Lincoln Laboratory

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

Lincoln Laboratory's mission is to advance system and technology development in support of national security. The majority of research and development carried out at the Laboratory is in the areas of sensors, integrated sensing, information extraction (signal processing and embedded computing), decision support, and communications, all supported by a broad research base in advanced electronics. Projects focus on developing and prototyping new technologies and capabilities to meet DOD needs that cannot be met as effectively by existing government or contractor resources.

The Laboratory maintains its relevance by continually leveraging its expertise to meet new challenges presented by the evolving needs of the nation and its military forces. Cyber security, critical to protecting the vast amounts of data generated in this age of electronic communications, is a growing mission area. The demand for intelligence, surveillance, and reconnaissance (ISR) systems remains strong, as is the interest in capabilities for unmanned vehicles. The Laboratory is applying its competencies in advanced signal and image processing, electronics and optics, complex system analysis, and biological defense to developing advanced biomedical technologies and systems to address national health-care needs and enhance soldiers' fitness and resilience. Research into quantum information sciences (QIS) is yielding more powerful ways to process information; current QIS work is focused on superconducting quantum bits (qubits), trapped-ion qubits, and quantum photonic technologies. Rapid prototyping efforts continue to be important elements of the Laboratory's portfolio.

For fiscal year July 1, 2011, to June 30, 2012, Lincoln Laboratory received approximately $990.7 million to support the efforts of approximately 1,730 professional, technical, and managerial staff, and 2,015 support personnel and subcontractors; outside procurement will exceed $426 million. While most of the research is sponsored by DOD, funding is also received from the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), the Department of Homeland Security (DHS), and the National Oceanographic and Atmospheric Administration (NOAA). In addition, Lincoln Laboratory carries out noncompetitive research with industry under approved Cooperative Research and Development Agreements and other collaborative activities with academic institutions.

On April 1, 2010, the Department of Defense awarded a five-year reimbursement contract option to MIT for the operation and management of Lincoln Laboratory as an FFRDC. The award continues the long-standing relationship that has existed between the federal government and MIT, which has operated Lincoln Laboratory since its establishment.

Laboratory Operations

Lincoln Laboratory operations are marked by the following fundamental attributes: high-caliber staff, streamlined organizational structure, high-quality infrastructure, well-defined strategic focus, and strong alignment with the MIT campus.

Organization

Lincoln Laboratory's success has been built on the core values of technical excellence and integrity, which are exemplified by the Laboratory's exceptional staff. The three-tiered organizational structure—Director's Office, divisions and departments, and groups—encourages interaction between staff and line management. Sponsor interest in conducting research and development in complex integrated systems has raised the level of collaboration between divisions. In addition, service departments, as providers of standardized support, and the Safety and Mission Assurance and Program Support Office, as a primary advisor, enable cross-divisional research teams to coordinate and manage the technical and programmatic challenges of large-scale developments.

Changes to the Laboratory's Structure

A number of organizational changes implemented during FY2012 were at the group level and reflected transitions into areas of growing importance to national security.

- The Homeland Protection and Air Traffic Control Division established a new group, Bioengineering Systems and Technologies. Drawing its multidisciplinary technical staff from groups across the Laboratory, the new group focuses on programs related to biometrics and forensics, biomedical systems, synthetic biology, and bioinformatics.
- In the Communication Systems and Cyber Security Division, the Netcentric Operations Group became the Cyber Systems and Operations Group, realigning its focus on systems that provide situational awareness and command and control in the cyber domain.
- Within the ISR and Tactical Systems Division, the group that conducted research and development in high-performance computing was reorganized into two groups to better concentrate efforts in two areas of growing national importance: open systems architecture and "big data" analytics and computing.
- Two groups in the Air and Missile Defense Technology Division were restructured to shift emphasis to air defense systems. The Advanced Sensor Systems and Test Beds Group focuses on airborne air defense, over-the-horizon radar, and real-time open system applications, while the Advanced Concepts and Technologies Group conducts programs on surface-based air defense, electronic warfare, and test assets and infrastructure.

Changes to Leadership

The Mission Assurance and Safety Office merged with the Program Support Office. Deborah A. Valley, who formerly headed up the Program Support Office, was named the head of the new office that will provide technical, safety, and business management support to Lincoln Laboratory programs.

Dr. Robert G. Atkins was appointed head of the Advanced Technology Division, effective August 1, 2012. Formerly, he was the associate division head in ISR and Tactical Systems. Dr. Simon Verghese was named assistant division head in Advanced Technology, and he will assume that position on 1 November 2012.

Dr. David C. Shaver, former head of the Advanced Technology Division, accepted an Intergovernmental Personnel Act assignment as program manager in the Defense Advanced Research Projects Agency's (DARPA) Microelectronics Technology Office.

