetic Biology*. Lincoln Laboratory staff members also organized and led four non-credit activities:

- *Hands-on Holography* — Led by Dr. Robert Freking, Dr. Christy Cull, and Dr. Evan Cull
- *Hands-on Computational Imaging and Spectroscopy* — Led by Dr. Christy Cull, Dr. Evan Cull, and Dr. Robert Freking
- Two radar courses: *Build a Small Phased Array Radar System* and *Build a Small Radar System* — Led by Dr. Bradley Perry with participation by Dr. Patrick Bell (co-lead on the second course), Dr. Shakti Davis, Dr. Alan Fenn, Dr. Jeffrey Herd, Kenneth Kolodziej, Todd Levy (co-lead on the first course), Joseph McMichael, John Meklenburg, Dr. Nicholas O'Donoughue, Dr. Raoul Ouedraogo, and Dr. Gordon Wichern

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 the campus for intensive, week-long courses designed to expand participants' familiarity with emerging technologies.

For the 2014 Short Programs, a number of Lincoln Laboratory technical staff members have led three radar courses: *Build a Small Phased Array Radar Sensor*, *Build a Multichannel Search and Track Radar*, and *Build a Small Radar System*. Dr. Patrick Bell, David Conway, Dr. Shakti Davis, Dr. Alan Fenn, Dr. Jeffrey Herd, Kenneth Kolodziej, Todd Levy, Joseph McMichael, John Meklenburg, Dr. Nicholas O'Donoughue, Dr. Bradley Perry, and Dr. Gordon Wichern are working with MIT professors Michael Watts and Gregory Wornell to deliver hands-on engineering experiences in building and testing laptop-based radar sensors. A 2013 participant in *Build a Small Radar System* described the class as "somewhere between incredible and fantastic."

Michael Boulet, working with Prof. H. Harry Asada, reprised the popular *Rapid Robotics: Autonomous Systems with Open-Source Software*, an introduction to applied robotics software programming in which two-person teams work on a robotic system.

VI-A Master of Engineering Thesis Program

Students in MIT's VI-A Master of Engineering Thesis Program can 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 2014, three VI-A students participated in the program, gaining experience in testing, design, development, research, and programming.

Research Assistantships

Lincoln Laboratory employs 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. Currently, 32 research assistants, 14 of whom are military officers studying at MIT, are working in various groups across the divisions.

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 2014, 10 undergraduates were hired in the summer as UROP interns and six as UPOP interns.

MIT Lincoln Laboratory Beaver Works

Beaver Works, a joint venture between Lincoln Laboratory and the MIT School of Engineering, was established as an incubator for research and innovation. The center facilitates project-based learning and leverages the expertise of MIT faculty, students, and researchers, and Lincoln Laboratory staff to broaden research and educational partnerships. By encouraging collaborative projects, Beaver Works strengthens the potential of both institutions to make an impact on pressing global problems.

Beaver Works supports student involvement in a broad range of research and educational pursuits, including two-semester, course-based capstone projects; joint and individual research initiatives; and UROP internships.

Photos: David Sun Kong

The 2014 for-credit MIT course Open-Source Microfluidics for Synthetic Biology, offered during the Independent Activities Period by David Kong of the Laboratory's Bioengineering Systems and Technologies Group, was held jointly at the Beaver Works Center (above) and the MIT Synthetic Biology Center. Dr. Kong is seen here with the students who learned how to use a three-dimensional (3D) microfluidic device to assemble a genetic circuit. Below, a student holds a polydimethylsiloxane (PDMS) device cast from a 3D-printed mold.

>> *Technical Education, cont.*

SPOTLIGHT

Beaver Works Capstone Project: Power an Unmanned Undersea System

In fall 2011, 35 undergraduates in the MIT Mechanical Engineering Department enrolled in a new course, Engineering Systems Design, which revolved around a capstone design project to develop a long-endurance power source for an unmanned undersea vehicle (UUV). The students understood that this course would influence the follow-on spring semester course, Engineering Systems Development, which focused on building a working prototype. They did not envision that their solution to this challenge would become the catalyst for capstone projects in the courses for the next three years.

At the Beaver Works Center, students in the 2013–2014 Engineering Systems Design/Development courses are just beginning to turn their ideas into a physical model for the prototype they will later build.

The project is a collaborative venture between Prof. Doug Hart's students and researchers from MIT Lincoln Laboratory. Technical staff members from Lincoln Laboratory posed the real-world problem—how to significantly increase the endurance of UUVs—and provide experienced advice to the class. Research conducted by the students in the 2011–2012 class became the starting point for the 2012–2013 design and build challenge: to develop and build a power source that allows the UUV to remain submerged for 30 days. The proof-of-concept model constructed in this second UUV project makes use of the energy released when aluminum reacts with water, which is converted to electricity to recharge UUV batteries without the UUV's having to surface for air intake. For students in the 2013–2014 courses, the goal is to further develop the design from the prior years, demonstrated only in lab conditions, and to build and integrate a full-scale prototype into an actual UUV platform that can withstand the harsh ocean environment.

This multiyear effort involving Prof. Hart's classes and the Laboratory is one of the early Beaver Works collaborations. With the opening in fall 2013 of the MIT Lincoln Laboratory Beaver Works Center, the students now have a well-equipped, modern, dedicated space in which to fabricate prototypes. "They [students] love this space," says Nicholas Pulsone, senior staff in the Advanced Sensor Techniques Group and the Lincoln Laboratory lead on these projects. "The space we used before was much less functional." He and colleagues Alex Bockman, Paul Calamia, Joseph Edwards, and Chris Lloyd have enjoyed teaming up with the undergrads. "They are highly energetic, intelligent, and completely open minded. They aren't constrained by preconceived ideas and often come up with novel ideas," says Pulsone.

On capstone projects, students are motivated by the knowledge that they are investigating tangible problems people really care about. In fact, the Woods Hole Oceanographic Institution, which is designing and building UUVs, is interested in the systems the engineering classes have developed and is supplying two engineers as consultants for the current courses. In summer 2014, engineers from Lincoln Laboratory and Woods Hole worked with students to test and demonstrate their system at sea.

Students of the MIT Mechanical Engineering Department's two-semester course sequence taught by Prof. Doug Hart (back row, center) are photographed with the 2012–2013 proof-of-concept model of an energy subsystem for an unmanned undersea vehicle. At far right is Nicholas Pulsone, who was the lead organizer of Lincoln Laboratory's participation in this collaborative project.

EDUCATIONAL PROGRAMS WITH UNIVERSITIES

Summer Research Program

In 2014, 181 undergraduate and graduate students from 75 schools nationwide participated in Lincoln Laboratory's Summer Research Program, which offers students internships in technical groups. Students gain hands-on experience while contributing to projects that complement their courses of study. The Laboratory also hosted 49 cadets and midshipmen from the military service academies.

University Cooperative Education Students

Technical groups at Lincoln Laboratory offer cooperative education internships to students from area colleges. Students work full time with mentors during the summer or work/study semesters and part time during academic terms. Highly qualified students selected for co-op jobs become significant contributors to technical project teams. During the spring 2014 semester, 47 students worked in divisions and departments at the Laboratory.

