Lincoln Laboratory

Lincoln Laboratory, a federally funded research and development center (FFRDC) operated by the Massachusetts Institute of Technology, is also designated a Department of Defense (DoD) Research and Development Laboratory. Operating under a prime contract with the Department of the Air Force, Lincoln Laboratory conducts research and development pertinent to national security on behalf of the military services, the Office of the Secretary of Defense, the intelligence community, and other government agencies.

Lincoln Laboratory's mission is to advance system and technology development in support of national security. Most of the research and development carried out at the Laboratory revolves around three core areas: sensors, information extraction (signal processing and embedded computing), and communications, all supported by a broad research base in advanced electronics. Projects focus on developing and prototyping new technologies and capabilities for which the government cannot rely on in-house or private-sector resources.

For federal fiscal year 2008, Lincoln Laboratory will receive approximately $665 million that will support the efforts of approximately 1,400 professional technical staff and 1,200 support personnel; outside procurement will exceed $325 million. Although most of the research is sponsored by the DoD, funding is also provided by the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), 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, 2005, the DoD awarded a five-year reimbursement contract with a five-year option to MIT for operation and management of Lincoln Laboratory as an FFRDC. The award continues a long-standing relationship existing between the US government and MIT, which has operated Lincoln Laboratory since its inception in 1951. For 57 years, Lincoln Laboratory has provided advanced technological solutions to meet national security needs, earning a Secretary of Defense Medal for Outstanding Public Service in 2001 for a half-century of distinguished technical innovation and scientific discoveries.

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

The Laboratory's success has been built on the strengths of its staff: technical excellence, integrity, and innovativeness. The three-tiered organizational structure—Director's Office, divisions and departments, and groups—encourages interaction between staff and line management. Increasing demands to conduct research and development of more complex, integrated systems have raised the level of collaboration among staff,

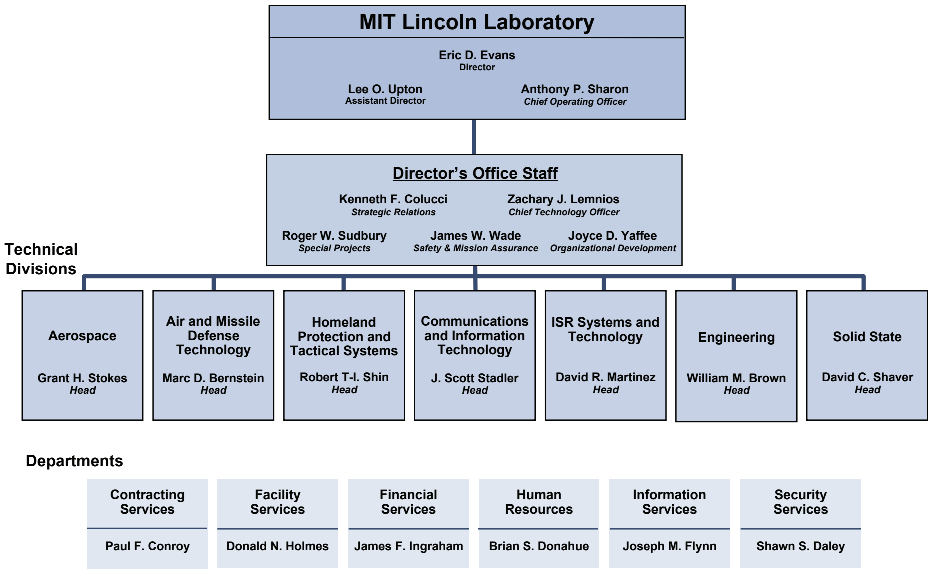

Figure 1. MIT Lincoln Laboratory organizational structure.

facilities, and services. Service departments, as providers of standardized support, enable cross-divisional research teams to focus on technical challenges rather than on administrative services.

Key Changes to the Laboratory's Senior Management

Dr. Bernadette Johnson was appointed assistant head of the Homeland Protection and Tactical Systems Division. William M. Brown was appointed head of the Engineering Division. Dr. Grant H. Stokes was appointed head of the Aerospace Division, and Lawrence M. Candell was named assistant head of that division. Dr. Antonio F. Pensa, Dr. Darryl P. Greenwood, and Dr. Richard W. Ralston stepped down from the steering committee.

Key Changes to the Laboratory Service Departments

Two new managers joined Lincoln Laboratory during the past year. Joseph M. Flynn, chief information officer, is heading up the Information Services Department, which is responsible for providing central information technology services to the Laboratory. William H. Kindred, diversity and inclusion manager, joined the Human Resources Department, where he is responsible for enhancing recruiting efforts, training programs, and ongoing initiatives to increase the representation of underrepresented groups at the Laboratory. Please refer to Figure 1 for an overview of the current Laboratory organizational structure.