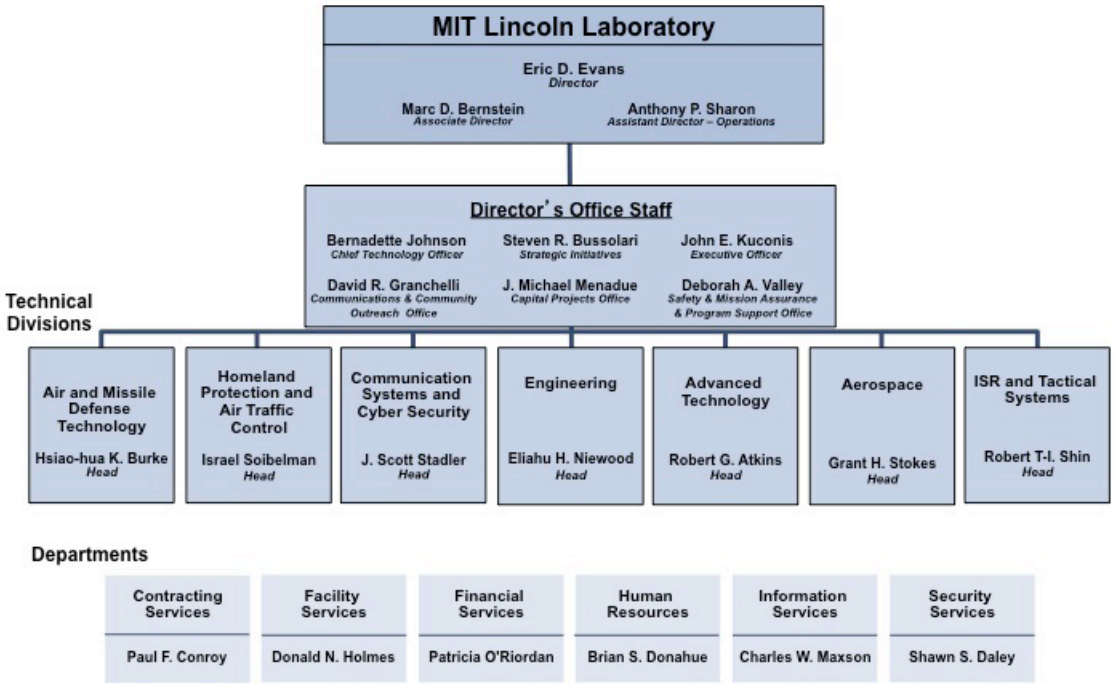

Figure 1. Lincoln Laboratory organizational structure.

Staff

Key to maintaining excellence at Lincoln Laboratory is its technical staff of highly talented scientists and engineers. Sixty-five to 75 percent of the Laboratory's new staff are hired from the nation's leading technical universities. The Laboratory recruits at more than 65 colleges and universities nationwide. The makeup of the Laboratory staff by degree and academic discipline is shown in the following charts.

Composition of Lincoln Laboratory Staff

Professional technical staff	1,736
Support staff (including technical support personnel)	1,444
Subcontractors	573
Total laboratory employees	**3,753**

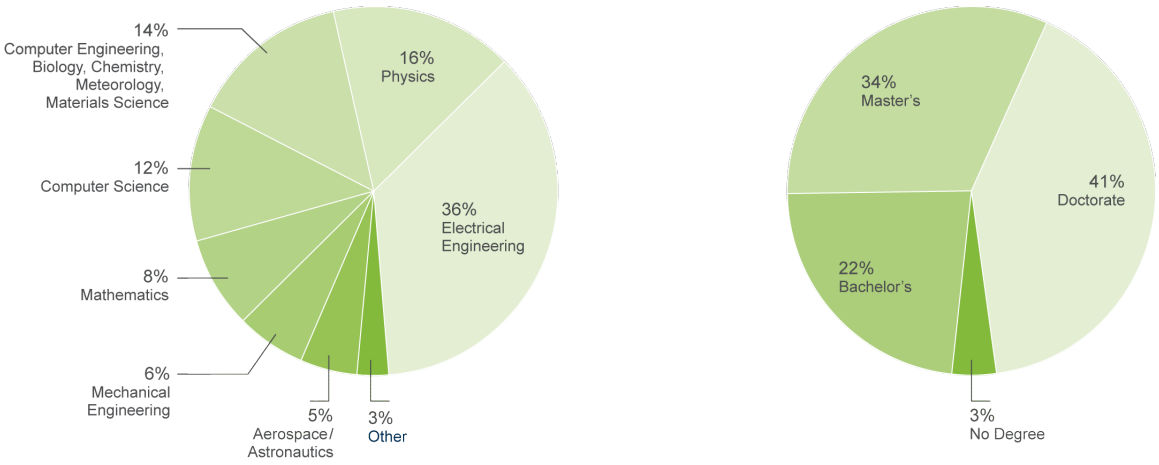

Figure 2. Composition of professional technical staff by (a) academic discipline and (b) academic degree.

Staff Honors and Awards

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

Lincoln Laboratory was chosen as the site for the IEEE Milestone in Electrical Engineering and Computing plaque awarded for the development of the Semi-Automatic Ground Environment (SAGE) system.

Dr. Jane Luu was a co-recipient of the Kavli Prize in Astrophysics and the Shaw Prize in Astronomy for the discovery of objects in the Kuiper Belt. Dr. Luu performed this research during the late 1980s and early 1990s while conducting postdoctoral research at the Harvard Smithsonian Center for Astrophysics.

William P. Delaney, Director's Office Fellow, was elected a member of the National Academy of Engineering for contributions to radar systems for national defense.

Dr. Theodore H. Fedynyshyn and Dr. Don M. Boroson were named fellows of the Society of Photo-Optical Instrumentation Engineers in January 2012. Dr. Fedynyshyn was recognized for achievements in photoresist materials and process technology, and Dr. Boroson for achievements in satellite laser communications.

Dr. Richard P. Lippmann and Dr. Gary F. Hatke received MIT Lincoln Laboratory 2011 Technical Excellence Awards.

Dr. Todd H. Rider, Christina E. Postema-Zook, Tara L. Boettcher, Scott T. Wick, Jennifer S. Pancoast, and Benjamin D. Zusman received the 2011 MIT Lincoln Laboratory Best Paper Award for "Broad-Spectrum Antiviral Therapeutics," published in *PLOS ONE* in July 2011.

Dr. Tso Yee Fan and Dr. Antonio Sanchez-Rubio of MIT Lincoln Laboratory and Dr. Bien Chann of TeraDiode (formerly at Lincoln Laboratory) received the 2011 MIT Lincoln Laboratory Best Invention Award for development of external-cavity, one-dimensional, multi-wavelength beam combining of two-dimensional laser elements.

Michael T. Boulet and Mykel J. Kochenderfer received 2011 MIT Lincoln Laboratory Early Career Technical Achievement Awards.

The Aegis Ballistic Missile Defense (BMD) Excellence Award and an Aegis BMD flag were presented to Lincoln Laboratory for significant contributions to the Aegis BMD program.

Dr. Bryan S. Robinson received the NASA Space Communications and Navigation Achievement Award for his outstanding work on the Lunar Laser Communications Demonstration project.

2012 R&D 100 Awards

Four Lincoln Laboratory technologies were named 2012 recipients of R&D 100 Awards. The 100 most technologically significant innovations introduced during the previous year are selected annually by *R&D Magazine* as award recipients. The winning technologies listed below represent work in four distinct areas of research:

- *Lincoln Open Cryptographic Key Management Architecture*—a highly portable software library that enables cryptographic protection for communication devices
- *Route Availability Planning Tool*—an automated decision support tool that predicts the availability of air traffic routes during thunderstorms
- *Wavelength Beam-Combining Fiber-Coupled Diode Laser*—a high-intensity diode laser that combines unprecedented brightness, efficiency, and reliability
- *Wide Field-of-View Curved Focal Plane Array*—a curved, charge-coupled device that corrects for inherent aberrations of the mirrors and lenses in optical systems

Professional Development

Lincoln Laboratory's commitment to the professional development of its staff is seen in the diversity of opportunities presented through the Human Resources Department's educational program, the Technology Office, and the library.