Worcester Polytechnic Institute Major Qualifying Project Program

In summer 2014, seven students worked as Laboratory interns under the Worcester Polytechnic Institute's Major Qualifying Project Program, which requires students to complete an undergraduate project equivalent to a senior thesis. Under this program, students participate in Laboratory programs that are applicable to their senior projects, learning to apply their skills and knowledge to problems typical of those encountered in industry.

Graduate Fellowship Program

In 2013–2014, three students were awarded grants through this program that offers graduate fellowships to science and engineering students pursuing MS or PhD degrees at partner universities. Funds support a fellow's stipend, supplement an assistantship, or subsidize other direct research expenses.

The 2013 CTF competition participants—40 hours after they embarked on the challenge! Students came from MIT, Boston University, UMass-Boston, Northeastern University, Brandeis University, Wellesley College, Worcester Polytechnic Institute, Rensselaer Polytechnic Institute, New York University's Polytechnic School of Engineering, and Dartmouth College.

Capture the Flag

From 25 to 27 October 2013, 150 college students from 10 schools met at MIT to play Capture the Flag (CTF). While many were dressed in athletic shoes and t-shirts, these students were not there to compete in an outdoor, team-tag-like game. They came ready to attack and defend in cyberspace, applying their considerable computer skills either to infiltrate and impair opponents' applications or to protect their own apps from unwanted intrusions.

A team puzzled over strategies. While exciting, the competition is intense, with some of the top college students from computer science and engineering disciplines vying to be the best cyber defenders.

For the third year, staff members from Lincoln Laboratory's Cyber Security and Information Sciences Division have partnered with faculty from Northeastern and MIT to host a CTF event. Each year, participation has grown in these events modeled after the CTF competitions introduced at the world's largest hackers' convention, DEF CON (so-called to allude to the armed forces' acronym for defense readiness condition). Prof. Wil Robertson from Northeastern University invented the 2013 challenge attempted by teams of student cyber defenders: devise methods to protect your simulated Android apps and back-end services while attacking adversaries' apps and services to grab "flags" (code evidencing a successful attack).

These CTF contests are dynamic learning opportunities for students and are raising their awareness of the growing field of cyber security and of Lincoln Laboratory's cyber research, in particular. In turn, Laboratory staff members are meeting some potential colleagues; two recent hires are former CTF participants.

Lincoln Laboratory CTF volunteers, including Timothy Leek, Andrew Davis, Kyle Gwinnup, and William Leonard, run mini-events during the year to acquaint students with the CTF format. Held at the MIT Lincoln Laboratory Beaver Works Center in Cambridge, the events are part practice, part strategy critique.

>> *Technical Education, cont.*

MILITARY FELLOWS PROGRAM

Each year, MIT Lincoln Laboratory awards fellowships to support the educational pursuits of active-duty military officers from all the Services. 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 the 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.

Currently, 28 Military Fellows are conducting research in various divisions throughout the Laboratory.

SPOTLIGHT
Ensign Erica Leinmiller, U.S. Navy

ENS Leinmiller (left), pictured with Maureen Hunter, is interested in the strategies, policies, and legal structures that govern cyberspace and the national and foreign dialogue required to maintain cyberspace as a secure virtual environment that promotes efficiency, economic prosperity, and global interchange.

"The exposure to people working on difficult national security problems has opened my mind to new ways of thinking and inspired a deeper appreciation for the work that civilians do to support the Department of Defense," says Ensign Erica Leinmiller. ENS Leinmiller, a Naval Academy graduate, is a Military Fellow in the Laboratory's Cyber Systems and Operations Group and a graduate student in the public policy program at the Harvard John F. Kennedy School of Government. Her policy-oriented knowledge and understanding of human-computer interaction provides unique social sciences- and humanities-based perspectives that inform the group's approach to devising effective network defense strategies. "Without Lincoln Laboratory and other places like it, the American military could not be the superior fighting force it is today," says ENS Leinmiller.

SPOTLIGHT
Ensign Jordan Foley, U.S. Navy

Ensign Foley, a Naval Academy graduate and MIT dual master's degree candidate in technology policy and political science, was the Navy liaison to the Space Systems Analysis Group. A fluent Mandarin speaker who has lived in China and served on two official exchange visits to the country, ENS Foley offered insights into the lingual and cultural factors critical to understanding the strategic implications of China's space program—the focus of his research at the Laboratory. ENS Foley's fellowship opened the door to several travel opportunities, including a research assistantship at the United Nations Office for Outer Space Affairs in Vienna and a program at the Beijing University of Aeronautics and Astronautics. "These trips, along with opportunities to deliver presentations and work with committed advisors who are invested in my progress, cannot be matched elsewhere," he says.

ENS Jordan Foley (front) provides colleagues (left to right) Eric Wahl and Scott Uebelhart with unique perspectives on the Chinese space program. "ENS Foley's command of the Chinese language and his perceptive insights into China's foreign culture and science and technology policy are extremely important to our Space Systems Analysis Group, whose role is to understand the big picture in the space mission area," says Uebelhart.

PROFESSIONAL DEVELOPMENT

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

2014 Software Engineering Symposium
Sponsored by the Director's Office and the Safety, Mission Assurance, and Program Support Office, the Software Engineering Symposium offers Laboratory staff an opportunity to discuss best practices for software and firmware applications in the research and development environment. This year's event was held on 16 October and attracted more than 200 attendees. Keynote speakers were Dr. Ivan Sutherland, developer of the Sketchpad computer application and a Turing Award winner, and Dr. Alan Kay, also a Turing Award winner and president of Viewpoints Research Institute.

Lincoln Scholars Program
Currently, 26 staff members are enrolled in the Lincoln Scholars Program, a competitive program for which staff members are eligible to apply and under which participants are funded by the Laboratory for full-time pursuit of an advanced degree at MIT or another local university. Lincoln Scholars contribute to the Laboratory under terms arranged with the Graduate Education Committee and work at the Laboratory during summer breaks.

Distance Learning
Distance learning programs coordinated by the Graduate Education Committee enable technical staff to earn master's degrees while continuing to work full time at the Laboratory. Carnegie Mellon University offers degrees in information technology and information assurance, while Pennsylvania State University offers a master's program in information sciences. Currently, three staff members are enrolled at Carnegie Mellon and one at Pennsylvania State.

Boston University Program
Boston University is offering core and elective courses from their master's program in computer science onsite at Hanscom Air Force Base. These courses can be taken independently or as part of a certificate or master's degree program through Boston University. Since the program started in 2013, 33 staff members have completed one or more of the eight course offerings held during the spring, summer, and fall semesters.

Onsite Courses
A range of courses in both technical areas and management techniques are taught by either Laboratory technical experts or outside instructors. During 2013–2014, more than 60 staff members participated in the creation and delivery of these courses.