Staff

A key factor in maintaining excellence at Lincoln Laboratory is the quality and diverse talents of its staff. The Laboratory obtains 65–75 percent of its new staff directly from the nation's leading technical universities. The Laboratory conducted on-campus interviews

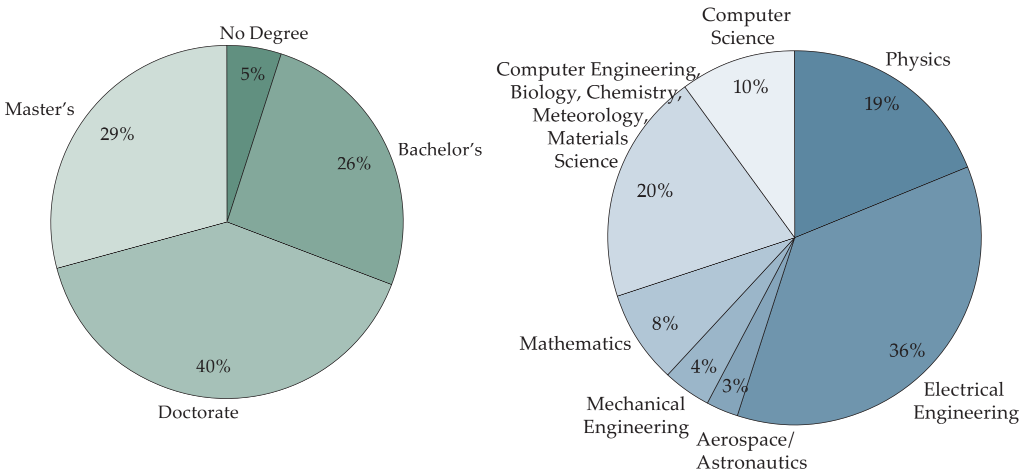

Figure 2. Composition of professional staff at MIT Lincoln Laboratory by academic degree (left) and academic discipline (right).

at more than 50 universities this past year. The makeup of Laboratory staff by degree and academic discipline is shown in Figure 2.

Professional technical staff	1,391
Total Laboratory employees	2,627

During the past year, several Lincoln Laboratory staff members were recognized for achievements in their fields and for their commitment to professional activities. Dr. Antonio F. Pensa, assistant director of Lincoln Laboratory, received an Outstanding Engineering Alumnus Award from the Pennsylvania State University. Roger W. Sudbury, Director's Office staff, was elected as Institute of Electrical and Electronics Engineers (IEEE) director-elect for its Division IV, Electromagnetics and Radiation; he will serve as director-elect in 2008 and on the IEEE Board of Directors in 2009 and 2010. William P. Delaney, Director's Office fellow, was presented with a Department of the Navy Superior Public Service Award. Dr. David C. Shaver, head of the Solid State Division, was named a fellow of the IEEE for his leadership in semiconductor microlithography and microfabrication technology. David R. Martinez, head of the Intelligence, Surveillance, and Reconnaissance (ISR) Systems and Technology Division, received an Eminent Engineer Award from New Mexico State University College of Engineering.

Lincoln Laboratory's commitment to the professional development of its staff is evidenced by the variety of onsite courses offered in technical fields, computing, and management skills. During this past year, the Technical Education Program offered semester-length courses on a range of topics: basic optics, optical discrimination, radio frequency (RF) design techniques, semiconductor device physics and technology, analog CMOS circuit design, and analog filter design. The Technology Awareness Series was designed to foster creative thinking about how emerging technologies can be integrated into existing systems; during this first year, one- to two-day seminars on communication technology, computer security, and mini/micro unmanned aerial vehicles (UAVs) were offered. The Training and Development Program sponsored courses in Matlab techniques, project management, and negotiating skills. Division and staff seminars on current research continued to be presented every week, and special seminars are often brought to the Laboratory.

In addition, the Laboratory encourages its staff to pursue advanced education. For highly qualified candidates, the Laboratory offers the opportunity to apply to the Lincoln Scholars program, which supports the pursuit of advanced degrees. This year, under the Lincoln Scholars program, three staff members earned doctorates and 14 earned master's degrees, primarily in electrical engineering and computer science; for FY2009, 31 advanced-degree candidates are enrolled in the Lincoln Scholars program. Also, 15 Lincoln Laboratory staff members completed master's degrees and seven completed doctorates.

Technical Program Highlights

Research at the Laboratory focuses on national security problems in diverse areas: tactical and ISR systems technology, air and missile defense, space situational awareness, biological-chemical defense, communications and information technology, 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 FY2008, the Laboratory has been working 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

Principal 2008 Accomplishments

- Development of the Space Surveillance Telescope (Figure 3) is proceeding through optical processing, with the tertiary mirror complete and polishing commencing on the larger primary mirror. Assembly of the azimuth base and yoke has been completed and motor testing is under way. Groundbreaking for the telescope enclosure at Atom Site on the White Sands Missile Range occurred in January 2008.
- The Extended Space Sensors Architecture (ESSA), a net-centric test bed for space situational awareness, is now providing real-time radar imagery of satellites to military users. ESSA is also incorporating Net-Centric Enterprise Services software, developed by the Defense

Figure 3. The Space Surveillance Telescope will provide advanced ground-based optical system capability to detect and track space objects.

Information Systems Agency, to facilitate use of ESSA across multiple sensors and military organizations.

- The Lexington Space Situational Awareness Center (LSSAC) successfully supported the launch of the Wideband Global SATCOM Flight 1 satellite in October and Defense Support Program Flight 23 in November 2007. LSSAC also supported the tracking and characterization of 59 newly launched satellites.
- Optical Processing Architecture at Lincoln (OPAL) has continued its development toward a common processing architecture for a broad range of sensors. OPAL provides mission planning and data processing for space surveillance sensors. Deliveries of the OPAL system were completed to a number of sensor installations, and new sensors were identified that will utilize the OPAL software in the future.
- Advanced technologies and processing techniques for future NOAA missions continue to be developed and demonstrated. The Laboratory is incorporating an infrared digital focal-plane array into a Fourier transform interferometer system, demonstrating 1.5x improved performance with 100x improved speed in atmospheric sounding products, and establishing a path from phenomenology to product development through modeling.

