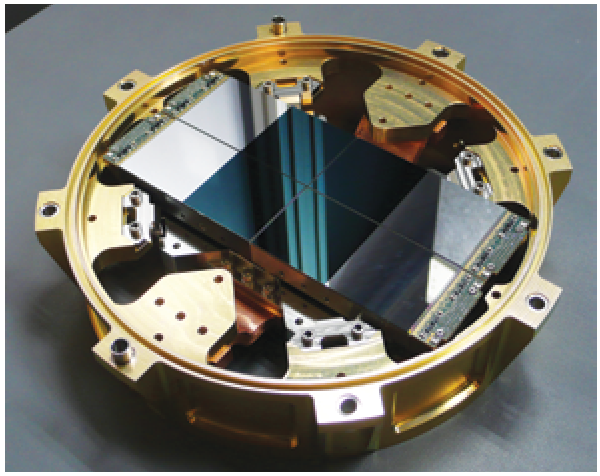
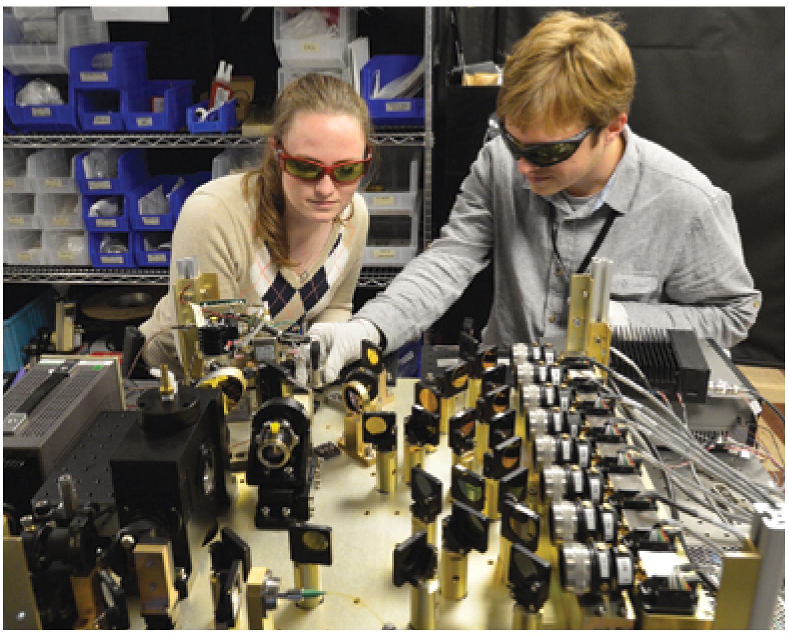
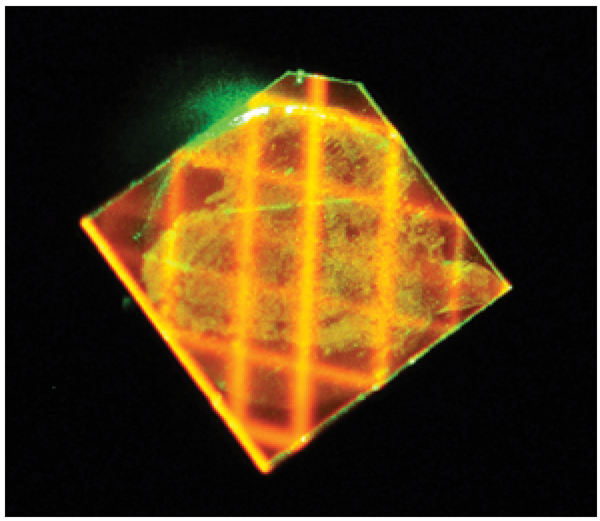


MIT Lincoln Laboratory

2016

ANNUAL REPORT





TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

Massachusetts Institute of Technology

MIT Lincoln Laboratory

MIT LINCOLN LABORATORY 2016

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 65 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 (right)
Vice President for Research

MIT Lincoln Laboratory

Dr. Eric D. Evans
Director

Dr. Marc D. Bernstein (left)
Associate Director

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

ORGANIZATIONAL CHANGES

Robert A. Bond

Chief Technology Officer

Robert A. Bond was appointed the Chief Technology Officer of MIT Lincoln Laboratory. The former associate head of the Intelligence, Surveillance, and Reconnaissance (ISR) and Tactical Systems Division, he has extensive experience in ISR systems, high-performance embedded computing, signal processing, artificial intelligence, and radar systems. Mr. Bond is a past recipient of an MIT Lincoln Laboratory Technical Excellence Award, and he was instrumental in the establishment of the Laboratory's new Supercomputing Center.

Bernadette Johnson

Chief Scientist, Defense Innovation Unit–Experimental

Dr. Bernadette Johnson, formerly Lincoln Laboratory's Chief Technology Officer, is on an Intergovernmental Personnel Act assignment as Chief Scientist of the Defense Innovation Unit–Experimental, a Department of Defense startup that serves as a bridge between those in the U.S. military executing on our nation's toughest security challenges and companies operating at the cutting edge of technology.

Katherine A. Rink

Associate Division Head, Air, Missile, and Maritime Defense Technology

Dr. Katherine A. Rink was promoted to associate head of the Air, Missile, and Maritime Defense Technology Division. Formerly an assistant head in that division, she is involved in high-level strategic studies for the U.S. Navy's air and missile defense systems and previously served in leadership positions in several of the division's groups.

Mark A. Gouker

Assistant Division Head, Advanced Technology

Dr. Mark A. Gouker was appointed assistant head of the Advanced Technology Division. Prior to this appointment, he was the leader of the Quantum Information and Integrated Nanosystems Group, directing research and development of quantum computing and quantum sensing systems that employ superconducting, complementary metal-oxide semiconductor, and integrated photonics technologies.

Richard M. Heinrichs

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

Dr. Richard M. Heinrichs was named an assistant head of the Intelligence, Surveillance, and Reconnaissance and Tactical Systems Division. He recently completed an Intergovernmental Personnel Act assignment at the Defense Advanced Research Projects Agency, where he led the development of advanced optical systems. Prior to this assignment, he served as the leader of the Active Optical Systems Group.

Robert D. Solis

Chief Information Officer and Department Head, Information Services

Robert D. Solis was appointed Chief Information Officer (CIO) and the head of the Information Services Department. He comes to Lincoln Laboratory from the University of Massachusetts System, where, as vice president and CIO, he was responsible for the information technology services at the university system's four campuses and medical school. He is also a board member for the Massachusetts Green High Performance Computing Center.

Letter from the Director

In 2016, MIT Lincoln Laboratory celebrated its 65th anniversary, and we continue to strengthen and grow programs that are providing prototypes and advanced technology for national security needs. The recent modernization of the optical and radar systems at the Reagan Test Site on the Kwajalein Atoll has enhanced our ability to provide high-quality measurements for missile defense and space protection. New materials and electronics pioneered in the Advanced Technology Division are enabling the development of innovative RF, imaging, and computing systems. Research in cyber security is expanding to meet the critical need to protect the nation's data networks, and this year's establishment of the Lincoln Laboratory Supercomputing Center will support programs that involve the processing of massive amounts of data.

Our recently established Energy Systems Group is developing solutions to the problem of supplying power to sites in remote or contested environments, and our Advanced Undersea Systems and Technology Group is investigating new applications for unmanned underwater vehicles. New initiatives in bioengineering, chemical sensing, and decision support are helping to support civilian and military health needs, and U.S. disaster relief operations.

During the past year, the Laboratory has reached significant milestones in several areas.

- The Laboratory demonstrated a coordinated autonomous formation of more than 100 miniature unmanned aerial vehicles after they were dispensed from three F/A-18 Super Hornets.
- The Multi-look Airborne Collector for Human Encampment and Terrain Extraction (MACHETE) three-dimensional ladar completed more than 294 sorties. The MACHETE system was designed to collect data on activities under heavy foliage, exploiting new noise-filtering and data-aggregation algorithms to produce imagery with dramatically improved resolution.
- A beam-combined fiber laser system built by researchers at the Laboratory demonstrated record brightness. The coherently combined beam was generated from 10s of optical fiber amplifiers and had near-ideal beam quality and high beam-combining efficiency.
- Advanced technologies were prototyped for a new airborne signals intelligence system that is currently being transferred to an industrial partner for production and fielding.
- The Laboratory completed the integration and test of a prototype compact airborne laser communications terminal that supports robust spatial tracking and near-theoretical communications performance against a low-average-power burst-mode signal.
- Automated video analysis software developed for site security significantly accelerates the process of extracting information from videostreams.
- The Laboratory developed advanced graph analytics algorithms to rapidly detect cyber threat actors within communication networks.
- The Laboratory fabricated, integrated, and tested the detector arrays and optical subsystem for the science payload that will be carried on the Transiting Exoplanet Survey Satellite (TESS), which is expected to launch in April 2018 on a mission to discover Earth-like planets that orbit stars other than the Sun. The payload was jointly developed by the MIT Kavli Institute for Astrophysics and Space Research and the Laboratory under funding from the National Aeronautics and Space Administration.

We encourage you to read through our latest annual report to learn more about our technical programs and directions. As we close our 65th anniversary celebration, we look forward to extending our proud legacy of technical excellence and integrity by continuing to develop innovative solutions for challenging problems of national security.

Sincerely,

Eric D. Evans
Director

MIT Lincoln Laboratory

MISSION: TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

VISION

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

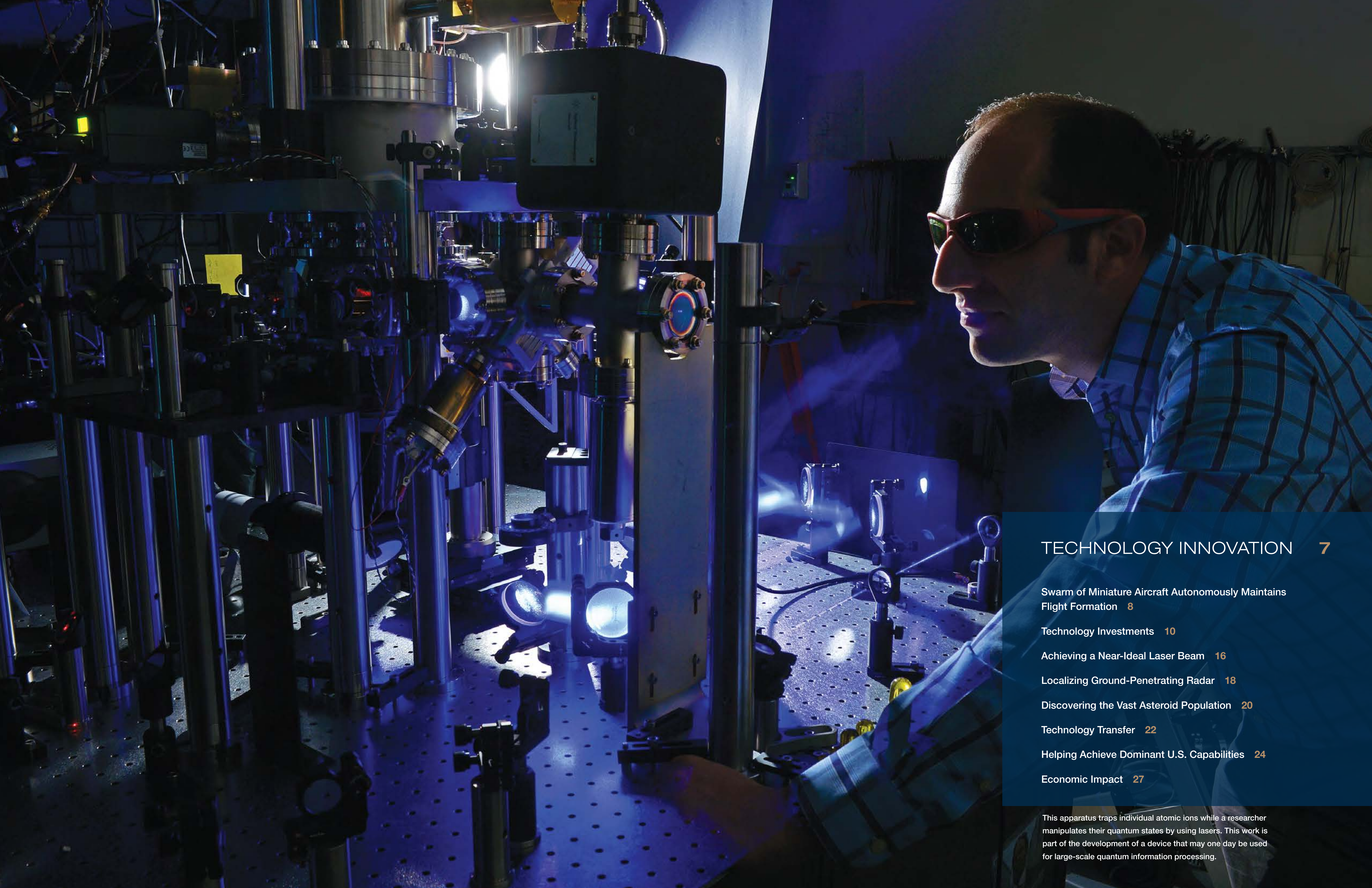
- To work in the most relevant and difficult technical areas
- To strive for highly effective program execution in all phases

VALUES

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

STRATEGIC DIRECTIONS

- Continue evolving mission areas and programs
- Strengthen core technology programs
- Increase MIT campus/Lincoln Laboratory collaboration
- Strengthen technology transfer to acquisition, user, and commercial communities
- Find greater efficiencies and reduce overhead process
- Improve leverage through external relationships
- Improve Laboratory diversity and inclusion
- Enhance Laboratory facilities
- Enhance Laboratory community outreach and education



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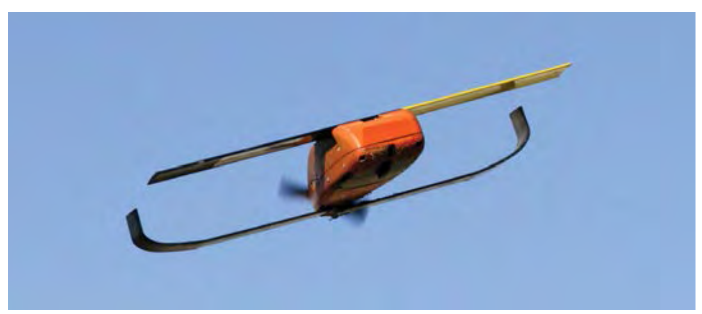
This apparatus traps individual atomic ions while a researcher manipulates their quantum states by using lasers. This work is part of the development of a device that may one day be used for large-scale quantum information processing.

The Perdix field-test team in China Lake, California, was photographed with vehicles recovered after the swarm demonstration filmed by *60 Minutes*.

Swarm of Miniature Aircraft Autonomously Maintains Flight Formation

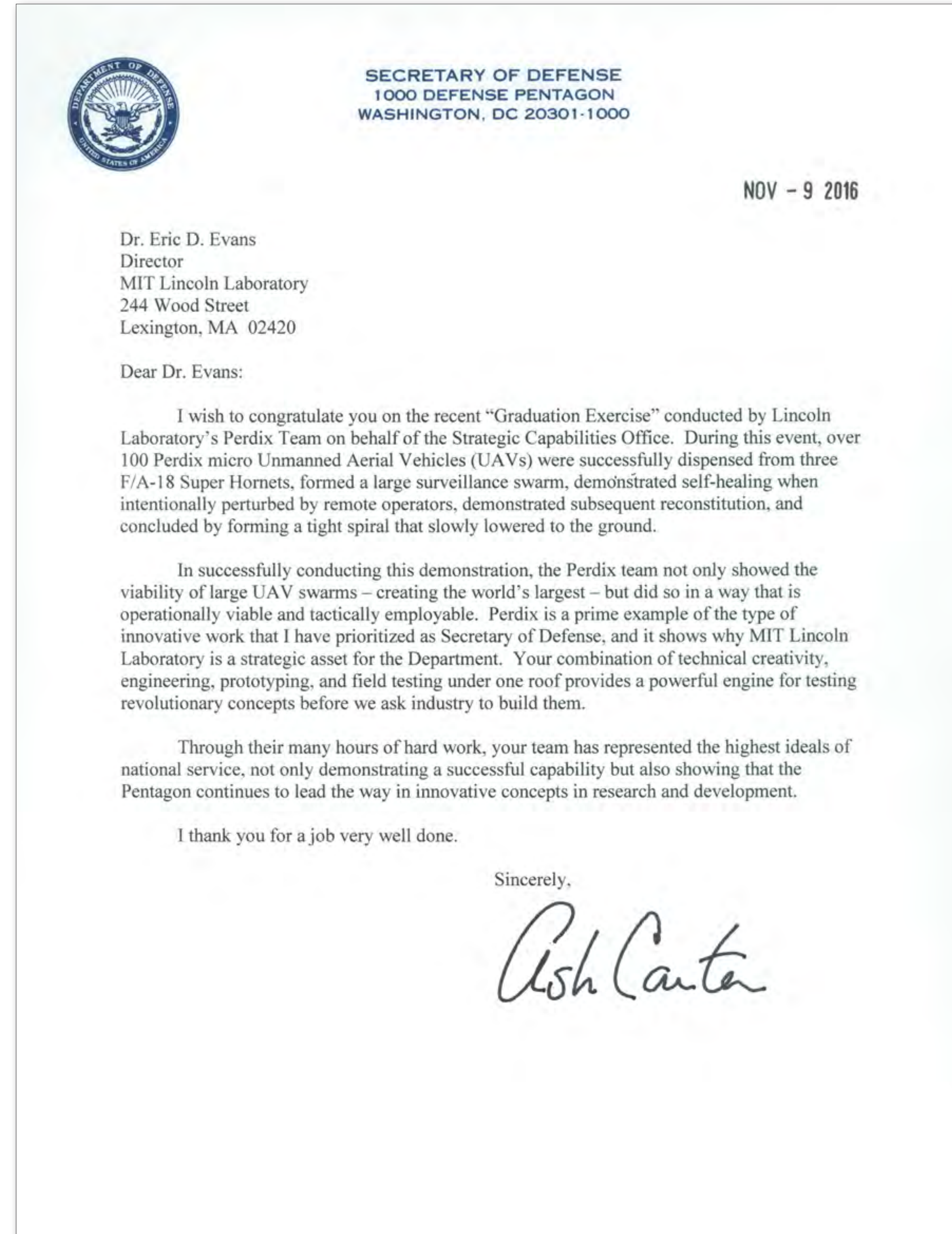
In what former Secretary of Defense Ashton Carter described as “the kind of cutting-edge innovation that will keep us ahead of our adversaries,” Lincoln Laboratory recently completed a successful demonstration of a coordinated, autonomous swarm of 103 miniature unmanned aerial vehicles (micro-UAVs) that were dispensed from three F/A-18 Super Hornet aircraft. The demonstration, which was filmed and reported on by *60 Minutes*, was sponsored by the Department of Defense’s Strategic Capabilities Office and took place at the U.S. Navy’s air station at China Lake, California, in October 2016.

Lincoln Laboratory developed the Perdix micro-UAV and deployment system, leveraging an initial hardware design created by students in a capstone course offered by the MIT Department of Aeronautics and Astronautics. Laboratory researchers then operationalized this design through the addition of advanced miniature avionics, an air-launched deployment



system, communication systems, autonomy algorithms, and modular payloads to enable a variety of tactical missions. Rapid manufacturing approaches, such as 3D printing and an aggressive design-build-fly test program, allowed the Laboratory team to quickly progress from initial flight tests with the Air Force Test Pilot School at Edwards Air Force Base, California, in September 2014, to proof-of-concept trials of swarms of 20 drones flown in the U.S. Pacific Command’s 2015 Northern Edge Exercise in Alaska, and finally to the demonstration of a large-scale swarm at China Lake.

In all, more than 670 Perdix have been flown to date. Data obtained from the tests will help Lincoln Laboratory researchers further develop advanced swarm behavior algorithms and transition the system for operational capabilities.



SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

NOV - 9 2016

Dr. Eric D. Evans
Director
MIT Lincoln Laboratory
244 Wood Street
Lexington, MA 02420

Dear Dr. Evans:

I wish to congratulate you on the recent “Graduation Exercise” conducted by Lincoln Laboratory’s Perdix Team on behalf of the Strategic Capabilities Office. During this event, over 100 Perdix micro Unmanned Aerial Vehicles (UAVs) were successfully dispensed from three F/A-18 Super Hornets, formed a large surveillance swarm, demonstrated self-healing when intentionally perturbed by remote operators, demonstrated subsequent reconstitution, and concluded by forming a tight spiral that slowly lowered to the ground.

In successfully conducting this demonstration, the Perdix team not only showed the viability of large UAV swarms – creating the world’s largest – but did so in a way that is operationally viable and tactically employable. Perdix is a prime example of the type of innovative work that I have prioritized as Secretary of Defense, and it shows why MIT Lincoln Laboratory is a strategic asset for the Department. Your combination of technical creativity, engineering, prototyping, and field testing under one roof provides a powerful engine for testing revolutionary concepts before we ask industry to build them.

Through their many hours of hard work, your team has represented the highest ideals of national service, not only demonstrating a successful capability but also showing that the Pentagon continues to lead the way in innovative concepts in research and development.

I thank you for a job very well done.

Sincerely,

Ash Carter

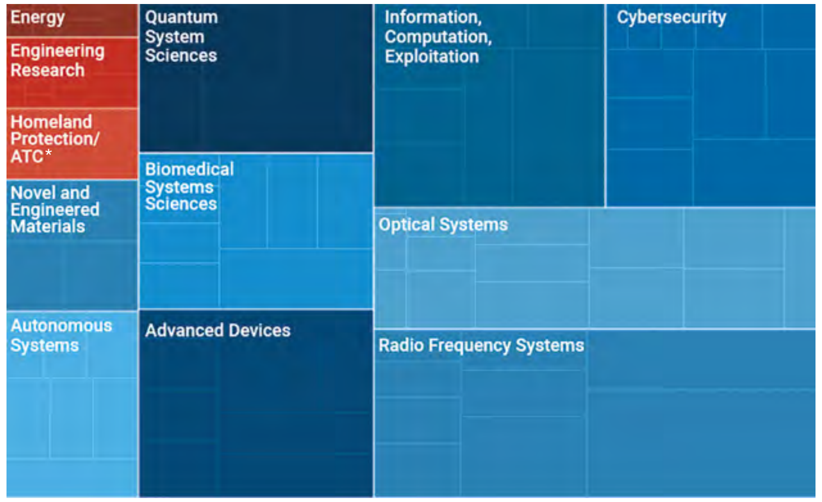
Technology Investments

Lincoln Laboratory invests in applied research to develop new technologies and capabilities that support long-term needs across the Laboratory mission areas.

The Technology Office develops and directs strategic research at the Laboratory through targeted investments in both existing and emerging mission areas. Research is conducted not only on critical problems that threaten national security today but also on future challenges for which innovative technology solutions could have a significant positive impact. To identify future technology needs, the Technology Office conducts strategic internal assessments and considers the assessments of many government agencies within and outside the Department of Defense (DoD). Interactions with the Assistant Secretary of Defense for Research and Engineering (ASD[R&E]), the Defense Advanced Research Projects Agency, the Department of Homeland Security, and other agencies help the Laboratory maintain awareness of critical national security issues and grow strategic technical relationships. By encouraging collaborations with university researchers, the office helps to provide the Laboratory with access to cutting-edge research and technology innovation and, importantly, to facilitate the transition of laboratory research into operable prototypes.

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

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



*Air Traffic Control

The aggregate internal R&D funding is portrayed in this graphic. The entire block represents the total funding, and the smaller blocks represent funding in specific technology areas. Blue blocks refer primarily (but not exclusively) to projects that are supported by the ASD(R&E)-administered funding and are, hence, germane to DoD needs. Red blocks refer primarily to innovative research that is not necessarily related to current DoD needs.

MISSION-CRITICAL TECHNOLOGY INVESTMENTS

The 2016 investments are enabling the development of technologies to address the long-term challenges and the emerging issues within the Laboratory's core mission areas.

Optical Systems Technology

The DoD uses increasingly sophisticated optical technologies for communications, surveillance, advanced electronics, and navigation. Work in this area focuses on the development, analysis, and demonstration of novel concepts that enable the next generation of optical systems. In 2016, investments are being made in

- Undersea laser transmitter and receiver hardware and system components to significantly extend the range of communications in open ocean
- Photothermal speckle modulation for remote sensing of chemicals and standoff discrimination of object substrate characteristics, such as thermal conductivity
- Computational imaging sensors that support big data applications by using microprocessors located at each pixel to achieve orders of magnitude increase in processing speed
- A miniature lidar system that has sub-kilogram mass and that can be integrated on unmanned air vehicles and other small platforms for applications such as foliage-penetrating mapping

Radio-Frequency Systems

Research and development in RF systems is exploring innovative technologies and concepts in radar, signals intelligence, communications, and electronic warfare. Projects being pursued in 2016 include

- Development of an advanced airborne radar test bed for rapid assessments and demonstrations

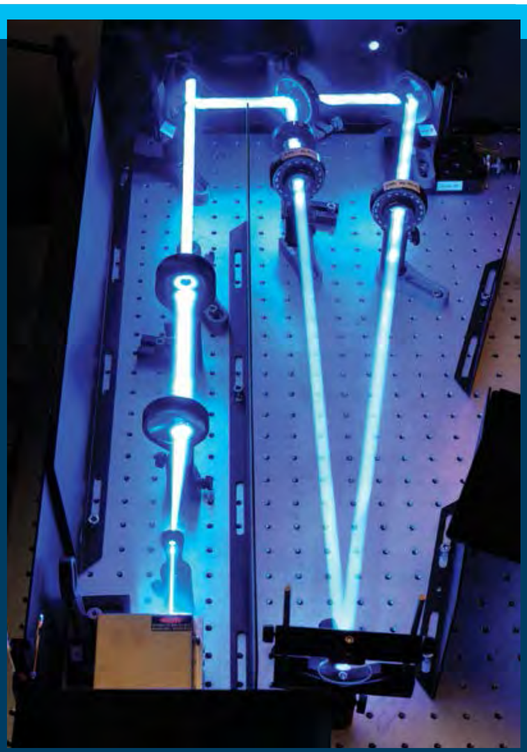
TECHNOLOGY HIGHLIGHT

High-Speed, Wide-Angle Beam Steering

Many optical systems, including laser communication systems, ladar, and infrared countermeasures, need to steer a laser beam rapidly over a large field of view. But existing beam-steering technology has limited agility. One promising alternative is the Pancharatnam phase device (PPD), a liquid-crystal-like, thin-film polymer that can steer a circularly polarized laser at angles up to 50 deg.