2013–2014 Multisession Courses
- Decision Making Under Uncertainty
- Digital Signal Processing 1: Signals and Systems
- Digital Signal Processing 2: Discrete Fourier Transform, Digital Filters, Filter Banks
- Digital Signal Processing 3: Statistical Signal Processing
- Electromagnetics and Antennas
- Semiconductor Device Physics and Technology
- Probabilities and Statistics
- Electromagnetic Interference/Electromagnetic Compatibility Shielding and Grounding
- Electronic Warfare
- Introduction to Radar 1
- Systems Engineering
- Introduction to Cyber Security: Models, Technologies, and Applications
- Radar Systems and Signal Processing
- Developing Serious Games at Lincoln Laboratory
- Rapid Robotics: Autonomous Systems with Open-Source Software
- Communications at MIT Lincoln Laboratory
- Theory and Methods for Modern Graph Analysis
- Prototyping of Complex Systems at Lincoln Laboratory

2013–2014 Technical Short Courses
- Software Architecture: Principles and Practices
- Software Architecture: Design and Analysis
- Apache Subversion software introduction
- Cyber warfare course
- Windows Internals introduction
- JMP software training
- NVIDIA/CUDA training

Technical Programming Courses
- A wide range of programming courses in areas such as C++, HTML, Linux, PHP, Perl, Python, UML, UNIX, and XML
- A complete MATLAB curriculum with courses in signal processing, MATLAB programming techniques, interfacing MATLAB with C code, and statistical methods for MATLAB
- Certified Information Systems Security Professional and VMware certification courses

>> *Technical Education, cont.*

WORKSHOPS AND SEMINARS

Workshops at Lincoln Laboratory

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 its 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. 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.

2014 Schedule of Onsite Workshops

APRIL 2014

7–11 Defense Technology Seminar
16–17 Advanced Technology for National Security Workshop
29 April–1 May Space Control Conference

MAY 2014

6–8 Air Vehicle Survivability Workshop
20–21 Lincoln Laboratory Communications Workshop

JUNE 2014

4–5 Air and Missile Defense Technology Workshop
17–19 Cyber and Netcentric Workshop
24–25 Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop

AUGUST 2014

21–22 Graph Exploitation Symposium

SEPTEMBER 2014

29–30 Mechanical Engineering Technology Symposium

OCTOBER 2014

16 Software Engineering Symposium
28–29 Human Language Technology and Applications Workshop

NOVEMBER 2014

4–6 Anti-access/Area Denial Systems and Technology Workshop

DECEMBER 2014

9–11 Homeland Protection Workshop

Advanced Technology for National Security Workshop

The newest addition to the slate of workshops offered at Lincoln Laboratory is the Advanced Technology for National Security Workshop. The goal of this forum for sharing novel concepts from the Laboratory's programs with system architects and advanced technology developers is to enable future national security systems that "will make a difference."

The workshop's five technical sessions cover technologies that address emerging challenges:

- RF Technologies for Anti-access/Area Denial
- Advanced Imagers for Intelligence, Surveillance, and Reconnaissance
- High-Energy Lasers in Defense
- Advanced Computation for Big Data
- Systems for Chemical and Biological Defense and Intelligence

Offsite Workshops

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

2014 schedule of offsite workshops

- The Homeland Protection Workshop Series hosted two one-day sessions at the U.S. Geological Survey in Reston, Virginia: Incident and Disaster Response Workshop on **28 May** and Borders and Maritime Security Workshop on **29 May**.
- High Performance Extreme Computing Workshop, an IEEE conference held during **9–11 September** in Waltham, Mass.
- IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference held during **6–9 October** in San Francisco.
- Air Traffic Control Workshop coordinated with the Federal Aviation Administration (FAA) and held on **18 November** at the FAA Headquarters in Washington, D.C.
- Advanced Research and Technology Symposium, sponsored by the Lincoln Laboratory Technology Office and held at the MIT Media Lab on **2–3 December**.

2014 Defense Technology Seminar

The 2014 Defense Technology Seminar was held at Lincoln Laboratory in April. Fifty-three military officers and Department of Defense civilian employees (above) attended the week-long event that focused on evolving military challenges. Technical staff from the Laboratory and nationally prominent guest speakers presented seminars on new technologies under development for national security and current geopolitical issues. A one-day Defense Technology Seminar was held on 25 April for cadets of the U.S. Military Academy.

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 share engineering and scientific knowledge.

2014 schedule of onsite courses

- Technology for Intelligence, Surveillance, and Reconnaissance, **3–5 June**
- Introduction to Radar Technology, **17–19 June**
- Networking and Communications, **24–26 June**

Available offsite for government agencies

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.

A number of times a year, members of the Cyber Security and Information Sciences Division offer a course in anti-tamper technology for government agencies requesting the two-day seminar at their locations.

Technical Seminar Series

Members of the technical staff at Lincoln Laboratory present technical seminars to interested college and university groups. The 2014–2015 slate of 61 available seminars covers a wide range of topics in radar technology, air traffic control, advanced electronics, cyber security, human language technology, and communication systems.

Awards and Recognition

The commitment to excellence that characterizes our staff has enabled the Laboratory's 63 years of achievements and its sustained reputation for innovation.

2014 SPIE Frits Zernike Award for Microlithography

Dr. Mordechai Rothschild, for significant contributions to the advancement of lithography through the exploration and demonstration of deep-ultraviolet and vacuum-ultraviolet materials, lasers, and systems.

2013 MIT Lincoln Laboratory Technical Excellence Awards

Dr. Jeremy Kepner, for "his leadership and vision in bringing supercomputing to Lincoln Laboratory through the establishment of LLGrid; his pivotal role in open systems for embedded computing; his creativity in developing a novel database management language and schema; and his contributions to the field of graph analytics."

Dr. Roderick R. Kunz, for "his outstanding technical contributions to the team that developed the 193-nm lithography process for integrated circuit device fabrication, and for subsequent advancements in lithography, such as the world's first photolithography exposure tool and procedures for improving the durability of 193-nm lenses."

2013 MIT Lincoln Laboratory Early Career Technical Achievement Awards

Dr. Brooke E. Shrader, for "her work on a new class of network protocols that mitigate channel impairments commonly encountered by mobile communication networks, for the development of a protocol capable of exploiting the inherent link diversity in heterogeneous tactical networks, and for innovations in the concept of network routing overlays."

Scott Van Broekhoven, for "his technical understanding, execution ability, initiative, and innovative thinking in work on advanced energy systems and miniature unmanned aerial vehicles; and for his ability to lead the execution of major design and test efforts with their rigorous controls and processes."

Defense Science Board Vice Chair

Dr. Eric D. Evans, Director of Lincoln Laboratory, has been appointed by the Office of the Secretary of Defense as vice chair of the Defense Science Board (DSB). He has been a member of the DSB since 2010, serving on several task forces and co-leading two studies—Improvised Explosive Devices and Cyber Security and Reliability in a Digital Cloud—that investigated the significance of these emerging issues to the Department of Defense (DoD).

The DSB, founded in 1956, is composed of leading U.S. scientists and engineers who provide the DoD with informed, independent assessment of the impacts and opportunities presented by new technologies. The current DSB is made up of 34 members who are preeminent authorities in science and technology fields pertinent to military operations and acquisitions and eight senior fellows who are leaders in DoD advisory committees.

2013 MIT Lincoln Laboratory Best Paper Award

Dr. Andrew L. Puryear, Prof. Jeffrey H. Shapiro (MIT), and **Dr. Ronald R. Parenti**, for "Reciprocity-Enhanced Optical Communication Through Atmospheric Turbulence—Part I: Reciprocity Proofs and Far-Field Power Transfer Optimization" and "Part II: Communication Architectures and Performance." The papers were published in December 2012 and August 2013 in the *IEEE/OSA Journal of Optical Communications and Networking*.