Future Outlook

- Emerging technical areas include advanced radar development, radar surveillance, space object identification, electro-optical deep-space surveillance, collaborative sensing, and identification fusion and processing.
- Lincoln Laboratory is pursuing several initiatives in the space area that include the next generation of sensor systems and downstream processing/information-extraction systems, such as:
    - a small-aperture space-based space surveillance system to provide wide-area search of the geosynchronous belt every 90 minutes for submeter-sized objects
    - a passive, ground-based, wide-angle “fence” search system for detecting low Earth-orbiting satellites, utilizing unique curved charge-coupled-device focal planes to achieve the wide coverage
    - net-centric machine-aided decision support algorithms to allow the operators in the Joint Space Operations Center to react to emerging threats to space assets
    - incorporation of space environment monitoring as part of integrated space situational awareness
    - initiation of efforts in climate-change modeling via novel sensor design in the far long-wave infrared.

Air and Missile Defense Technology

Principal 2008 Accomplishments

Figure 4. An X-band radar (XTR-1) will be integrated on a ship to support missile-defense testing in the broad ocean area.

- An advanced discrimination architecture for the Aegis AN/SPY-1 radar was installed on the Aegis Ballistic Missile Defense (BMD) cruiser *USS Port Royal* and successfully participated in a recently successful Aegis BMD intercept test. The architecture correctly identified the object of interest in real time. The architecture and processing algorithms have been transferred to a contractor for incorporation in the planned 2010 Aegis BMD upgrade.
- The development of a mobile X-band instrumentation radar (XTR-1) proceeded into the system integration and check-out phase at the Lincoln Space Surveillance Complex in Westford, Massachusetts. The XTR-1 (Figure 4) will become the radar component of the Missile Defense Agency's mobile range concept. The radar is based on the modern Radar Open Systems Architecture originally developed for the suite of instrumentation radars at the Reagan Test Site (RTS). The XTR-1 will begin participating in Ballistic Missile Defense System (BMDS) flight testing in 2009.
- Lincoln Laboratory, in cooperation with the Australian Defence Science and Technology Organisation, completed the first demonstration of critical components of a next-generation over-the-horizon (OTH) surveillance radar using modifications to the Australian Jindalee Operational Radar Network. New radar waveforms and adaptive processing techniques were developed and utilized to significantly reduce the effects of multiple propagation paths on target detection. The Laboratory is integrating the technology into a radar test bed for the next-generation US OTH radar.
- The RTS Distributed Operations project successfully completed several engineering and test milestones, including a critical design review in December 2007. The development and integration of this modern net-centric control, communication, and sensing architecture for the RTS allow missile test and space operations occurring at RTS to be conducted from the US Army Space and Missile Defense Command in Huntsville, Alabama.
- The Laboratory continues to have a significant role in the development of a new radar system for the Navy's E-2D Advanced Hawkeye airborne early-warning system. Lincoln Laboratory collected and analyzed data from the E-2D test bed flight-test program and provided an independent assessment of the performance of the new radar system. An additional flight-test campaign was conducted using

Lincoln Laboratory's airborne test bed to examine the performance of advanced waveforms and algorithms for the E-2D upgrade.

- The Laboratory continues to assess the capabilities of US Air Force and joint air defense systems in operational scenarios. Ongoing assessments focus on the impact of an electronic attack on US airborne surveillance systems.

Future Outlook

- The Laboratory will have a large role in characterizing the capabilities and limitations of the recent initial operational deployment of the BMDS and in helping to develop, refine, and verify techniques to optimize performance. The Laboratory will also be actively engaged in analyzing, developing, testing, and implementing capabilities for the BMDS beyond initial deployment. Areas of particular focus will be system-wide tracking and discrimination, system-level testing, and advanced counter-countermeasure techniques.
- The Laboratory will be working to define architectures for the defense of the US homeland against asymmetric attacks by cruise missiles or short-range ballistic missiles launched from ships off the US coast. An initial prototyping effort is being examined in the National Capital Region as an extension of the Enhanced Regional Situation Awareness system currently in place to provide a defensive capability against such threats.
- The Laboratory will support the development and integration of advanced technologies into naval ships, with emphasis on a new S-band radar and electronic countermeasures for ship self-defense. Several key technologies, including wideband digital beamforming, are being developed for the next-generation S-band solid-state radar for the CG(X) cruiser. The Laboratory will also begin working on enhancements to an active decoy system to defend ships against future missile threats.

Communications and Information Technology

Principal 2008 Accomplishments

- Lincoln Laboratory collaborated with industry to validate design standards for the critical technologies needed for transformational communications: RF signaling waveforms and formats, network protocols, and lasercom (pointing, acquisition and tracking, and optical waveforms). Validation of industry hardware was performed on a

Figure 5. The Large-Aperture Ka-Band Test Terminal was used to perform early characterization of the first Wideband Global System satellite communications payload.