Human Resources Department

The Human Resources Department coordinates programs in graduate education, technical education, professional leadership development, and computer/software training. For highly qualified candidates, the Laboratory offers the opportunity to apply to the Lincoln Scholars program that supports the full-time pursuit of advanced degrees. The candidates accepted into the program perform their thesis research work at the Laboratory while serving as contributing members of the staff. This year, under the Lincoln Scholars program, four staff members earned doctorates and seven earned master's degrees. Twenty-eight staff members enrolled in the Lincoln Scholars program.

The Graduate Education Committee also coordinates distance learning programs—master's degree programs in information technology and in information science (with a focus on cyber forensics and incident response) from Carnegie Mellon University, and a master's degree program in information sciences from Pennsylvania State University. Currently, five people are enrolled in the Pennsylvania State program.

The technical education program offers semester-length courses taught by Lincoln Laboratory technical staff or by outside experts, often professors from MIT. The 2011–2012 schedule included the following courses:

- Introduction to ISR Systems and Technology
- Optical Systems Overview
- Signal Processing on Graphs and Databases: A Detection Theory Approach to Network Science
- Satellite Laser Communications

The professional and leadership development program sponsors courses in leadership techniques, project management, and scientific and technical writing.

Computer training in common software applications (Word, PowerPoint, Excel, Illustrator, and Photoshop, etc.) and in technical software (MATLAB, Simulink, VxWorks, etc.) is offered on-site throughout the year.

Technology Office

The Technology Office coordinates an extensive program of seminars presented at the Laboratory by leading researchers from universities and industry. The office expanded the number and range of seminars this year; the talks addressed diverse topics such as bio-inspired robot design, compressive depth acquisition cameras, new metamaterials, future trends in national security, and the intersection of biology, computer science, and engineering.

Library

The Laboratory's library, in collaboration with the MIT Library, makes a variety of online learning opportunities available to the Laboratory staff:

- IEEE eLearning Library, which offers nearly 200 online courses
- MIT seminars, accessed through MITWorld
- MIT's Microsystems Technology Laboratories seminars, accessible through their web page

In addition, division and staff seminars on current research are presented every week, and the service departments offer courses and training specific to their areas. The internal website provides collaboration tools that are enabling special interest groups, such as the Satellite Toolkit Users Group, to share information.

Diversity and Inclusion

The Laboratory continues to foster an inclusive workplace that leverages and supports the talents and perspectives of the Laboratory's staff. Recruiting at a broad range of universities, programs in mentoring, affinity groups such as the New Employee Network, and flexible work options are contributing to the hiring and retaining of a more diverse workforce.

The establishment of four new mentorship programs was announced in early 2011. These new mentoring programs are being phased in during 2011–2012. The programs are designed to provide employees with support during different stages of their careers:

- New Employee Guides—introduction for new employees to their groups, divisions, and departments
- Early Career Mentoring—six-month, one-on-one mentoring for professionals starting out in their careers
- Circle Mentoring—small, often topic-specific, discussion groups led by experienced employees. The Circle Mentoring program successfully completed one six-month series and will begin a new session in fall 2012.
- New Assistant Group Leader Mentoring—mentoring of a new assistant group leader by an experienced group leader

The newly established Lincoln Laboratory Veterans Network (LLVET) works with the Professional and Community Enhancement Committee (PACE) to assist veterans who are moving directly from the military to the Laboratory. LLVET supports local community outreach to US troops and veterans, and keeps members informed of activities and policies that affect veterans.

Technical Program Highlights

Research and development at the Laboratory focus on national security problems in diverse areas: tactical and intelligence, surveillance, and reconnaissance systems; air and missile defense; space situational awareness; chemical and biological defense; and communications, cyber security, and advanced electronics technology. In addition,

the Laboratory undertakes related nondefense work in areas such as air traffic control, weather sensing, and environmental monitoring, for agencies such as the FAA, NASA, and NOAA. A principal activity of the Laboratory's technical mission is the development of components and systems for experiments, engineering measurements, and tests under field operating conditions.

During 2011–2012, the Laboratory worked on approximately 500 sponsored programs that range from large-scale hardware projects to small seedling initiatives. Notable highlights for each mission area, as well as future directions, are listed below.

Space Control

Continuing its history of developing passive microwave remote sensing systems and exploitation algorithms, the Laboratory explored novel concepts for hyperspectral microwave sounding. This year, the first CUBESAT bus and payload concept were developed.

The Laboratory, leveraging its accomplishments on the Extended Space Sensors Architecture Advanced Concept Technology Demonstration, is now working with the Air Force and the broader space community on incorporating the lessons learned into a comprehensive netcentric system for meeting space surveillance needs.

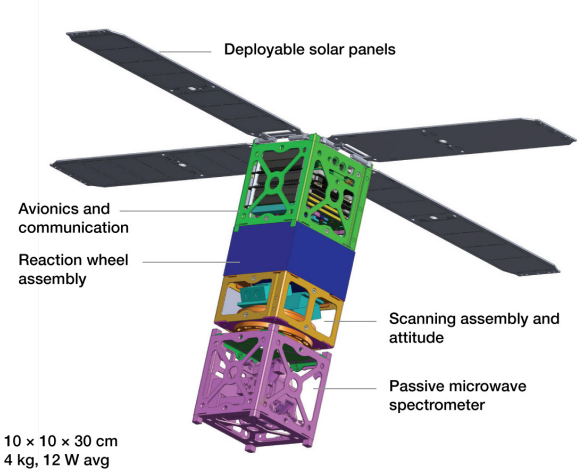

Figure 3. This rendering shows an MIT and Lincoln Laboratory computer-aided design of a passive microwave sounder concept packaged in a nanosatellite (CUBESAT) form factor.

Lincoln Laboratory contributed significantly to the development of the overall system architecture for the nation's space control capability. Analyses and results are heavily influenced by experiments with prototype hardware, algorithms, and software systems. Close connections to the operations and the user community allow implementation of real user needs into the emerging architecture.