2013 MIT Lincoln Laboratory Best Invention Award

Dr. Michael W. Kelly, **Dr. Daniel L. Mooney**, **Curtis B. Colonero**, **Dr. Robert Berger**, and **Lawrence M. Candell**, for the "Digital Readout Method and Apparatus (better known as the Digital-Pixel Focal Plane Array, [DFPA])." A patent for this technology was issued in May 2012.

2014 MIT John S.W. Kellett '47 Award

Lincoln Laboratory Out Professional Employee Network (OPEN), for embodying the activism of John S.W. Kellett by "improving the experience of lesbian, gay, bisexual, transgender, and questioning individuals."

2014 Fellow of SPIE

Dr. Keith B. Doyle, for achievements in advances in optomechanical engineering and integrated modeling.

2014 AFCEA International Distinguished Award for Excellence in Engineering

Dr. Eric D. Evans, for a career exhibiting a strong commitment to engineering and outstanding technical accomplishments; presented by the Armed Forces Communications and Electronics Association (AFCEA).

2013 Superior Security Rating

Awarded to Lincoln Laboratory's collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office.

2014 MIT Excellence Awards

Photo: G.G. Ramsay

The Virtual Conference Development Support Team accepts an "Unsung Hero" award. The team consists of (front row, left to right) Daniel DiPrima, Tom Schultz, Laura Bloom, Steven Schoeffler, and (second row, left to right) Matthew Ellis, Kevin Zablonski, Justin Lacroix, and Kevin Van Steensel. In the back row are (left to right) Edmund Bertschinger, Institute Community and Equity Officer, MIT; Eric D. Evans, Director, MIT Lincoln Laboratory; Martin A. Schmidt, Provost, MIT; and Israel Ruiz, Executive Vice President and Treasurer, MIT.

Bringing Out the Best Award: **J. Darby Mitchell**, for fostering a team-oriented approach for developing software.

Serving the Client Award: **Michael R. Doiron**, for his ability to create clear, precise illustrations that effectively communicate complex technical concepts; **Albert L. Traniello**, for his support to the engineering staff and his willingness to mentor others.

Unsung Hero Award: **Stefan C. Wolpert**, for development of innovative technology for border security; and the Virtual Conference Development Support Team: **Laura Bloom**, **Daniel R. DiPrima**, **Matthew C. Ellis**, **Justin M. Lacroix**, **Steven M. Schoeffler**, **Tom H. Schultz**, **Kevin J. Van Steensel**, and **Kevin J. Zablonski**.

2014 Irwin Sizer Award

Dr. Robert T-I. Shin, head of Lincoln Laboratory's Intelligence, Surveillance, and Reconnaissance (ISR) and Tactical Systems Division and director of the MIT Lincoln Laboratory Beaver Works Center, is the recipient of the 2014 Irwin Sizer Award for the Most Significant Improvement to MIT Education. This Institute Award is presented annually by MIT's Graduate Student Council to an individual or group to recognize "significant innovations and improvements to MIT education." Dr. Shin was honored for his vision and sustained effort in developing both the Beaver Works model of project-centric educational collaborations between MIT campus and Lincoln Laboratory, and the center designed to facilitate those collaborations. The Sizer Award is a tribute to the impact the Beaver Works approach is making by actively engaging students in real-world engineering projects.

2014 MIT Lincoln Laboratory Administrative and Support Excellence Awards

Administrative Category: **Joseph S. Ciampi**, for demonstrating leadership that has significantly improved quality and efficiency throughout the Microelectronics Laboratory; and **William H. Kindred**, for creating a lasting positive impact on diversity and inclusion at Lincoln Laboratory and MIT through commitment and strategic vision.

Support Category: **Kenneth L. Burkett**, for contributing to Lincoln Laboratory's successful flight-test programs and for serving as a resource for various user groups at the Flight Test Facility; and **Cynthia J. Wallace**, for promoting a positive community environment and applying outstanding organizational skills in support of a department office.

The 2014 recipients of Support and Administrative Excellence Awards are (left to right) Kenneth Burkett, Cynthia Wallace, William Kindred, and Joseph Ciampi.

>> *Awards and Recognition, cont.*

2014 NASA Agency Honor Awards

NASA Exceptional Technology Achievement Medal

Dr. Bryan S. Robinson, for "superior achievement in the development and flight of the Lunar Laser Communications Demonstration."

NASA Group Achievement Award

The **Lunar Laser Communication Demonstration (LLCD) team** (above), for "successful teamwork on the LLCD project and the achievement of demonstrating optical communications from the Moon at record-breaking data rates."

2014 Rotary National Award for Space Achievement—Stellar Award

The Rotary National Award for Space Achievement Foundation presented a 2014 Stellar Award to the **Space Surveillance Telescope development team**, sponsored and led by the Defense Advanced Research Projects Agency. The unique curved charge-coupled-device technology integrated into a very large pixel-count camera and the high-speed shutter, both developed at Lincoln Laboratory, enable the exceptional imaging capabilities of this telescope.

U.S. Navy Letter of Recognition

Bryan Barnett and **Bryan A. Babcock**, for their technical support to the Technical and Operational Evaluations of the Cobra Judy replacement ship, the Cobra King.

2014 National GEM Consortium Awards

Executive Committee Member of the Year

Frank D. Schimmoller, for his "generous commitment of time, support, and inspiration to the GEM [National Consortium for Graduate Degrees for Minorities in Engineering and Science] mission."

Employer Representative of the Year

William H. Kindred, for his "generous commitment to the GEM mission and exceptional volunteerism."

Carl G. Sontheimer Prize

Michael L. Stern, a Lincoln Scholar, received MIT Mechanical Engineering Department's Sontheimer Prize for creativity and innovation in design.

Aviation Week Twenty20s Honoree

Michael L. Stern, was selected by *Aviation Week* as one of its Twenty20s, 20 innovators in their twenties who are recognized for their early-career contributions to the aerospace and defense industries.

2014 Massachusetts Excellence in Commuter Options Award

The **Facility Services Department** was honored with a Leadership in Commuter Options ranking, a Pinnacle Award, and two Spotlight Awards for Leadership in Commuter Options by the MassCommute coalition, which works to encourage commuters to choose alternatives to drive-alone travel. The Pinnacle Award recognized the Laboratory's comprehensive commuter services program, and the Spotlight Awards recognized the successful carpool and vanpool initiatives.

The Facility Services Department team that ran the program that earned a 2014 Massachusetts Excellence in Commuter Options Award includes, left to right, Joseph Dolan, Richard Powers, Anna Maherakis, James Armao, and Donald Holmes.

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.

Percy Pierre delivers the keynote address at the Laboratory's inaugural Martin Luther King, Jr. Breakfast.

First Annual Martin Luther King, Jr. Breakfast

On 27 January, Lincoln Laboratory held its first annual Martin Luther King, Jr. Breakfast at the Minuteman Commons Community Center on Hanscom Air Force Base. Hosted by the Lincoln Employees' African American Network, the event gathered more than 200 attendees and raised awareness within the Laboratory community of MLK's long-lasting impact to the nation and of the progress yet to be made in the realm of civil rights. This year's theme, "Lead by Example," encouraged attendees to share in MLK's dream by working toward ensuring that laws enacted to guarantee equality are actually implemented. Following opening remarks from Director Eric D. Evans, former division head Dr. Wade M. Kornegay, the first African American division head at Lincoln Laboratory, offered his "lessons learned." Dr. Percy A. Pierre, Vice President Emeritus and Professor of Electrical and Computer Engineering at Michigan State University and the first African American to earn a doctorate in electrical engineering in the United States, delivered the keynote address. He traced the historical roots of the African American Civil Rights Movement, shared some of the educational and employment inequalities he faced while growing up in 1950s New Orleans, and urged the continued progress toward equality for all.