The PPD consists of a holographic pattern written into a photo-alignment layer. Successive layers of liquid-crystal molecules self-align to this layer and are cured in place. When a voltage is applied, the device steers left-circular polarized light to a certain angle that is dependent on the spatial frequency of the holographic pattern, and right-circular polarized light steers to the negative of that angle (with respect to the undeflected beam). Polarization controllers operating at kilohertz rates could generate a laser beam that can scan over a 100 deg field of view in milliseconds. No other technique is capable of high-speed beam steering over such a large field of view.

Working with PPD experts at the Liquid Crystal Institute at Kent State University, Lincoln Laboratory researchers have fabricated and demonstrated ±25 deg beam steering in a PPD. The PPDs have high transmission (>85%) with a 2 cm aperture (built on a 5 cm substrate). The team is continuing to optimize the parameters for building the PPDs to enable operation with high-power lasers at high efficiency.



The blue laser beams are being used to fabricate a liquid crystal Pancharatnam phase device for agile wide-angle electro-optic beam steering.

>> *Mission-Critical Technology Investments, cont.*

- Creation of integrated-circuit process technology that uses gallium nitride and complementary metal-oxide semiconductor transistors
- Design and fabrication of lightweight deployable X-band antennas for space-based platforms
- Embedded microjet cooling in silicon for thermal management of high-power devices

Cyber Security

The Laboratory's applied research on cyber security focuses on improving the security of computer networks, hosts, and applications. In 2016, this work includes several challenging projects:

- Characterization and assessment of vulnerabilities created by programmable malicious integrated circuits applied, for example, to measuring the visibility of synthetic computer Trojans
- Creation of new functional encryption definitions and protocols for secure cloud computing
- Development of a portfolio of analysis tools to perform automated reverse engineering of software systems and malware
- Development of a cloud processing architecture for just-in-time encryption of individual threads; if successful, such a system would greatly enhance security in cloud computing

Information, Computation, and Exploitation

Encompassing research in data processing, computation, exploitation, and visualization, this area tackles challenges posed by the increasing growth in the volume and the variety of data available to the DoD and intelligence community. Currently, the Laboratory is

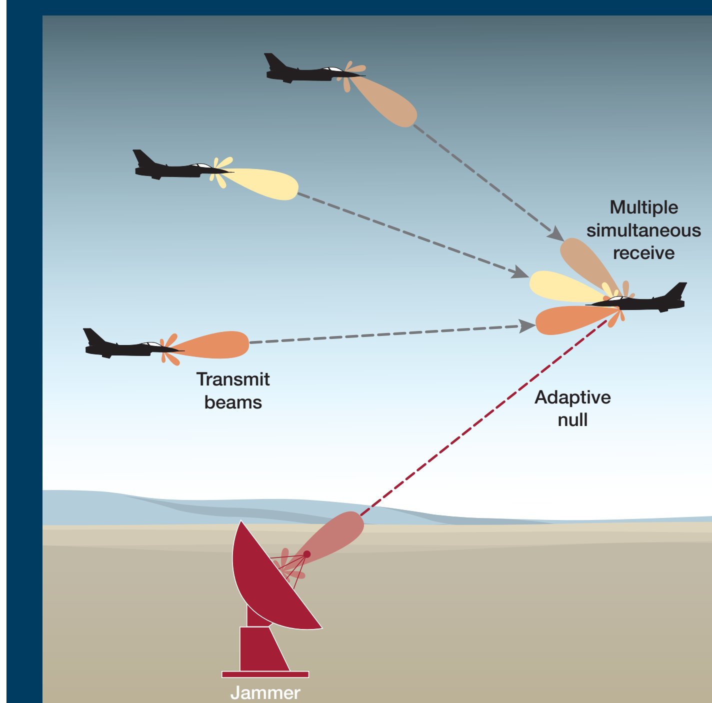
- Creating a highly efficient processor for running large-scale graph algorithms
- Jointly mining time-aligned audio and visual data to facilitate content-based search and exploitation of large collections of unstructured, uncooperatively collected video
- Developing an autonomous processing, exploitation, and dissemination system that allows an analyst to exploit large amounts of data

TECHNOLOGY HIGHLIGHT

Multiple-Beam Directional Networking for Contested Environments

Advances in multibeam digital antenna arrays, coupled with novel networking protocols, can help satisfy the increasing demand for robust airborne communications networking in contested spectrum environments where radio nodes are subject to interference, jamming, and surveillance threats. Digital antenna arrays allow users to directionally form multiple transmit or receive beams to communicate simultaneously with multiple users within the same frequency channel while adaptively steering nulls to minimize interference, mitigate jamming, and avoid radio-frequency surveillance.

However, numerous technical challenges remain to be overcome before these promising new capabilities are available to the warfighter. Advanced digital array processing techniques must be implemented to enable adaptive multibeam transmission and reception at extremely short timescales. At the network layer, low-complexity channel access and topology-management schemes are needed to efficiently use the resources provided by these advanced antenna technologies. Finally, a full system design that integrates these new technologies is necessary. New theoretic results and practical algorithms have been developed for both array processing and directional networking, and work continues on the proposal for a realistic system for potential integration onto a future platform.



Military communications can be improved through the use of multiple, simultaneous beam patterns that independently adapt to signals of interest (various colored beams) while suppressing unwanted interference via adaptive nulls.

Advanced Devices

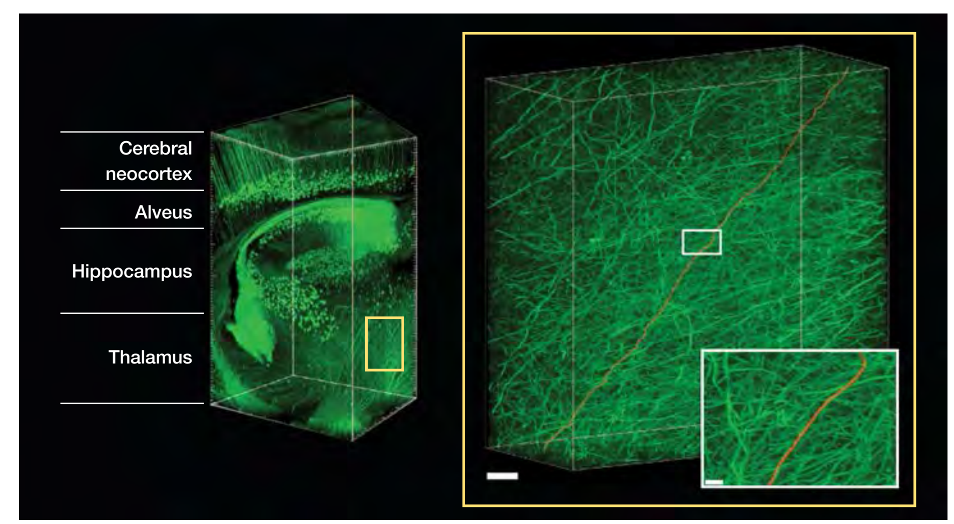
Work in advanced devices focuses on developing novel components and modalities to enable new system-level solutions to national security problems. The broad range of research in this area is currently exploring

- Design and fabrication of high-efficiency long-wave infrared quantum cascade lasers
- Fabrication of large-format, short-wave infrared imagers for space surveillance and hyperspectral imaging
- Development of diamond transistors for use in extreme environments
- Methods for achieving zero-crosstalk in infrared Geiger-mode avalanche photodiodes
- Development of a small navigation-grade gyroscope that uses a photonic integrated circuit

A researcher works on germanium charge-coupled devices for large-format short-wavelength infrared imaging.

EMERGING TECHNOLOGY INVESTMENTS

The Technology Office supports projects in a number of areas that are of growing importance to the DoD and non-DoD government agencies, such as the Department of Homeland Security and the Federal Aviation Administration. Several of these efforts have a development horizon of 5 to 10 years. Other research focuses on developing engineering solutions for projects in multiple mission areas.



The human brain is an astoundingly complex structure that has tens of billions of neurons connected through trillions of synapses. This circuitry is the result of our development and experience, and has a great impact on the brain's functioning. The Cellular-Resolution Brain Mapping project is investigating methods that can provide a better picture of the brain-wiring diagram in order to advance understanding of brain functions and seek new ways to treat and prevent brain disorders. The figure on the left shows neuron projections at the cellular level in an adult mouse brain; the image was acquired by CLARITY intact-tissue brain imaging, a technology developed by Prof. Kwanghun Chung at MIT. The figure on the right is an example subset of the neuron axon fibers. The red line is a traced axon fiber. Lincoln Laboratory is collaborating with the MIT Chung Lab in developing an automated neuron-tracing algorithm to enable the high-throughput brain mapping and analysis.

Biomedical Sciences

The biomedical sciences initiative is developing technologies to address national healthcare needs and to enhance warfighter performance. Researchers are creating integrated-circuit neuron-size chiplets that can interface with the nervous system. New cloud-based image processing techniques will advance the state of the art in brain image analysis. Work on in vivo cellular programming aims to restore volumetric muscle loss after battlefield injuries, and a noncontact ultrasound imaging system is being developed to enhance physicians' ability to diagnose and visualize injury and disease.

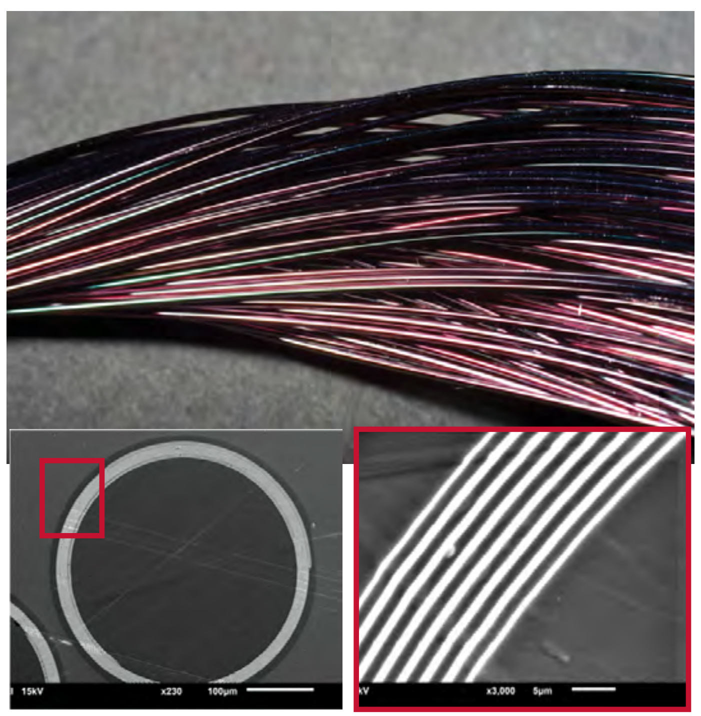
>> Emerging Technology Investments, cont.

Autonomous Systems

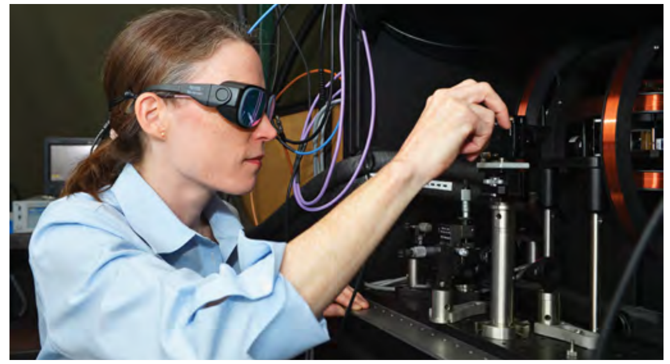
The applied research in autonomy enables unmanned systems to perform meaningful tasks in real-world environments as robotic teammates rather than as teleoperated tools. Project teams are investigating a data-driven human-robot collaboration; an integrated hydrodynamic model of unmanned underwater vehicles; a system that enables an autonomous aircraft to plan a route and navigate in unstructured, dynamic environments at low altitudes; biomimetic sonar sensors; unique electroaerodynamic propulsion for unmanned aerial platforms; and approaches for the decentralized coordination of the actions of swarming autonomous systems.

Novel and Engineered Materials

This area seeks to invent new materials and establish novel processing capabilities to rapidly advance manufacturing technologies. Current projects are developing three-dimensionally printed materials to enable the fabrication of mechanical assemblies that are smaller and lighter than current constructs. In addition, work on the growth and characterization of transition metal dichalcogenides (i.e., monolayer structures with novel electronic properties) may accelerate a revolution in microelectronics.



The top image shows a bundle of low-emissivity fibers. Woven into textiles, such fibers would enable low-observable fabrics. In the bottom left, the micrograph of one of the fibers was taken with a scanning electron microscope; the multilayer structure lining the fiber's outer surface is designed to reflect long-wave infrared radiation in the 8–12 micron range. The bottom right image is a zoomed-in view of the multilayer photonic structure.



The quantum sensing laboratory designs next-generation vector magnetometers based on ensembles of quantum systems interstitially located in a diamond lattice. The researcher is aligning a test setup for magnetic field calibration of a prototype device.

Quantum System Sciences

In quantum system sciences, R&D seeks to connect emerging quantum technologies to national security needs in sensing, communications, and processing power. Researchers in quantum computing are exploring superconducting qubits with long coherence times and two-dimensional trapping of two ion species on an electronic chip for qubit processing and detection. Quantum sensing with nitrogen vacancies in diamond has resulted in vector magnetic-field sensors with picoTesla sensitivity.

Homeland Protection and Air Traffic Control

Investments support advances in transportation safety, border and maritime security, critical infrastructure protection, and disaster response. The 2016 projects include the development of a test bed for interactive flight-management scenarios, use of communication network topologies to assess post-disaster damage, development of mutual device authentication of physical systems on a network, and demonstration of the use of the Laboratory's airborne sensors during crises.

Energy

Lincoln Laboratory's R&D supports DoD energy security and the sustainability of the national energy system. Work in 2016 focused on developing novel energy sources, such as aluminum for unmanned platforms and compact solid-state batteries for emergency use; investigating the use of renewable energy within existing processes and systems, such as desalination; exploring technology to ensure the resilience of the power grid under climate change; and modeling energy systems.

Engineering Research

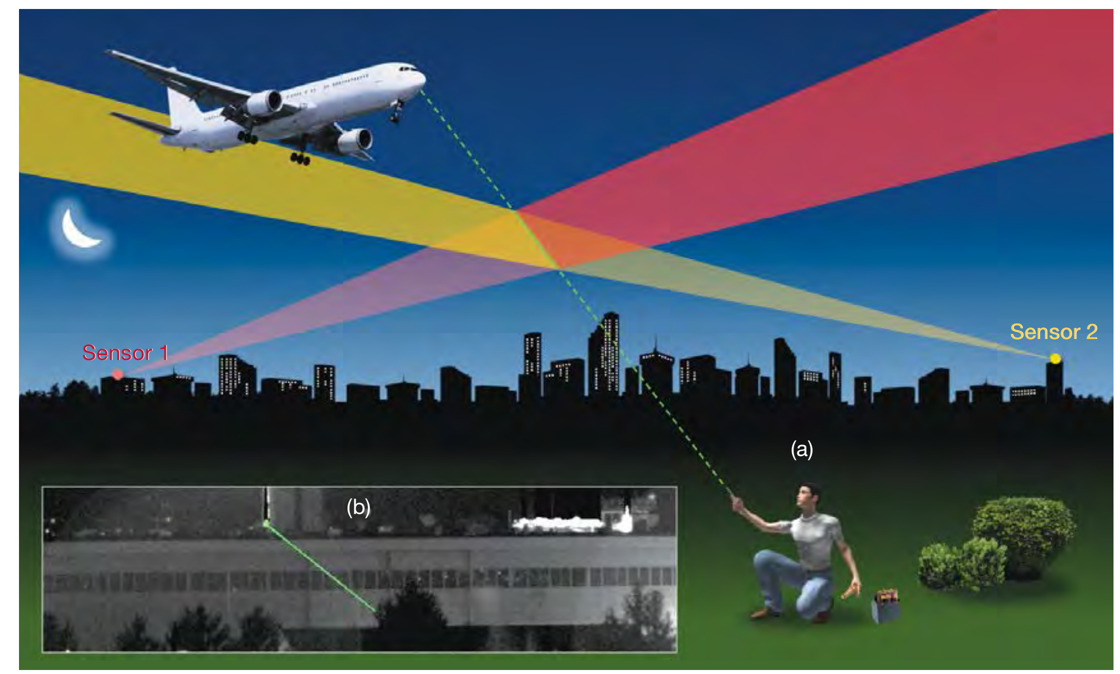
The Laboratory's divisions depend on state-of-the-art engineering capabilities to facilitate the development of prototype systems. Advancing these capabilities is achieved through investments in five areas of engineering research: advanced materials, mechanical and thermal technologies, optical technology, software for control systems, and propulsion systems.

BASIC AND APPLIED RESEARCH INVESTMENTS

Basic and applied research projects focus on concept development. Funding is administered through committees that solicit and review proposals from Laboratory staff and MIT researchers. Investments in basic and applied research support many projects (see the infographic on page 10), two of which are highlighted here.

Geolocation of Laser Strikes on Commercial Aircraft

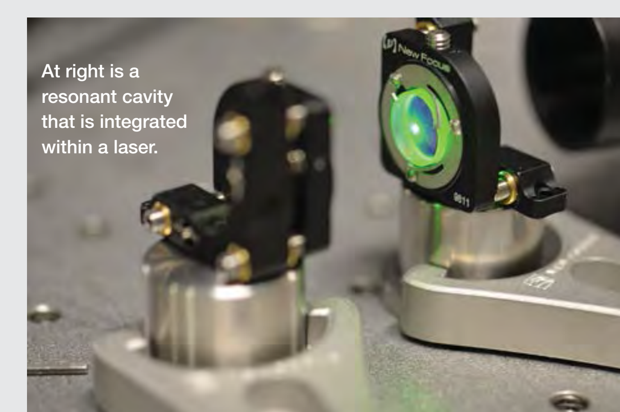
Laser strikes against commercial aircraft are a growing problem nationwide. In 2015, pilots reported more than 5000 incidents of a person on the ground shining a laser pointer at an aircraft. Such laser strikes can cause pilots to experience temporary loss of night vision, flash blindness, and eye pain. Currently, fewer than 1 in 200 perpetrators are caught. Lincoln Laboratory engineers are designing, building, and testing a prototype for a network of ground-based sensors capable of rapidly geolocating the source of the laser light. The sensors detect laser beams by their scatter in the atmosphere. Data fused from multiple sensors could pinpoint within seconds the location of the person aiming the laser. If the prototype is successful, similar systems could be installed at airports and used to cue law enforcement to apprehend perpetrators.



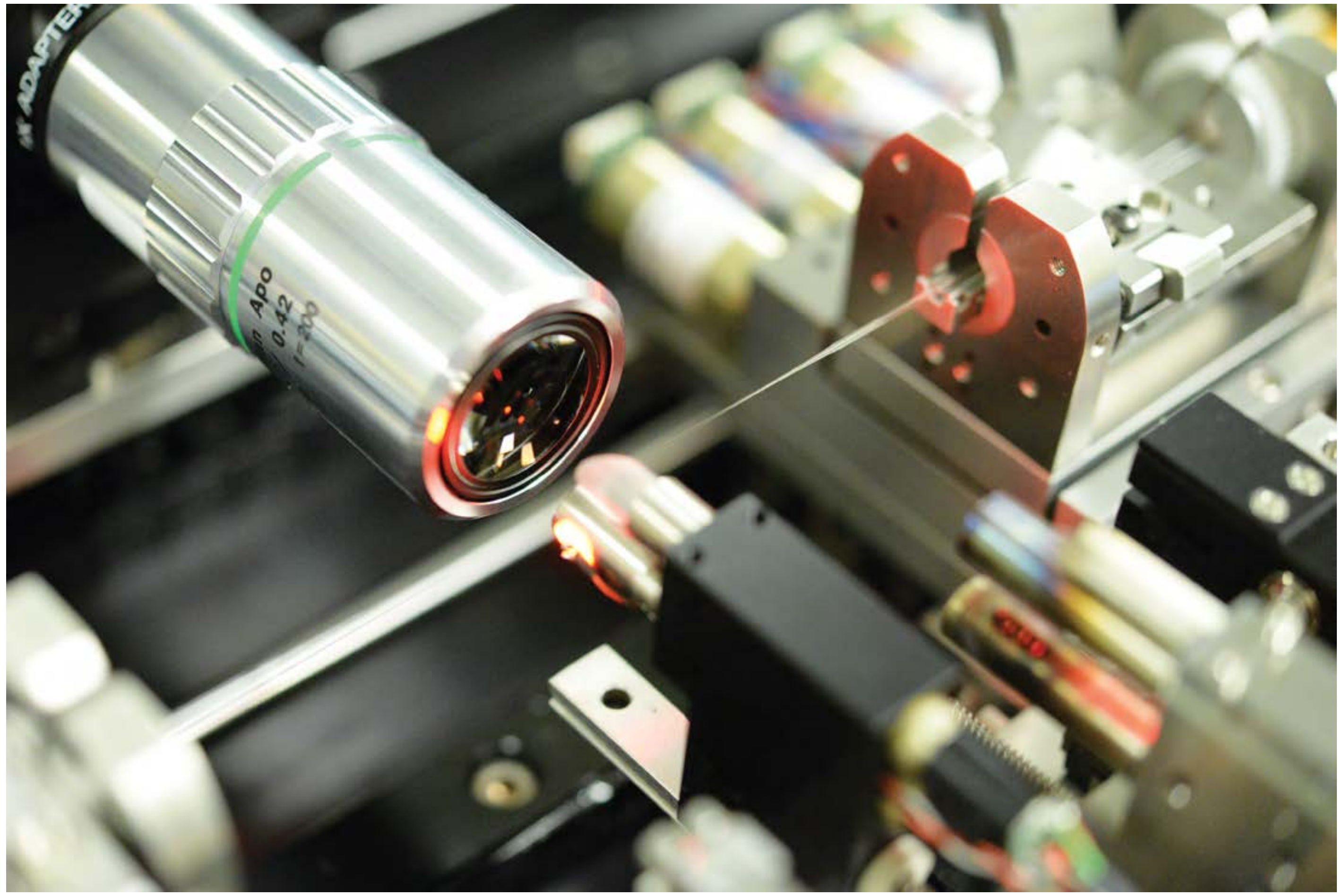
This illustration of a laser strike and detection shows a perpetrator aiming a green laser pointer at a flying aircraft and two sensors that coordinate their detections of the pointer's beam to quickly geolocate the perpetrator (a). The inset (b) is a photograph of a demonstration of the technique with a single sensor. The beam from 1 mi away is detected.

Resonantly Enhanced Ultraviolet Laser for Raman Spectroscopy

For some chemicals and bioagents, Raman spectroscopy is the most sensitive detection technique. Resonant cavities can increase sensitivity by several orders of magnitude but require active feedback. Lincoln Laboratory is investigating a method to integrate the resonant cavity inside a laser while eliminating active feedback requirements. This resonantly enhanced laser detection technique offers a potential for developing chemical and biological sensors with low size, weight, power, and cost. A successful demonstration could lead to small portable systems on unmanned aerial vehicles or robots that could identify chemical and biological threats or aid in site decontamination.



At right is a resonant cavity that is integrated within a laser.



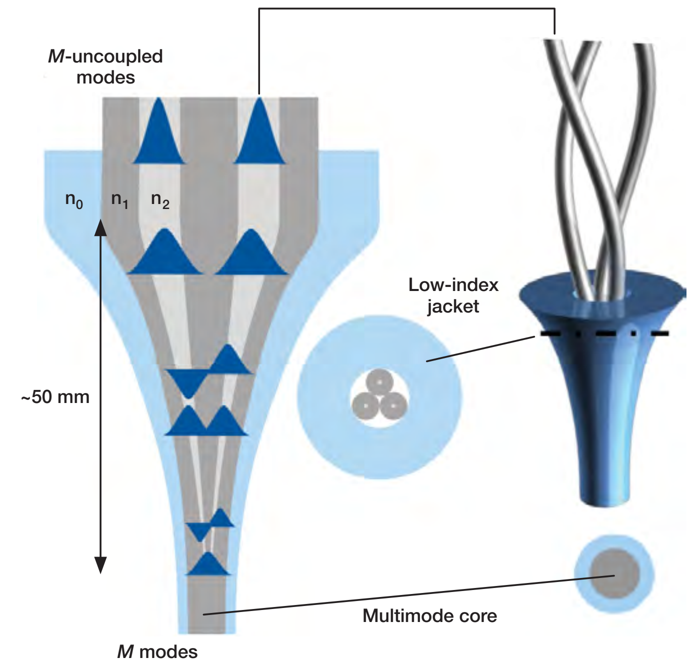
The photonic lantern is fabricated on a high-precision mechanical system. The tip of the photonic lantern is inspected with a microscope objective prior to the lantern's being spliced to the high-power kW-class fiber.