Air and Missile Defense Technology

Installation of the Laboratory-developed XTR-1 (X-band transportable) radar onto the Missile Defense Agency's *Pacific Tracker* was completed. The radar has an 11-meter dish and a two-frequency (X- and S-band) feed. XTR-1 and the two forward telemetry antennas will provide valuable data during testing of the Ballistic Missile Defense System.

Figures 4a, 4b. The XTR-1 radar installed on the stern of the Pacific Tracker.

A major design and risk-reduction effort continued for a ship-based electronic countermeasure that will improve the US Navy's capability to defend ships against advanced missile threats. The Laboratory designed and built a prototype system and conducted an initial test campaign at a Navy field site at Dahlgren, VA.

The Laboratory is developing a design for a new airborne electro-optical/infrared tracking system. The system includes a large-aperture sensor with medium- and short-wave infrared and visible channels as well as a processing architecture that uses an open, layered-element design.

Communication Systems

A disruption-tolerant networking protocol was adapted for multi-hop long-haul communication applications and was evaluated by using a transmission protocol network test bed to perform detailed characterization of the protocol over a wide range of link conditions.

Lincoln Laboratory performed an initial demonstration of a tactical radio test range that will provide comprehensive instrumentation and evaluation of emerging tactical communications systems and waveforms on ground and airborne mobile radio platforms.

The Laboratory initiated proof-of-concept development of a small-form-factor, protected satellite communications (SATCOM) modem for ground-based SATCOM-on-the-move applications. In addition, the high-data-rate military SATCOM waveform that the Laboratory developed and demonstrated for intelligence, surveillance, and reconnaissance (ISR) readout was provided to more than 25 industry and government teams.

Figures 5a, 5b. A researcher operates the Portable Army Communications-on-the-move Terminal Block 1 mobile SATCOM terminal (atop vehicle), demonstrating the ability to have mobile communications that are robust to disruption by jamming or other attacks.

In the Human Language Technology area, a new framework for speaker recognition achieved a fivefold reduction in equal error rate. It was transferred to the Federal Bureau of Investigation (FBI) Forensic Audio, Video, and Image Analysis Unit. Vocal biomarkers developed for depression monitoring were derived automatically from phonologically based measures of speech rate and showed stronger relationships with depression severity than previously reported for speech-rate measures.

Cyber Security

Context-enriched analysis and display capabilities were developed that provide national cyber situational awareness for cyber-threat operations centers. High-speed analysis techniques providing characterization of large-volume cyber data through the use of a historical behavioral context have been deployed for operational evaluation. Cyber tools to fuse and visualize cyber threats in the context of organizational mission and tasking priorities have been developed and are in operational use.

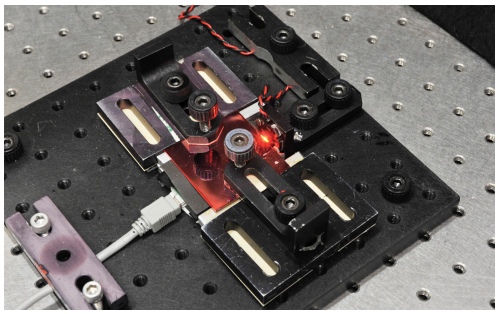

Figure 6. Lincoln Laboratory researchers are developing an open architecture for providing tamper resistance to hardware and software systems. Physically unclonable functions are used to embed cryptographic key material in a coating around a computing module, permitting detection of tampering.

The Laboratory developed a suite of tools to automatically analyze malicious software. The Lincoln Automated Malicious Binary Data Analyzer is a malicious software triage system that incorporates many diverse software analysis tools into an automated workflow and produces an aggregated analysis result. The Laboratory has also developed a whole-system information-flow tracking tool that allows an analyst to mark chosen information in memory as tainted, then later identify the effects of program execution on the tainted data. These tools have been used effectively to analyze thousands of malicious software samples.

The Laboratory is developing a tool that can automatically modify field-programmable gate array–based cores to improve their resistance to differential power analysis. The

tool will eventually permit system developers to trade cost for security, depending on the intended use of the system and the threat environment.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

The Airborne Ladar Imaging Research Testbed system was integrated into a government-furnished aircraft and delivered to a sponsor for operational use. A next-generation ladar system with enhanced sensitivity and discrimination performance is under development for foliage penetration and other missions.

The Laboratory developed a high-resolution, long-wave infrared immersive video system that supports day/night force protection. The Wide-area Infrared System for Persistent 360° Surveillance effort includes rapidly developing a custom sensor, as well as developing the processing and exploitation software. The system will provide context and cueing for other ISR sensors, and long-term data storage for forensic exploitation.

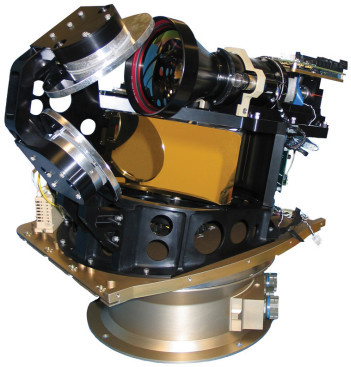

Figure 7. The Wide-area Infrared System for Persistent 360° Surveillance provides situational awareness in support of force protection applications. The sensor shown above is secured inside a housing that is then mounted on a tower for surveillance applications.

The Laboratory developed and tested an adaptive-data-rate, medium-range (100 m–1 km) radiofrequency data link that supports data rates from 1 Mb/s up to 1.9 Gb/s. This system uses advanced multiple-input, multiple-output techniques and very-high-performance adaptive space-time coding. The system sets new standards for non-line-of-sight, low-power communication links and enables efficient data exchange among ground-based distributed ISR systems.

The Laboratory has developed technology for the use of unmanned undersea vehicles (UUVs) in antisubmarine warfare. Autonomous detection algorithms that process UUV sensor array data to produce contact reports were developed, implemented, and tested in at-sea experiments.

Advanced Technology

In spring 2011, a tool upgrade for the Microelectronics Laboratory was completed to covert from 150 mm diameter wafers and a 150 nm IC technology node to 200 mm diameter wafers and a 90 nm technology node Upgraded circuit processes were refined for charge-coupled-device imagers and fully depleted silicon-on-insulator ICs. The latter provide the basis for the 3D multiproject research foundry available to Department of Defense contractors.