Larry Robinson (right), a member of the event's planning committee, presents Wade Kornegay with a small token of appreciation for speaking at the breakfast.

>> Diversity and Inclusion, cont.

Members of the Lincoln Laboratory Hispanic/Latino Network (LLHLN), including (left to right) Rosa Velez, Nestor Lopez, and Karen Gettings, attended MIT's 40th annual Martin Luther King, Jr. Breakfast celebration on 6 February. The LLHLN received a 2014 MLK, Jr. Leadership Award from MIT for embodying the spirit of Dr. King's work through service to the community.

2014 MIT Institute Diversity Summit

Lincoln Laboratory personnel attended MIT's annual on-campus Institute Diversity Summit held on 27–29 January. This year's theme, "Demystifying Diversity," encouraged attendees to challenge, expand, and broaden their perspectives on race, gender, socioeconomic class, sexual orientation, and other differences. LTC (Ret) Consuelo Castillo Kickbusch, founder of Educational Achievement Services, Inc., delivered the keynote address. Throughout the event, a variety of workshops addressed topics ranging from dispelling myths and fears surrounding disability, to building community across generations, to responding to everyday biases. William Kindred, manager of diversity and inclusion programs at Lincoln Laboratory, presented the Laboratory's diversity initiatives, including K–12 educational outreach to underrepresented minority students and the annual Veterans' Appreciation Luncheon, on a panel discussing the many levels of MIT's engagement in diversity efforts.

Career Development Presentations

March 2014

"Managing Your Career: How to Survive, Thrive, Excel, and Succeed Pursuing Career/Life Success." Dr. Howard G. Adams, the first executive director of the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) and a nationally recognized speaker and leading expert on mentoring, helped attendees create plans to maximize opportunities for growth in the workplace and in life.

"Mentoring: A Strategy for Transitioning New Employees into the Workplace." Adams examined how formalized transition mentoring can aid new employee retention, development, and performance.

Employee Resource Groups

Lincoln Laboratory's resource groups provide support to staff members during the transitions they make as they advance in their careers. From helping new staff acclimate to the Laboratory's work environment, to encouraging professional development, to facilitating involvement in community outreach activities, the groups below help promote the retention and achievement of employees:

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

Highlights

The Lincoln Employees' African American Network provided technical guidance to the organizers of a radar workshop held in January at the National Society of Black Engineers Aerospace Systems Conference. The Director's Office donated five single-channel radars for the event.

Jen DeLuca, executive director of the Fisher House Boston, and retired U.S. Air Force and Army staff sergeants visited the Laboratory in March to discuss the mission of the Fisher House, a foundation that donates "comfort homes" near major military medical centers so military families can be close to loved ones during times of illness or injury.

On 6 November, the Office of Diversity and Inclusion and the Director's Office cohosted the fourth annual Veterans' Appreciation Luncheon on Hanscom Air Force Base. The event drew more than 200 attendees and featured a talk presented by Admiral Jonathan W. Greenert, Chief of Naval Operations, U.S. Navy.

Keynote speaker Admiral Jonathan W. Greenert provides attendees of the Veterans' Appreciation Luncheon with an operational perspective of the U.S. Navy's capabilities.

Mentorship Programs

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

- The 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 career growth.
- Assistant Group Leader Mentoring partners a newly promoted assistant leader with an experienced group leader to help with the transition into new responsibilities.

In 2014, a total of 381 employees participated in these programs: 98 mentors and 283 mentees.

National GEM Consortium

Through partnerships with universities and industries, the National Consortium for Graduate Degrees for Minorities in Engineering and Science (GEM) provides support to students from underrepresented groups who are seeking advanced degrees in science and engineering fields. In August, Lincoln Laboratory Director Eric D. Evans attended the 2014 GEM Annual Board Meeting and Conference in San Diego, California. Evans, who was appointed to a two-year term as president of GEM in 2012, was accompanied by William H. Kindred, manager of the Laboratory's diversity and inclusion programs, and Frank D. Schimmoller, senior administrative staff of the Director's Office, both of whom were recognized at the event with awards for their support to the GEM mission. At the meeting, GEM officers and partnering organizations were engaged in discussions on strategies for transforming how the United States educates and prepares the next generation of engineers and scientists.

Lincoln Laboratory Technical Women's Network Hosts "WOW! That's Engineering" Event for Girls

"Through programs like 'WOW! That's Engineering,' the Society of Women Engineers introduces engineering to young women in an exciting and inspiring way."

Yari Rodriguez, event coordinator and LLTWN workshop volunteer

As part of their goal to promote the professional development and achievement of women in technical fields, the Lincoln Laboratory Technical Women's Network (LLTWN) participates in community outreach events catered toward girls to encourage their pursuit of careers in science, technology, engineering, and mathematics. On 22 March, LLTWN hosted a Society of Women Engineers (SWE)–sponsored "WOW! That's Engineering" event that engaged girls in hands-on engineering workshops. Volunteers from LLTWN and SWE's Boston section (pictured above) organized and conducted the activities.

A group of girls, led by LLTWN workshop volunteer Anita Rupich, measures the distances traveled by various objects launched from catapults built during the first part of the workshop.