Achieving a Near-Ideal Laser Beam

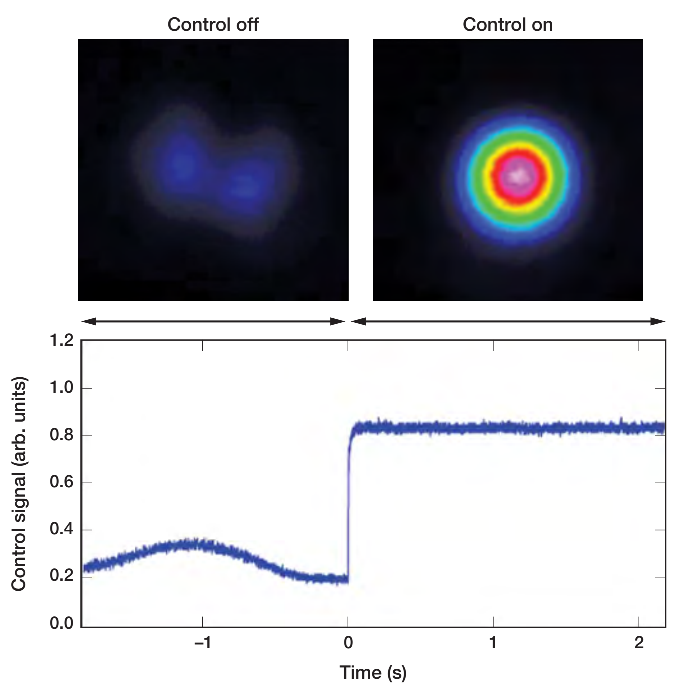
Lincoln Laboratory researchers have demonstrated an all-fiber-based adaptive optical system that can output a high-quality nearly diffraction-limited beam

Adaptive optics, technology that corrects for distortions in beams of light caused by atmospheric turbulence, is a key enabler for various laser systems and astronomical telescopes. Since the 1970s, Lincoln Laboratory has conducted pioneering research in adaptive optic systems that correct for beam propagation through turbulent environments.

Recently, Lincoln Laboratory has developed all-fiber-based adaptive optical systems that leverage photonic lantern technology, originally developed for astronomy applications, to correct for disturbances in high-power fiber amplifiers. The light guided in a fiber can be decomposed into a number of modes (i.e., spatial distributions of amplitude and phase) that are guided in the fiber. Typically, the lowest-order mode (i.e., the one using the most direct path through the waveguide) is the most desired because it is the brightest, containing the most power on axis. The power in today's fiber amplifiers is limited by a number of nonlinearities that scale inversely with the size of the beam in the fiber. Scaling the power per fiber has involved increasing the fiber cross-sectional area to increase the size of the beam. Unfortunately, as the area increases, so does the higher-order mode content, thereby creating modal instabilities that degrade the quality and brightness of the beam.



This schematic shows the photonic lantern mode-control approach. *M* single-mode input fibers are used to control the modes in a multimode fiber that supports *M* modes. The number of input fibers must match the number of modes in the multimode fiber for arbitrary mode control. As an individual input fiber is tapered, the core of index n_2 become vanishingly small, and the mode expands and couples to its neighbors until it emerges as a superposition of the modes supported by the multimode fiber. The multimode fiber consists of a core of index n_1 and cladding index n_0. By controlling the phase and amplitude of the individual input fibers, one could excite any mode supported by the multimode fiber on the output.



(Top) The output beam is shown before and after Lincoln Laboratory's adaptive control algorithm is applied; the algorithm iteratively adjusts the phase on the input fibers to achieve a high-quality beam on the output of a multimode high-power fiber. (Bottom) The on-axis intensity component is shown before and after our adaptive control algorithm is applied. With our control algorithm on, the on-axis intensity increases, resulting in a brighter output beam.

The Laboratory has demonstrated that an all-fiber-based adaptive optical system can output a high-quality nearly diffraction-limited beam when one injects an appropriate superposition of modes on the input. This process may be best described by considering the operation of a multimode-fiber adaptive optic system in reverse. When a high-quality beam is launched, the presence of optical disturbances in the fiber gives rise to the creation of several modes *M* supported by the fiber. A photonic lantern can be used to convert the *M* multiple modes in the multimode fiber into *N* single modes on the input. For low loss, the number of degrees of freedom must be conserved and the number of input fibers must match the number of modes in the multimode fiber ($N = M$). In other words, the number of inputs must match the number of outputs that are needed to be controlled. Each of the *N* modes in the *N* single-mode fibers can be described by an amplitude A_i and phase θ_i. The job of the Laboratory's adaptive algorithm is to determine the amplitude A_i and conjugate phase θ_i on the input to faithfully reproduce the desired mode on the output. In essence, the optical disturbance process could be reversed and a predistorted input may be launched to achieve the desired mode on the output.

In conventional approaches, the desired mode would be launched on the input. As the fiber area increases, the conventional approach fails to provide a high-quality beam. The insight leveraged in the adaptive optics approach entails intentionally launching an undesired mode on the input so that it evolves to become the high-quality desired mode on the output. This approach counters conventional wisdom in that we input what we don't want to get what we want on the output.

Lincoln Laboratory's demonstrated three-channel photonic lantern is made by arranging single-mode input fibers in an equilateral geometry within a tube. As the single-mode fibers and tube are heated and stretched, they come together to form the multimode output waveguide in a low-loss way. The Laboratory's all-fiber-based adaptive optic system measures the power on axis, which is largest for the high-quality fundamental mode of the output of the fiber. By using an adaptive algorithm, the phase and amplitude of the single-mode input fibers are adjusted dynamically and iteratively to apply a correction to maximize the intensity on axis.

Using a photonic lantern that was fabricated at the Laboratory, researchers from the Laser Technology and Applications Group conducted a low-power proof-of-concept demonstration that achieved mode control and output powers as high as 10 W. The lantern is mode-matched and spliced to high-power kW-class fiber. This photonic lantern approach shows promise for continued modal area and power scaling with immediate applications to high-power fiber amplifiers.

The Localizing Ground-Penetrating Radar is installed underneath the Laboratory's Autonomous Systems Mobile Test bed; a Velodyne lidar is mounted on top. The vehicle has been test driven under various conditions.

Localizing Ground-Penetrating Radar

Innovative technology may help advance the use of autonomous vehicles

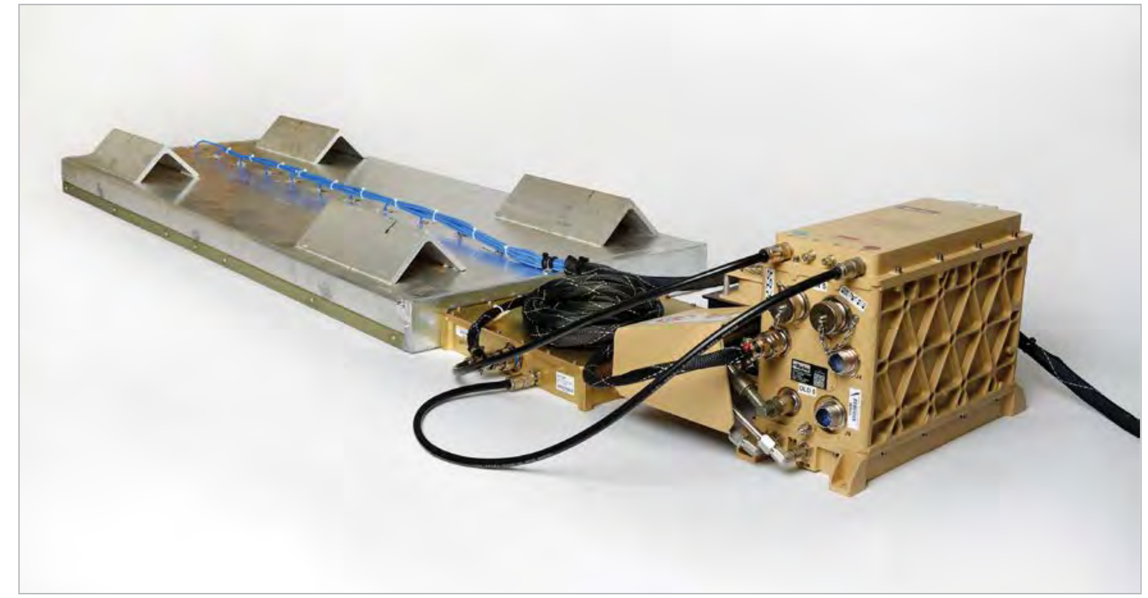
The Motivation

The strong interest in developing reliable autonomous vehicles is in part driven by their potential to decrease the number of serious injuries to and fatalities of riders. Self-driving vehicles may help prevent the more than 30,000 deaths that the National Highway Traffic Safety Administration (NHTSA) reports are caused by traffic accidents in the United States each year. Autonomous vehicles could correct for some of the driver behaviors that the Auto Insurance Center discovered are the leading reasons behind fatal crashes. Using 2009–2013 data from NHTSA's Fatal Accident Reporting System, the center determined that failure to stay in the proper lane is the most prevalent reason for these accidents. Drivers' inability to adjust to road surfaces and obstructions and drivers' overcorrection for skids or for drifting offroad are among the other prime causes that could be mitigated by vehicles that navigate autonomously.

In addition, military organizations envision using autonomous vehicles as an alternative to sending personnel into dangerous regions to deliver supplies or conduct reconnaissance. For example, according to recently released Pentagon documents, between 2006 and 2011 in Iraq alone, 196 deaths and 861 severe injuries were caused by roadside bombs hitting U.S. troops who were traveling on missions.

A Novel Solution

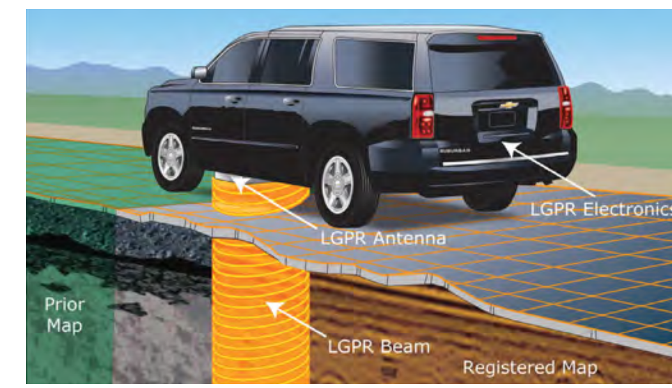
Lincoln Laboratory has been investigating technology to address a fundamental requirement for an autonomous ground vehicle (AGV) that dependably maneuvers roadways and follows maps: the capability to consistently localize itself and stay in its lane. Currently, few AGVs navigate successfully in adverse conditions, such as during snowstorms or in areas denied Global Positioning System (GPS) coverage, because the AGVs are limited by the optical sensors used for localization. When the sensors' optical surfaces are obscured—for example, by snow, heavy rain, fog, or dirt—there is no highly accurate way to localize the vehicle because GPS and inertial navigation systems (INS) alone are insufficient for lane keeping. In addition, GPS/INS solutions fail because of multipath interference, jamming, and signal blockages caused by buildings, trees, or other tall objects.



The miniature Localizing Ground-Penetrating Radar system consists of an antenna array (left-hand silver component) and the electronics and processing unit (right-hand section). The system is 1.5 m wide, 7.6 cm tall, and 0.6 m long.

Lincoln Laboratory has demonstrated the use of a novel subsurface map-based registration that offers the potential for low sensitivity to the limitations that cause optical sensors, such as lidar, cameras, and GPS/INS sensors, to fail to localize AGVs. This technique, Localizing Ground-Penetrating Radar (LGPR), overcomes the constraints of optical sensors that measure location through aboveground topography by using a new class of GPR technology to profile the environment below the road. The LGPR captures features, such as soil layering and deeply buried rocks and roots, that are inherently static even when aboveground conditions appear homogeneous or highly dynamic. The LGPR system, comprising both hardware and processing components, maps the subsurface features by using very-high-frequency (VHF) radar reflections that are insensitive to small objects (which present with small VHF radar cross section), thereby enabling the system to image only substantial underground features that remain stable over time. In addition, VHF radio waves can penetrate through rain, fog, soil, dust, and snow. From the underground features, the LGPR develops a map of the road's subsurface that is then used as a reference for estimating an AGV's location on its subsequent revisits along the road.

The location estimates are generated in real time at a fast rate (126 Hz). When fused with GPS/INS data, these estimates can serve as a high-fidelity navigation input to an autonomous planning and control system. In field tests, the LGPR has demonstrated accurate localization at speeds of 60 mph on roads, bridges, and highways and has provided 4 cm cross-track accuracy (i.e., a metric that indicates side-to-side positional accuracy), an order of magnitude better than differential GPS positioning.



The Localizing Ground-Penetrating Radar (LGPR) array is shown mounted under the vehicle in this concept drawing. Radio-frequency signals bounce off underground features to localize a vehicle by using a prior map of the subsurface features.

An AGV carries multiple sensors that enable it to maintain awareness of its environment. The LGPR can be a valuable complement to these sensors. Because the LGPR deduces location on the basis of underground features, it can operate under conditions that incapacitate optical or infrared localization sensors, providing position estimates even if the AGV encounters severe weather, obscured or unpaved roads, disrupted or altered roads, or GPS-denied areas.

Lincoln Laboratory researchers are working on developing techniques for enabling the LGPR to localize in regions where GPS coverage is extensively denied. They are looking into miniaturizing the current LGPR array even further than its 7.6 cm height so that it will fit under most passenger vehicles. In addition, they are seeking to demonstrate the system's functionality under a wider set of conditions, such as water-saturated ground or poor weather conditions.

The Space Surveillance Telescope is housed in a rotating dome enclosure at North Oscura Peak on the White Sands Missile Range in New Mexico.

The Space Surveillance Telescope is seen inside its dome enclosure.

Discovering the Vast Asteroid Population

The Space Surveillance Telescope is enabling enhanced observations of near-Earth objects, including millions of asteroids

Since January 2014, Lincoln Laboratory's Near-Earth Asteroid Research (LINEAR) program has reported more than nine million observations of minor planets (commonly referred to as asteroids) and comets to the Minor Planet Center (MPC), the agency recognized by the International Astronomical Union as responsible for international efforts to identify, designate, and maintain orbits for all known minor planets, including near-Earth objects (NEOs).

The LINEAR program supports the National Aeronautics and Space Administration (NASA) in the fulfillment of Congressional mandates to find and catalog by 2020 90% of NEOs that have a diameter of 140 m or greater. As the manager of one of the very first asteroid surveys funded by NASA's Near-Earth Object Observations Program, the Laboratory has an 18-year history of applying space surveillance technologies to the problem of searching for asteroids whose orbits cross dangerously close to Earth.

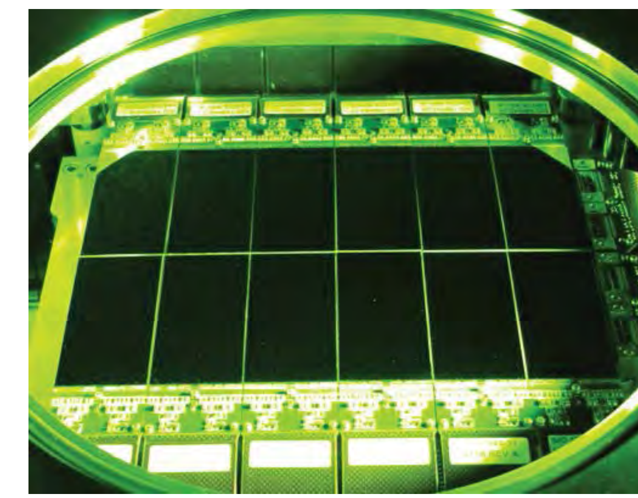
During the first 15 years of the LINEAR program, Laboratory scientists employed two 1 m ground-based electro-optical telescopes at the Experimental Test Site on the U.S. Air Force's White Sands Missile Range in New Mexico. In 15 years of operations, these telescopes discovered 231,082 objects, including 2503 NEOs. These discoveries have contributed significantly to the astronomical community's understanding of the asteroid population.

The recent surge in LINEAR's minor planet observations is due to the use of a new, highly capable telescope whose innovative curved focal plane is enabling deep, wide-area searches of the night sky—the Space Surveillance Telescope (SST). In 2013, the LINEAR program began transitioning asteroid search operations to the SST located at White Sands. The SST, developed by Lincoln Laboratory under sponsorship from the Defense Advanced Research Projects Agency, was designed to detect small objects in geosynchronous orbits. The f/1 SST combines a 3.5 m aperture with a very large (6 square degree) field of view and agile step-and-settle to achieve highly sensitive, rapid, wide-area sky surveys well suited to asteroid search and detection.

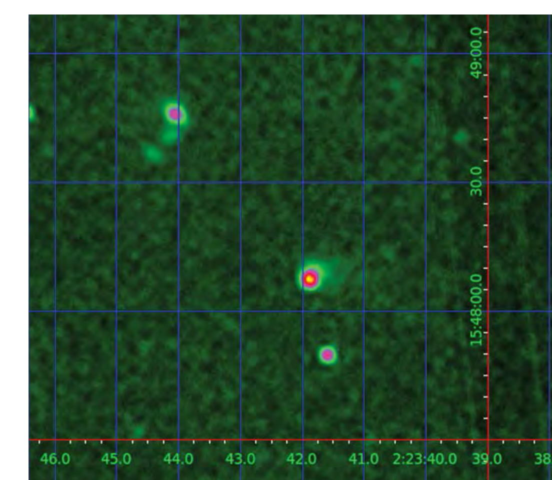
The submission of 7.2 million observations in 2015 made SST the most productive asteroid search instrument ever in terms of number of observations submitted to the MPC by a search program in a single calendar year. Since 2014, SST has found 4548 new objects, including 69 previously undiscovered NEOs and four potentially hazardous objects; in addition, SST has detected three new comets since April 2015.

In 2013, the U.S. Department of Defense and Australian Department of Defence signed a memorandum of understanding to relocate SST to Western Australia to enhance coalition space surveillance capabilities in the Southern Hemisphere. The relocation is planned to begin in late 2017, and until that time SST is expected to continue contributing to NASA's NEO search and discovery mission. NASA and Air Force Space Command have also started discussions on the multimission use of SST for space surveillance and asteroid search from SST's new location.

Two 1 m ground-based electro-optical deep-space surveillance (GEODSS) Test System telescopes, such as the one above, provided LINEAR data to the Minor Planet Center for 15 years.



Lincoln Laboratory developed the Space Surveillance Telescope's unique wide-field-of-view, curved focal plane, which won an R&D 100 Award in 2012. The SST camera was upgraded in summer 2016 to incorporate a new focal plane with improved performance.



The first comet discovered by the Space Surveillance Telescope, Comet C/2015 TQ 209 (LINEAR), was detected on 10 October 2015.

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.

2016 TECHNOLOGY TRANSITIONS

Cyber Security and Information Sciences

The Lincoln Adaptable Real-Time Information Assurance Testbed (LARIAT) was transitioned to a commercial startup company.

Lincoln Laboratory's Secure High-Assurance Micro Crypto and Key-management (SHAMROCK) processor was transferred to a commercial partner in support of a U.S. Air Force (USAF) effort to develop foundations for agile and resilient embedded systems.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Open architecture technologies based on prototypes developed over the past several years for the USAF Distributed Common Ground System were transitioned to the to the Air Force Research Laboratory's Information Directorate in Rome, New York.

Air, Missile, and Maritime Defense Technology

To support the Missile Defense Agency's (MDA) initiatives to improve homeland defense capabilities, the Laboratory is developing prototype flight articles that can be used to test the Ballistic Missile Defense System (BMDS). This year, the Laboratory successfully built and flight-tested prototype hardware; these designs are being transferred to industry for production and deployment on future flight tests.

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

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

Communication Systems

The fifth-generation advanced training waveform (5G-ATW) specifications, models, and the prototype implementation were transferred through the Air Force Research Laboratory to defense industry participants in the USAF's Live, Virtual, and Constructive Advanced Technology Demonstration program.

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

Selected Patents Fiscal Year 2015–2016

Methods and Apparatus for In-Pixel Filtering in Focal Plane Arrays Including Apparatus and Method for Counting Pulses Representing an Analog Signal
Kenneth I. Schultz, Brian Tyrrell, Michael W. Kelly, Curtis Colonero, Lawrence M. Candell, and Daniel Mooney
Date issued: 13 October 2015
U.S. Patent no.: 9,159,446

Assisted Video Surveillance of Persons of Interest
Jason R. Thornton, Daniel J. Butler, and Jeanette T. Baran-Gale
Date issued: 17 November 2015
U.S. Patent no.: 9,189,687

Terahertz Sensing System and Method
Mohammad J. Khan, Sumanth Kaushik, and Jerry C. Chen
Date issued: 1 December 2015
U.S. Patent no.: 9,200,959

Wavelength Beam Combining of Quantum Cascade Laser Arrays
Anish Goyal, Benjamin G. Lee, Christian Pfluegl, Laurent Diehl, Mikhail Belkin, Antonio Sanchez-Rubio, and Federico Capasso
Date issued: 26 January 2016
U.S. Patent no.: 9,246,310 B2

Assisted Video Surveillance of Persons-of-Interest
Jason R. Thornton, Daniel J. Butler, and Jeanette T. Baran-Gale
Date issued: 2 February 2016
U.S. Patent no.: 9,251,424

Aerosol Generation for Stable, Low-Concentration Delivery
Jesse A. Linnell, Trina R. Vian, Joseph R. Morency, Aulong Dai, Mark E. Bury, Thomas Sebastian, Carlos A. Aguilar, Joseph J. Lacirignola, and Jay D. Eversole
Date issued: 9 February 2016
U.S. Patent no.: 9,254,500

Method and Apparatus for Phase Shift Keyed Optical Communication
David O. Caplan, Neal W. Spellmeyer, Bryan S. Robinson, Scott A. Hamilton, Don M. Boroson, Hemonth G. Rao, and Marc C. Norvig
Date issued: 16 February 2016
U.S. Patent no.: 9,264,147

Methods and Apparatus for True High Dynamic Range Imaging
Michael W. Kelly, Megan H. Blackwell, Curtis B. Colonero, James Wey, Christopher David, Justin Baker, and Joseph Costa
Date issued: 23 February 2016
U.S. Patent no.: 9,270,895

Pathogen Detection Biosensor
Eric Schwoebel, James Harper, Martha Petrovick, Frances Nargi, Mark Hollis, Bernadette Johnson, Joseph Lacirignola, Richard Mathews, Kristine Hogan, Trina Vian, Allan Heff, Mark Hennessy, Songeeta Palchaudhuri, and Todd Rider
Date issued: 22 March 2016
U.S. Patent no.: 9,291,549

Retroreflectors for Remote Detection
Michael Switkes and Mordechai Rothschild
Date issued: 19 April 2016
U.S. Patent no.: 9,316,593

Optimized Transport Layer Security
Roger I. Khazan and Daniil M. Utin
Date issued: 17 May 2016
U.S. Patent no.: 9,344,405

Generating a Multiple-Prerequisite Attack Graph
Richard P. Lippmann, Kyle W. Ingols, and Keith J. Piwowarski
Date issued: 17 May 2016
U.S. Patent no.: 9,344,444

Knowledge Registry Systems and Methods
Suresh K. Damodaran, Benjamin D. O'Gwynn, and Tamara H. Yu
Date issued: 14 June 2016
U.S. Patent no.: 9,367,610

Assisted Surveillance of Vehicles-of-Interest
Michael T. Chan, Jason R. Thornton, Aaron Z. Yahr, and Heather Zwahlen
Date issued: 21 June 2016
U.S. Patent no.: 9,373,033

Digital Readout Method and Apparatus
Michael Kelly, Daniel Mooney, Curtis Colonero, Robert Berger, and Lawrence Candell
Date issued: 5 July 2016
U.S. Patent no.: 9,385,738

Photonic Integrated Circuits Based on Quantum Cascade Structures
Anish K. Goyal, Laurent Diehl, Christian Pfluegl, Christine A. Wang, and Mark Francis Witinski
Date issued: 20 September 2016
U.S. Patent no.: 9,450,053

Helping Achieve Dominant U.S. Capabilities

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

Better Buying Power (BBP) is the implementation of best practices to strengthen the Department of Defense's buying power, improve industry productivity, and provide an affordable, value-added military capability to the warfighter. The overarching theme of BBP, now in its third iteration, is "achieving dominant capabilities through technical excellence and innovation."

As a Department of Defense (DoD) federally funded research and development center, Lincoln Laboratory is committed to being an effective partner in the DoD's acquisition process. The Laboratory's efforts are addressed through three key areas: maintaining technological superiority, improving the affordability of future government acquisition programs, and institutionalizing efficiency.

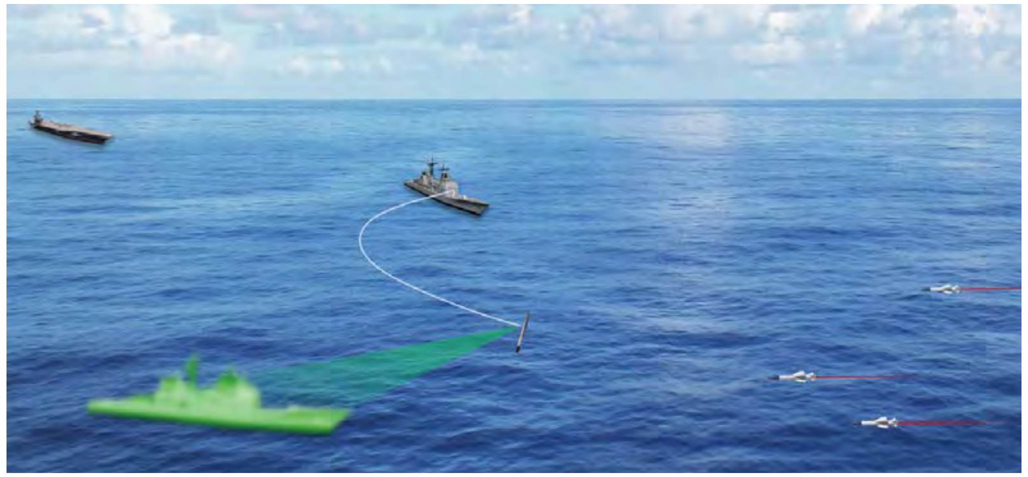
Maintaining Technological Superiority

Lincoln Laboratory conducts research and development of innovative technology to solve the most difficult national security problems. Directing its efforts to areas of strategic importance to current and emerging DoD missions, the Laboratory is building, demonstrating, and testing novel systems, applications, components, and prototypes. Many new technologies, solutions, and innovations are highlighted throughout this report. Several examples are provided in the table at right.