Lincoln Laboratory–constructed test and evaluation infrastructure under government supervision.

- Early on-orbit checkout of the Wideband Global System satellite communications payload was performed using a Lincoln Laboratory–developed Ka-band "over-the-air" test capability at Camp Parks, California (Figure 5). The test terminal implemented key components of a new Ka-band waveform for the Air Force's Family of Advanced Beyond Line-of-Sight Terminals. This waveform will be used for wideband readout of airborne intelligence, surveillance, and reconnaissance sensors on unmanned aerial vehicle platforms.
- The Laboratory developed an over-the-air interim payload command-and-control (IC2) capability that will also be used for testing and calibrating the Advanced EHF (AEHF) payload. The IC2 capability was deployed to Lincoln Laboratory, Colorado, and California.
- A net-centric software toolkit was developed to enable the rapid deployment of multisensor applications. This toolkit was demonstrated in a cross-mission scenario, showing how space situational awareness and missile-defense assets could be used cooperatively.
- Lincoln Laboratory participated in the most recent government-sponsored international evaluation of language-identification systems. The Laboratory's systems exhibited best-of-breed performance across most evaluation conditions.
- The Laboratory developed the first system that performs both joint static and dynamic analysis of source code to find vulnerabilities in software. Quantitative evaluation of the system demonstrated that this hybrid system yields better vulnerability detection than either static or dynamic analysis alone.
- Lincoln Laboratory developed a government reference implementation of a next-generation airborne networking waveform for the Joint Tactical Radio System (JTRS) and built and delivered a simulation and test environment for the JTRS enterprise networking services gateway.
- Optical free-space communication at high data rates (multiple gigabits/second) was demonstrated at efficiencies of better than 1 bit per photon.

Future Outlook

- Lincoln Laboratory will use the IC2 capability to support the initial operation of the AEHF satellite.
- Transformational communications satellite test beds and government-reference systems will be enhanced to permit testing of evolving industry systems.
- Development and deployment of computer network attack and analysis tools will be undertaken to evaluate the robustness of the Army's future combat system and other future DoD systems.
- The Laboratory will design and develop a ground node capable of on-the-move communication with the AEHF satellite system.

Intelligence, Surveillance, and Reconnaissance Systems and Technology

Principal 2008 Accomplishments

- Lincoln Laboratory conducted a large-scale surface surveillance experiment with multiple airborne sensors, including electro-optic imagers and moving-object indication radars. The objectives were to assess the feasibility of detecting and tracking difficult objects moving between open rural areas and cluttered urban environments, and to develop the required processing techniques and multiple-sensor data-fusion and handover concepts.
- The Laboratory has developed techniques for detecting dismounted personnel and is researching the feasibility of discriminating between personnel and other object types. A field exercise to collect dismount radar phenomenology was planned and conducted.
- Lincoln Laboratory's active experimental campaigns included several collections performed to demonstrate architectural concepts using an active electronically scanned array together with a command-and-control suite. These efforts led to the insertion of fusion and exploitation tools into an experimental suite of capabilities used by the National Geospatial-Intelligence Agency.
- Lincoln Laboratory has developed new passive sonar beamforming algorithms for submarine bow sphere arrays. New computationally efficient approaches for conventional beamforming were developed and shown to outperform legacy systems (Figure 6). This modernization has enabled the application of adaptive beamforming for additional benefit in dense contact environments. The new approaches have demonstrated significant benefits with recorded fleet data, and the Laboratory is working closely with the Navy and industry on algorithm technology transitionThe Laboratory completed a prototype microprocessor chip showing the ability to cancel nonlinearities commonly found in complex receiver systems. This capability will permit lower-performing analog-to-digital converters to be used without sacrificing performance.

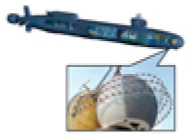

Figure 6. Adaptive beamforming approaches are being developed for large 3D submarine sensor arrays such as this spherical array in the bow of a Virginia-class submarine.

- In support of transitioning technology, sharing results with the community, and reaching national consensus, Lincoln Laboratory hosts several annual workshops that have had significant impacts on their respective communities: High Performance Embedded Computing, Integrated Sensing and Decision Support, Adaptive Sensor Array Processing, and Surface Surveillance Technology.

Future Outlook

- Lincoln Laboratory is developing imaging sensors, automated processing algorithms, and processor technologies to improve the capabilities of persistent electro-optical systems for the Army and other agencies.

- Overland and maritime ISR exploitation techniques are being developed for next-generation airborne and space-based radars.
- Miniaturized digital receivers and sensor payloads are in development for small unmanned aerial vehicles, high-performance wideband passive geolocation, and high-resolution surface surveillance radar.
- The Laboratory will demonstrate the use of THz imaging for identification of explosive residues present on a person's clothing and hair.
- The first annual ISR08: Intelligence, Surveillance, and Reconnaissance Systems and Technology Workshop will provide a forum for Laboratory researchers and key members of the national ISR community to engage with representatives from academia, industry, and government. The workshop will promote the dissemination of technical information, which is a principal activity within the Laboratory's mission.

Advanced Electronics Technology

Principal 2008 Accomplishments

- A unique device called the orthogonal transfer array was developed for the Air Force's Panoramic Survey Telescope and Rapid Response System (Pan-STARRS), which is a fast sky-survey system comprising four telescopes, each with a 1.4-gigapixel focal plane array (FPA) (Figure 7). The first 1.4-gigapixel FPA was integrated into a recently constructed wide-field-of-view 1.8m-aperture telescope, and the first astronomical images were acquired.