Figure 8. In the re-outfitted Microelectronics Laboratory, a technician performs bright-light inspection of a 200 mm wafer prior to 3D bonding.

A slab-coupled optical waveguide laser previously invented at Lincoln Laboratory was configured in an external cavity and demonstrated the highest power and lowest relative intensity noise at 1.5 μm wavelength.

A cryogenically cooled Yb:YAG amplifier with a fiber-based seed laser demonstrated 40 mJ output (80 W, average power) in 15 ps pulses at 2 kHz pulse-repetition rate. This joint effort with the MIT Research Laboratory of Electronics is targeted at sources for extreme ultraviolet lithography and hyperspectral radiography.

Quantum-cascade lasers in a master-oscillator power-amplifier architecture have achieved 1.5 W output power at 7.26 μm wavelength in single-longitudinal/single-transversal mode. Operation was at 300 K temperature under pulsed conditions (20 kHz/100 ns). This collaboration with Harvard University is yielding bright mid-infrared sources suitable for field-portable applications.

Homeland Protection

The Accelerated Nuclear DNA Equipment program, sponsored jointly by the Departments of Defense, Homeland Security, and Justice, is developing common, core, automated DNA analysis instrument prototypes that can be used by minimally trained personnel to produce five human DNA profiles from reference samples within one hour. Lincoln Laboratory, as the integrator and system architect, is working to improve forensic DNA sampling techniques.

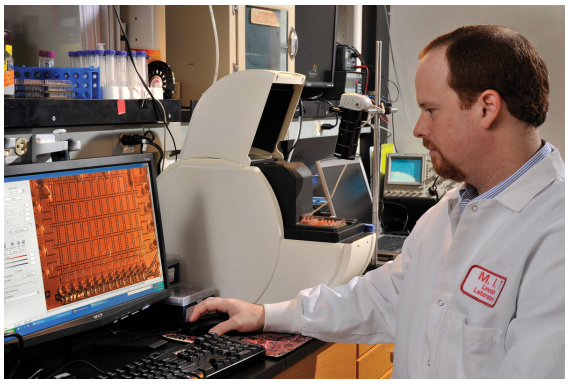

Figure 9. Lincoln Laboratory is developing, integrating, and evaluating microfluidic systems to enable new capabilities in biometrics, forensics, synthetic biology, and biomedical applications. Dr. Jeffrey Palmer is evaluating the performance of a digital microfluidic platform (through a research collaboration with Advanced Liquid Logic) for use in the rapid DNA analysis program.

New biomedical initiatives emphasize medical diagnostics for the DOD and leverage Lincoln Laboratory's strengths in sensing, signal processing, algorithms, and data communications to develop technologies at molecular, cellular, and human system scales.

The Next-Generation Incident Command System (NICS), initiated in partnership with the California Department of Forestry and Fire Protection, was evaluated by first responders in multiple operational settings, including wildland fires and large-scale floods. NICS enables collaborative command and control by integrating technologies such as resource tracking, full-motion video, and robust data communication.

The Imaging System for Immersive Surveillance, which provides 360-degree video surveillance of an area, is being operationally tested with the Massachusetts Port Authority. The Laboratory is also developing a video analytics software prototype that

performs an attribute-based search (e.g., hat, black jacket, blue jeans) and then generates a track of a suspect across arrays of security cameras.

Tactical Systems

The Laboratory continued a comprehensive assessment of US Air Force airborne electronic attack options against foreign air defenses. Systems analysis, detailed radar and electronic protection system modeling, and testing of electronic attack systems informed acquisition decisions regarding next-generation electronic attack systems.

Capabilities of the Laboratory's Airborne Countermeasures Test System aircraft were enhanced to support captive-carry testing of threat representative electronic attack emulators and testing for advanced US fighter aircraft radar development.

The Laboratory developed a ground-penetrating radar technology for counterterrorism applications. Significant antenna array and processing advances were demonstrated, and a field-worthy prototype is in development.

Advanced architectures and technologies were transitioned to the next generation of counter-improvised explosive device electronic attack systems.

Figure 10. Researchers in the Tactical Systems mission area are developing a prototype Ku-band radar.

Air Traffic Control

The Route Availability Planning Tool (RAPT) was deployed to Chicago to facilitate airport departure management during severe weather conditions. A successful operational evaluation during the summer storm season demonstrated the capability to adapt the RAPT concept of operations to Chicago's four-corner-post environment. Ongoing RAPT operations in New York City provided high benefits in this most-delay-beset metroplex in the US.

The Tower Flight Data Management (TFDM) prototype developed by the Laboratory was deployed to Dallas/Fort Worth International Airport to support successful initial shadow evaluations of TFDM and the Staffed NextGen Tower (SNT) concept. TFDM and SNT significantly improve airport operations by providing high-quality situational awareness, cross-domain collaboration capabilities, and decision support automation.

Figure 11. The Tower Flight Data Management prototype was developed to explore new, more efficient air traffic control concepts.

In support of the FAA's Traffic Alert and Collision Avoidance System program, the Laboratory developed extensive data sets, high-fidelity aircraft encounter models, and novel collision-avoidance algorithms to assess current alerting capabilities and next-generation concepts. The Laboratory also leads DOD and DHS efforts to address collision-avoidance issues limiting airspace access for unmanned aerial systems.

Engineering

Lincoln Laboratory began assembly, integration, and testing of the qualification version of a 5-inch optical module for high-data-rate laser communication from space. Following qualification module assembly, the flight version of the module for the Lunar Laser Communication Demonstration will be built.

Laboratory engineers built an innovative system for detecting chemical or biological agents within shipping containers. The system, which is designed to be mounted on a large crane, was demonstrated on a crane test bed.

The first phase in the development of an autonomous system for leading mounted patrols was completed. The system incorporates GPS waypoint following and automated station-keeping on a follower vehicle.

Lincoln Laboratory successfully developed a state-of-the-art process for attaching ceramic column grid array devices to printed circuit boards for use in spacecraft. Samples were tested to failure, and the process was endorsed by outside experts.

Figure 12. Michael Stern, a technical staff member in the Rapid Prototyping Group, is shown building thermoplastic parts using a fused deposition modeling production system located in the Laboratory's new rapid prototyping facility. The system is used to rapidly produce parts and iterate designs, including fabrication of functional parts using advanced high-strength materials.

Technology Transfer

The culmination of many of Lincoln Laboratory's development projects is the transfer of technology to government agencies, industry, or academia. The mechanisms for this transfer include delivery of hardware, software, algorithms, or advanced architecture concepts to government contractors under the auspices of a government sponsor; Small Business Technology Transfer projects, which are joint research partnerships with small businesses; and Cooperative Research and Development Agreements, which are privately funded by businesses to transfer the Laboratory's technology.

Technology transfer activities over the past year include the following:

- The Laboratory developed the prototype autonomous processing and sensor control computer for the Missile Defense Agency's airborne infrared optical sensing capability for tracking ballistic missile threats. The hardware design and prototype software implementation was then transferred to Raytheon for further development and production.
- The Laboratory has transferred open system architecture technical concepts, algorithms, and standards for use in the US Air Force's next-generation radar systems.
- Iterative Clutter Calibration, an antenna calibration technique for airborne radars, is being transferred to Northrop Grumman, Boeing, and the Commonwealth of Australia (through the US Air Force). The technique uses ground clutter to improve the calibration of an airborne radar antenna to compensate for effects such as airframe interaction and failed antenna elements. Two patent applications have been filed.
- A Laboratory-developed government reference implementation of a high-data-rate waveform for intelligence, surveillance, and reconnaissance (ISR) applications was released to 15 industry participants. The release included VHDL (a hardware description language), software, models, test vectors, and documentation.
- The Laboratory's patented cyber attack graph modeling and analysis system (Network Security Planning Architecture, or NetSPA) was transferred to FireMon, LLC.
- Several cyber range network emulation and instrumentation tools were transitioned to government ranges to support testing and experimentation. The Lincoln Adaptable Real-time Information Assurance Testbed network emulation suite was integrated into DARPA's National Cyber Range program, and the low-observable physical host instrumentation tools were transferred to several government organizations.
- Demonstration flights of the BAE Systems ARGUS-IS sensor were completed in 2011, with integration of this sensor into the US Air Force's Gorgon Stare Increment 2 system expected to be completed in 2012. The ARGUS-IS visible-band sensor system represents technology initially developed and demonstrated in Lincoln Laboratory's Multi-Aperture Sparse Imager Video System sensor, the first prototype gigapixel-class persistent surveillance system.
- Under US Navy sponsorship, sonar signal processing software for enhanced detection, classification, and localization was transferred to Lockheed Martin Corporation for subsequent integration into submarine sonar systems.
- Algorithms and a real-time software implementation for processing data from wide-area motion imaging sensors were transferred to Mercury Computer Systems, as part of the US Air Force's Gorgon Stare program.
- A robot-mounted payload designed for tactical counterinsurgency missions was initially transitioned to industry for limited production in 2010, and subsequent algorithm developments were transitioned to industry and to operationally fielded systems in 2011.

- The startup company TeraDiode, whose founders include two former Lincoln Laboratory staff members, is commercializing technology pioneered at the Laboratory that uses breakthroughs in wavelength beam combining to achieve the brightness and power required for demanding applications such as high-speed cutting and remote welding.
- Between July 1, 2011, and June 30, 2012, MIT was awarded 13 US patents for technologies developed by Lincoln Laboratory researchers.

Dissemination of Technical Knowledge

The dissemination of information to the government, academia, and industry is a principal activity of Lincoln Laboratory's technical mission. Wide dissemination of technical information is achieved through annual technical workshops and seminars hosted at Lincoln Laboratory. These events bring together members of technical and defense communities to share technology advances, to discuss innovative concepts, and to foster a continuing dialogue that strengthens technology development and provides direction for future research. The following events were held this year:

- High Performance Embedded Computing Workshop
- Mechanical Engineering Technology Symposium
- Subthreshold Microelectronics Conference
- Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop
- Software Engineering Symposium
- Air Traffic Control Workshop
- Homeland Protection Workshop
- Space Control Conference
- Air Vehicle Survivability Workshop
- Ballistic Missile Defense Workshop
- Lincoln Laboratory Communications Conference
- Cyber and Netcentric Workshop

In addition, the Laboratory presents technical courses for military officers, DOD civilians, and defense subcontractors:

- Defense Technology Seminar
- Introduction to Radar Systems Course
- Homeland Protection Course
- Technology for Intelligence, Surveillance, and Reconnaissance Course

- Networking and Communications Course
- Anti-tamper Policy, Technology, and Application Course

Courses in ballistic missile defense, net-centric and cyber operations, and space technology and policy were presented, in a joint effort with Tufts University, at the Naval War College in Newport, Rhode Island

Publications

Knowledge dissemination is also achieved through the diverse venues in which Lincoln Laboratory researchers publish. The technical staff publish articles in peer-reviewed journals and present at national technical conferences, such as the IEEE Military Communications Conference and the Annual Meeting of the IEEE Lasers and Electro-Optics Society. Between July 1, 2011, and June 30, 2012, Lincoln Laboratory staff published 119 papers in proceedings from such conferences and 85 articles in technical journals.

In addition, the Laboratory publishes the *Lincoln Laboratory Journal*, which contains comprehensive articles on current major research and journalistic pieces highlighting novel projects, and supplies sponsoring agencies with technical reports, some of which are available through the DOD's Defense Technical Information Center.

In December 2011, Lincoln Laboratory issued the second edition of its history book. The nearly 600-page volume chronicles the establishment of the Laboratory and traces the evolution of research and development conducted during the Laboratory's 60 years. More than 100 staff members contributed to this updating of the original book, which was published in 1995. The doubling in the book's length reflects the broad range of work that has been undertaken since the early 1990s.

Collaboration with the MIT Campus

Initiatives supported by the MIT campus and Lincoln Laboratory promote research collaborations, foster knowledge exchange, and enhance professional development. In addition, the exceptional MIT alumni who join the Laboratory increase the opportunities for establishing joint projects. This year, 26 MIT alumni joined Lincoln Laboratory.

Below are some of the cooperative initiatives that strengthen research at both institutions.