Examples of Maintaining Technological Superiority

Activity	Impact/Benefit
Devised a method to uniquely encode and decode the channels of an optically multiplexed imaging system rapidly and precisely in a novel, compact optical design architecture	Enables the imaging system to have low size, weight, and power and to image a wide field of view with high resolution; these attributes are suitable for a variety of applications, such as navigation and data collection for intelligence, surveillance, and reconnaissance
Developed the Video Content Summarization Tool, which provides the capability for analysts to view video content at a small fraction of the raw video duration	Allows analysts to comb through surveillance footage more quickly, from hours compressed to minutes or even seconds
Created and tested a prototype system that uses a new approach to protect tactical communications	Significantly decreases the range and detection capabilities of adversaries
Developed and demonstrated an advanced sensor prototype for missile defense	Improved advanced sensing technology for future architectures; necessary to improve persistent sensor coverage and robust discrimination

The dense concentration of people in an enclosed area presents a potential target for chemical or biological attacks. Beneath New York City, researchers collected data at the Metropolitan Transportation Authority subway system to validate and improve dispersion models used to help inform responses to biological threats.



The Self-Defense Distributed Engagement Coordinator is an automated decision support tool that helps operators determine appropriate responses against missiles threatening U.S. naval assets. The tool's novel algorithm assesses critical factors and recommends a strategy that allocates resources to defeat incoming threats while minimizing weapon usage. An engagement summary displays the options for assigning defenses to maximize the survivability of the ships.

Improving the Affordability of Future Government Acquisition Programs

In executing the Laboratory's core mission of developing and applying advanced technology, program requirements are optimized, open system architectures are used, and technology is then transitioned to the government and industry. The results are increased affordability of government programs and a competitive industry base.

Examples of Improving Affordability

Activity	Impact/Benefit
Developed the open mission systems standard, which defines the architectural building blocks and promotes the use of nonproprietary interfaces	Simplifies avionics system integration, enables third-party competition, and supports cross-platform reuse of software
Designing and developing a 100 kg–class microsatellite to perform geostationary search; these microsatellites are expected to be launched in 2017	Decreases time of satellite development from 72 months to ~36 months, and lowers development costs from more than $1 billion to less than $100 million; these benefits are achieved by relying heavily on commercial off-the-shelf components
Upgraded the optical systems at the Reagan Test Site, combining state-of-the-art commercial focal plane technologies with a wide-area, network-centric, open-system design	Saved development costs for distributed system command and control while achieving record-high metric accuracy

Institutionalizing Efficiency

Lincoln Laboratory's commitment to careful stewardship of its financial resources supports the continued excellence of its research and development activities. The Laboratory held its first Financial Management Review (FMR) on 19 January 2016. The FMR, chaired by the Assistant Secretary of Defense for Research and Engineering, examined the cost-control measures the Laboratory employed in executing its programs and operating the facilities, with a focus on efficiencies and productivity. The FMR is an opportunity for Lincoln Laboratory to highlight its many success stories in the following areas:

- Prototyping
- Better Buying Power
- Support for science, technology, engineering, and mathematics (STEM) education
- Open architectures
- Cost-control initiatives
- Agile new project starts
- Facility modernization
- Technology transfer

A major theme discussed during this year's FMR was a concept called "should cost." A should-cost review is designed to identify and eliminate process inefficiencies and embrace cost-savings opportunities throughout an enterprise. As inefficiencies are reduced, productivity and savings should increase. The should-cost concept is embodied in the Laboratory's implementation of the BBP principles developed and promoted by the Under Secretary of Defense for Acquisitions, Technology and Logistics.

>> *Helping Achieve, cont.*

The Laboratory is taking steps to further institutionalize efficiency. This past year, an extensive Lab-wide study resulted in dozens of improvements. One outcome is the establishment of a standing Laboratory Efficiency Team made up of personnel from across the divisions and departments. The team will serve as the focal point for ensuring efficiency, productivity, and cost savings while capturing success stories to inform future FMRs. For example, by upgrading videoteleconferencing capabilities, the Laboratory reduced travel demands and saved an estimated $2.7 million.

The Efficiency Team will also work with the Laboratory technical teams to increase focus on affordable acquisition by using the previously mentioned techniques.

Examples of Institutionalizing Efficiency

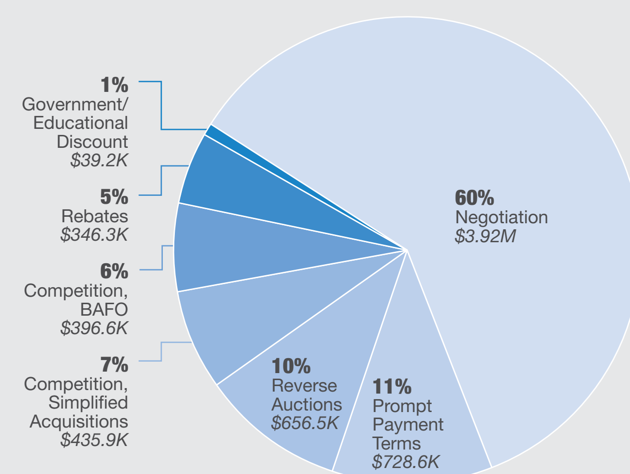
Activity	Impact/Benefit
Participate in the Massachusetts Energy Incentive Program	Saves ~$150,000 per year
Eliminated the need to install an intrusion-detection system in two rooms	Saved $40,000 on a sponsored project
Negotiated an extension of the lease and renovations for the Crystal City field office	Saves ~$900,000 over the term of the lease

Improving Cost Savings through Subcontracts

To realize more than $6.5 million in savings in subcontract awards, Lincoln Laboratory's Contracting Services Department has employed strategies that support BBP: (1) improve methods for sourcing goods and services, (2) eliminate unproductive, superfluous procurement processes and documentation, (3) promote effective competition for goods and services, and (4) develop a highly qualified staff of contracting professionals.

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

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



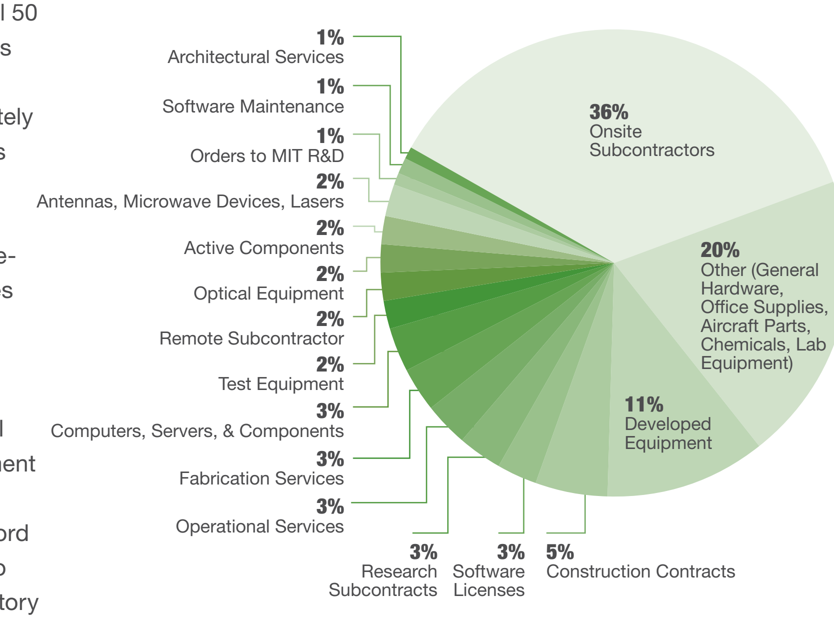
Economic Impact

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

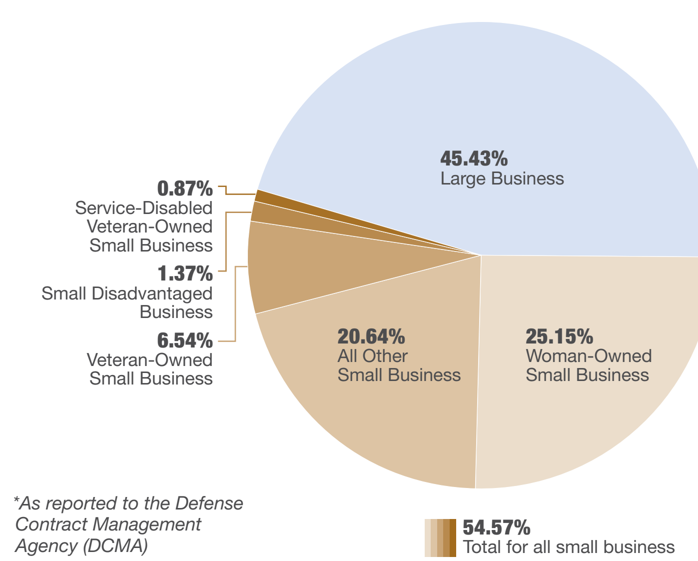
During fiscal year 2016, the Laboratory issued subcontracts with a value of approximately $462 million. The Laboratory awarded subcontracts to businesses in all 50 states and purchased more than $279 million in goods and services from New England companies in 2016, with Massachusetts businesses receiving approximately $222 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 2016, more than 54% 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 2016)

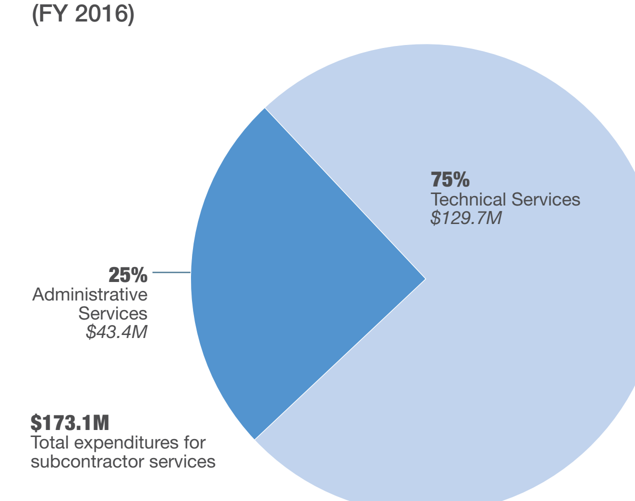


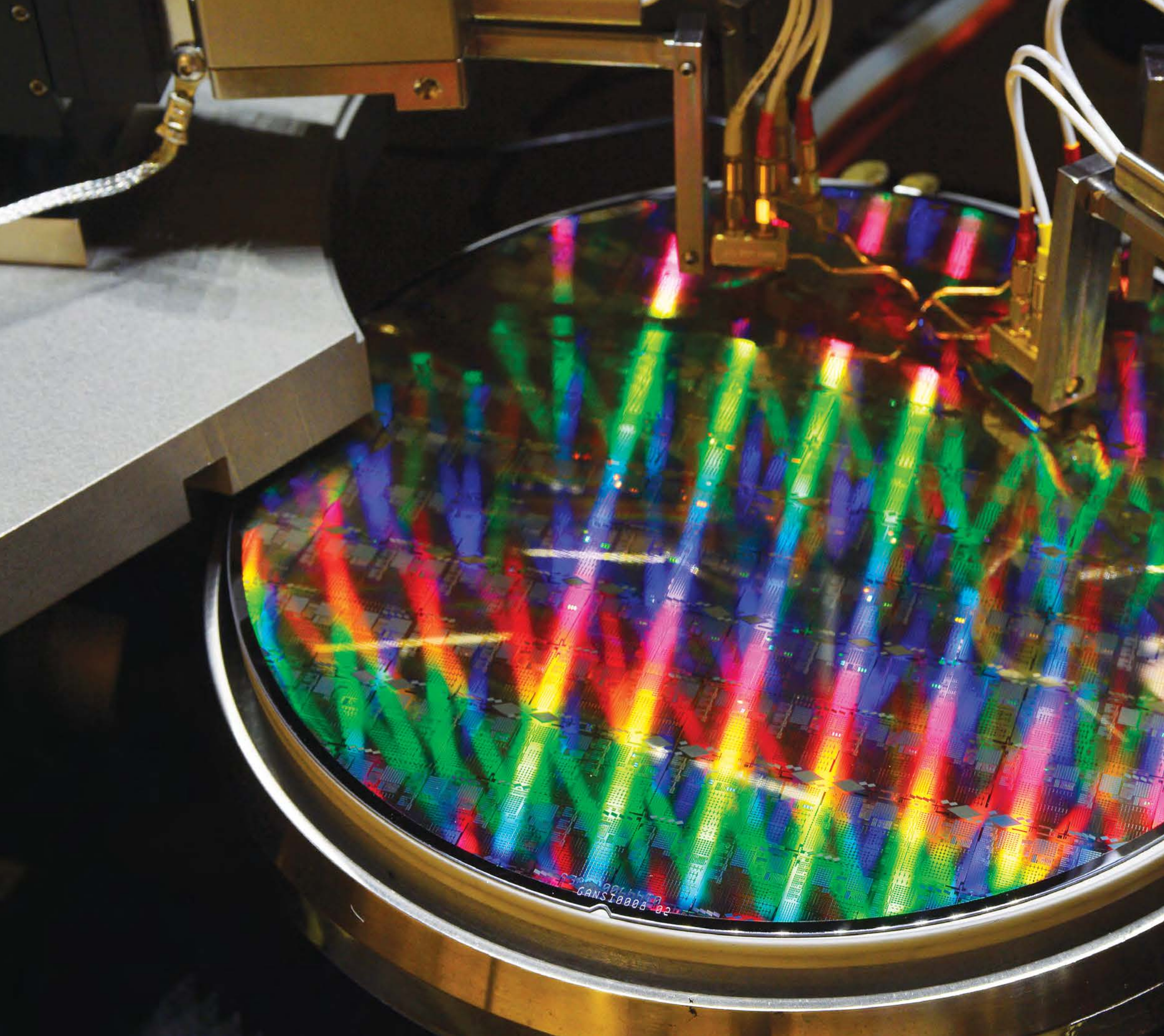
Contract awards by category of businesses (FY 2016)*



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

Subcontractor services (FY 2016)





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A gallium nitride-on-silicon wafer under fabrication in the Microelectronics Laboratory sits on a probe station. The many layers of material that are deposited on the wafer act like a prism, diffracting the light into the vibrant colors seen here.

Space Control

Leadership

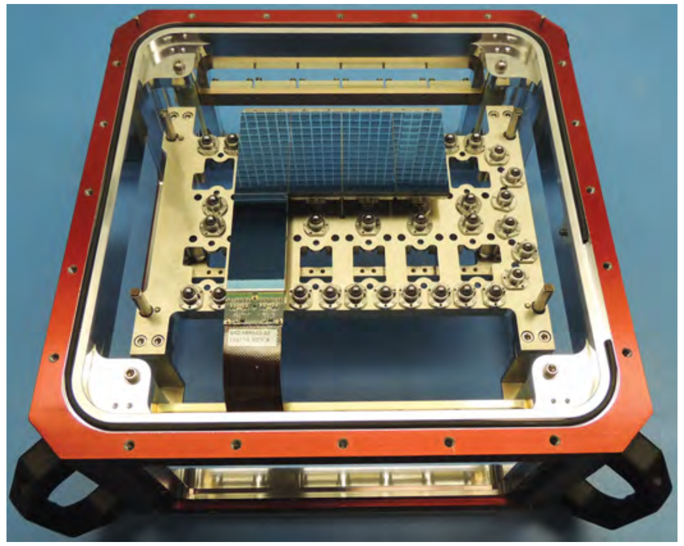

Dr. Grant H. Stokes

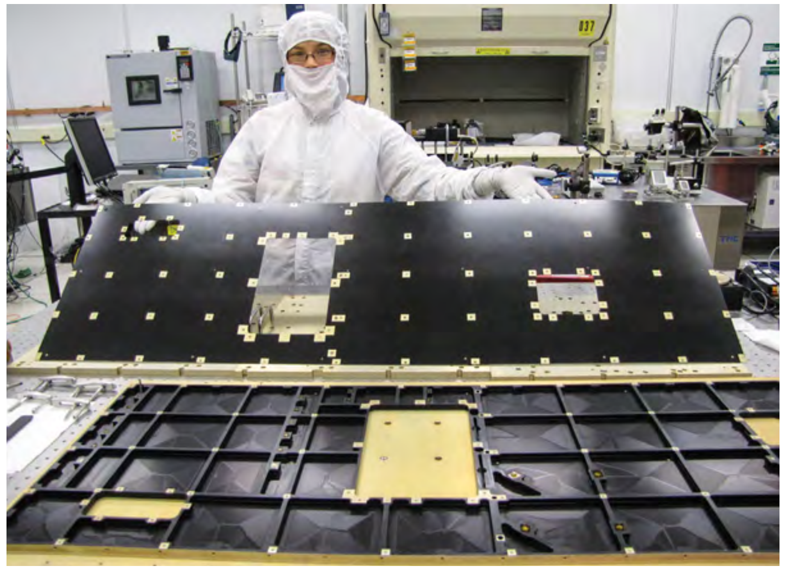

Mr. Lawrence M. Candell

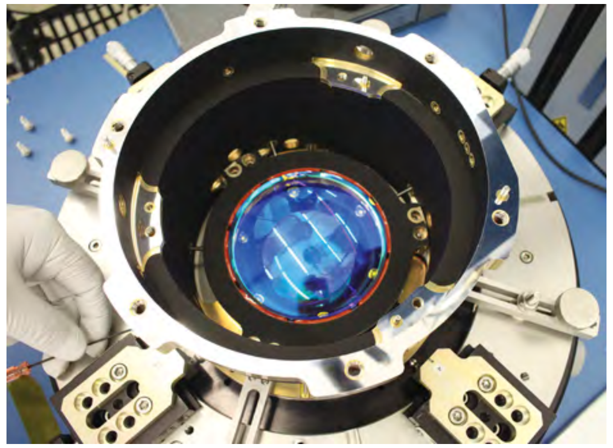

Dr. William J. Donnelly III


Mr. Craig E. Perini

Lincoln Laboratory develops technology that enables the nation to meet the challenges of an increasingly congested and contested space domain. The Laboratory develops and utilizes systems to detect, track, identify, characterize, and assess the growing population of resident space objects, and investigates technologies to improve monitoring of the space environment. Given the emerging potential for conventional conflict to extend to space, the Laboratory is examining space mission resilience to determine critical services and is assessing the impact of potential threats. The Laboratory is proposing alternative disaggregated architectures and prototyping advanced sensors and systems.


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


The SensorSat flight hardware fabrication and assembly have been completed. Above, a technical staff member presents one of the satellite's structural panels. The satellite will be used to address a U.S. Strategic Command space situational awareness need.


The Laboratory is developing and assembling four flight cameras for the Transiting Exoplanet Survey Satellite payload. Each camera consists of four Lincoln Laboratory charge-coupled devices (CCDs) behind a custom all-refractive, wide-field-of-view, color-corrected, cryogenic lens (shown above during assembly). The CCDs provide the sensitivity and resolution required to map the celestial sphere for exoplanets orbiting the brightest stars in the solar neighborhood.

Principal 2016 Accomplishments

- Performance upgrades to the Space Surveillance Telescope (SST) Wide-Field Camera-2 were demonstrated during a successful Defense Advanced Research Projects Agency (DARPA) evaluation period. The SST transitioned from DARPA to the Air Force Space Command on 18 October 2016.
- The Laboratory has completed the procurement, fabrication, and assembly of all major subsystems for the ORS-5 SensorSat, a small satellite for the Operationally Responsive Space (ORS) Office. Flight space vehicle hardware integration and testing are under way.
- For the Transiting Exoplanet Survey Satellite (TESS) payload, Lincoln Laboratory finished the fabrication, assembly, and subsystem integration of the four camera lenses, electronics, and focal plane arrays. The Laboratory provided the detector arrays, optical subsystem, system engineering, integration and testing, and program management for the science payload, which was jointly developed with the MIT Kavli Institute for Astrophysics and Space Research under funding from the National Aeronautics and Space Administration (NASA).
- The Microwave Radiometer Technology Acceleration (MiRaTA) CubeSat, developed by MIT Space Systems Laboratory and Lincoln Laboratory, is ready for its scheduled delivery to NASA in June 2017, following its successful integration and testing in October 2016. MiRaTA will use multiband radiometer measurements and Global Positioning System radio occultation for weather and climate forecasting.
- The Micro-sized Microwave Atmospheric Satellite-2 (MicroMAS-2) CubeSat commercial subsystems were procured, and MicroMAS-2 payload fabrication was completed. The compact microwave sounder will provide high-resolution images of tropical cyclones and other severe weather.
- Lincoln Laboratory has established a Space Blue Team to execute systems analysis and architecture assessments to help guide U.S. national security space investments. The Space Blue Team has conducted assessments and studies focused on constellation coverage and capacity, system designs, space mission resiliency metrics and employment concepts, and defensive operations for current and future space systems.
- In response to the national need to rapidly develop a Space Battle Management capability, Lincoln Laboratory created the Battle Management, Command, Control, and Communications Testbed to develop mission-critical decision support tools. These tools perform key functions, such as rapid event detection and dynamic scheduling of space surveillance assets, to develop courses of action. The facility provides a real-time environment to ensure interoperability of service-oriented-architecture systems; to evaluate and operationalize the contributions of new sensors and sources; to develop and assess the performance of new decision support algorithms; and to provide a simulation capability for red-versus-blue team exercises.

Future Outlook

- Construction of the Australian SST facility at Harold E. Holt Naval Communications Station (HEH) has begun. The telescope is expected to be transported to HEH by 2018 and become a dedicated Space Surveillance Network sensor in 2020.
- Following integration and testing, the TESS payload will be delivered to the spacecraft vendor in June 2017, and integrated with the spacecraft and launch vehicle. The launch is currently scheduled for April 2018.
- The MiRaTA CubeSat will be a secondary payload on the National Oceanic and Atmospheric Administration (NOAA) Joint Polar Satellite System-1 mission launch currently scheduled for late 2017.
- The MicroMAS-2 CubeSat will be assembled, integrated, and tested to meet a delivery date of April 2017. MicroMAS-2 will be launched as a secondary payload on an Indian Space Research Organisation launch currently planned for July 2017.
- Completion of the SensorSat small satellite integration and testing is expected in May 2017, with launch planned for July 2017.
- Lincoln Laboratory will sustain critical space domain operational support to the Joint Space Operations Center and deploy tools and expertise to the recently established Joint Interagency Combined Space Operations Center.

Air, Missile, and Maritime Defense Technology

Leadership


Dr. Justin J. Brooke


Dr. Katherine A. Rink


Dr. Kevin P. Cohen


Mr. Dennis J. Keane

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

The Advanced Sensor and Technology Applications program developed, installed, and is currently operating a ground-based risk-reduction sensor prototype. Critical technologies were integrated and installed on the Firepond telescope mount in late 2015 (left). Analysis of the collected data demonstrates that the sensor is operating as designed and has future ballistic missile defense mission capability.

Lincoln Laboratory is developing novel signal processing and machine learning techniques to address clutter in a maritime environment. An instrumentation sensor (above) was deployed to collect instrumented measurements on clutter, air, and maritime targets to explore and demonstrate the efficacy of these advanced techniques.

A Lincoln Laboratory research team developed and prototyped wind turbine interference-mitigation approaches for the Advanced Dynamic Aircraft Measurement System of Patuxent River Naval Air Station. During the demonstration, wind turbine interference was emulated by using a coherent repeater device (front right) on a ship in the Chesapeake Bay. This work will inform future research into mitigating radar clutter produced by wind turbines.

Principal 2016 Accomplishments

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

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

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

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

- Lincoln Laboratory developed the Self-Defense Distributed Engagement Coordinator (SDDEC), a novel algorithm and highly customizable decision support technology, to manage a fleet's antimissile resources, including sensors, interceptors, jammers, and decoys, and to make intelligent, real-time decisions about their usage against missile threats. SDDEC, which has been recognized nationally, won a 2015 R&D 100 Award.

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

- Lincoln Laboratory and MITRE continued to lead the Technical Direction Agent (TDA) team for the Missile Defense Agency (MDA) Ground-based Missile Defense (GMD) program office, providing technical expertise and objective guidance for the office's development and acquisition programs. This year, the TDA team played a critical role in the development of requirements for MDA's Redesigned Kill Vehicle program and provided important analysis for other key GMD system components

- To facilitate technology transition, the Laboratory installed a sidecar at the Aegis Ashore Missile Defense Test Complex. The sidecar provides a critical test bed to prototype mitigation techniques against both electronic and physical countermeasures.

Future Outlook

- Development, testing, and deployment of credible counters to the ballistic missile threat will continue to be a significant national priority. Lincoln Laboratory will focus on new capabilities for homeland ballistic missile defense, including the Redesigned Kill Vehicle, an improved ground-based interceptor, upgraded radar and optical sensors, and enhanced discrimination capabilities. In addition, the Laboratory will work to evolve the capabilities to defend against regional threats.

- Defense of land and sea bases against increasingly capable regional threats remains a high priority for the DoD. A significant focus for the Laboratory will be the development and testing of multiple defenses, including left-of-launch capabilities and improved kinetic and electronic defenses. Emphasis will be on advanced sensors, signal processing, and techniques for optimizing spectrum usage, including developing, testing, and transitioning electronic attack capabilities to counter advanced threats, waveforms, and processing techniques for sensor electronic protection.

- The Laboratory will continue to grow its portfolio of systems analysis and advanced concept development programs to ensure U.S. dominance in the undersea domain. The scope of system-level assessments will be expanded to enable an understanding of potential submarine vulnerabilities against conventional and unconventional threats.