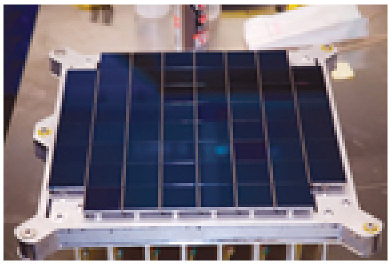

Figure 7. A unique orthogonal transfer array has been developed for synoptic space surveys in Pan-STARRS. The 60-chip array is 40×40 cm.

- A 128-×128-pixel, 50-sample charge-coupled-device imager and supporting electronics were provided to Lawrence Livermore National Laboratory (LLNL) for field tests. Measurements done at LLNL demonstrated that the imager operates at more than two million frames per second and is capable of exposure times as short as 200 ns.
- The superwideband compressive receiver program completed a second measurement campaign aboard an Air Force aircraft. The highlight of this test was the demonstration of full real-time processing of threat signals across a 4.0-GHz instantaneous bandwidth. The compressive receiver met or exceeded aggressive performance targets for sensitivity, dynamic range, and frequency accuracy.
- The Laboratory's unique three-dimensional integrated circuit technology was used to demonstrate functional four-side-abuttable imaging modules for large "mosaic" FPAs. In this architecture, the electronics for each pixel reside in tiers behind the high-fill-factor photodetection tier, enabling many key improvements,

such as integration of multiple material and process technologies for optimized functionality.

- The slab-coupled optical-waveguide laser (SCOWL) invented at Lincoln Laboratory is being used in novel, coherent-beam-combining architectures with individually addressable array elements. Record combined power levels were achieved. The SCOWL structure produced semiconductor optical amplifiers that have power higher than previously reported and that enable narrow line widths with low noise in a compact package. Mode-locked SCOWL devices have demonstrated record output powers in short-pulse operation.
- Cryogenic Yb:YAG laser technology is migrating into systems such as the Enhanced Track Illuminator Laser (ETILL) being built for the airborne laser. ETILL will provide 2.5 times larger pulse energy and better beam quality than the current Track Illuminator Laser. After a successful critical design review in FY2007, fabrication of ETILL has started.
- The Laboratory's low-loss (<0.15 dB), broadband (3–110 GHz), fully packaged RF microelectromechanical switch technology surpassed 300-billion-cycle reliability testing and is in its final stages of technology transfer to a domestic foundry that will make this state-of-the-art, high-reliability technology available to the entire DoD contractor community.

Future Outlook

Additional applications will emerge in three general areas: (1) imaging and RF technologies in support of the intelligence community, (2) laser technologies in support of communication and targeting systems, and (3) cryoelectronics for longer-term impact in infrared sensing and high-speed computation.

The following are some specific focuses:

- There is continued "system pull" on Geiger-mode single-photon detection technology. The range of applications continues to expand, from laser radar to communication and passive low-light-level imaging.
- Ever-larger focal planes are desired, placing a premium on continued investment in tiling and packaging technologies. Work being done on the specialized elements of integrated circuit fabrication, tiling, and packaging technology is relevant for both CMOS active-pixel sensors and charge-coupled imagers.
- The use of the slab-coupled optical waveguide structure continues to provide significant performance improvements in a variety of device structures optimized at different wavelengths and for different applications, from coherent combining of laser arrays to amplifiers for low-noise oscillators.
- The more mature microchip solid-state laser continues to find broad application in DoD systems, with optimized sources recently deployed in both laser radar and biosensing systems.

Homeland Protection

Principal 2008 Accomplishments

Figure 8. The Rapid Agent Aerosol Detection Program is developing technology for high-performance, lightweight, integrated chemical and biological aerosol detection. Field trials showed reduced false-positive rates and higher agent sensitivity over prior-generation detectors.

- Lincoln Laboratory continued the refinement and technology transition of the Enhanced Regional Situation Awareness system in support of Homeland Air Defense around the National Capital Region.
- A biological and chemical facility protection test bed was demonstrated that allows for the development and testing of detection technologies and response strategies in a realistic setting (Figure 8).
- The Laboratory demonstrated prototype rapid biological trigger devices, including a high-performance sensor employing multiple measurement modalities that was shown to be best-in-breed in FY2006 field tests and a low-cost alternative that uses ultraviolet light-emitting diodes.
- In support of the Department of Homeland Security (DHS), the Laboratory initiated measurements/analysis of the feasibility of rapid detection of biological and chemical threats in shipping containers.
- Lincoln Laboratory led a consortium effort to design tools that simplify the process of securing critical infrastructures.
- Lincoln Laboratory supported the need of the DHS for safe, on-demand operation of unmanned aircraft through the development of modeling and simulation tools that will be critical for system certification.
- The Laboratory developed speaker-comparison software tools, demonstrated their state-of-the-art performance in independent evaluations, and transitioned them to the DHS, where they are used in forensic voice-examination casework.

Future Outlook

- The Laboratory foresees studies relating to architecture development for urban biodefense as well as test and evaluation of bio-chem systems for facility defense, including buildings of military and civilian significance.
- Further development and transition of rapid biological trigger technology to the DoD and DHS are expected.
- The Laboratory will investigate the biological and chemical defense needs and requirements of DHS organizations such as the Transportation Security Administration, Federal Emergency Management Administration, Customs and Border Protection, and the Office of Health Affairs.
- Further development and testing of a universal and rapid biological sample preparation are planned.

- The Laboratory will apply its analytical expertise to provide an independent safety assessment of sense-and-avoid system concepts for unmanned aircraft to support Customs and Border Protection missions.

Tactical Systems

Principal 2008 Accomplishments

- Lincoln Laboratory conducted a comprehensive assessment of options for US Air Force airborne electronic operations. This assessment included systems analysis of various proposed options, development of detailed models of surveillance radars and their electronic protection systems, and testing of various electronic systems and surveillance radars.
- The Laboratory conducted initial flight testing of a new pod on the Airborne Seeker Test Bed with three infrared sensors. These sensors were tested against a variety of targets, including business jets, helicopters, and fighter aircraft with and without countermeasures.
- A number of assessments were performed examining the impact of exporting advanced military systems. These assessments were used by the Office of the Under Secretary of Defense for Acquisition, Technology and Logistics and by Congress as part of the decision-making process for a number of major export programs.
- The Laboratory completed development of an advanced signals-intelligence receiver designed for counterterrorism applications. The multichannel receiver is unique to this application in its use of adaptive beamforming to suppress interference sources and to preserve receiver sensitivity. The receiver system, along with a custom-built antenna array, was flight tested. The Laboratory is now working with the user community to transition this technology to theater as a quick-reaction capability.
- Countermeasures to several counterinsurgency devices were assessed and tested. Devices were measured and analyzed to understand their behavior and to determine exploitable characteristics. A number of exploitation approaches were

Figure 9. The Laboratory is actively engaged in integrating advanced sensors on unmanned aerial vehicle systems such as the AAI Shadow 200 shown above.

laboratory tested, and the results of these tests were used to assess the viability of concepts of operations employing these approaches.

- Lincoln Laboratory is supporting a number of air traffic control–related efforts for the US Air Force. As part of these efforts, the Laboratory is developing a prototype collision-avoidance system for the Global Hawk UAV. This system will be based on a dynamic simulation facility developed by Lincoln Laboratory to model system performance over a wide range of encounter situations.

Future Outlook

- The Laboratory will continue to play an important role in helping the US Air Force develop advanced electronic protection systems and will continue to develop new systems to evaluate future air defense threats. One planned effort is to use an existing passive surveillance system as a baseline for examining the impact of potential advanced signal processing techniques on passive system performance.
- The Laboratory will also continue the development of an advanced electronic operations test bed aircraft. This aircraft will be used primarily to support testing of the electronic protection features of US aircraft radars. This test bed will also be used in the development of advanced electronic protection.
- Lincoln Laboratory is planning continued enhancements of its rapid development capabilities to address needs in counterterrorism and other applications. The Laboratory's broad technical expertise and its agility in assessing and prototyping novel and complex systems strongly position the Laboratory to rapidly respond to threats in the continuing global war on terrorism. The greater use of software-defined systems, activities to better understand and exploit consumer electronics, and dedicated rapid innovation facilities are being planned to further enhance the Laboratory's ability to rapidly develop.

Aviation Research

Principal 2008 Accomplishments

- The Laboratory-developed Corridor Integrated Weather System (CIWS) is being reengineered to provide continental United States coverage and a robust configuration suitable for handoff to the FAA for long-term operation (Figure 10). The initial phase for this national CIWS was deployed in June 2008.

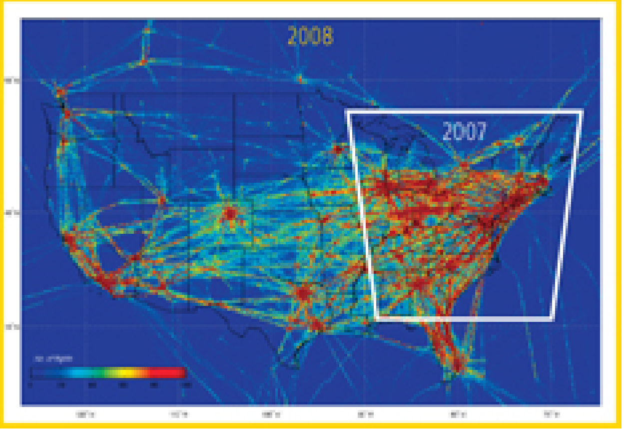

Figure 10. The 2007 CIWS domain is shown as a white outline overlaid on a map of the air traffic density on a clear weather day. The ongoing CIWS reengineering effort permits coverage of the continental United States in 2008.

- The Runway Status Lights system continues operation at Dallas/Fort Worth International Airport. The system was expanded to additional runways and is undergoing testing of a final approach runway occupancy signal to prevent landing accidents. A shadow evaluation (without lights installed) was also performed at Chicago O'Hare International Airport to assess algorithms to prevent conflicts at runway intersections.
- The Laboratory is supporting the FAA's acquisition of a national Automatic Dependent Surveillance–Broadcast (ADS-B) system. The Laboratory analyzed surveillance requirements and radar/ADS-B fusion algorithms needed for air traffic control (ATC) at key ADS-B sites. This included the analysis of wide-area multilateration (locating aircraft by computing time difference of arrival of multiple radio signals) as a backup for ADS-B.
- The Laboratory is working with the FAA to refine concepts for a next-generation Multifunction Phased Array Radar (MPAR) that would provide the surveillance services currently acquired from separate ATC and weather radar networks. Current activities include analysis of how MPAR might improve thunderstorm-forecasting capabilities, an assessment of its role as a backup for ADS-B, and demonstration of ultra-low-cost S-band array technology.
- Enhanced air traffic management tools were developed that exploit emerging weather-forecast capabilities to assist with the execution of reroute and delay programs. This work includes the operation of a Route Availability Planning Tool (RAPT). RAPT has been identified by the FAA as a component of the government's strategy to reduce flight delays affecting New York City airports during severe weather.
- The Laboratory completed the development of a national airspace encounter model under the joint support of the FAA, DoD, and DHS. This model is being used to design and evaluate collision-avoidance systems for manned and unmanned aircraft, including the Global Hawk and Predator.
- Based on successes at Lincoln Laboratory, the FAA has begun fielding a national monitoring program to assess and improve the performance of the Traffic Alert and Collision Avoidance System (TCAS) across the United States.

Future Outlook

- A modern FAA communications architecture will encompass sensor data, decision-support applications, and efficient sharing of information among the decision makers involved in operating the National Airspace System.
- Applications are planned that will leverage ADS-B to improve safety, efficiency, and capacity in congested airspace.
- Increased emphasis is being placed on developing and testing next-generation paradigms for aircraft-separation assurance on the airport surface and during flight. This effort includes evolution of deployed collision-avoidance technologies such as TCAS and runway status lights, as well as simulation, analysis, and robustness testing of future concepts.

- The Laboratory will develop concepts and prototypes of enhanced air-traffic-management decision support tools focused on weather-delay reduction.
- Development and test of an MPAR prototype array with associated control and processing functions are under way to demonstrate aircraft and weather surveillance.
- The Laboratory will develop low-cost sensors and advanced algorithms to improve the safe integration of unmanned aircraft into civil airspace.

Collaboration with MIT Campus

Lincoln Laboratory participates in the Campus Interaction Committee to strengthen its ties and alignment with the MIT campus. The Committee's principal focus is joint research and policy seminars and is chaired by Professor Jeffrey Shapiro. The Lincoln Laboratory/MIT Campus Seminar Series, a program that promotes an exchange of innovative research ideas, has entered its second year. During FY2008, seven speakers from MIT gave talks at Lincoln Laboratory, and nine researchers from the Laboratory spoke at the campus. Seminar topics ranged from high-performance embedded computing to current energy challenges to air traffic management during thunderstorms.

One of our most valued ties to the campus is the exceptional alumni who join the Laboratory. This year, 12 MIT graduates became staff members at Lincoln Laboratory.

Integrated Photonics Initiative

A unique collaboration 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. During the past year, the IPI funded three on-campus students and two students working primarily at the Laboratory.

Advanced Concepts Committee

Other collaborative efforts with the campus are supported through the Advanced Concepts Committee. The committee provides seed funding and proactive technical and liaison support for developing advanced concepts that address high-priority national problems. These concepts may enable new systems or promote significant improvement of current practices. The FY2007–2008 projects are listed below (* denotes an MIT researcher):

- Compressive Sensor Networking—Researchers: J. Goodman, B. Miller, J. Yeh, K. Forsythe, and V. Goyal*
- Bonded-Wafer Process for Optimized Avalanche Photodetectors—Researchers: D. Oakley, Z. Liau, J. Donnelly, H. Li*, and V. Diadiuk*
- High-Index Solid Immersion Lenses for Enhanced Microscope Resolution and Contrast Enhancement for Biomedical/Biodefense Applications—Researchers: Z. Liau, J. J. Chen*, and M. D. Fleming*

- Phase Tightening Feedback for Improved ADC Sampling Accuracy—Researchers: Charlie Sodini* and Helen Kim
- Carbon Nanopipe Membrane Filters—Researcher: M. Switkes
- Perching Control for Fixed-Wing UAVs—Researcher: R. Tedrake*
- Novel Nanoparticles for Optical Limiting Applications—Researchers: V. Liberman and F. Stellacci*

The Advanced Concepts Committee also sponsors the Defense Studies Seminar Series. This year's speakers included Professor Stephen Van Evera of the MIT Political Science Department; Professor Barry Posen, director of the MIT Security Studies Program; and Jennifer Lind, assistant professor in the Department of Government at Dartmouth College.

Industrial Liaison Program

The Laboratory also supports activities conducted by the Industrial Liaison Program staff through presentations by Laboratory staff on cooperative research and development opportunities and technical licensing options.

Technology Transfer

Lincoln Laboratory's focus on adapting and demonstrating advanced capabilities to enhance existing systems results in important technology transfer opportunities. A common strategy for achieving transition is to share the "architectural recipe" and work with commercial component and subsystem suppliers to ensure that technology advances demonstrated by the Laboratory can be duplicated by industry.

Recently, Lincoln Laboratory contributed foundation technologies to two systems that received Packard Excellence in Acquisition Awards:

- The Joint Biological Point Detection System—bioaerosol sensing and microlaser technologies for this system are in commercial production
- Geosynchronous Lightweight Integrated Technology Experiment (GeoLITE)—the optical communications technologies used in the GeoLITE free-space optical communications satellite demonstration system are now commercially available for use in follow-on optical communications programs

Working through the MIT Technology Licensing Office, the Laboratory has made 23 technology disclosures, has applied for 10 US patents, and was awarded 7 US patents between 1 July 2007 and 19 June 2008.

Dissemination of Technology/Technical Education

Dissemination of information to the government, academia, and industry is one of the principal activities 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. Listed below are some of these workshops and seminars:

- High Performance Embedded Computing Workshop
- Surface Surveillance Technology Workshop
- Bio-Chem Defense Systems Workshop
- Space Control Conference
- Air Vehicle Survivability Workshop
- Ballistic Missile Defense Technical Seminar
- Communications and Networking Workshop

In addition, the Laboratory presents a number of technical courses for military officers, DoD civilians, and defense subcontractors:

- Defense Technology Seminar
- Ballistic Missile Defense Technology Course
- Introduction to Radar Systems Course
- Homeland Defense and Counterterrorism Course (offered collaboratively at the Naval War College in Newport, Rhode Island)

Knowledge dissemination is also achieved through the many venues in which Lincoln Laboratory researchers publish. The technical staff publish articles in peer-reviewed journals and present at national technical conferences. During the past year, Laboratory staff published 70 technical articles in professional journals and 47 technical presentations in the proceedings of major public conferences. The Laboratory also publishes the *Lincoln Laboratory Journal*, which contains comprehensive articles on current major research and journalistic pieces highlighting novel projects.

The technical staff author books and contribute chapters to collaborative publications. Books on multiple-antenna technology and parallel computing are in development. Of particular note is *High Performance Embedded Computing Handbook: A Systems Perspective*, a 600+-page reference work that will be available in July 2008. Three members of the leadership in the ISR Systems and Technology Division—David R. Martinez, division head; Robert A. Bond, leader of the Embedded Digital Systems Group; and M. Michael Vai, assistant leader of the Embedded Digital Systems Group—coordinated and edited this multiauthor book, in addition to authoring one-third of the chapters. Seventeen other staff members, as well as a number of researchers from outside the Laboratory, contributed to this handbook.

Lincoln Laboratory continues to promote technical education and knowledge exchange through partnerships with local universities. This year, under the sponsored research program, the Laboratory hosted 44 graduate and 44 undergraduate students. Under collaborative programs with MIT, the Laboratory recently hosted eight VI-A MEng students and two Undergraduate Research Opportunities Program students. In an ongoing partnership with the Worcester Polytechnic Institute, 18 seniors completed their major qualifying projects at Lincoln Laboratory. The collaboration with Tufts University Department of Electrical and Computer Engineering has allowed four students to carry out research projects at Lincoln Laboratory. In addition, 35 students from Northeastern University's cooperative study program were employed at the Laboratory.

Community Outreach

The Lincoln Laboratory Community Outreach (LLCO) was established to promote service and education in partnership with the MIT Public Service Center.

Recognizing the importance of encouraging young people to pursue careers in science, technology, engineering, and mathematics, the LLCO has focused substantial attention on educational outreach. This year, more than 2,200 local K–12 students, their parents, and teachers attended science demonstrations given by Laboratory technical staff under the Science on Saturday program (Figure 11). This year's demonstrations included hands-on engineering design, robotics, archaeology, and "math for world domination."

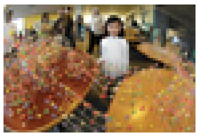

Figure 11. At a Science on Saturday workshop on engineering, children and adults tested their architectural prowess by creating structures from gumdrops and toothpicks.

Technical staff volunteers have given classroom presentations at local elementary, middle, and high schools, delivering presentations on science and engineering to more than 6,000 students. As a partner in the regional Leadership Initiatives for Teaching and Technology (LIFT^2) program, which provides summer employment opportunities for science teachers, Lincoln Laboratory hosted three high school teachers whose first-hand experiences in engineering design and prototype development will enrich their classroom teaching.

In community-service initiatives this year, the LLCO divided proceeds from events such as a used book drive/sale between the United Way and the MIT Community Service Fund. The LLCO continued promoting participation in the benefit bike/hike event for the Multiple Sclerosis Society and the ongoing collection of goods for US soldiers overseas.

Summary

The demand for Lincoln Laboratory's research remains strong. Current programs cover a broad spectrum, from fundamental investigations to developmental engineering, and the sources of sponsorship are diverse. Emerging national concerns are leading to more opportunities for research and development in areas such as biological-chemical sensing, network security and information assurance, and net-centric capabilities for systems. Prototyping efforts continue to experience significant growth, and expansion in development programs has been valuable to the recruitment of talented technical staff members. The Laboratory is working to strengthen its technology transfer activities and, complementary to that goal, to improve external communications. Community outreach efforts continue to provide resources to outside communities; the educational programs have been particularly successful. Ongoing improvements to support engineering, administration, and infrastructure are enhancing the Laboratory's ability to achieve its mission. In conclusion, Lincoln Laboratory is well positioned to take on the challenges and responsibilities inherent in its mission to be of service to the nation.

Eric D. Evans
Director

More information about Lincoln Laboratory can be found at http://www.ll.mit.edu/..