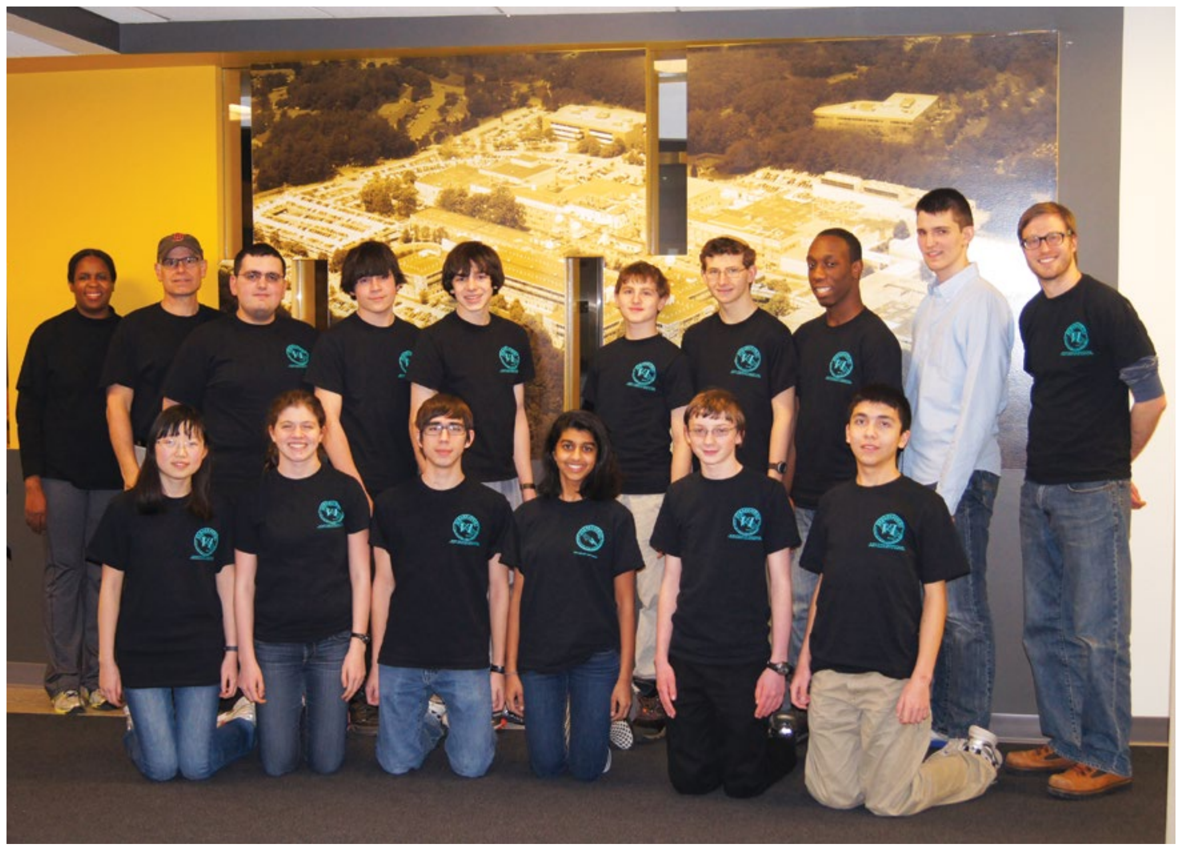
EDUCATIONAL AND COMMUNITY OUTREACH

Attendees of "Hands-on Science" show off their gumdrop towers, made using engineering concepts to reinforce stability.

Educational Outreach

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

LINCOLN LABORATORY COMMUNITY OUTREACH



The three combined Laboratory CyberPatriot teams for the 2013–2014 season, along with coach Chiamaka Agbasi-Porter, Communications and Community Outreach Office, and mentors Robert Cunningham (back row on the left) and Kevin Bauer (back row on the right) gather after a six-hour competition. This season marked the first time the Laboratory sponsored more than one team.

CyberPatriot

Lincoln Laboratory recruited and sponsored three CyberPatriot teams for the 2013–2014 season of the Air Force Association's annual CyberPatriot competition for high-school students. Kevin Bauer and Robert Cunningham of the Cyber Systems and Technology Group served as mentors, drawing on expertise across the Cyber Security and Information Sciences Division and the Communication Systems Division. One of the Laboratory-sponsored teams was named the Northeast regional winner, and all teams attended the national semifinal competition. The six-hour competition required each five-member team to secure a Windows 8 client, a Windows 2008 server, and a Ubuntu Linux 12.4 computer. Teams also completed digital forensics and networking challenges. The Laboratory teams, who achieved 16th, 20th, and 29th places in the nation, plan to increase their computer security skills in preparation for next year's national finals.

Dr. Machanda shares her research on chimpanzees' social behavior. Children note the similarities between chimpanzee and human skeletal structure.

Science on Saturday

Lincoln Laboratory's winter offerings for Science on Saturday included an always-popular robotics demonstration hosted by the Robotics Outreach at Lincoln Laboratory (ROLL) group and a hands-on science event hosted by the Technical Women's Network. This event featured activity stations for throwing a ball and measuring its speed with a radar gun, building a stable gumdrop tower using engineering concepts, and examining technology that measures specific biological features. A new Science on Saturday show featured Harvard primatologist Dr. Zarin Machanda, who taught about chimpanzees.

Science on Saturday participants listen to scientists explain how electrical circuits work (left) and explore robots built out of Legos (above).

>> Educational Outreach, cont.

Leslie Watkins of the Advanced Capabilities and Systems Group helps a “WOW! That’s Engineering!” participant understand the wiring connections on an electronic matching game.

WOW! That’s Engineering!

In March, Lincoln Laboratory and the Society of Women Engineers–Boston offered the “WOW! That’s Engineering!” event for girls in grades 6 to 8. This daylong event, which exposes girls to the creativity and innovation of engineering and technology with fun hands-on activities, “wows” girls with what they can accomplish. Participants engaged in different types of engineering by constructing a mechanical catapult (mechanical engineering), lunar lander (design/mechanical engineering), diaphragm dome (bioengineering), and electronic matching game (electrical engineering).

MIT Mini Maker Faire

In October, MIT Lincoln Laboratory Beaver Works hosted a booth at the first MIT Mini Maker Faire held on MIT campus. Volunteers explained the student-developed power source for an autonomous underwater vehicle to visitors and demonstrated small radars built in Lincoln Laboratory’s build-a-radar courses. The radar exhibit of colorful, live Doppler images drew in many visitors and prompted good discussion. Also at the booth was a display of an unmanned aerial vehicle. The Beaver Works Center, located just off campus, was open for two tours during the day.

Massachusetts State Science and Engineering Fair

Since 2000, Lincoln Laboratory technical staff members have volunteered as judges for the state science fair. The 16 staff members volunteering this year each evaluated six to eight high-school projects. Lincoln Laboratory awards $500 scholarships from the John Welch Memorial Fund to the second-place winners in the physics and engineering categories.

Daughters and Sons Days

Lincoln Laboratory celebrated its 20th Daughters and Sons Days, extending outreach activities to employees’ children between the ages of 9 and 17. The 2014 events featured eight stations designed to spark children’s interests in science and technology. Among the stations were interactive demonstrations of robot sensors, 3D printing, and laser light traveling through water and optical fibers. The Flight Test Facility and RF System Test Facility were open for tours.

Daughters Day visitors view various flood-level scenarios on a 3D-printed city model in the Technology Office Innovation Laboratory.

MINUTEMAN HIGH SCHOOL INTERNSHIPS

Each year, Lincoln Laboratory offers internships for one or two students enrolled at Minuteman High School. Through their work at the Laboratory, the interns receive a behind-the-scenes look at an engineering career while being mentored by a Laboratory staff member.

Graham Fortier-Dube (right), a senior at Minuteman High School, works with Laboratory mentor Ryan Lewis in the Airborne Radar Systems and Techniques Group. Graham organized code to ensure smooth operation of multiple mobile units working together in the field.

Cambridge Science Festival

Chiamaka Agbasi-Porter, STEM outreach coordinator, Communications and Community Outreach Office, directs a robotics demonstration with help from students on Lincoln Laboratory’s sponsored robotics teams. In the back, Jacob Huang, associate staff member in the Advanced Satcom Systems and Operations Group and a robotics team mentor, explains the Laboratory’s robotics program to a visitor.

Each April, Lincoln Laboratory takes part in the Cambridge Science Festival, which offers hundreds of science demonstrations and activities to the Greater Boston area in what has been called the largest citywide science festival in the United States. This year, Laboratory volunteers showed the 15,000 attendees a “zoo” of interactive robots and invited them to measure the changing speed of objects by using “coffee can” radars built by high-school students in the Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) program.

In addition, MIT Lincoln Laboratory Beaver Works Center opened its doors for tours and activities. Here, visitors viewed prototypes developed to extend the endurance of a power system for a mid-sized autonomous undersea vehicle, including the internal combustion engine that drives a generator and an aluminum-water reactor. Lawrence Candell, assistant head, Aerospace Division, served as a speaker in the “Big Ideas for Busy People” seminar.

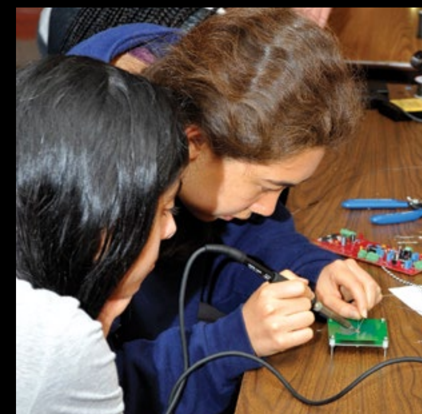
Raoul Ouedraogo explains how to make a coffee can into an antenna at the MIT Lincoln Laboratory Beaver Works Open House during the Cambridge Science Festival.

LINCOLN LABORATORY RADAR INTRODUCTION FOR STUDENT ENGINEERS

Lincoln Laboratory's summer engineering workshop for high-school students, Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), was first offered in 2012 to 12 students from local towns. This program proved so successful that, for the second year of the program, the number of students increased to 18, and registration was expanded from a statewide to a national level. For this third year, 18 students were accepted from around the United States to receive a hands-on introduction to radar.

The two-week residential, project-based enrichment program is offered to outstanding students who have completed their junior year. Under the mentorship of talented scientists and engineers, participants build Doppler and range radars by using creative problem-solving strategies. This year, LLRISE coordinator Chiamaka Agbasi-Porter of the Communications and Community Outreach Office was supported by eight instructors from within Lincoln Laboratory: Dr. Alan Fenn, Dr. Nestor Lopez, Wingyan Beverly Lykins, James McIntire, Dr. Raoul Ouedraogo, Dr. Bradley Perry, Dr. Alexis Prasov, and Dr. Mabel Ramirez.

The rising seniors attended college-level classes on physics, electromagnetics, mechanics of Doppler radar, modular radio-frequency (RF) design circuitry, MATLAB, computer-aided design (CAD), pulse compression, signal processing, and antennas. To build their radars, the 18 students formed six teams—The Doppler Squad, TETRA (Three Engineers Trying Radar Assembly), Aperture



LLRISE
LINCOLN LABORATORY
RADAR INTRODUCTION
FOR STUDENT ENGINEERS

Students solder circuit boards.

Science, X-Men, Tesla Wins, and Teal Dolphins on the Lambda—and worked in the Technology Office Innovation Laboratory to create CAD drawings for 3D printing of their radar components.

The students also visited Lincoln Laboratory's Flight Test Facility and RF System Test Facility, and MIT Haystack Observatory in Westford, Massachusetts. They attended a session on career exploration and toured MIT campus. At Lincoln Laboratory and MIT Museum, students gave final presentations demonstrating the imaging capability of their radars. A trip to the Boston Museum of Science and sightseeing around Boston provided participants with breaks from the rigorous workload and gave out-of-staters a taste of the city.

David Granchelli, manager, Communications and Community Outreach Office (far left), and Director Eric Evans (far right) are shown with the 2014 LLRISE instructors and students.

Robotics Outreach

A student on the "Flaming Ninja Waffles" robotics team, mentored by ROLL, demonstrates the robot's ability to move around the competition course as programmed.

FIRST Robotics

At the end of 2013, Lincoln Laboratory's participation in For Inspiration and Recognition of Science and Technology (FIRST) robotics programs was stronger than ever, with 15 children in the category for 6- to 9-year-olds, 100 children in the category for 10- to 13-year-olds, and 20 children in the category for 14- to 18-year-olds. Thirty-three Laboratory staff members served as coaches and mentors for the robotics programs.

Sister Teams

The FIRST Tech Challenge (FTC) team "Battery-Powered Picklejar Heads" from Lexington participated in the state competition for students in grades 7 to 12 and won the Parametric Technology Corporation (PTC) Design Award. The award is given to teams that incorporate industrial design elements into their solution. Indicative of the success of the FIRST program, all five graduating team members have chosen a STEM-related undergraduate course of study, joining five team alumni who are pursuing either engineering or science degrees.

FTC team "LiMITless" makes adjustments to their robot in preparation for the competition.

Community Giving

The 58-member Alzheimer's Awareness and Outreach Team ranked 1st in the region and 20th in the nation for fundraising at the annual Walk to End Alzheimer's.

Walk to End Alzheimer's

The Lincoln Laboratory Alzheimer's Awareness and Outreach Team participated in the 2014 Walk to End Alzheimer's in Boston and raised more than $36,562, surpassing their $25,000 goal. Since their start just six years ago, the team has raised more than $150,000 for the Alzheimer's Association.

The Laboratory's Alzheimer's support group also sends participants to the annual Ride to End Alzheimer's each summer, but this year was the first time a member of the Laboratory community, Dr. Eliahu H. Niewood, head, Engineering Division, participated in a triathlon, raising money for the Alzheimer's Association. "This event," said Niewood, "is incredibly rewarding on many different levels."

Heart Walk

The Laboratory's Heart Walk Outreach Team raises donations for the American Heart Association's Boston Heart Walk throughout the year. In 2014, the team helped raise $5438 and promoted physical activity as part of a heart-healthy lifestyle.

Bike & Hike the Berkshires

Hikers enjoyed the views and trails of Mt. Greylock, while cyclists experienced the rolling terrain of Berkshire County, all while supporting the National Multiple Sclerosis Society. The MIT Lincoln Laboratory team raised $7420.

Harbor to the Bay

Team Lincoln rides 125 miles from Boston to Provincetown, Massachusetts, to raise awareness of HIV/AIDS care and services. Support from the Laboratory community helped the five-member team raise $3165.

Autumn Escape Bike Trek

The Laboratory team, The Mechanix, rode 160 miles from Plymouth to Provincetown, Massachusetts, to support the American Lung Association. The team raised $6920 with support from the Laboratory community.

Walk for Hunger

In May, the newly formed Lincoln Laboratory Walk for Hunger Team participated in Project Bread's 46th Walk for Hunger in Boston and raised $785.

Greater Boston Food Bank

Thirteen members and allies of Lincoln Laboratory's Out Professional Employee Network volunteered at the Greater Boston Food Bank in February, assisted by the Lincoln Employees' African American Network (LEAN). Together, they stocked enough food to feed three families of four for one year.

Fisher House Boston

In March, the Laboratory's Veterans Network sponsored a bake sale to benefit the Fisher House Foundation. The outreach event raised $1100 to help the Fisher House provide military families with housing close to a loved one receiving treatment at a military medical center.

Care Packages for Troops

Donations for care packages for soldiers were collected, and three packing events were held, each resulting in more than 100 boxes shipped to 21 troops stationed in Iraq and Afghanistan.

Coats for Kids

Lincoln Laboratory participates each winter in the Coats for Kids drive to collect warm coats for people of all ages. All coats are delivered to Anton's Cleaners for cleaning and given to those in need through an extensive distribution partnership. The Coats for Kids program provides 60,000 coats to needy families in the Greater Boston area. Laboratory employees generously donate approximately 500 coats each December.