Communication Systems

Leadership


Dr. J. Scott Stadler

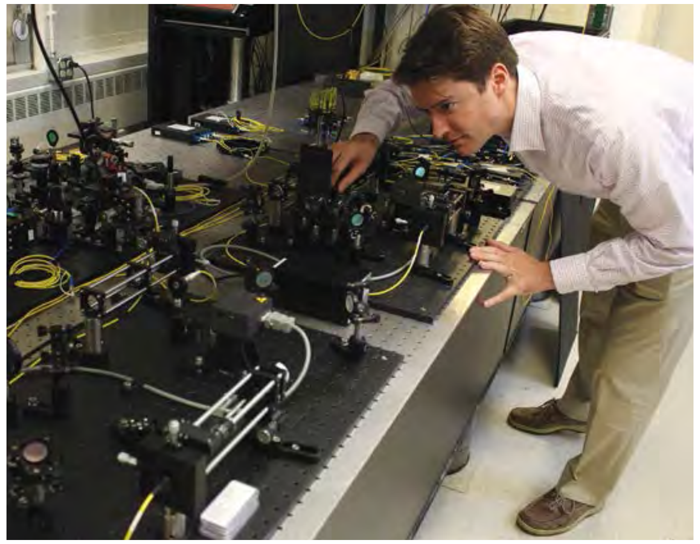

Dr. Roy S. Bondurant


Dr. James Ward

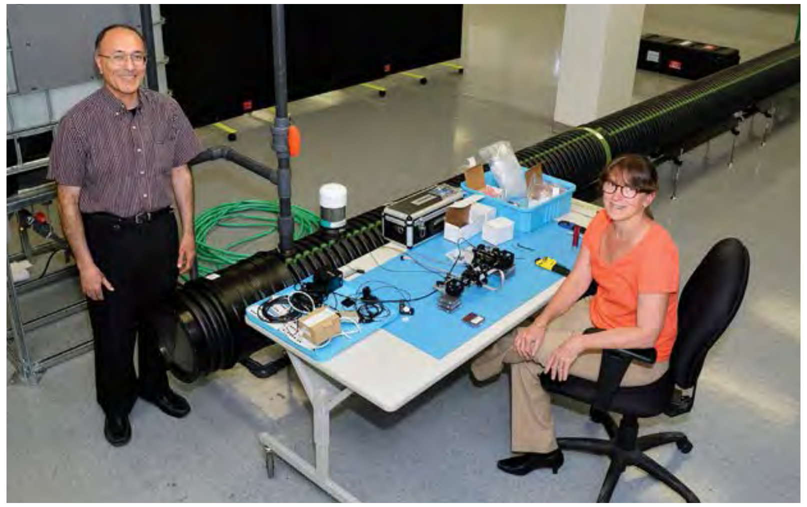

Dr. Don M. Boroson


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 (RF) military satellite communications, free-space laser communications, tactical network radios, quantum systems, and spectrum operations.


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


The command-and-control terminal designed by Lincoln Laboratory for the Enhanced Polar System was installed at Clear Air Force Station, Alaska, and used for system checkout and characterization of the on-orbit payload.


Lincoln Laboratory developed a real-time undersea optical communication transceiver that achieves <1 photon-per-bit sensitivity for link loss near ~100 dB (e.g., up to 450 m in clear ocean). Transceiver performance was characterized in a laboratory undersea test bed that emulates optical channel propagation for a wide variety of ocean water conditions.

Principal 2016 Accomplishments

- In collaboration with MIT campus, Lincoln Laboratory developed a compact prototype eight-channel transmitter and high-sensitivity frequency-shift keying (FSK) optical receiver suitable for photonic integration.
- The Laboratory developed an architecture that enables a small low-Earth-orbiting spacecraft to downlink >100 Tbits per day to a small ground receiver. Critical technology risk-reduction activities for this technology include a feasibility demonstration of ultralow size, weight, and power (SWaP) integrated fiber telecommunications transceivers for use in turbulent free-space communications links.
- The Advanced Extremely High Frequency test infrastructure continues to support the development and proliferation of protected military satellite communications (MILSATCOM) capabilities. Activities over the past year include supporting the Very Important Person Special Air Mobility terminal and the characterization of the Presidential and National Voice Conferencing system.
- The Laboratory demonstrated high-sensitivity, coherent field detection and lossless combining of four independent optical apertures. This optical system is digital and can track millisecond-scale phase and intensity changes.
- Designs for extending the F-35 Multifunction Advanced Data Link to improve network performance were implemented in simulation and in a prototype software-defined radio architecture.
- Algorithms for multichannel adaptive beamforming were tested against collected field measurements to verify expected performance. Prior to these algorithms' transition to tactical aircraft radio receivers, they are implemented in high-fidelity simulations and prototype hardware.
- Lincoln Laboratory completed the integration and development test activity of a prototype compact airborne laser communications terminal that utilizes an aerodynamic interface and operates over a wide field of regard. The terminal supports robust spatial tracking and near-theoretical communications performance against a low-average-power burst-mode signal.
- A wireless network system to support advanced aircrew combat training was developed and demonstrated on prototype hardware in the laboratory and on Lincoln Laboratory's test aircraft.
- Lincoln Laboratory has successfully conducted initial tests demonstrating real-time multiantenna adaptive interference suppression for megabit-per-second terrestrial non-line-of-sight RF links.

Future Outlook

- Advanced space-time adaptive processing techniques developed at Lincoln Laboratory will be enablers for antijam and low-probability-of-detection communications in terrestrial, airborne, maritime, and space applications.
- The Laboratory's expertise in protected SATCOM waveforms will be employed to define the next generation of military communication satellites.
- Technologies for wideband directional networks for ground and air applications will provide increased data rates and protection from electronic threats. Scalable implementations of these technologies will permit their use with aircraft ranging from low-cost unmanned aerial vehicle swarms to next-generation fighter planes.
- The Laboratory will demonstrate prototypes of architectures that jointly optimize spectral utilization of communications, electronic warfare, and sensing functions in different scenarios.
- The high data rates, low SWaP, and directionality of laser communications will enable missions in areas as diverse as space and undersea. The Laboratory will support research and development activities that extend from early concept development to technology transition to industry.

Cyber Security and Information Sciences

Leadership


Mr. Stephen B. Rejto


Mr. David R. Martinez


Dr. Marc A. Zissman

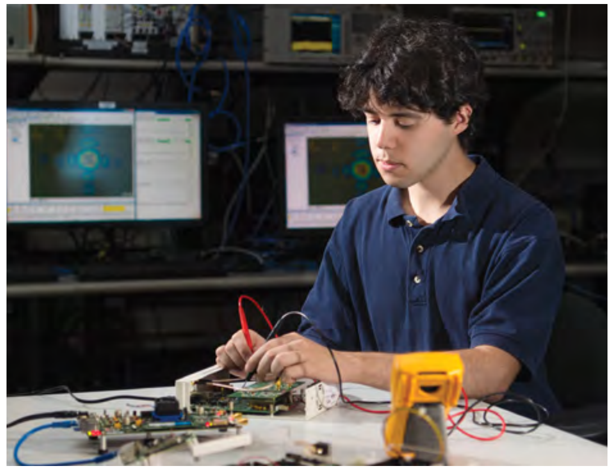

Dr. Jeremy Kepner


Dr. Richard P. Lippmann

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


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


Martine Kalke and Tamara Yu review information about prototype situational awareness tools in the Lincoln Research Network Operations Center. Researchers use these tools, plus a variety of analysis techniques, to discover emerging cyber threats and to support the security of the Laboratory.


Daniel Souza is developing a new cyber electronic warfare (EW) capability in the mobile device lab. Researchers use tools such as this software-defined radio being tested to demonstrate emerging cyber EW threats to Department of Defense systems and to create realistic hybrid cyber and RF testing and training environments.

Principal 2016 Accomplishments

- Lincoln Laboratory's embedded key-management system processor successfully underwent the National Security Agency's security verification testing.
- A quantitative, threat-based, cyber modeling and simulation capability was developed and applied to the evaluation and assessment of nationally recommended cyber defensive mitigations.
- Lincoln Laboratory led a comprehensive, multi-participant study on the cyber defense of satellite communications (SATCOM). Conducted for the Assistant Secretary of Defense for Research and Engineering (ASD[R&E]) and the Office of Net Technical Assessments, the study assessed the problems of cyber protection for SATCOM and identified concrete high-impact solutions.
- A tactical cloud security architecture was defined and developed for the U.S. Navy.
- A Tactical Cyber Range to emulate a cyber-electromagnetic warfare environment was developed and deployed in the Marine Expeditionary Force's Bold Alligator and Dawn Blitz fleet amphibious exercises.
- The Laboratory developed advanced graph analytics to rapidly detect communities of threat actors within communication networks.
- Lincoln Laboratory researchers completed an independent assessment of a major, national-level intrusion detection and prevention system. The final report identified several paths toward improving the protection provided by the system.
- Working closely with the U.S. Cyber Command's leadership, the Laboratory helped to define and establish a Capabilities Development Group that will develop rapid operational capabilities for the nation's Cyber Mission Force.
- Lincoln Laboratory delivered technology that substantially increases the efficiency of foreign language proficiency tests at the Defense Language Institute Foreign Language Center.
- Pioneering research in the analysis and exploitation of the acoustics of the lower vocal tract is enabling new techniques for forensic speaker characterization.
- New techniques for named-entity resolution and linking, developed by the Laboratory under support from the Defense Advanced Research Projects Agency, will be employed to help resolve the identities of refugees.
- The Laboratory established the MIT Lincoln Laboratory Supercomputing Center to better address supercomputing needs across all missions, develop new supercomputing capabilities and technologies, and spawn even closer collaborations with MIT campus supercomputing initiatives.
- Lincoln Laboratory deployed the third largest supercomputer located at a U.S. university to enable new research in machine learning, advanced physical devices, and autonomous systems.

Future Outlook

- The Laboratory will develop and transition a new Visualization, Summarization, and Recommendation system that will summarize audio/video datasets, visualize relations among entities, and recommend analyst-relevant searches.
- Lincoln Laboratory will perform system assessment, develop new architectural concepts, and integrate, deploy, and assess the efficacy of a next-generation national-level intrusion detection and prevention system.
- Results from an ASD(R&E) study on the cyber defense of SATCOM that Lincoln Laboratory led will guide the expansion of the Laboratory's research into securing the terrestrial and orbital components of U.S. space assets through leveraging cryptography and system security technology.
- Building on work in secure multiparty computation and other cryptographic techniques, the Laboratory will pursue additional research in enabling mutually distrusting parties to collaborate securely.
- The Laboratory will lead advances in the emerging cyber electronic warfare (cyber-EW) discipline by creating the Lincoln Cyber-EW Testbed as a focal point for research, development, and assessment of technologies that connect the cyber domain with the traditional Lincoln Laboratory mission areas.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Leadership

Dr. Robert T-I. Shin

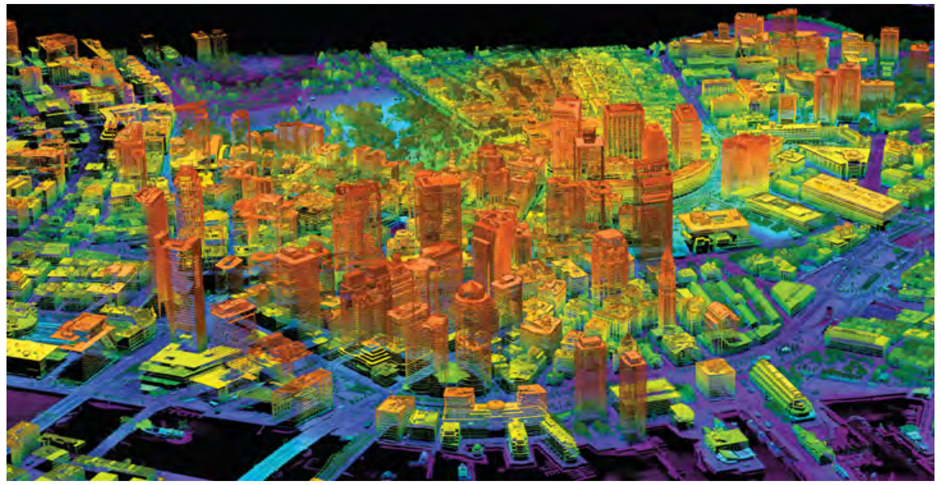
Mr. Robert A. Bond

Dr. Richard M. Heinrichs

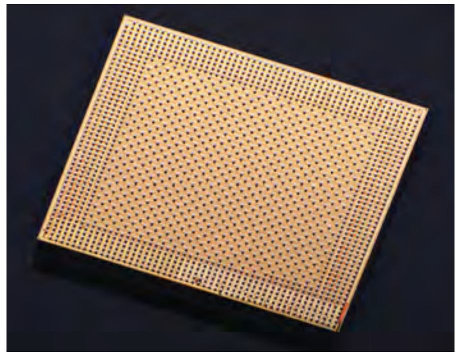
Dr. Marc N. Viera

To expand intelligence, surveillance, and reconnaissance (ISR) capabilities, Lincoln Laboratory conducts research and development in advanced sensing, signal and image processing, automatic target classification, decision support, and high-performance computing. By leveraging these disciplines, the Laboratory produces novel ISR system concepts for surface and airborne applications. Sensor technology for ISR includes passive and active electro-optical systems, surface surveillance radar, and radio-frequency (RF) geolocation. 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 demonstrated and transitioned to industry and the user community.

The objective of the Wide-area Infrared Sensor for Persistent Surveillance (WISP) system, shown here during a test flight, is to improve nighttime surveillance by using readily available detector array technology mated to a custom digital pixel readout integrated circuit developed by Lincoln Laboratory.



This high-resolution, three-dimensional (3D) image of the Boston skyline was collected with Lincoln Laboratory airborne ladar that uses state-of-the-art large-format single-photon-sensitive detector arrays. This image, representing a small fraction of the full 9 km^2 collection, demonstrates approximate 3D resolution of 25 cm, which is about the diameter of a volleyball.



Shown above is a two-trillion-operations-per-second system on chip (SoC) developed for the Defense Advanced Research Projects Agency. The SoC, measuring only 10 mm on each side, enables small ground-based mobile radios to operate at high data rates in hostile environments.

Principal 2016 Accomplishments

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

- The Airborne Wide-area Infrared System for Persistent Surveillance (AirWISP) demonstrated 500-megapixel long-wave infrared wide-area motion imagery at 1 frame per second. Also, a miniaturized high-pixel-count situational awareness sensor designed for rapid deployment on a tethered multi-rotor unmanned aerial vehicle (UAV) completed its first flight campaign.

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

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

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

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

- Working with the Defense Advanced Research Projects Agency (DARPA) on wireless communication technologies, the Laboratory successfully fabricated a two-trillion-operations-per-second system on chip that enables radio system operation in challenging environments. The chip was integrated into handheld radio prototypes whose use in multi-month field experiments demonstrated a measured performance that matched the expected theoretical performance.

- Technical evaluations were provided to the USAF's Joint Surveillance and Target Attack Radar System (JSTARS) Recapitalization program and the U.S. Navy's Triton program. Enhancements to airborne radar target detection and classification were transitioned to operational radars. The Laboratory developed test systems to enable the development of novel approaches to making radars more robust to electronic attack. Work also began on an airborne radar test bed for prototyping advanced RF and processor technology and novel radar modes.

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

Future Outlook

- Lincoln Laboratory will continue its significant support to the Department of Defense (DoD) and the intelligence community by providing architecture engineering, systems analysis, technology development, and advanced capability prototyping.

- A major focus will be on evaluating the mission utility of new ISR capabilities in future potential conflicts. This work will inform development and acquisition programs within the USAF, DARPA, and elsewhere within the DoD.

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

- The Laboratory will help the government develop, prototype, and employ open-system architecture paradigms for sensors, avionic 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.

- Air- and space-based radar systems will evolve to support new unmanned and manned platforms while exploiting advances in antennas, signal processing, and low-power embedded processing. Electronic warfare capabilities will continue to be a major focus.

Tactical Systems

Leadership


Dr. Robert T-I. Shin


Mr. Robert A. Bond

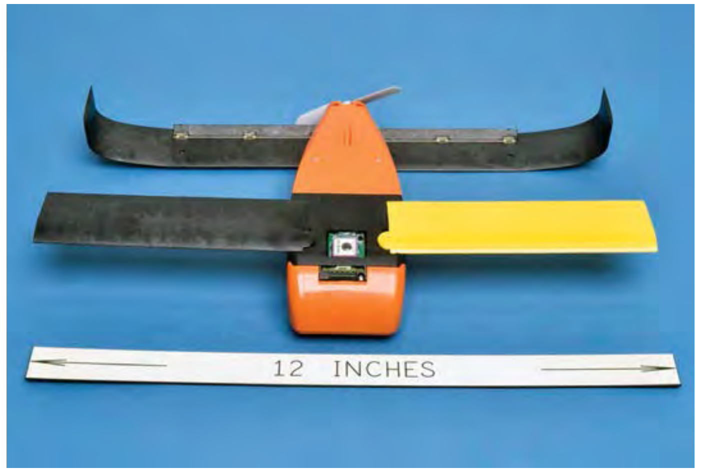

Dr. Richard M. Heinrichs


Dr. Marc N. Viera

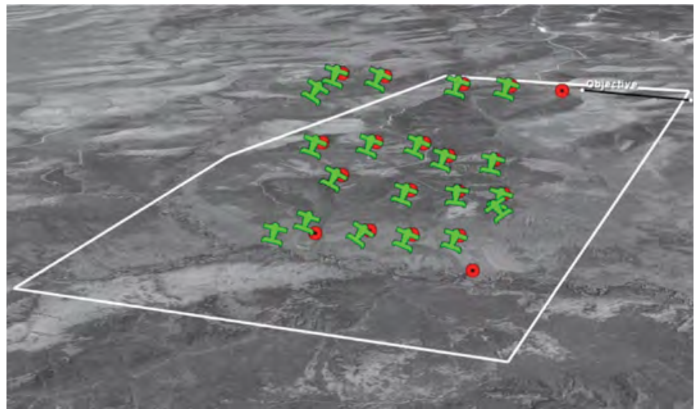

Dr. Christopher A.D. Roeser

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


The Airborne Infrared Imager (AIRI) podded system is one of the mid-wave and long-wave infrared sensors developed and custom built by the Laboratory in the 1990s. AIRI will be upgraded during a recapitalization process.



Perdix, an air-launched micro-sized folding unmanned aerial vehicle (UAV) developed at Lincoln Laboratory, was successfully tested during a June 2015 exercise in Alaska and an October 2016 exercise in California.


Twenty Perdix micro-UAVs flew in formation at the Northern Edge operational exercises in June 2015. This screenshot from a ground operator's display shows in green the locations of the UAVs as they autonomously execute a grid formation.

Principal 2016 Accomplishments

- Lincoln Laboratory completed multiple assessments of U.S. Air Force (USAF) aircraft performance and limitations against current and future foreign threats. These assessments included systems analysis, backed by laboratory and flight-testing, of advanced infrared and radio-frequency (RF) sensor kill chains, electronic attack and electronic protection, and missile systems. Findings were briefed to DoD leadership to inform their decision-making process for future system capabilities and technology investments.

- The Laboratory continues to provide comprehensive evaluation of options for USAF airborne electronic attack against foreign surveillance, target acquisition, and fire-control radars. This work involves systems analysis of proposed options, development of detailed models and fielded prototypes of threat radars, and testing of various electronic attack systems.

- New system concepts for enhancing USAF air dominance in future contested environments were developed and analyzed. These concepts incorporate advanced hardware and signal processing technology to expand capabilities in wide-area surveillance and counter-air kill chains.

- The Laboratory has continued to conduct overarching assessments of the USAF Family of Systems architectures. Mission-based assessments were performed to provide input on force structure requirements for tactical intelligence, surveillance, and reconnaissance (ISR) and strike aircraft, as well as on needed communications, sensors, and weapons systems in future stressing scenarios.

- Prototyping of advanced technologies for airborne signals intelligence (SIGINT) is continuing. Significant technical upgrades were made to an existing system, and the upgraded capabilities are currently under transfer to an industrial partner for production and fielding. In addition, a novel sensor system was successfully tested and demonstrated for an operational assessment of its potential for law enforcement applications.

- The Laboratory has begun a new counterterrorism focus area to develop novel sensors and algorithms in the areas of ground-penetrating radar, active seismic imaging, and electromagnetic gradiometry for the detection of deep improvised tunnels.

- Lincoln Laboratory conducted a field test in Toronto, Canada, of a new ground-penetrating radar design for deep tunnel detection applications. The RF-absorbing tiles on the antenna improve radiation performance of the radar.

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

- Three hundred people attended the 38th annual Air Vehicle Survivability Workshop held in May at Lincoln Laboratory.

Future Outlook

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

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

- Continued growth in electronic warfare for the DoD and intelligence community is expected, predominantly in the areas of electronic attack and electronic protection for tactical aircraft and missiles, and electronic support measures for airborne SIGINT capabilities.

- Persistent evolution is expected in global counterterrorism and counterinsurgency needs. The Laboratory will work to assess emerging threats and rapidly develop and prototype innovative system prototypes for force protection.

- Lincoln Laboratory will continue to develop and assess new ISR and tactical system concepts to understand mission utility in future potential conflicts. This work informs development and acquisition programs within the DoD.

Advanced Technology

Leadership

Dr. Robert G. Atkins

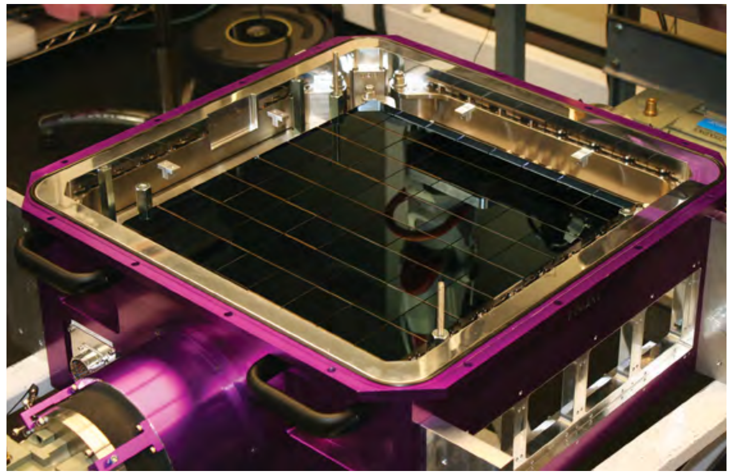
Dr. Craig L. Keast

Dr. Mark A. Gouker

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.

Lincoln Laboratory uses this prototype photon-timing 32 x 32 Geiger-mode receiver in proof-of-concept underwater laser communication and laser radar experiments. Each pixel in the receiver can detect single photons with sub-nanosecond accuracy. The receiver provides ultimate sensitivity in a small, lightweight, low-power package.

The Multifunction Phased Array Radar (MPAR) design team celebrates the completion of the MPAR 10-panel demonstrator.



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

Principal 2016 Accomplishments

- For the Joint Biological Point Detection System (JBPDS) Joint Technology Refresh program, the Rapid Agent Aerosol Detector (RAAD) was integrated into the JBPDS. The RAAD is a bioaerosol detector that dramatically reduces JBPDS life-cycle costs and false alarms. The system is undergoing testing to the JBPDS performance specification and is preparing for whole-system, live-agent, biological warfare agent testing.

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

- The Multifunction Phased Array Radar (MPAR) 10-panel demonstrator was completed and installed at the National Severe Storms Laboratory in Norman, Oklahoma, in May 2015. The system is the first dual-polarized phased array weather radar ever fielded, and the Federal Aviation Administration and the National Oceanic and Atmospheric Administration are using it to collect data on aircraft and weather targets.

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

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

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

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

Future Outlook

- The development of new sensor capabilities is motivated by the need to search for increasingly small signatures representative of threats from emerging terrorism or weapons of mass destruction. The Laboratory will continue to explore new component technologies to enable advances in sensors.

- Activities in advanced computation will continue to increase with the pursuit of quantum information systems, cryogenic CMOS, ultralow-power CMOS, and other technologies to provide more efficient specialized computation.

- The Laboratory's low-cost RF phased array panel technology will begin to transition into Department of Defense applications. The Laboratory will continue to develop wideband receiver technology for next-generation electronic warfare capabilities.

- The Laboratory will continue its development of high-energy lasers and supporting sensor systems for future fielded applications of national interest.

Homeland Protection

Leadership


Dr. Melissa G. Choi


Mr. James M. Flavin


Mr. Edward C. Wack

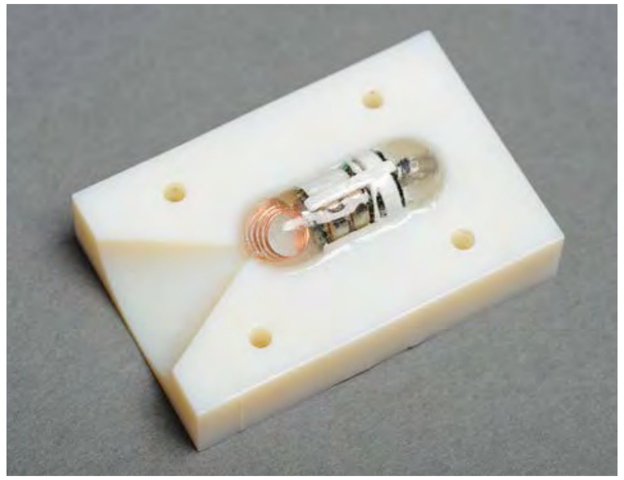

Dr. Timothy J. Dasey


Dr. Ted David

The Homeland Protection mission supports the nation's security by innovating technology and architectures to help prevent terrorist attacks within the United States, to reduce the vulnerability of the nation to terrorism, to minimize the damage from terrorist attacks, and to facilitate recovery from either man-made or natural disasters. The broad sponsorship for the mission area spans the Department of Defense (DoD), the Department of Homeland Security (DHS), and other federal, state, and local entities. Recent efforts include humanitarian assistance and disaster response architectures and technologies, new microfluidic technologies for DNA assembly and transformation and for gene synthesis, improvement of the detection and classification for air vehicle threats, and technologies for border and maritime security.