Integrated Photonics Initiative

A unique partnership between Lincoln Laboratory and the MIT campus is the Integrated Photonics Initiative (IPI), a multiyear, Laboratory-funded effort that enhances the research experience for PhD candidates working on integrated photonics devices and subsystems for potential insertion into advanced communications and sensor systems. The IPI has been developing new devices and subsystems to advance the field of coherent optics, which are of increasing interest for use in applications such as optical communications, laser radar, and microwave photonics. William Loh, an MIT graduate

student performing his thesis research at Lincoln Laboratory as a member of the IPI, has been working to understand the noise properties of both high-power semiconductor optical amplifiers and narrow-linewidth semiconductor external-cavity lasers.

Beaverworks

Lincoln Laboratory is engaged in ongoing collaborations with departments and centers at MIT to provide project-based educational experiences to undergraduate and graduate engineering students. Capstone projects afford students a year-long involvement in the research, design, fabrication, and test phases of the development of a prototype system. The program leverages the technical staff's expertise and the Laboratory's prototyping resources to "scale up" campus-led projects, and draws on campus expertise to develop new Laboratory-led projects. This collaborative effort generates innovative solutions in areas as diverse as unmanned aerial vehicles, cyber security, supercomputing, energy systems, imaging sciences, and signal processing. The initiative has been dubbed "Beaverworks" in a nod to both the MIT mascot and the term *skunk works,* an industry name that came to denote an assignment-specific group working on a specialized project.

Sample Beaverworks initiatives include a project in which students from the Department of Aeronautics and Astronautics developed the Microsized Microwave Atmospheric Satellite, a three-unit miniaturized satellite designed to provide observations of hurricane dynamics and severe storms. In another project, senior-level undergraduates in the Department of Mechanical Engineering designed and built a proof-of-concept hybrid power system for an unmanned underwater vehicle. Students in Electrical Engineering and Computer Science worked on a cyber security problem, analyzing code for malicious attacks.

Research Collaborations

There are multiple mechanisms for direct support of and collaboration with MIT campus researchers. Each year, the Laboratory spends approximately eight to ten percent of its internal research and development funding on campus through these mechanisms. Campus Collaborations are three-year renewable grants to MIT faculty and research staff working on topics of relevance to Lincoln Laboratory's primary mission areas. These grants are intended to foster the development of long-term working relationships between Laboratory staff and MIT researchers. In addition, the Advanced Concepts Committee provides short-duration grants to MIT faculty and staff for focused research in basic and applied science and technology areas of potential interest to the Laboratory. Collaborative mission-focused projects are also supported directly from the Line as well from external program sponsors in the DOD, Department of Energy, NASA, and other government agencies.

Infrastructure

Facility

Of primary importance is the availability of adequate physical facilities for the evolving needs of the Laboratory's advanced technology programs. Steady growth in programmatic areas has brought a gradual increase in personnel, so that the Laboratory is now "stretched to the seams." A long-range plan for adding modern laboratory spaces and alleviating office overcrowding is being developed. Renovations to existing buildings are one way to provide appropriate spaces for new work demands. A series of moves will be needed as the first step toward reconfiguring spaces and relieving overcrowding. In late 2011, most of the Air and Missile Defense Technology Division moved into leased space in an industrial park about a mile and a quarter from the main laboratory complex, thus beginning the process of relocating staff and spaces. The laboratory is exploring options to move staff from multiple departments into leased, refurbished office space on Hanscom Air Force Base property.

Another goal is to add a new, modern facility with purpose-built spaces for fabrication, integration, and rapid prototyping as well as electronics laboratories and clean rooms. The Laboratory has drafted a plan to finance the construction of a new building and is awaiting DOD and congressional approval of the plan.

The Facility Services Department manages Lincoln Laboratory's capital renewal program, which encompasses two main pieces: annual capital investment projects and the Deferred Maintenance Program (DMP). "Deferred maintenance" refers to building and systems maintenance that was postponed because of limited resources or funding.

The Laboratory initiated a formal DMP in 2009 to direct critical updates to the facility. On the basis of a comprehensive facility condition evaluation, the department allocates a yearly budget to the DMP. Total program expenses to date equal $25 million. Deferred maintenance projects are continually prioritized based on their impact or criticality relative to the Laboratory's mission. Project categories include life safety, building envelope repairs, HVAC and systems upgrades, electrical improvements, aesthetics, and other renewal needs. The department monitors the program's progress through reiterative facility condition assessments.

A few of the major DMP projects completed in 2012 were B-building air system replacement, C-building roof replacement, electrical-system panel board upgrade, and the toxic-gas detection system upgrade. The projected FY2013 DMP budget is $10 million.

Services

The Laboratory continues to augment support services. Some of the improvements are highlighted below.

In 2012, the Information Services Department (ISD) implemented a new content management system. The Lincoln Information Sharing Application (LISA) is designed to help employees organize files, share information, and engage in collaborative projects.

The system provides a permissions structure to let "owners" of information control access to it. Users can customize their space on LISA to facilitate finding and accessing files.

The Business Process Improvement Program, coordinated by ISD and the Financial Services Department, continues to roll out new tools that will aid in analyzing, forecasting, and managing the Laboratory's funding. This program is a multiphase initiative to provide an integrated system that ensures data integrity and transparency. In June 2012, new financial reporting is being implemented; new reports will streamline and consolidate some functions, and outdated report types will be retired.

The Financial Services Department focused its efforts this year on making improvements to accounts receivable collections and implementing some efficiencies in financial systems and processes. Changes in the billing process resulted in an improvement in invoice collection days. In the last six months of the year, approximately 72% of invoices were liquidated within 20 days and approximately 92% within 90 days. A new SAP Funds Management module was implemented in the fall and allows more detailed tracking and reporting of sponsored research funding.

The substantial effort put into identifying key reports from the Laboratory Data Warehouse helped in standardizing and streamlining the report catalog. With the uncertainty in the government budget timeframe and the possible imposition of sequestration in FY2013, a more robust financial modeling capability was developed so that the department could model various funding scenarios for current and future years. General process improvements included implementing electronic approvals for local travel and beginning the conversion of vendor payments to Automated Clearing House payments, thereby reducing the amount of check processing that had to be done.

With support from the Security Services Department, the Laboratory received its sixth consecutive "superior" rating from the US Air Force's 66th Air Base Group Information Protection Office. The Security Services Department strengthened its program at the Laboratory by accomplishing the following strategic goals:

- Completed a Red Team vulnerability assessment
- Expanded its forensic analysis center with the addition of more robust forensic and malware analysis tools
- Updated the Laboratory's remote access and data encryption requirements
- Enhanced the Laboratory's physical security and information technology (IT) emergency communications with the implementation of a comprehensive emergency notification system and web-based IT security alert system
- Increased security education through methods such as computer-based training modules, awareness campaigns, and seminars
- Developed an improved system of delivering security resources and automated numerous request forms via the department's internal website

Within the Contracting Services Department, the Small Business Office (SBO) advanced opportunities for small businesses to work with the Laboratory.

- A Small Business Fair and an active schedule of vendor demonstrations (50 vendor demonstrations in 2012) introduced new businesses to Laboratory staff.
- The SBO's new interactive database on the Laboratory's internal website allows staff to search for small businesses by product or service type, and a 2012 "sweep" of almost 2,000 small vendors is identifying those whom the SBO can help with the representations and certifications necessary to do business with Lincoln Laboratory.

CSD continued to expand its electronic procurement program, adding eight new catalogs. A 22% growth in electronic transactions was realized in 2012. The department also implemented a successful Procurement Assistant Program, under which trained support personnel handle micropurchase orders, allowing contracts specialists to focus on more complex procurements in support of research programs.

Community Outreach

Education

Recognizing the importance of preparing young people for careers in science, technology, engineering, and mathematics (STEM), Lincoln Laboratory Community Outreach (LLCO) administers a significant program of STEM activities. Several 2011–2012 educational outreach activities bear highlighting.

Figure 13. Technical staff member Raoul Ouedraogo (left) helped students from the LLRISE program configure their small radar system.

In July 2012, the Laboratory ran a two-week residential program for 12 high-school students entering their senior years. The program, Lincoln Laboratory Radar Introduction for Student Engineers (LLRISE), includes instructional sessions on the basics of radar systems and radar imaging; workshops to build radar systems that can perform range-Doppler imaging; and hands-on exercises using the radars built in the workshops. During the two weeks, students were housed in a dormitory at MIT and attended sessions on campus to learn more about the college application and financial aid processes.

A team of five students mentored by Laboratory staff participated in the national CyberPatriot competition in which teams are challenged to respond to simulated cyber attacks. The team made a perfect score in the first challenge round and progressed through two more rounds to become one of the 12 teams (out of 1,000 teams that entered the first round of competition) to compete in the finals in Washington, DC, in late March.

Laboratory staff members are helping local Boy Scouts earn merit badges in inventing and robotics. Scouting@Lincoln presents hands-on workshops so scouts can participate in activities that count toward badges. In addition, this group, along with 20 to 30 local scouts, is participating in the development of a new game design merit badge.

In summer 2012, the Laboratory, in partnership with the Boston chapter of the Society of Women Engineers, held an all-day, hands-on, engineering immersion program for middle-school-age girls. This *Wow! That's Engineering!* program has been offered four times at the Laboratory, reaching 400 girls.

Lincoln Laboratory's robotics initiative, Robotics Outreach at Lincoln Laboratory (ROLL), continues to mentor teams in the FIRST (For Inspiration and Recognition of Science and Technology). ROLL added a new workshop for middle- and high-school students; the Roboworkshop used 1:10–scale radio-controlled cars to explore the physics of motorsports. ROLL also advises "sister teams" sponsored at local schools. Two staff members who are very active in ROLL, John Peabody and Loretta Bessette, became affiliate partners with the Massachusetts FIRST Technical Challenge.

Figure 14. Technical staff member Eric Shank briefed students from MIT's Minority Introduction to Engineering and Science (MITES) program on work being done for the FAA. The MITES group visited this air traffic management lab during a day-long tour at Lincoln Laboratory.

"Science on Saturday," the Laboratory's first STEM program, is still drawing 700 K–12 students, parents, and teachers to each of the five annual onsite science demonstrations given by technical staff members during the academic year.

Lincoln Laboratory is continuing its partnership with the MIT Department of Engineering's Office of Engineering Outreach Programs (OEOP). The Laboratory sponsors students in each of four OEOP programs, provides tours of Lincoln Laboratory's unique facilities to the student groups, and offers courses or presentations given by members of the Laboratory's technical staff.

The Laboratory's other established educational outreach programs—classroom presentations at local schools by technical staff members, the LIFT2 internship program for teachers, the Ceres Connection that names asteroids in honor of science fair winners—are all continuing.

Community Service

The Laboratory's community service programs continue to grow. This year's initiatives included participation in a Veterans' Day fun run and the Run-Walk to Home Base event at Fenway Park. The ongoing campaign to collect and mail food, toiletries, and books to US soldiers overseas sent 200 care packages to US troops in Afghanistan. The Memory Walk for the Alzheimer's Association raised more than $17,600 to provide services to patients in Massachusetts and New Hampshire. The LLCO again facilitated participation in the Bike and Hike the Berkshires event that raises funds for the Multiple Sclerosis Society; $9,000 was raised by the bike and hike team. The Great Strides for Cystic Fibrosis team raised $12,465, and the TeamWalk for Cancer brought in $5,035. The annual holiday clothing, food, and gift drive brought in warm coats, food, and gift items. More than 300 toys were donated by Lincoln Laboratory employees to the MIT Federal Credit Union's annual drive for Toys for Tots.

Summary

Demand for Lincoln Laboratory's research remains strong, and the sources of sponsorship are diverse. Current programs extend from fundamental investigations to developmental engineering to operational testing of systems. The Laboratory's portfolio is well balanced with system development in the core missions, innovative research projects, and large-scale programs.

Emerging national concerns are leading to opportunities for research and development in areas such as cyber security, quantum information sciences, and biomedical technologies. Work in the Advanced Technology Division is increasingly multidisciplinary, and the broad scope of the division's work on enabling technologies includes high-performance detectors and focal planes, three-dimensional integrated circuits, microelectromechanical devices, and unique lasers. The growing rapid prototyping efforts are supported by redesigned workspaces and the addition of new tools such as a fused deposition modeling production system and a five-axis milling machine.

Ongoing improvements to administration and infrastructure sustain the Laboratory's ability to achieve technical excellence. Charitable giving activities are providing needed resources to local communities and organizations, and the educational outreach program is expanding, particularly in its reach to students in underserved communities. In conclusion, Lincoln Laboratory is well positioned to take on the challenges of its mission of service to the nation.

Eric D. Evans
Director