Soldier Ride

Lincoln Laboratory's Veterans Network participated in Soldier Ride through Lexington and Concord, Massachusetts. Soldier Ride is a Wounded Warrior Project initiative that provides rehabilitative cycling across the country to help wounded warriors restore their physical, emotional, and mental well-being. Our veterans cycled 30 to 60 miles, raising $5050.

Laboratory veterans cycle together in September, raising funds for the Wounded Warrior Project.

The Laboratory helped Boston Marathon runner Sarah Lewis raise money for the Sean A. Collier Memorial Fund during a bake sale at the Laboratory in February. Lewis raised more than $6000, surpassing her fundraising goal of $4000.

Going Strong on the MIT Strong Team

The purpose of the MIT Strong team is not only to run the 26.2 miles of the Boston Marathon but also to raise money for the Sean A. Collier Memorial Fund, established to carry forward fallen MIT Police Officer Sean Collier's legacy of support for the MIT community. The team has raised more than $207,000 for the fund, which is being used to build a permanent memorial to Officer Collier on campus, to annually recognize individuals who demonstrate the values and character of Officer Collier by awarding them the Collier Medal, and to support other causes.

Lincoln Laboratory's Sarah Lewis, project manager in the Information Services Department, applied to be one of the 40 members of the MIT Strong team because she was near the finish line hours before the April 2013 bombing. Lewis, who regularly passes by Sean Collier's temporary memorial on Vassar Street on her way to work, shared photographs of the memorial on Instagram, with the hashtag "#MITStrong," a few days following his passing. The 2014 Boston Marathon was Lewis' second run in memory of Sean Collier; she proudly participated in the Run to Remember Half Marathon in May 2013. "MIT needed to be part of the 2014 marathon," says Lewis. "We want to remember Sean, and show that MIT Strong is part of Boston Strong."

The MIT Strong team consists of runners from all parts of the MIT community: graduate and undergraduate students, alumni from last year and from 50 years ago, faculty from several departments, and staff. "#MITStrong" has a whole new meaning for Lewis now. She is excited to have been part of the MIT Strong team and continues to train in the Boston and Cambridge areas.

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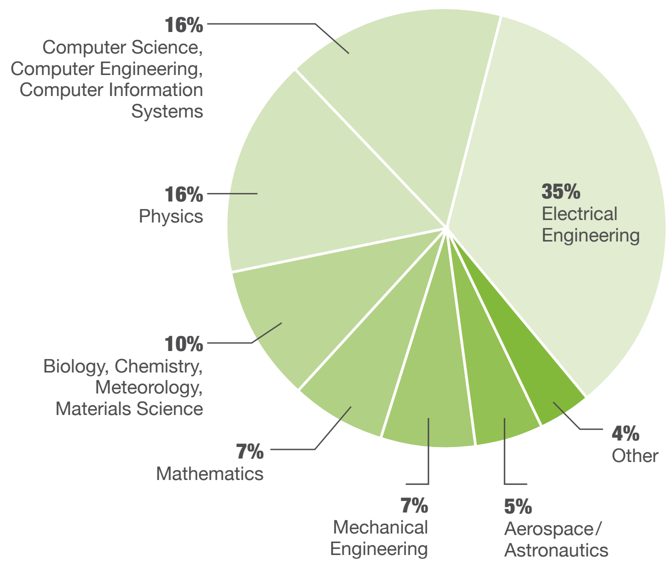
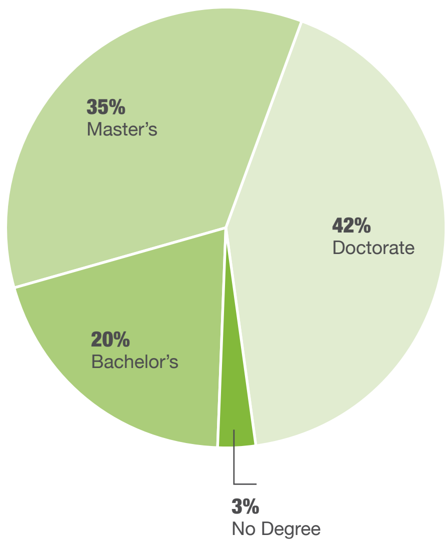
1740	Professional Technical Staff
1055	Support Personnel
433	Technical Support
520	Subcontractors
3748	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

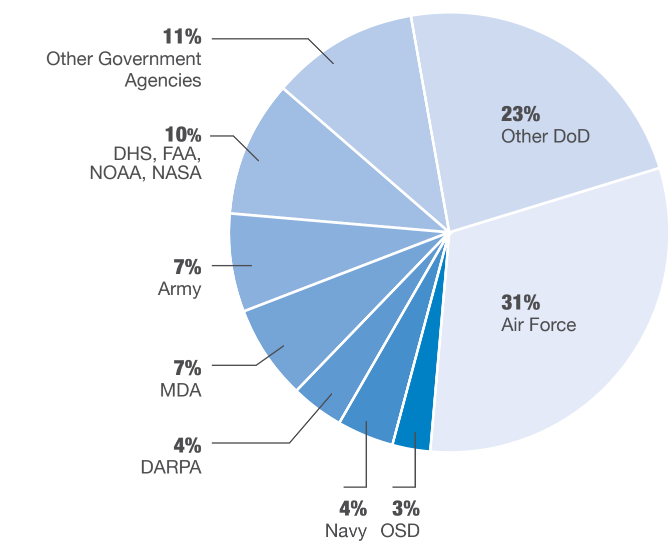


Academic Degree

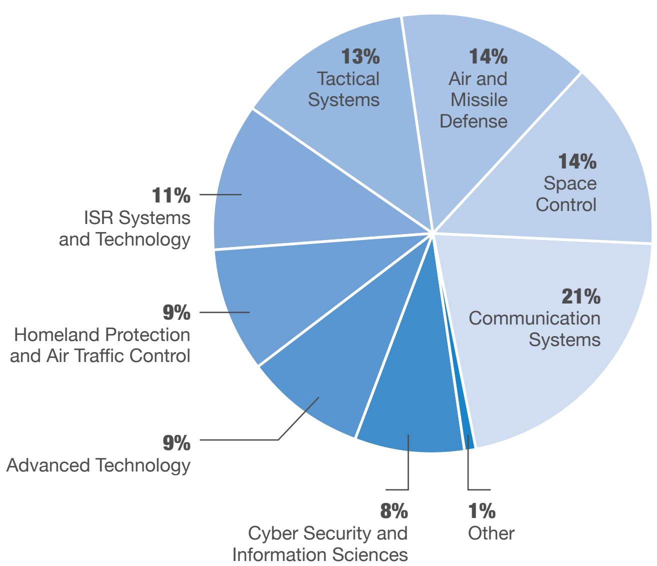


Breakdown of Laboratory Program Funding

Sponsor



Mission Area



Lincoln Space Surveillance Complex, Westford, Massachusetts

Reagan Test Site, Kwajalein Atoll, Marshall Islands

LINCOLN LABORATORY
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Approved for public release; distribution is unlimited.
This work is sponsored by the Department of the Air Force under Air Force Contract FA8721-05-C-0002. Opinions, interpretations, conclusions, and recommendations are those of the author and are not necessarily endorsed by the United States Government.

TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

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