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


To ensure an effective homeland defense, researchers must understand how advanced commercial technologies could be used as potential threats and then use that information to identify adequate countermeasures to those threats. Jesse Linnell is working to rapidly prototype an unmanned aerial vehicle that uses advanced autonomy technology and that will be used to define defense capability needs.


The EnteroPhone™ is a miniature hydrophone assembly that, when ingested, "hears" the sounds of a person's heart and lungs. The device collects heart and breathing rates and wirelessly sends the data to an external receiver. The EnteroPhone also features a thermometer that measures core body temperature, an accelerometer that measures gastrointestinal motility, and a barometer that collects ambulatory manometry data.

Principal 2016 Accomplishments

- Lincoln Laboratory hosted its first workshop on neurodegeneration and hearing injury to help continue the involvement of cross-Service leadership with technical innovation to reduce the impact of noise-induced hearing injury on warfighter health and performance. The Laboratory also created algorithms based on noninvasive physiological signatures (e.g., heart rate, temperature, blood pressure) that provide warning of viral infection prior to the onset of fever.
- The Laboratory, in collaboration with the U.S. Government Chemical and Biological Defense Program and its international partners, continued to conduct a series of weapons of mass destruction (WMD) threat impact measurements that inform modeling capabilities and advanced counter–WMD technology development. Activities include measurement-based threat phenomenology studies, technology assessments, critical infrastructure remediation, and improvised-explosive-device forensics development.
- Through a partnership with the U.S. Army Research Institute of Environmental Medicine and the Marine Expeditionary Rifle Squad, the Laboratory conducted a successful field demonstration of an ultralow-power wearable physiological monitoring system that monitors warfighter heat strain in real time and operates securely in tactical environments.
- In collaboration with the Joint Improvised-Threat Defeat Agency, the Laboratory developed technologies and measurement capabilities that enhance asymmetric threat detection, defeat, and attribution.
- In support of the DHS Science and Technology Directorate and Federal Emergency Management Agency efforts to insert new technology into national hurricane-evacuation decision support tools, the Laboratory initiated the rebuilding and expanding of web-based prototypes to develop new decision analytics, improve training through an integrated serious games platform, and create planning tools for evacuation zones.
- In synthetic biology work, the Laboratory has designed and prototyped cell-based biochemical sensors that reduce sensor response time from hours to seconds.
- The Laboratory led architecture development and technology assessments for the National Capital Region's air defense system.
- A multimodal immersive laboratory was built for noninvasive cognitive and physiological monitoring research. The facility includes a virtual-reality dome that features 360-degree visualization, motion capture via 18 cameras, a reversible, dual-belt, high-acceleration treadmill with integrated force plates and 6-degrees-of-freedom actuation, and wearable sensors.
- Video analysis automation for law enforcement, border patrol, and mass transit security has been developed to significantly accelerate the ability of operators to extract information from videostreams. Operational pilots were deployed to drive system refinement.

Future Outlook

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

Air Traffic Control

Leadership

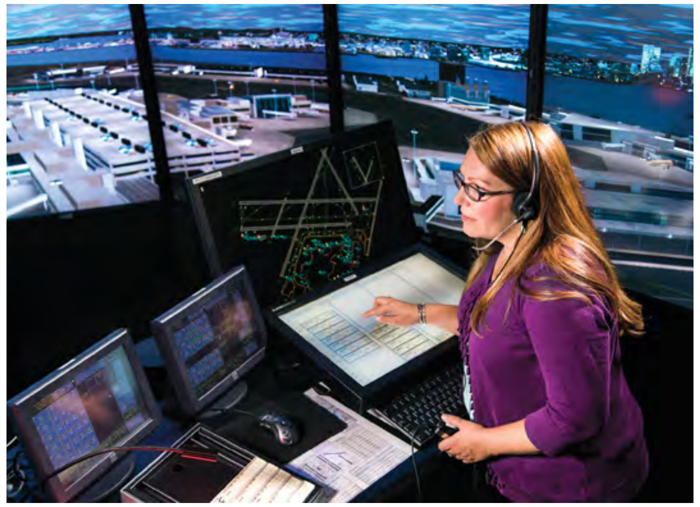
Mr. James M. Flavin

Dr. James K. Kuchar

Dr. Gregg A. Shoults

Dr. Marilyn M. Wolfson

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



The Laboratory is developing technologies and procedures to improve airport surface operations. In the Laboratory's control tower simulation facility, Amy Alexander uses integrated electronic flight data and surveillance systems to direct an aircraft to taxi toward the runway.

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

This Zeta Science FX-61 Phantom is part of the Laboratory's small unmanned aircraft system test bed that is used to rapidly evaluate advanced surveillance and collision avoidance technologies. In 2016, to assess ACAS X, several Phantoms performed mid-air encounters that were too dangerous to conduct with manned aircraft.

Principal 2016 Accomplishments

- The recently constructed 10-panel Multifunction Phased Array Radar (MPAR) prototype will be used to refine requirements and quantify dual-polarization performance for weather observations. In partnership with the FAA and the National Oceanic and Atmospheric Administration, the Laboratory began the design of a full-scale 76-panel array.
- Development work was initiated on a Small Airport Surveillance Sensor that has the potential to provide low-cost terminal-area surveillance. Two prototype apertures have been developed to demonstrate real-time passive surface surveillance of aircraft.
- Algorithm improvements continued for the Offshore Precipitation Capability (OPC), which uses lightning, satellite, and meteorological model data to generate a global radar-like view of convective weather that is beyond the coverage of radars. The Laboratory will continue to expand the OPC domain and utilize data from the next-generation Geostationary Operational Environmental Satellite–R Series.
- Lincoln Laboratory is playing a key role in developing the Airborne Collision Avoidance System X (ACAS X), which will support new flight procedures and aircraft classes. In conjunction with the FAA Technical Center, the Laboratory conducted a full system test of the ACAS X architecture. The successful flight test allows the ACAS X program to begin operational evaluation in 2017.
- Standards and algorithms are being developed for unmanned aircraft system (UAS) sense-and-avoid capabilities for the Department of Defense (DoD), Department of Homeland Security, and FAA. The Laboratory is working to extend the "well clear" separation standard, initially developed for large UAS (over 55 lb) to small UAS (under 55 lb).
- The Laboratory completed the development of ground-based sense-and-avoid (SAA) systems and is transitioning them to U.S. Army and U.S. Air Force sites. This transition will enable the first general-purpose SAA systems for unmanned aircraft in the National Airspace System (NAS).
- Analyses are being conducted to guide the FAA on wind information needs for NextGen applications, including four-dimensional trajectory-based operations and interval management procedures. These analyses are guiding performance requirements and standards for efficient NextGen procedures.
- Operational improvements are being developed to mitigate the environmental impacts of aviation. The Laboratory is developing and assessing decision support tools that reduce taxiway congestion, efficiently balance queues of aircraft at departure runways, save fuel, reduce emissions, and mitigate noise during aircraft approach.
- The Laboratory is supporting the FAA in assessing potential cyber security safety risks on commercial transport aircraft and is working with the FAA Cyber Test Facility to enhance their test and evaluation capabilities for protecting systems within the NAS.

Future Outlook

- Lincoln Laboratory will apply its expertise in surveillance processing, data management, algorithms, and human systems integration to increase its role in developing future NextGen concepts, including trajectory-based operations, interval management, Automatic Dependent Surveillance–Broadcast applications, environmental impact mitigation, and surface operations management.
- Requirements definition, prototyping, and technology transfer support for next-generation weather capabilities will be ongoing. These capabilities include improvements in sensing technology, data dissemination architectures, decision support tools for managing air traffic at congested airports during severe weather, and algorithms for estimating airspace capacity reductions caused by thunderstorms.
- Work beginning in 2017 for ACAS X will focus on an operational evaluation of the ACAS X version for manned aircraft. Planning is under way to conduct a flight test of a UAS version of ACAS X that will incorporate an updated logic and support noncooperative surveillance.
- The Laboratory will continue supporting national and international efforts to integrate UAS into civil airspace. This support includes developing standards and requirements, safety evaluation methods, threat detection and maneuver algorithms, and real-time prototypes that will culminate in the transfer of technology to the FAA, DoD, and industry.

Engineering

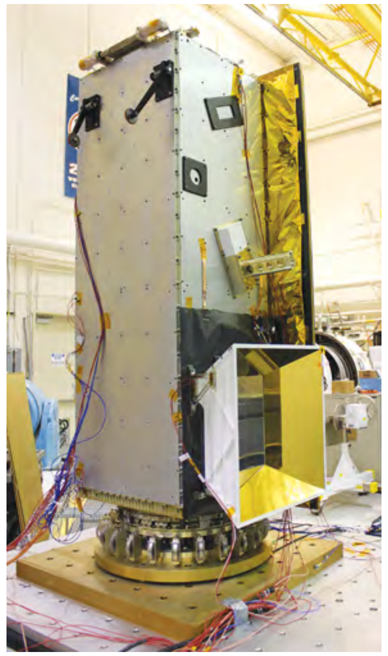
Leadership


Dr. Michael T. Languirand


Dr. William R. Davis


Dr. William D. Ross

The ability to build hardware systems incorporating advanced technology is fundamental to the success of Lincoln Laboratory. These systems are used as platforms for testing new concepts, as prototypes for demonstrating new capabilities, and as operational systems for addressing warfighter needs. To develop the variety of systems used in programs across all mission areas, the Laboratory relies on its extensive capabilities in mechanical, structural, aeronautical, thermal, optical, controls, electrical, and systems engineering, as well as its engineering expertise in energy and autonomous systems. Hardware development activities are supported by state-of-the-art mechanical and electrical fabrication and environmental testing facilities. These capabilities are centered in the Engineering Division, which is an important contributor to the Laboratory's many successful efforts.



An important activity in Lincoln Laboratory's Engineering Division is to ensure that prototype systems will survive and operate in harsh environments. For example, missile launchers impose challenging vibration, acoustic, and shock loads on satellites. The photo at left shows a structural mockup of the 1.5 m Operationally Responsive Space–5 SensorSat that is undergoing vibration qualification tests on an electrodynamic shaker capable of imposing loads of up to 20,000 lb.

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

Expeditionary autonomy explores how first responders and warfighters can effectively work with robots. Researchers are investigating opportunities to use sight, touch, and gesture tracking to intuitively understand data gathered by autonomously operated unmanned aerial and ground vehicles.

Principal 2016 Accomplishments

- The Laboratory continues to take advantage of the unique fabrication geometries provided by additive manufacturing technology. Plastic parts are now widely used in prototype systems. The Laboratory acquired a new selective laser melting (SLM) machine for metal parts and has focused research efforts on understanding the properties of SLM-produced metals. In collaboration with MIT, the Laboratory is developing a multimaterial printer that uses micron-scale particles.
- Environmental testing of the Transiting Exoplanet Survey Satellite (TESS) instrument is coming to a close, and the instrument will ship for integration onto the spacecraft in 2017. The Laboratory had responsibility for lens design, fabrication, test, and environmental qualification for TESS and the charge-coupled device packaging.
- The Laboratory continues to invest in test equipment to meet the demands of current programs and to provide capabilities for the Engineering Prototyping Facility. Equipment acquisitions included an SLM additive manufacturing printer, a 20,000 lb vibration shaker, and a thermal vacuum chamber for testing space payloads.
- A Small Satellite Cell was established to support Laboratory efforts in developing small satellite concepts and prototypes. Efforts completed this year include the Advanced Radiometric Calibration Satellite, Operationally Responsive Space–5 SensorSat, and two CubeSats for weather forecasting. In addition, research is being conducted on hydrogen peroxide propulsion and deployable antenna concepts for CubeSats.
- In the field of computational imaging, new types of optical sensors are being developed. Laboratory efforts focus on an array camera with digital super-resolution that can achieve a reduction in the size of the optics; optically multiplexed imaging to increase field of view and resolution; and time-encoded multiplexed imaging to turn a digital focal plane array into a multidimensional imager.
- The Energy Systems Group continues to focus on advancing critical Department of Defense and national capabilities, including tactical microgrids and energy solutions for soldiers and unmanned vehicles. Recent work includes an emphasis on enhancing the resiliency of the regional electric grid.
- The annual engineering workshop was renamed the Advanced Prototype Engineering Technology Symposium. The sixth annual symposium, held in November 2016, focused on advanced materials and fabrication, precision engineering, autonomous systems, and small satellites.

Future Outlook

- Work will continue on the design of the new Engineering Prototyping Facility, which will provide a significant increase in space for fabrication, integration, and testing.
- New technology investment will be focused on developing a model-based engineering approach for more efficient program execution.
- The capability to assemble circuit boards with chip-scale packages and bare die will be added to existing surface-mount circuit board assembly capabilities to aid in electronics miniaturization and performance improvement.
- Technology efforts will focus on evaluating emerging new materials, including hierarchical and multifunctional materials, with advanced structural and thermal properties for reduced size, weight, and power of prototype systems.

LABORATORY INVOLVEMENT

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Awards and Recognition 61

Committee members of the Lincoln Employees' African American Network received a 2016 MIT Excellence Award for their efforts to advance inclusiveness in the workplace and to support outreach programs in local communities.

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

Independent Activities Period at MIT
Lincoln Laboratory technical staff led activities offered during MIT's Independent Activity Period (IAP), a four-week term from 4 to 29 January. Under the IAP program, for-credit classes are available for registered MIT students, and non-credit activities, which may span the full four weeks or a limited number of days, are open to all members of the MIT community. IAP offerings range from academic classes to hands-on engineering projects to artistic pursuits.

During the 2016 intersession, David Sun Kong taught a for-credit course offered by the MIT Department of Biological Engineering: *Fluidics for Synthetic Biology: Prototyping Microbial Communities*.

Lincoln Laboratory staff members developed and led eight non-credit offerings in 2016:

- *Build a Small Radar System*
- *Designing Systems for Humanitarian Assistance and Disaster Relief*
- *Developing Systems for Humanitarian Assistance and Disaster Relief*
- *Hands-on Holography*
- *Introduction to Lasercom: Build a Laser Audio Link*
- *RACECAR: Rapid Autonomous Complex-Environment Competing Ackermann-steering Robot*
- *Software Radio*
- *Software Reverse Engineering*

During the *Introduction to Laser Communications* IAP course, Lincoln Laboratory senior staff member David Caplan helps students learn to use diagnostic tools and test optical receiver terminals.

Lincoln Laboratory technical staff member Robert Freking guides students through an interactive exercise in computational holography during a Laboratory-sponsored course, *Hands-On Holography*, held at Beaver Works during the 2016 MIT Independent Activities Period.

BEAVER WORKS SPOTLIGHT

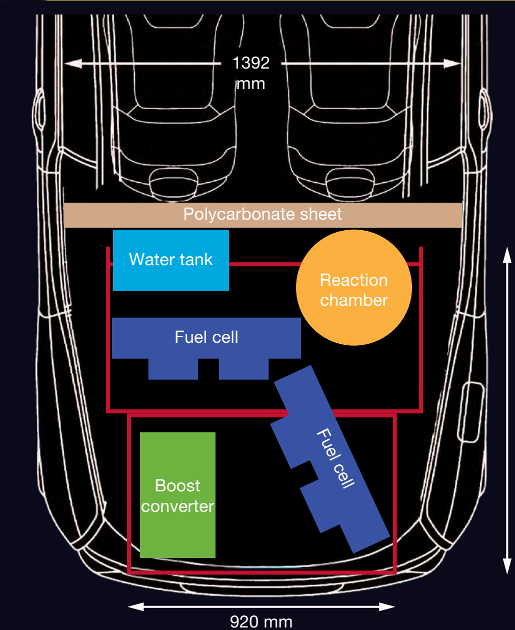
Exploring Aluminum as a Fuel

Students in the MIT undergraduate courses Engineering Systems Design and Engineering Systems Development, offered by MIT's Department of Mechanical Engineering in collaboration with Lincoln Laboratory, are investigating the potential for aluminum as a fuel source. Aluminum reacts with water to generate hydrogen gas that can be harnessed to drive a fuel cell. If this reaction can be optimized for use as a power source, what applications could take advantage of aluminum fuel? This is the question teams in these 2015–2016 capstone courses are seeking to answer.

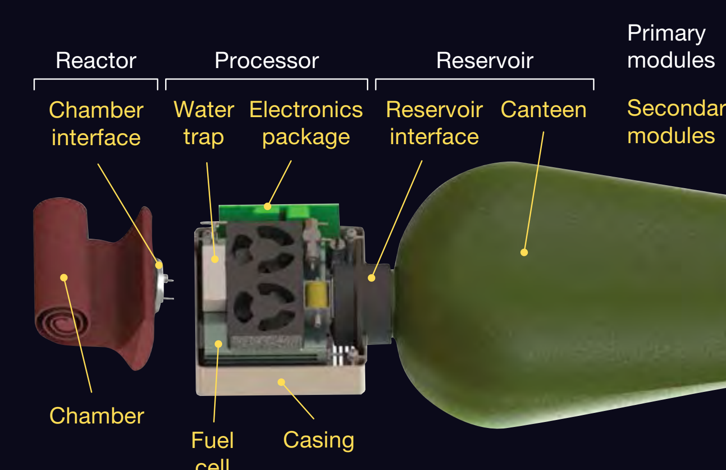
One team is exploring how to optimize the aluminum fuel chemistry to make it reliable and efficient. Three other teams are attempting to use the fuel for various systems—an all-electric vehicle, a recharging system for unmanned underwater vehicles, and a lightweight emergency power pack for soldiers.

The aluminum-water fuel cell is an attractive power source because aluminum is abundant, safe, and energy dense, i.e., it contains a lot on energy in a relatively small volume. However, aluminum does not inherently react with water; the reaction must be activated by the introduction of another chemical element. Determining what to use as an activation element and how to fuse it with the aluminum is the challenge of developing the aluminum fuel. The research team is currently using another metal, gallium, as the activation element.

This two-semester sequence of courses is one of the projects conducted under the Beaver Works initiative, a collaborative venture between Lincoln Laboratory and the MIT School of Engineering. This year's sequence builds upon the work of three previous sets of capstones that have researched aluminum fuel and built power sources for an unmanned underwater vehicle. Lincoln Laboratory researchers have continued serving as advisors for these capstones, providing expertise in engineering design and fabrication of the proof-of-concept models the students build.



BMW donated a new model i3 electric vehicle to the class to modify with their fuel system. As seen in the drawing, the back seats will be removed to make room for the complete system that includes the water tank, reaction chamber, fuel cells, and a boost converter. The students envision repainting and detailing the vehicle to look like the conceptual image seen above. The new vehicle was named Sindri after a character in Norse mythology whose name translated to "Spark-maker" and who created magical devices, such as the god Thor's hammer



The design of the man-portable emergency power pack calls for a heavyweight nylon canteen-sized water reservoir that funnels water to the reactor chamber that contains the gallium-infused aluminum fuel. The resulting hydrogen energy powers the fuel cell, which produces electrical power. This entire device weighs about 740 grams, and after use, the reactor chamber can be collapsed to become a smaller package.

>> *Technical Education, cont.*

Advanced Concepts Committee

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

The 2016 slate of ACC projects includes two investigations that are joint efforts with MIT faculty:

- Prof. Lydia L. Bourouiba, Department of Civil and Environmental Engineering, and William Lawrence, Chemical and Biological Defense Systems Group, are exploring *How Bubbles Burst*. Bubbles are at the core of water-air exchanges of chemical and biological materials and are well known to produce millions of droplets that can be transported over long-distances in the air. This project combines experiments and theory to characterize the dissemination of airborne chemical and biological contaminants.

- Profs. Caroline Ross and Juejun Hu, Department of Materials Science and Engineering, are working with Reuel Swint, Paul Juodawlkis, and Gerald Dionne, Quantum Information and Integrated Nanosystems Group, on *Integrated Magneto-optical Isolators for Infrared-Visible (IR-Vis) Wavelengths*. This effort is exploring new magneto-optical materials and component designs to increase the performance of integrated isolators and circulators and to expand their range of operation from near-infrared into the visible. The goal is to reduce the size, weight, and power, as well as the cost, of optical systems.

VI-A Master of Engineering Thesis Program

Students in MIT's VI-A Master of Engineering Thesis Program spend two summers as paid interns at Lincoln Laboratory, contributing in projects related to their courses of study. Then, the students work as research assistants while developing their master of engineering theses under the supervision of both Laboratory engineers and MIT faculty. Typically, about a half-dozen VI-A students participate 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.

Undergraduate Research Opportunities and Practice Opportunities Programs

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

Most participants at the Laboratory are interns working under the direct supervision of technical staff members. The students engage in every aspect of onsite research—developing research proposals, performing experiments, analyzing data, and presenting research results. In summer 2016, eight undergraduates were hired as UROP interns and four as UPOP interns.

Lincoln Laboratory Showcases Technology at MIT Open House

On 23 April, MIT hosted an Open House to celebrate the Institute's move to Cambridge, Massachusetts, 100 years ago. At this community-wide event, MIT's diverse research initiatives, facilities, and cultural programs were featured in exhibits, tours, and performances. During the Open House, Lincoln Laboratory volunteers presented demonstrations of ten novel technologies developed by the Laboratory in recent years. Above, technical staff member Idahosa Osaretin (at far right) describes the capabilities of a small satellite designed to carry a sensor that makes weather observations.

In summer 2016, Lincoln Laboratory employed 215 undergraduate and graduate students from 88 different schools to work as interns in its technical groups.

INTERNSHIPS FOR UNIVERSITY STUDENTS

Lincoln Laboratory offers several opportunities for university students to engage in meaningful internships in technical groups. Under some programs, students fulfill an academic requirement, while other programs support thesis work at specific universities or offer paid intern positions. The students broaden their education through the experience of tackling real-world engineering problems, and their internships can evolve into post-graduation employment.

Summer Research Program

In 2016, 215 undergraduate graduate students from 88 different schools participated in Lincoln Laboratory's Summer Research Program, which offers students from top universities across the country internships in technical groups. The students gained hands-on experience in a foremost research environment while contributing to projects that complement their courses of study.

Each summer, cadets from the military academies accept internship positions at the Laboratory. They acquire engineering experience and insight into the ways advanced technology can solve problems faced by the military. In summer 2016, 57 cadets and midshipmen worked in technical groups across the Laboratory.

University Cooperative Education Students

Technical groups at Lincoln Laboratory employ students from area colleges under cooperative education arrangements. The students work full time with mentors during the summer or work/study semesters and part time during academic terms. Highly qualified cooperative education students are significant contributors to technical project teams. In 2016, 78 co-ops worked in divisions and departments at the Laboratory.

Worcester Polytechnic Institute Major Qualifying Project Program

In summer 2016, six 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.

>> *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 of the Service branches. This partnership acquaints military officers with the process if developing technologies that directly impact national security while providing the Laboratory with constructive insights of officers.

- Officers enrolled in a Senior Service School work in research programs at the Laboratory and take national security management courses at MIT campus.
- Senior officers participating in the Army's Training with Industry program are assigned full time to a Laboratory technical group.
- Fellows pursuing graduate degrees work on Laboratory-sponsored programs that complement their thesis research.
- Military liaisons are employed at the Laboratory, and 55 cadets and midshipmen from U.S. service academies served summer internships.

Currently, 45 active-duty Military Fellows are conducting research in various divisions throughout the Laboratory.

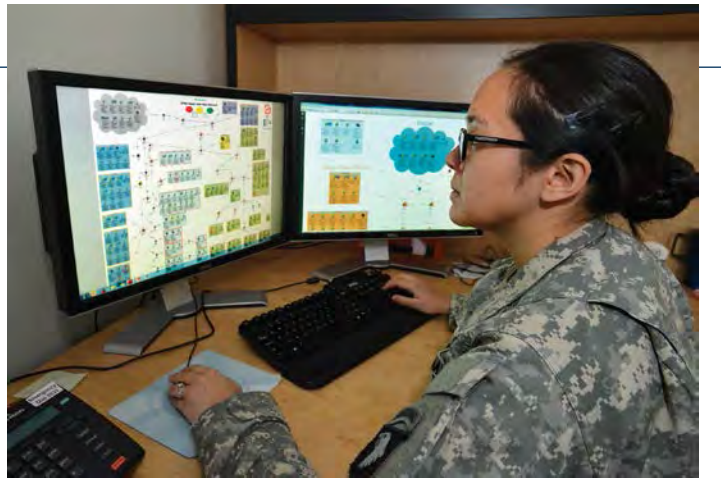
SPOTLIGHT
Colonel Stephen E. Gabavics, U.S. Army

Colonel Stephen Gabavics works with colleague Christina Zook of the Bioengineering Systems and Technologies Group to use a next-generation deoxyribonucleic acid (DNA) sequencing system.

After more than 20 years of Army experience, including operational deployments in Bosnia and Kosovo and two tours in Afghanistan, Colonel Stephen E. Gabavics undertook an assignment on home soil as a U.S. Army War College Fellow at MIT and Lincoln Laboratory. While enrolled in the Security Studies Program at MIT, COL Gabavics provided operational insights to several technical groups within the Laboratory. In turn, he learned about an array of Laboratory-developed technologies that could be advantageous to military operations. COL Gabavics' goal was to connect the Laboratory with government agencies, sponsors, and other sources that may be interested in the technologies under development. "It is great to have the opportunity to see what is being done here at the Laboratory," said COL Gabavics. "I am amazed at the amount of research and development that happens across the entire spectrum of technologies." Following the completion of his fellowship in June 2016, COL Gabavics began his new assignment in Guantanamo Bay, Cuba.

SPOTLIGHT
Captain Stephanie Stuck, U.S. Army

"My experience working at Lincoln Laboratory has been eye-opening. Because I usually see technology from a user-interface perspective, watching Laboratory researchers develop that technology from the back end gives me a different perspective about the technologies I use every day," said Captain Stephanie Stuck. As a participant in the Army's Training with Industry program, CAPT Stuck worked within several technical groups at the Laboratory, studying information systems management, cyber range assessment, and tactical networks. Her work at the Laboratory gave her the experience necessary to further her career within the Army's information systems and cyber fields. CAPT Stuck hopes to become a cyber warfare officer within the U.S. Army Cyber Command, which works to protect the nation from cyber adversaries.



Captain Stephanie Stuck reviews a network diagram that maps a cyber range used for operator training and evaluation. Cyber ranges are used for testing tools and evaluating cyber defensive systems.

WORKSHOPS AND SEMINARS

2016 Defense Technology Seminar

The 2016 Defense Technology Seminar was held at Lincoln Laboratory in April. Sixty-four military officers and Department of Defense civilian employees attended the weeklong event that focused on evolving military challenges. Technical staff from the Laboratory and nationally prominent guest speakers presented seminars on national security and current geopolitical issues.

2016 Schedule of Lincoln Laboratory Workshops

APRIL

5–6	Lincoln Laboratory Communications Workshop
11–15	Defense Technology Seminar for Military Officers

MAY

3–5	Space Control Conference
10–12	Air Vehicle Survivability Workshop
11	Advanced Research and Technology Symposium, at the MIT campus
17–19	Air, Missile, and Maritime Defense Technology Workshop
24–26	Advanced Technology for National Security Workshop

JUNE

7–9	Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
21–23	Cyber and Netcentric Workshop
28–30	Homeland Protection Workshop Series

OCTOBER

26–27	Human Language Technology and Applications Workshop

NOVEMBER

8–9	Advanced Prototype Engineering Technology Symposium
15–17	Anti-access and Area Denial (A2/AD) Systems and Technology Workshop

At workshops hosted throughout the year, Lincoln Laboratory shares its research advancements with the technical and defense communities. The workshops address technology developments in the Laboratory's 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 innovative technology to their fields. These events provide valuable exchanges of ideas and insights into the direction for future research. Most workshops run for two to three days. The exception is the Defense Technology Seminar, a week-long program of seminars and tours offered to approximately 50 to 75 invited guests from the military and government agencies.

2016 Offsite Workshops

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

10–12 May — 2016 IEEE International Symposium on Technologies for Homeland Security, Waltham, Massachusetts

18–19 May — Graph Exploitation Symposium, Dedham, Massachusetts

21–23 June — Cyber Endeavor, at the Naval Postgraduate School in Monterey, California

13–15 September — 2016 IEEE High Performance Extreme Computing Workshop, in Waltham, Massachusetts

Fall and winter 2016 — Air Traffic Control Workshop coordinated with the Federal Aviation Administration (FAA) and held in at the FAA Headquarters in Washington, D.C.

>> *Technical Education, cont.*

PROFESSIONAL DEVELOPMENT

Lincoln Laboratory's extensive research and development accomplishments are enabled by the strength of its staff. To support and build this strength, the Laboratory offers a variety of educational opportunities and technical courses to its employees.

Lincoln Scholars Program

Technical staff members are eligible to apply to the highly competitive Lincoln Scholars Program, under which the Laboratory funds full-time graduate study at MIT or other local universities. While pursuing a master's or doctoral degree, scholars complete thesis research that pertains to a Laboratory mission; work at the Laboratory in between semesters; and make substantial technical contributions to the Laboratory under terms arranged with the Graduate Education Committee. Each scholar is paired with a mentor who oversees his or her academic and Laboratory work throughout the duration of the program. After receiving their degrees, participants return to work at the Laboratory full time. Currently, 22 staff members are enrolled in the program.

Part-Time Graduate Studies Program

The Part-Time Graduate Studies Program (PGS) enables staff to work full time at the Laboratory while pursuing part-time technical and nontechnical graduate studies via distance learning or at local universities. Of the 16 employees participating in the pilot program, six have graduated from their degree programs.

Boston University Program

Core and elective courses from Boston University's (BU) master's program in computer science (MSCS) are offered onsite at Hanscom Air Force Base. These courses, which have included Computer Networks, Cryptography, and Software Engineering, can be taken independently or as part of a certificate or master's degree program through BU. Since the program started in 2012, nearly 130 staff members have taken courses through the MSCS program.

Technical Education Program Onsite Courses

Lincoln Laboratory offers technical education programs designed to help employees expand their knowledge and versatility in unique areas across the Laboratory. A range of technical, programming, and software application courses are taught by either Laboratory experts or outside instructors. Technical courses are typically multisession and are similar to college- or graduate-level courses. The sessions cover a wide range of topics such as microelectronics and undersea technologies. Certification courses for various operating systems and network devices and classes that cover programming languages and interactive computing environments are offered regularly.

Lincoln Laboratory Overview for Employees

Lincoln Laboratory provides comprehensive educational programs for new employees. The Lincoln Laboratory Overview for New Employees is a three-day program offered to technical and administrative staff. Participants are briefed by division and department leadership; tour Laboratory facilities; and network with colleagues. The Lincoln Laboratory Support and Service Overview is a two-day program for support and service staff in which employees learn about the Laboratory's critical research and development accomplishments and tour key facilities.

As part of the *Laser Physics, Technology, and Applications* technical education course, John J. Zayhowski, senior staff in the Laser Technology and Applications Group, discusses optical amplifiers during the Amplifiers, Nonlinear Optics, and Beam Combining lecture.

Diversity and Inclusion

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

Members of the 2016 Martin Luther King, Jr. Luncheon planning committee are pictured with keynote speaker Aprille Ericsson and Lincoln Laboratory Director Eric Evans.

Annual Martin Luther King, Jr. Luncheon

"We're here to honor a great American whose leadership and vision changed the direction of the nation," said Lincoln Laboratory Director Eric D. Evans during his opening remarks at the Martin Luther King, Jr. Luncheon held at the Minuteman Commons Community Center on Hanscom Air Force Base on 23 February. Organized by the Lincoln Employees' African American Network (LEAN), the event featured keynote speaker Dr. Aprille Ericsson, program manager for Small Business Innovative Research and Small Business Technology Transfer Research at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center (GSFC). Addressing the nearly 220 guests, Ericsson focused her talk on the theme "Converging on the Dream," detailing how Dr. King's legacy influenced her life and career. Ericsson was the first African American female to earn a doctorate in mechanical engineering from Howard University and the first African American female to receive a doctorate in engineering at NASA's GSFC. In 2015, *Business Insider* named Ericsson the eighth most powerful female engineer in the world. "Visionaries like Dr. King and Rosa Parks stood up for diversity so that I could be here today, and now I have a vision of diversity," said Ericsson. "I want to plant the seeds necessary to increase the number of women and minorities in aerospace and engineering."

"Diversity is at the core of Lincoln Laboratory's values. We need to follow Martin Luther King, Jr.'s example by refusing to rest until we are recognized for our diverse culture. We need to get it right."

Director Eric D. Evans, opening remarks

>> *Diversity and Inclusion, cont.*

Employee Resource Groups

Lincoln Laboratory's employee 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
- Women's Network
- Hispanic/Latino Network
- Out Professional Employee Network
- African American Network
- Veterans Network
- Pan Asian Laboratory Staff Network
- Employees with Disabilities Network

A new employee resource group, the Pan Asian Laboratory Staff Network (PALS), was established. The group celebrates the diversity of Lincoln Laboratory by adding a forum in which one can explore, understand, and share a variety of Asian cultures. In February, PALS hosted a Lunar New Year celebration, at which attendees learned how the Year of the Monkey (2016) is celebrated across Asia.

Several activities were held in June as part of Lesbian, Gay, Bisexual, and Transgender Pride Month, including an ice cream social and a Boston Pride Parade march.

Mentorship Programs

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

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

In 2016, 282 people participated in the mentorship programs. A new cycle of Career Mentoring began with 59 mentors and 59 mentees, while 18 mentors and 120 mentees are participating in Circle Mentoring, and 13 mentors and 13 mentees are participating in Assistant Group Leader Mentoring.

GEM National 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 and GEM President Eric D. Evans attended the 2016 GEM Annual Board Meeting and Conference in Miami Beach, Florida. At the event, GEM officers and partnering organizations engaged in discussions on strategies for transforming how the United States educates and prepares the next generation of engineers and scientists.

Lincoln Laboratory Director and GEM President Eric Evans is photographed with the 2016 GEM summer interns and their Laboratory staff mentors.

Awards and Recognition

The commitment to excellence that characterizes our staff has enabled the Laboratory's 65 years of achievements and its sustained reputation for innovation.

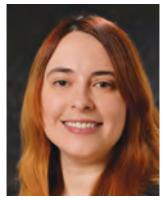
2015 Technical Excellence Awards

Dr. Daniel A. O'Connor, for his outstanding technical contributions to the field of ballistic missile defense (BMD), creativity in developing and demonstrating techniques for BMD, and leadership in initiating a major national effort in discrimination technology.

Joseph J. Scozzafava, for his leadership and creativity in developing laser communications technology, significant contributions to solving critical mechanical issues on major space payload and radar developments, and innovative work on mechanical rotary interface and electro-optical devices.

2015 Early Career Achievement Awards

Dr. Bow-Nan Cheng, for his work in the development, understanding, and standardization of radio-to-router interface technology as a means to separate radio and router functionality and to allow greater interoperability among systems.



Dr. Francesca D. D'Arcangelo, for her systems analyses and architecture development in the areas of counter–unmanned aircraft systems, chemical and biological threat detection, air security, border monitoring, and maritime security.

2015 MIT Lincoln Laboratory Best Paper Awards

Dr. Timothy M. Yarnall, Dr. David J. Geisler, Mark L. Stevens, Dr. Curt M. Schieler, Dr. Bryan S. Robinson, and **Dr. Scott A. Hamilton**, for their paper "Multi-aperture Digital Coherent Combining for Next-Generation Optical Communication Receivers," which was delivered at the IEEE International Conference on Space Optical Systems, 28 October 2015.

Dr. Danielle A. Braje, Hannah A. Clevenson, Matthew E. Trusheim, Carson A. Teale, Dr. Tim Schröder, and **Prof. Dirk R. Englund**, for their paper "Broadband Magnetometry and Temperature Sensing with a Light-Trapping Diamond Waveguide," which appeared in *Nature Physics Letters*, 6 April 2015.

Grant Stokes elected to the National Academy of Engineering

Dr. Grant H. Stokes was elected a member of the National Academy of Engineering (NAE) for his "innovations in systems for space situational awareness and the discovery of near-Earth asteroids."

The NAE, an independent nonprofit institution, promotes the engineering profession and provides the federal government with objective insights on technology matters. Elected on the basis of their contributions to research, engineering practices, and education, members of the NAE are among the most accomplished engineers in the world.

As head of the Space Systems and Technology Division, Grant is responsible for the Laboratory's programs in space control and electro-optical systems and technology. He supervised the demonstration and transition of the first space-based space surveillance system to Air Force operations. To develop next-generation technology for improving space situational awareness, he initiated several programs, notably the Space Surveillance Telescope, a 3.5-meter-aperture prototype ground-based surveillance search system, and the dual-band (X and W) Haystack Ultrawideband Satellite Imaging Radar, the highest-resolution, long-range satellite characterization sensor in the world.

Grant directs the development and operations of the Lincoln Near-Earth Asteroid Research program, which has become the world's premier asteroid search capability, finding ~50% of the near-Earth asteroids discovered since 1998.

In 2008, Grant was honored with the Air Force Meritorious Civilian Service Award for his four years of service to the Air Force Scientific Advisory Board. He chaired the 2006 Science and Technology Review of the Space Vehicles Directorate of the Air Force Research Laboratory and the 2007 review of the Air Force Office of Scientific Research. In 2010, he was named an IEEE Fellow for his leadership in the development and implementation of advanced space search systems.

>> *Awards and Recognition, cont.*

2015 Best Invention Award

Dr. Yaron Rachlin, **Dr. Tina Shih**, **Dr. R. Hamilton Shepard**, and **Vinay N. Shah**, for their invention “Rapid and Precise Optically Multiplexed Imaging,” for which a technology disclosure was filed March 2015 and a provisional patent application was filed May 2015.

2016 Fellow of the Institute of Electrical and Electronics Engineers

Dr. Dimitris G. Manolakis, for “contributions to signal processing education, algorithms for adaptive filtering, and hyperspectral imaging.”

2016 MIT Lincoln Laboratory Administrative and Support Excellence Awards

The 2015 recipients of Administrative and Support Excellence Awards are, left to right, Amy Grossman, Jon Barron, Donna Dickerson, and Anne Marie Cappucci.

Administrative category: **Donna E. Dickerson**, for her exceptional work to ensure the effective management of the finances of her group’s diverse portfolio of programs; **Amy S. Grossman**, for her comprehensive knowledge of security regulations that she applies to managing critically important components of the Laboratory’s Personnel Security Assurance Program.

Support category: **Anne Marie Cappucci**, for her excellent administrative skills that are instrumental in helping the Microelectronics Laboratory operate as a world-class silicon fabrication facility; **Jon C. Barron**, for his outstanding photography that contributes directly to maintaining the high-caliber of the Laboratory’s most important publications.

2016 MIT Excellence Awards

Seven individuals and a team from Lincoln Laboratory are among the 2016 MIT Excellence Award recipients:

Advancing Inclusion and Global Perspectives: Lincoln Employees’ African American Network (LEAN) Committee—**Dr. Raoul O. Ouedraogo**, **Dr. David C. Freeman**, **Bakari N. Hassan**, **Dr. Crystal A. Jackson**, **Dr. Shakti K. Davis**, **Jason B. Williams**, **Brandon K. Matthews**, and **John O. Nwagbaraocha**
Bringing Out the Best: **Dale A. Eastwood** and **Tamara H. Yu**
Innovative Solutions: **Dr. R. Hamilton Shepard**
Outstanding Contributor: **C. Chamee Cross**, **Dorothy S. Ryan**, and **Joshua W. Manore**
Sustaining MIT: **Matthew Hubbell**

2015 Superior Security Rating

Awarded to Lincoln Laboratory’s collateral security program from the U.S. Air Force 66th Air Base Wing Information Protection Office. This is the 10th consecutive Superior rating for the Laboratory.

2016 Aviation Week Network’s 20 Twenties Honorees

Jillian M. James and **Sophia Yakoubov** were selected by Aviation Week Network as two of its 20 Twenties, an annual recognition of 20 engineers in their twenties whom the network, in partnership with the American Institute of Aeronautics and Astronautics, identified as having already made significant contributions to research and innovation in engineering, math, and science.

Robert H. Goddard Award for Exceptional Achievement for Engineering

The Optical Multiple-Access Innovation Team, composed of scientists from NASA and **Drs. Don M. Boroson** and **Bryan S. Robinson** from Lincoln Laboratory, was recognized for their contributions to the development of an architecture for the Space Mobile Network, a NASA effort to provide users with a space-based communications and navigation experience that is closer to that of terrestrial mobile network users.

Robert H. Goddard Award for Exceptional Achievement for Science

The Solar Dynamics Observatory Team, which included **David M. Weitz** from Lincoln Laboratory, received this NASA award for “operating the Solar Dynamics Observatory, enabling the scientific results, mesmerizing the public, and reaching full mission success!” The observatory is a satellite on a five-year mission to collect data on the Sun and its atmosphere.

Boy Scouts of America District Award

Dr. Sarah H. Klein received the 2016 Chartered Organizational Representative of the Year Award for her involvement with the Flintlock District (including towns spanning from North Reading southwest to Lexington, Lincoln, and Concord) Venturing program for young men and women.

2016 Popular Science Invention Award

The ingestible biosensor developed by **Dr. Albert J. Swiston**, **Tara L. Boettcher**, **Gregory A. Ciccarelli**, **Nancy D. DeLosa**, **Dr. Timothy M. Hancock**, **Dr. Tadd B. Hughes**, and **Frank C. Schiavone** of Lincoln Laboratory, Prof. Robert Langer of MIT, and Giovanni Traverso of MIT and Harvard Medical School was selected as a *Popular Science* invention of the year.

First-Place Honors in ACM Audio/Visual Emotion Challenge

A Lincoln Laboratory team consisting of **Dr. Kevin Brady**, **Dr. William M. Campbell**, **Miriam Cha**, **Dr. Charlie K. Dagli**, **Dr. Elizabeth C. Godoy**, **Dr. Youngjune L. Gwon**, **Jennifer T. Melot**, **Dr. Thomas F. Quatieri**, and **Dr. James R. Williamson** took first place in the the emotion-recognition subchallenge at the Association for Computing Machinery’s (ACM) annual Audio/Visual Emotion Challenge; the team earned second place in the depression estimation subchallenge. These challenges task researchers with predicting a subject’s psychological state by analyzing audio, visual, and physiological data.

2016 Combat Survivability Award for Technical Achievement

Dr. David J. Ebel was presented this award by the National Defense Industrial Association in recognition of “sustained technical leadership of numerous advanced aircraft systems and survivability studies, ‘must read’ assessments of U.S. stealth aircraft employment, as well as many studies of U.S. and threat aircraft, weapons, and air defense technology trends.”

Herschel Award

Lincoln Laboratory was awarded the Herschel Award by the Military Sensing Symposia’s Special Interest Group on Detectors and Materials for its development of Digital-Pixel Readout Integrated Circuits. This award recognizes technology that is a significant breakthrough in its field.

2016 MILCOM Best Paper Award

Omar M. Salama, **Benjamin Hamilton**, **Dr. Greg Kuperman**, **Dr. Frederick J. Block**, **Dr. Rahul Amin**, **Robert H. Spaanenburg**, **Michael Scott**, and **Dr. Aradhana Narula-Tam** received the 2016 Lieutenant General Gordon T. Gould Jr. MILCOM Award for the Best Paper in the Restricted Access Technical Program for “Link 16 Evolution: Implementation of Waveform Enhancements on Link 16.”

2016 40 Under 40 Honoree

Dr. Mabel D. Ramirez was selected by the *Boston Business Journal* as one of the 40 young professionals who exhibit exceptional leadership and are making significant contributions to Greater Boston business and industry.

2016 Missile Defense Agency Contractor of the Year Award for Technical Engineering

D. Jonathan Bernays, for his leadership on the Global Ballistic Missile Defense System Sensor Analysis of Alternatives project.

Selection for 2016 U.S. Frontiers of Engineering Symposium

Laura A. Kennedy was selected to participate in the National Academy of Engineering’s U.S. Frontiers of Engineering Symposium, a three-day forum on the role of technology in addressing global problems. Participants are young engineers who have demonstrated innovation and technical depth in their disciplines.

U.S. Army Commander’s Award for Public Service

Dr. Diane C. Jamrog and **Joanne C. Zukowski**, for exemplary service to the Homeland Protection Courses offered at MIT Lincoln Laboratory over the past few years. The Commander’s Award is one of the highest honors granted to civilians by the U.S. Army.

Bravo Zulu Award

Dr. Francesca D. D’Arcangelo was awarded this recognition by the Deputy Under Secretary of the Navy, Chairman of the Office of the Secretary of Defense for Acquisition, Technology and Logistics, for work on the Integrated Project Team’s Counter–Unmanned Aircraft Systems Working Group.

MassCommute 2016 Bicycle Challenge

MIT Lincoln Laboratory’s team earned first place among all organizations in the annual MassCommute competition to log miles commuted during Bike Week. The team rode 11,799.99 miles between 14 and 22 May.

2016 Massachusetts Excellence in Commuter Options (ECO) Awards

MassCommute presented Lincoln Laboratory with two honors: The Pinnacle Award and the Leadership in Commuter Options Award. These awards recognized the Laboratory for its extensive and highly successful program to encourage alternatives to single-occupancy vehicle travel.

>> *Awards and Recognition, cont.*

R&D 100 Awards

At far left, Eric Evans, director of Lincoln Laboratory, who accepted the R&D 100 Award for the Broadband Magnetometry and Temperature Sensing with a Light-Trapping Diamond Waveguide on behalf of inventor Danielle Braje, joins the other Lincoln Laboratory attendees at the R&D 100 Conference banquet. The group represents the Laboratory's nine R&D 100 Award finalists and includes principal investigators, left to right, Wes Hill, Hamed Okhravi, Wes Olson, Steven Campbell, Matt Johnson, Albert Swiston, Mark Veillette, Navid Yazdani, Nandini Rajan, and Andrew Siegel.

Six technologies developed at MIT Lincoln Laboratory were named 2016 recipients of R&D 100 Awards. Presented annually by *R&D Magazine*, these international awards recognize the 100 most technologically significant innovations introduced during the prior year. A panel of independent evaluators and editors of *R&D Magazine* selects the recipients from hundreds of nominated candidates that represent a broad range of technologies developed in industry, government laboratories, and university research facilities.

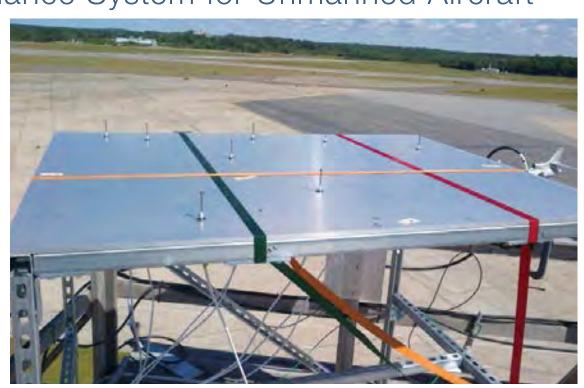
2016 R&D 100 Award Finalists

Three other technologies developed by Lincoln Laboratory researchers were named finalists for the 2016 R&D 100 Awards:

- High-Altitude Attritable Link Offset
- Second-Window Infrared Fluorescence Triband Imager
- Timely Address Space Randomization of computer memory

Airborne Collision Avoidance System for Unmanned Aircraft

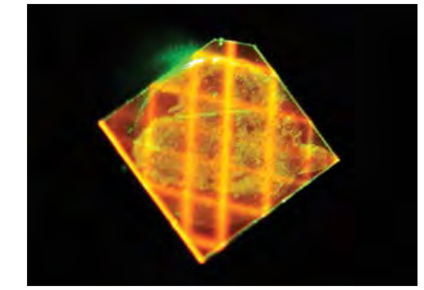
A system that processes multi-sensor data to allow unmanned aircraft to detect and track nearby aircraft and to enable ground operators to direct safe separation between unmanned vehicles and other air traffic.



DEVELOPMENT TEAM: Wesley Olson, Jeffrey Bezanson, Lawrence Capuder, Barbara Chludzinski, Ann Drumm, Tomas Elder, Matt Feldman, William Harman, Jessica Holland, Leo Javits, Robert Klaus, Jean-Paul LaPlante, Edward Londner, Justin MacKay, Evan Maki, Cynthia McLain, Robert Moss, Michael Owen, Adam Panken, Shirley Phillips, Thomas Teller, Randall Wiken, Richard Williams, James Won, Loren Wood, and Shannon Zareh (Lincoln Laboratory); Neal Suchy (Federal Aviation Administration); Mykel Kochenderfer (Stanford University); Brandon Abel and John Lepird (U.S. Air Force); Charles Leeper and Josh Silbermann (Johns Hopkins Applied Physics Laboratory); Andy Zeitlin (MITRE)

Broadband Magnetometry and Temperature Sensing with a Light-Trapping Diamond Waveguide

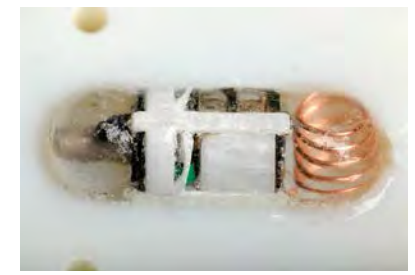
An ultrasensitive magnetic-field detector and temperature sensor that is 1000 times more energy-efficient than previous diamond-based magnetometers.



DEVELOPMENT TEAM: Danielle Braje, Scott Alsid, John Barry, Kerry Johnson, Christopher McNally, Michael O'Keeffe, and Linh Pham (Lincoln Laboratory); Hannah Clevenson, Erik Eisenach, Dirk Englund, and Matthew Trusheim (MIT)

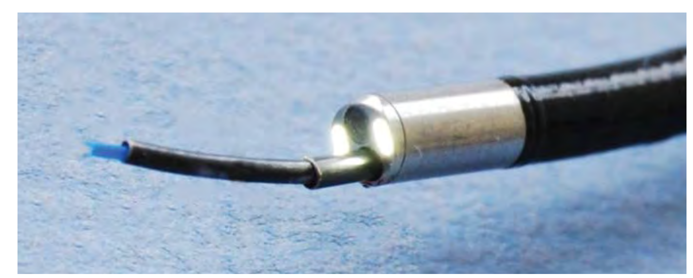
EnteroPhone

A wireless, ingestible device that monitors heart and breathing rates by listening to the body's sounds and that senses core temper-ature, all from within the gastrointestinal tract.



DEVELOPMENT TEAM: Albert Swiston, Tara Boettcher, Gregory Ciccarelli, Nancy DeLosa, Timothy Hancock, Mark Hernandez, Tadd Hughes, Kerry Johnson, Frank Schiavone, Steven Schwartz, and Christine Weston (Lincoln Laboratory); Giovanni Traverso and Ross Barman (MIT)

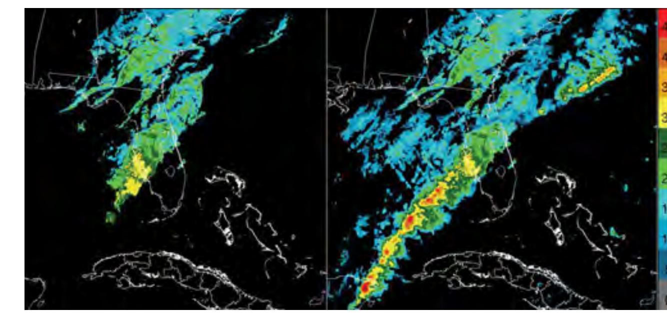
Laserscope



A tool set that offers surgical navigation and precise laser targeting within the spinal cavity to enable treatment of back pain with an outpatient procedure instead of with open back surgery.

DEVELOPMENT TEAM: Primary researchers: Matthew Johnson and Tara Boettcher (Lincoln Laboratory); Patrick Codd (Massachusetts General Hospital and Duke University); Wes Hill (Duke University). Support team: Catherine Cabrera, Kevin Cohen, Paul Devlin, Josh Erling, Emily Fenn, Geoffrey Geurtsen, Christopher Hwang, Roderick Kunz, Anil Mankame, Dale Martz, Thomas Matte, Frances Nargi, Peter O'Brien, Martha Petrovick, Darren Rand, Benjamin Robinson, Andrew Siegel, Nora Smith, Albert Swiston, Seth Trotz, Kathleen Varney, and Jonathan Wilson (Lincoln Laboratory)

Offshore Precipitation Capability



A system that provides weather information for air traffic controllers by generating "radar-like" depictions of storms in offshore regions that are outside radar coverage.

DEVELOPMENT TEAM: Mark Veillette, Eric Hassey, Haig Iskenderian, Patrick Lamey, Christopher Mattioli, and Marilyn Wolfson (Lincoln Laboratory); Randall Bass (Federal Aviation Administration)

Small Airport Surveillance Sensor

A low-cost secondary surveillance system that provides airport tower controllers with situational awareness of aircraft on the airport surface and in nearby airspace.

DEVELOPMENT TEAM: Steven Campbell, Brian Adams, Swaroop Appadwedula, Franz Busse, Kyle Cochran, Skip Copeland, Robert Downing, Derek Espinola, Paul Fiore, Joseph Finnivan, James Flavin, Jason Franz, William Harman, Gary Hatke, James Keefe, Binoy Kurien, John Maccini, Brendan O'Connor, James Pelagatti, C. Thomas Reardon, Matthew Rebholz, Thomas Reynolds, Gregg Shoults, Michael Spitalere, and Loren Wood (Lincoln Laboratory)

Laboratory staff and members of the Society of Women Engineers Boston chapter gathered at Lincoln Laboratory to assist high-school girls participating in the Wow! That's Engineering! workshop.

Educational Outreach

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

Lincoln Laboratory Community Outreach

The "Wow! That's Engineering!" workshop offers a reverse engineering station for girls to disassemble a variety of electronics, including the computer shown above.

WOW! THAT'S ENGINEERING

In March, 100 girls in grades six through eight attended a Wow! That's Engineering! Workshop at Lincoln Laboratory. The girls learned about reverse engineering by taking apart appliances, electrical engineering by connecting a circuit to make a light-emitting diode (LED) glove, chemical engineering by applying technology to filter water, and civil engineering by designing a tower on a budget. Each participant engaged in an hour of software coding as an introduction to programming and computer science. The activities proved to be educational and entertaining, best exemplified by a participant who asked, "Do you offer this every weekend? Because I had so much fun, I want to do this every weekend!"

CYBERPATRIOT

In the fall, Lincoln Laboratory sponsored three teams in CyberPatriot, a national competition for high-school students learning defensive computer security. The 17 students (six of whom were new to CyberPatriot) were mentored by Jorge Coll, Patrick Cable, and Andrew Fasano. After learning how to identify malware, "clean" a computer system, and establish a secure network, the teams competed in the statewide competition.

Two of the Laboratory-mentored teams achieved the ranks of first and third in state competitions in February. The teams also complete digital forensics and networking challenges. Every minute of the six-hour competition round is filled with team members cleaning systems, rooting out malware, and establishing a secure environment. The two teams advanced to compete in the Northeast Regional competition, but did not place.

At left, John Lessard, Eric Evans, William Flaherty, and David Scott do the honors at the ribbon cutting for the Stirling engine. Below, the Stirling engine was originally developed by Robert Stirling, who applied for its patent in 1816. The engine built in the TOIL (pictured here) was based on a model by Werner Wiggers.

SPOTLIGHT

Stirling Engine

In September, people passing by the auditorium welcomed the replica of a Stirling engine built as a permanent, museum-grade technology exhibit. The all-brass engine churned into action in front of a small crowd of Laboratory staff at the exhibit's ribbon cutting.

"Making something run continuously for eight hours a day has its challenges," said David Scott, manager of the Technology Office Innovation Laboratory (TOIL). Early on, Scott realized that the task would require an interdisciplinary team, including William Flaherty of the Structural and Thermal-Fluids Engineering Group, David Patterson of the Advanced Capabilities and Technologies Group, and John Lessard, TOIL cooperative education student from the University of Massachusetts Lowell. "Between us, we had a lot of expertise, but no practical experience in designing and building a Stirling engine," said Scott.

With a background in thermal energy, Flaherty took the lead in researching various engine designs. The team settled on a model that uses a displacer to move trapped air between heated and cooled sections of the engine. As the displacer nears the top of its range, the air inside the engine is warmed by an electrically resistant band heater and expands. Pressure builds inside the engine, forcing a power piston up. Then, as the displacer nears the bottom of its range, the air cools and contracts, causing the pressure to drop, the power piston to move down, and the air to compress. As the piston moves, it drives the motion of a flywheel.

The engine repeatedly heats and cools the air, establishing the Stirling cycle. The machine runs continuously between 120–150 rpm, equating to roughly 9,000 revolutions an hour—or approximately a million and a half revolutions per month.

The engine was designed, machined, assembled, and installed within six months. "I picked up so many industry skills while building the components of the engine and using many different machines in TOIL," said Lessard, who was responsible for the design of the flywheel.

Flaherty said when they look at the machine now, each team member can see his individual contribution and the larger team effort. "Projects like this just don't succeed if you don't have a cooperative team. Everyone did his part, and that's what made it so successful," he said. "I hope that people treat the engine with respect. It may look deceptively simple, but it represents a lot of effort and has been a true labor of love."

>> *Educational Outreach, cont.*

The winning technology of the Intern Innovative Idea Challenge was Blast Block, a collar that protects soldiers from traumatic brain injury associated with exposure to an explosive blast.

INTERN INNOVATIVE IDEA CHALLENGE

Lincoln Laboratory initiated a program that encourages interns to envision a new technique or device for solving a current problem. Eighteen teams undertook this Intern Innovative Idea Challenge, willingly devoting out-of-work hours to develop their concepts.

The challenge kicked off in June with the submittal of proposals. Each team was paired with a mentor and collaborated with staff members who offered feedback and advice. After a preliminary concept review at which each of the 12 top teams had three minutes to sell their idea to a judging panel, 7 teams moved on to the finals at which the audience chose the winner by casting votes via cell phones.

Raoul Ouedraogo, coordinator of Intern Innovative Idea Challenge, believes that this engaging competition may help attract creative engineers to the Laboratory's Summer Research Program.

GIRLS WHO BUILD CAMERAS

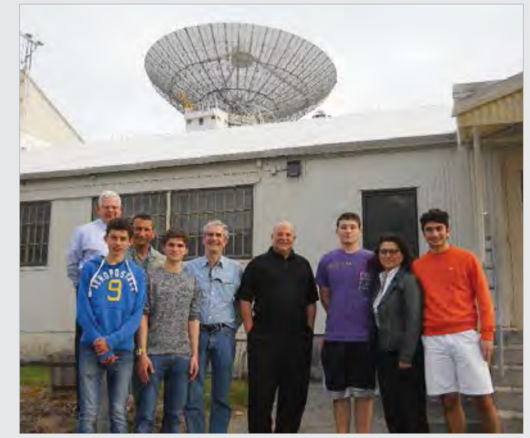
Kristen Railey, formerly of Lincoln Laboratory's Advanced Undersea Systems and Technology Group, gathered volunteers from the Laboratory, MIT, and Boston-area companies at Beaver Works to teach 40 high-school-aged girls how to build a camera and write code for Instagram-like filters. Railey explained that "cameras require versatile engineering, including optics, computer science, and mechanics, so the students learn which field of engineering they may be most interested in pursuing."

During the one-day Girls Who Build Cameras workshop, volunteers from Lincoln Laboratory spoke about their research involving image processing. Kristin Clark told the girls about her work on a NASA-funded project aimed at discovering exoplanets. Jessica Johnson displayed a light-field camera that captures the light density and direction in an image, and Robert Schulein demonstrated the use of photography to measure and map distances between objects.

Speakers from outside the Laboratory included Uyanga Tsedev, a mechanical engineering graduate student from MIT, who described her research into creating imaging probes for surgeons to identify tumors. Alex Lorman of Sea Machines Robotics demonstrated the specialty lenses and photography equipment used in his company's research. Tom Graves from DotProduct showed how three-dimensional (3D) scanning captures a 3D picture that can be used in verifying a building's construction and in mapping underwater naval infrastructure.

A participant builds her camera using a Raspberry Pi board (left) and is pleased when the end result starts to resemble a camera (above).

SCOUTING PROGRAMS



Explorer Post 1776 visited the Haystack radar site in Westford, Massachusetts, to learn about the research performed there.

EXPLORER POST

Exploring is a youth development program offered through the Boy Scouts of America. The program is based on a dynamic relationship between youth and the organizations in their communities. Exploring's purpose is to provide experiences to help young people mature and to prepare them to become responsible, caring adults. Explorer Post 1776, chartered by Lincoln Laboratory in October 2015, is organized by John Kuconis, Curtis Heisey, and David Granchelli. The post consists of seven youth members who meet monthly to focus on a hands-on design project. They gain in-depth experience in building engineering systems and are challenged to build prototypes by using creative problem-solving strategies. To learn about the latest technologies, Post 1776 has toured several scientific facilities, including Lincoln Laboratory and MIT's Haystack Observatory facility.

VENTURE CREW

Venture Crew, a co-ed STEM-focused high-adventure group chartered by Lincoln Laboratory and affiliated with the Boy Scouts, embarks on outings that include camping, archery, riflery, and mountain boarding. This summer, Venture Crew toured engineering facilities, such as Terrafugia, the flying-car company, and visited the Florida Keys to explore the ecosystem.

Students in the Girls Who Code program are provided with laptops and given lessons that cover HTML coding basics.

GIRLS WHO CODE

Lincoln Laboratory hosted a Girls Who Code (GWC) seven-week summer program at Beaver Works for 20 local seniors and juniors in high school. The students learned the basics of computer science, from robotics to web development. The curriculum covered HTML for web design and Python for programming robots.

The Laboratory provided guest speakers, including Laboratory Director Eric Evans, and mentors. During a mentorship event, 18 female Laboratory staff members visited the class to talk one-on-one about their experiences, discussing everything from college classes to gender bias to first jobs after college. A field trip to the Laboratory introduced the girls to a range of jobs in the technology industry.

The program culminated with demonstrations of final projects. One team created a smartphone application (app) named JunoBot that controls a robot via Bluetooth. Another group developed Pocket Kitchen, an app that generates recipes based on user-inputted ingredients.

ALL-GIRLS ROBOTICS TEAM

Among the many FIRST LEGO League (FLL) robotics teams sponsored by the Laboratory is an all-girls team. Coached by staff members Elisabeth Daley and Leslie Watkins, these 10 girls, ages 9 to 14, were eager to evaluate other teams' robots by analyzing the robots' speed, efficiency, and durability. According to Daley, this process helped the girls think more strategically about the competition: "Seeing the girls figure out the practicalities of what they can accomplish is a big part of the learning curve." Laboratory volunteers Meredith Drennan, Chelsea Curran, Tina Chen, and Allison King assisted in mentoring and instruction each week. "Robotics is the easy part of coaching a robotics team. The hard part is making sure the girls are having fun and learning," said Watkins, who believes that lessons learned along the way will stay with team members well after the competition.

>> *Educational Outreach, cont.*

THREE-DAY RADAR WORKSHOP

The Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE) workshop traveled off the continent this spring when Nestor Lopez and Juan Brunet Navarro coordinated the workshop at the University of Puerto Rico, Mayagüez (UPRM). They adapted the Laboratory's annual two-week onsite workshop covering radar concepts into a three-day offsite workshop. Twenty-one UPRM students built low-power small radar systems that support three modes: range-time intensity, Doppler, and synthetic aperture radar imaging. The lectures included Introduction to Radar, Modular Radio Frequency Design, Radar Signal Processing, Antenna Fundamentals, Target Ranging and Detection, Doppler, and Synthetic Aperture Radar Imaging.

Students at the University of Puerto Rico, Mayaguez, stand with their completed radars after a successful workshop. Students said the opportunity to assemble a working radar system helped them understand fundamental concepts not covered in their regular courses.

The workshop was offered as a one-credit activity to students, each of whom has plans to continue using the radar. The UPRM faculty is interested in hosting a program similar to LLRISE at the UPRM campus in the future. Lopez said of the effort, "It is great that the Laboratory encourages and enables this type of activity. At the end of the workshop, it is very rewarding to see the students use their self-built systems and ask good questions about radar."

SCIENCE ON SATURDAY

Each school year, more than 4000 local K–12 students, parents, and teachers attend Science on Saturday demonstrations hosted by Laboratory technical staff volunteers. Since the program's origin in 2006, attendees have enjoyed watching and participating in demonstrations on rockets, robotics, computers, acoustics, archaeology, lasers, thermal imaging, and many other topics.

Over the past year, Lincoln Laboratory's Science on Saturday demonstrations included

- An always-popular robotics demonstration that featured a "robot zoo" of homemade robots, which attendees could control to perform specific tasks
- A special Halloween edition, "Cyber Tricks and Cyber Treats," that taught children how to safely use the Internet
- A presentation on cryogenics and liquid nitrogen that answered the question, "How cold is cold?"
- Ten demonstrations and hands-on activities for all age groups at the MIT Open House celebration in April

During the Science on Saturday robotics event, participants use remote controls to "drive" the robots built by Lincoln Laboratory–sponsored high-school teams.

Community Giving

Lincoln Laboratory employees support worthy causes that contribute to the quality of life in local communities.

WALK TO END ALZHEIMER'S

$43,000

was raised by 46 walkers in 2016 to help support research. Since 2009, Lincoln Laboratory's Alzheimer's Support Community has raised $225,000 and has consistently ranked among the top five fundraising teams in the region.

RIDE TO END ALZHEIMER'S

The team raised more than **$10,000** and ranked fourth in fundraising at the Ride to End Alzheimer's in Portsmouth, New Hampshire.

HEART WALK

The Lincoln Laboratory Heart Walk team raised **$5000** to help promote physical activity and the American Heart Association.

FOOD DRIVE

The Lincoln Laboratory Hispanic/Latino Network collected more than **157** pounds of food.

SUPPORT OUR TROOPS

In 2016, Lincoln Laboratory sent **200** care packages and **150** signed holiday cards to soldiers overseas.

CHEMOTHERAPY ACTIVITY BAGS

Carrie Perry delivers activity bags to comfort patients undergoing chemotherapy. Perry has collected more than **1000** items and filled hundreds of bags.

CLOTHING DRIVE

In August and September, Richard Frederickson chaired a clothing drive for the Epilepsy Foundation of New England. Lincoln Laboratory donated **300** pounds of items.

PET SUPPLY DRIVE

In response to summer flooding in Louisiana, Sarah Lewis asked for donations of pet supplies to assist with the many displaced pets from flooded homes and kennels. In just four days, the Laboratory donated

20 bags of dog food

25 crates

50 towels and blankets

100 collars/leashes

150 bags/boxes of treats

200 cans of cat food

250 pet toys

RACE TO THE SUMMIT

Jesse Mills organized Race to the Summit—a half-marathon to the top of Mount Wachusett. The proceeds of the race funded the Marlene A. Mills Foundation. Mills said, "A third of the runners were Laboratory employees."

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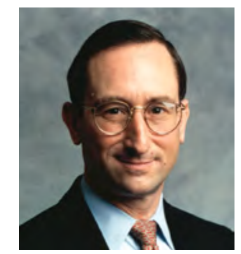

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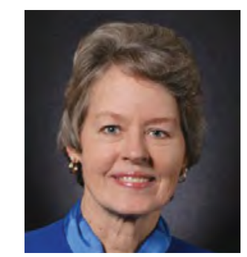

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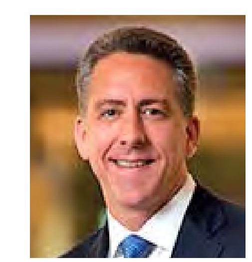

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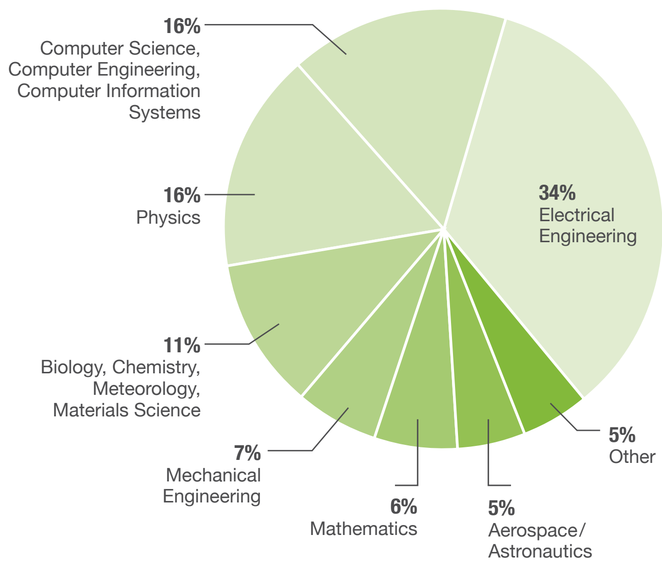
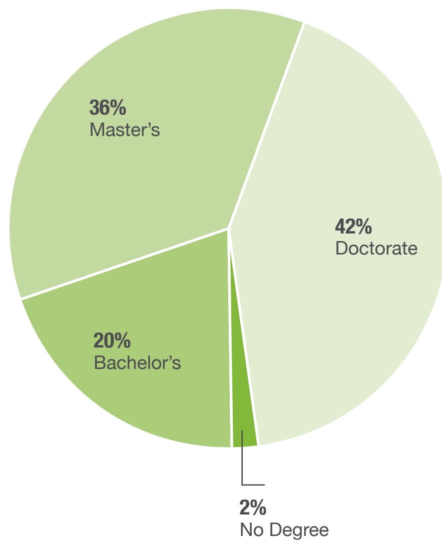
1863	Professional Technical Staff
1121	Support Personnel
492	Technical Support
512	Subcontractors
3988	**Total Employees**

Composition of Professional Technical Staff

Academic Discipline

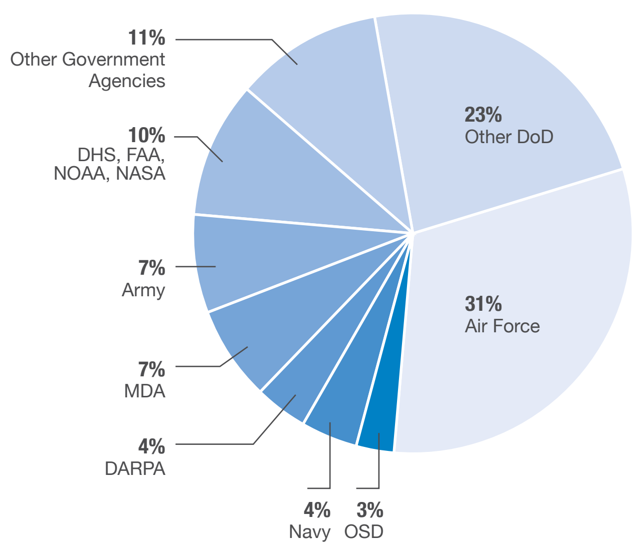


Academic Degree

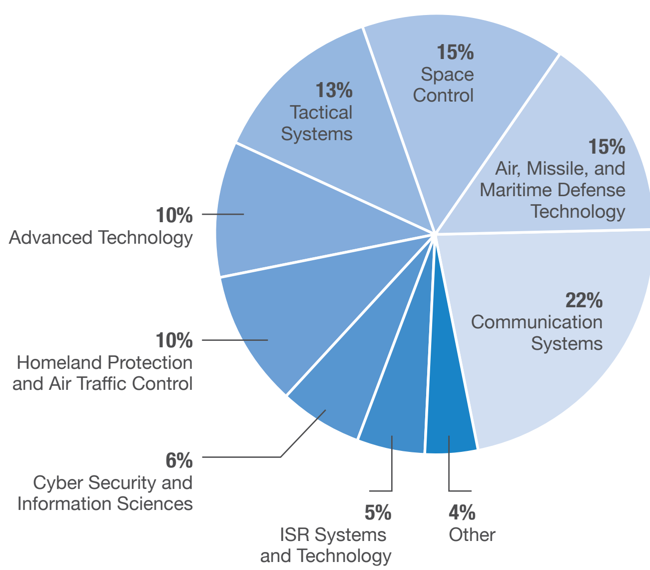


Breakdown of Laboratory Program Funding

Sponsor



Mission Area



Lincoln Space Surveillance Complex, Westford, Massachusetts

Reagan Test Site, Kwajalein Atoll, Marshall Islands

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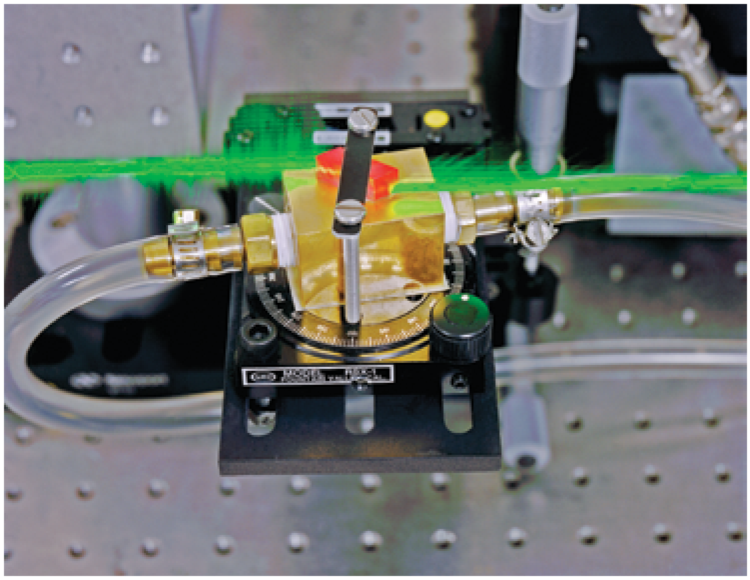

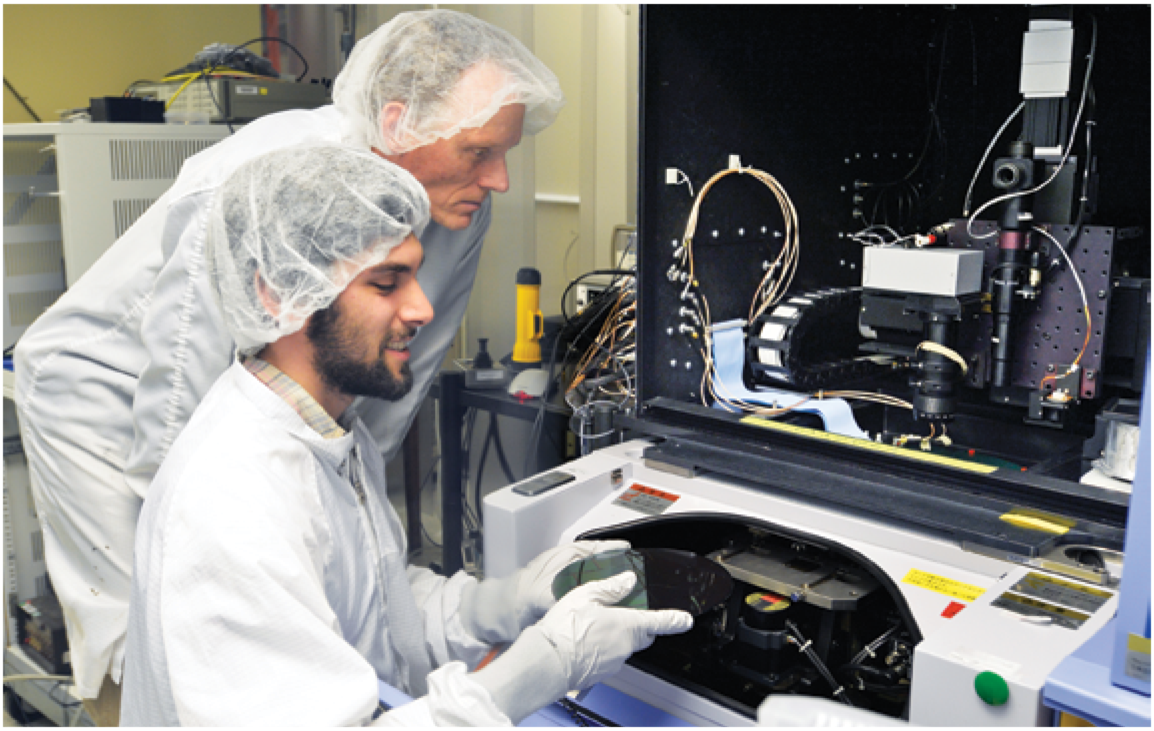

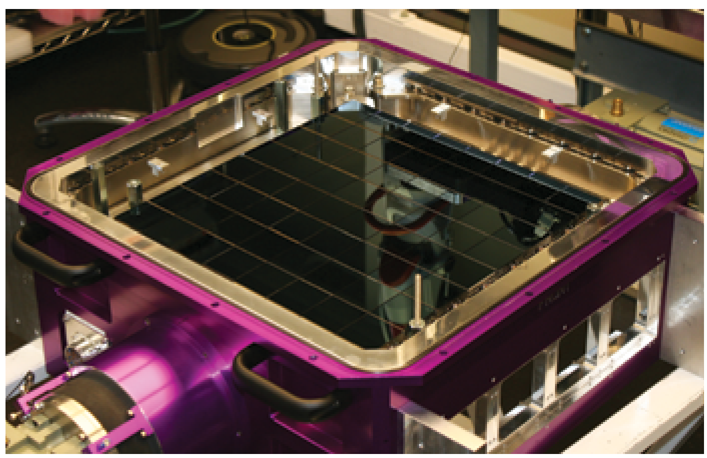

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY