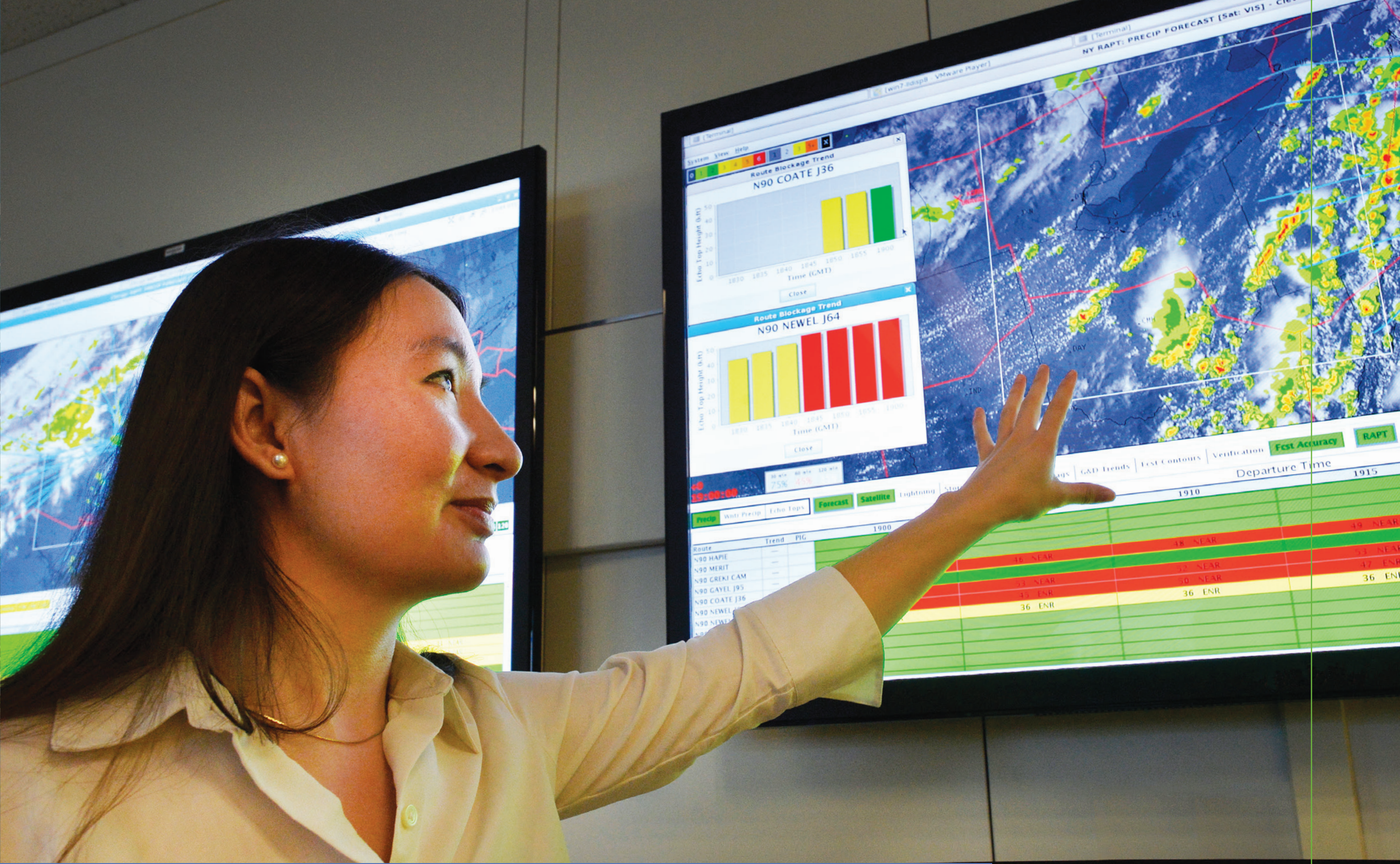
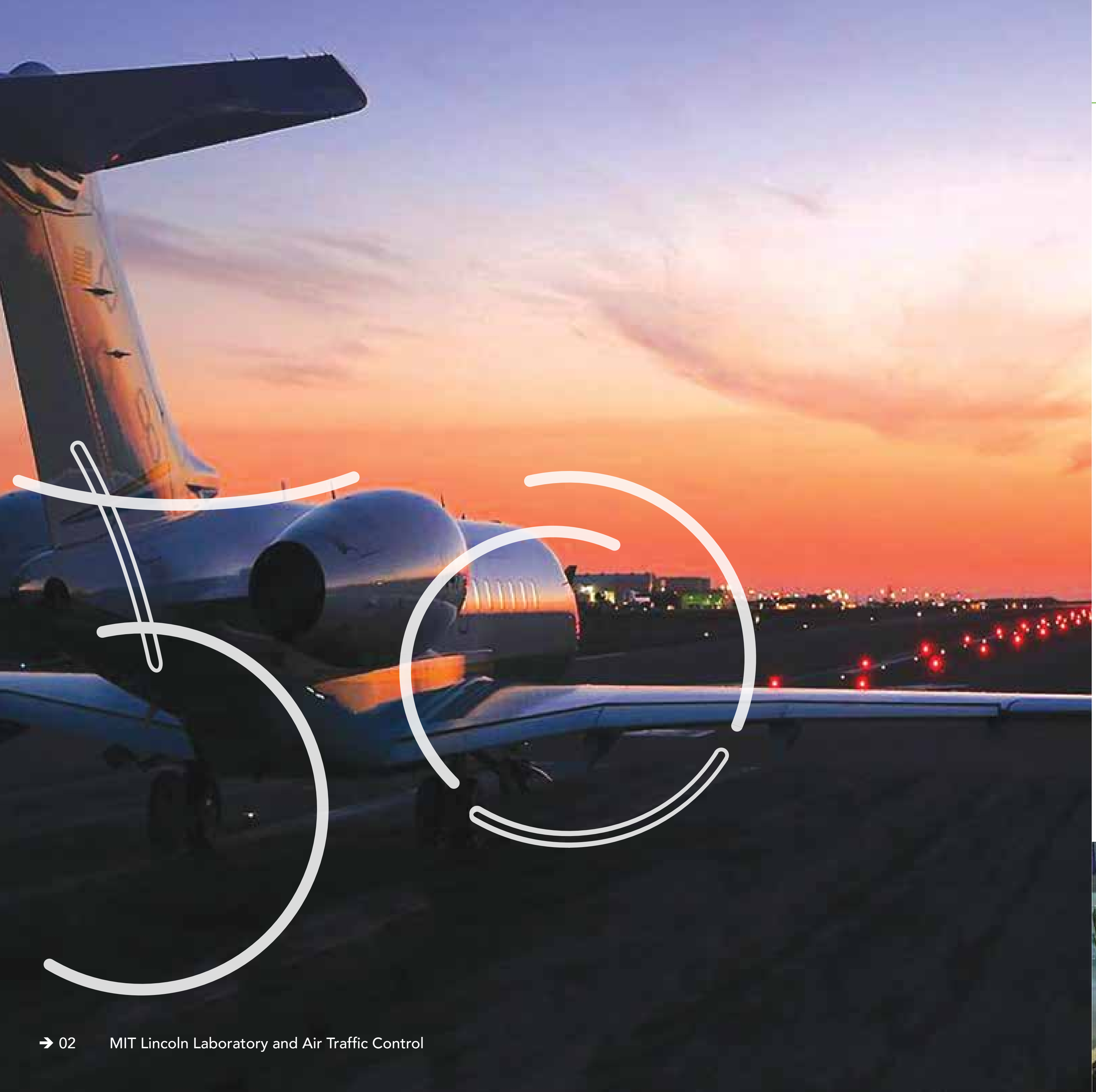


Celebrating 50 Years of Research and Innovation

MIT Lincoln Laboratory
Air Traffic Control

LINCOLN LABORATORY
Massachusetts Institute of Technology



From the Director of MIT Lincoln Laboratory

In the late 1960s, the U.S. air traffic control system was facing a dilemma. The rise of jet aircraft and the booming economy had stimulated an enormous growth in air traffic that led to increased flight delays. The nation was in need of a more efficient and effective air traffic control system to better prevent delays and safety risks such as mid-air collisions.

Because of its expertise and prior experience in radars, communications, and air defense, the Laboratory was well prepared to establish an air traffic control program. Thanks to the initiative of several Laboratory members—including Herbert Weiss, then the head of the Radar Division, and Walter Morrow, then an assistant director of Lincoln Laboratory—the Radar Division was restructured in early 1970 and became the Air Traffic Control Division.

A flight dispatcher at a major airline uses Lincoln Laboratory's Traffic Flow Impact weather forecast technology to coordinate flight schedule changes during a period of thunderstorms impacting the northeastern United States.

The Laboratory's first task for the Federal Aviation Administration was to develop the Discrete Address Beacon System, which allowed for improved data communication between ground controllers and individual aircraft. Since then, the Laboratory has continued to make significant technology advancements in the areas of collision avoidance, advanced surveillance techniques, air traffic control automation, weather sensing and forecasting, and many more. Ten of the technologies mentioned in this booklet have received R&D 100 Awards, annual awards that recognize the 100 most innovative technologies of each year.

In recognition of the Lincoln Laboratory air traffic control program's 50th anniversary, this booklet highlights key air traffic control technologies developed by the Laboratory since 1971 and the significant impact they have had on national security and air transportation safety. These accomplishments could not have been achieved without the exceptional staff who lent their expertise to the development of each technology. As the volume of air transportation continues to increase and more advanced aircraft are introduced, the Laboratory will be presented with new challenges, and we are ready to develop solutions to enable a safe and efficient future of air transportation.

Eric D. Evans
Director







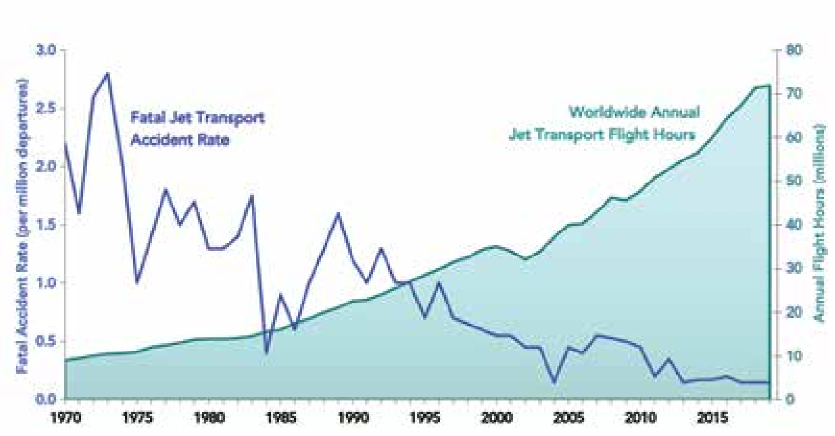


Introduction

In 2021, MIT Lincoln Laboratory celebrated 50 years of support to the Federal Aviation Administration (FAA) in developing and transitioning technologies for a safer, more efficient national air transportation system. This milestone affords the Laboratory with an opportunity to reflect on past challenges and accomplishments while looking forward to the next 50 years of transformation in aviation.

Since 1971, the volume of global jet transport air traffic has increased nearly eightfold while, at the same time, the fatal accident rate has decreased by a factor of approximately 15. More than 4.5 billion people traveled on 46.8 million flights in 2019—a pace of nearly 90 aircraft, on average, departing somewhere in the world every minute—with only eight fatal accidents and 204 fatalities. Although every accident is a tragic event, aviation has clearly achieved a level of volume and safety that is unprecedented and has led to significant benefits for commerce and the economy, personal mobility, and quality of life.

This expansion of safe air travel is largely due to advances in three major areas. First, improved aircraft systems and maintenance processes spanning propulsion, structures, and avionics, among others, led to significantly safer and more reliable flight vehicles. Second, an emphasis on aircrew and air traffic controller training and procedures enabled more robust human teaming and integration of automation systems. Third, development and deployment of air traffic control (ATC) systems provided the necessary foundation to efficiently support growing traffic densities and to improve flight safety levels. It is in this third area that Lincoln Laboratory has been focused during the last 50 years and continues to pursue new technologies and systems.



Technology has enabled exceptional improvements in aviation safety while supporting rapid growth in aircraft traffic volume.

Beginnings

The genesis of Lincoln Laboratory's Air Traffic Control mission area traces back to one man, Herbert Weiss, then head of the Radar Division, who began a personal campaign with the FAA in response to concerns about the growth in air traffic congestion and resulting delays. With Weiss' initiative, Lincoln Laboratory formed the Ad Hoc Committee on ATC in 1968 to perform a broad study of the ATC system, examining its problems and recommending a program for developing solutions. The committee met over several months and in May 1969 published its report, including a proposal for a Laboratory program in the ATC area.

In September 1969, a study group chaired by Walter Morrow, then an assistant director of Lincoln Laboratory, was convened to further investigate the possibility of new ATC programs. In addition to Lincoln Laboratory personnel, members of this group were drawn from the MIT Flight Transportation Laboratory in the Department of Aeronautics and Astronautics; the Electronic Systems Laboratory; the Measurement Systems Laboratory; and Draper Laboratory, then part of MIT. Over a three-month period, the study gave its participants a broad education in the various disciplines related to ATC and validated the idea that an ATC program should be pursued. Both the committee and the study group concluded that Lincoln Laboratory had the right mix of capabilities to make a unique contribution to ATC research and development.

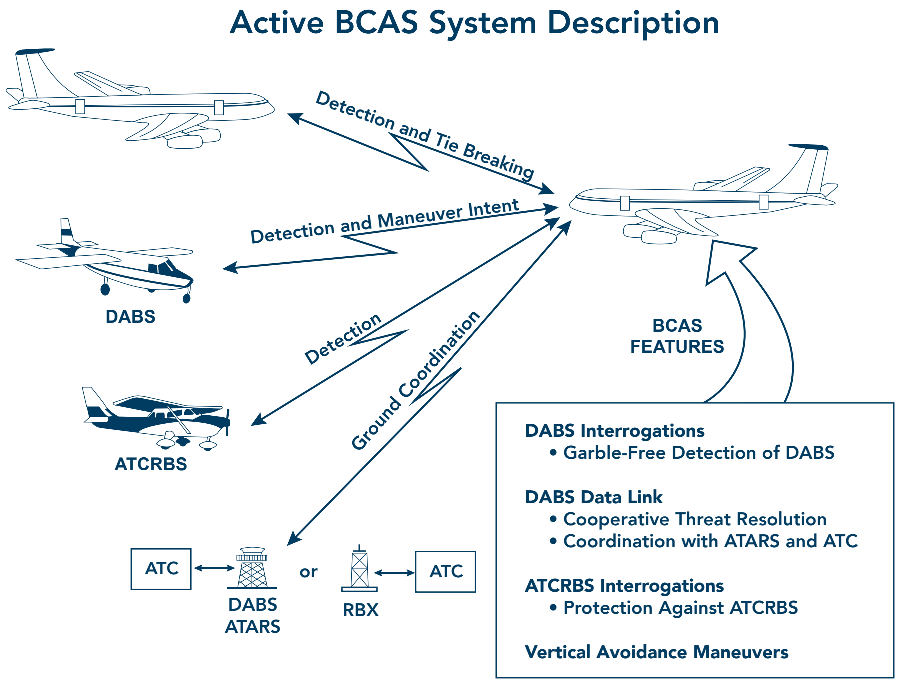
To give a focus to the development of an ATC program at Lincoln Laboratory, the Laboratory restructured the Radar Division in early 1970 and named it the Air Traffic Control Division. Ongoing defense-related activities were moved to other divisions, and the Air Traffic Control Division became the nucleus for the development of the ATC program. A small number of interested staff members from other parts of the Laboratory joined the Air Traffic Control Division to work with Weiss on the development of an ATC program. Paul Drouilhet Jr. was appointed leader of the newly formed Air Traffic Control Group. From this starting point, Lincoln Laboratory's ATC programs later branched into air traffic surveillance, weather sensing, and decision support domains, as illustrated throughout the following timeline.

Left, Walter Morrow; center, Herbert Weiss; and right, the 1969 Ad Hoc Report.

1971

First FAA Program at Lincoln Laboratory: Discrete Address Beacon System

The Air Traffic Control Radar Beacon System (ATCRBS), developed in the 1950s, could not scale to large traffic levels or provide a means for radars to communicate selectively with individual aircraft. In response to this problem, Lincoln Laboratory began an effort with the FAA to develop the Discrete Address Beacon System (DABS), which allowed for expanded data communication with individual aircraft by using an integral two-way data link. The principal technologies necessary to bring the concept to reality—radar, signal processing, digital communications, and data processing—were well matched to the capabilities and interests of Lincoln Laboratory. A key concern with the design of DABS was compatibility; signals from DABS could not be permitted to interfere with legacy users of ATCRBS. The Laboratory developed the technology needed to employ the same aircraft antennas and operate in the same frequency band, allowing the systems to coexist. The program included the development of a DABS experimental facility adjacent to the Laboratory and a transportable measurement facility for testing DABS around the country. Several aircraft were outfitted to make airborne measurements. Lincoln Laboratory completed the basic design of DABS in the mid-1970s. Subsequently, the Laboratory assisted the FAA in developing and testing three commercial prototype DABS sensors that demonstrated the compatibility of the DABS waveforms with existing ATCRBS equipment.



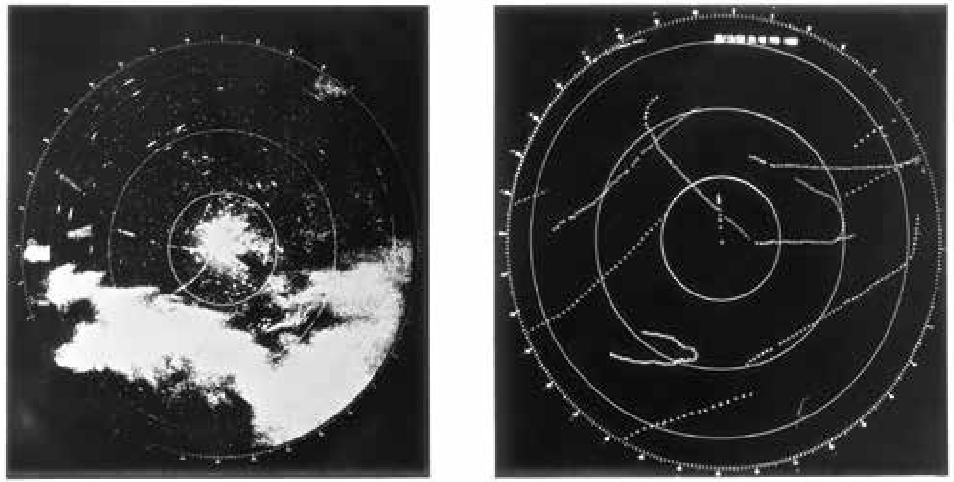
1974

Beacon Collision Alerting System

As air traffic grew in volume, the FAA and industry explored a variety of approaches to develop an airborne collision avoidance system. Starting in 1974, Lincoln Laboratory, under FAA sponsorship, began development of a Beacon Collision Avoidance System (BCAS) capability, concentrating primarily on the air-to-air surveillance subsystem. The surveillance subsystem detects the presence of nearby aircraft and then generates a surveillance track on each aircraft, issuing range and altitude reports once per second. The development effort consisted of airborne measurements complemented by simulation studies and analyses. The basic effects of ground-bounce multipath, interference, and power fading were assessed by air-to-air measurements. Interrogation and reply signal formats were transmitted between aircraft, and the results were recorded for later playback and computer processing with the BCAS surveillance algorithms. The Laboratory designed and built real-time BCAS experimental units, conducted initial flight tests, and delivered the technology to the FAA for more extensive flight testing.

MTD Performance in Rain

Normal Video | MTD Radar Tracker Output



Five Mile Range Rings

1977

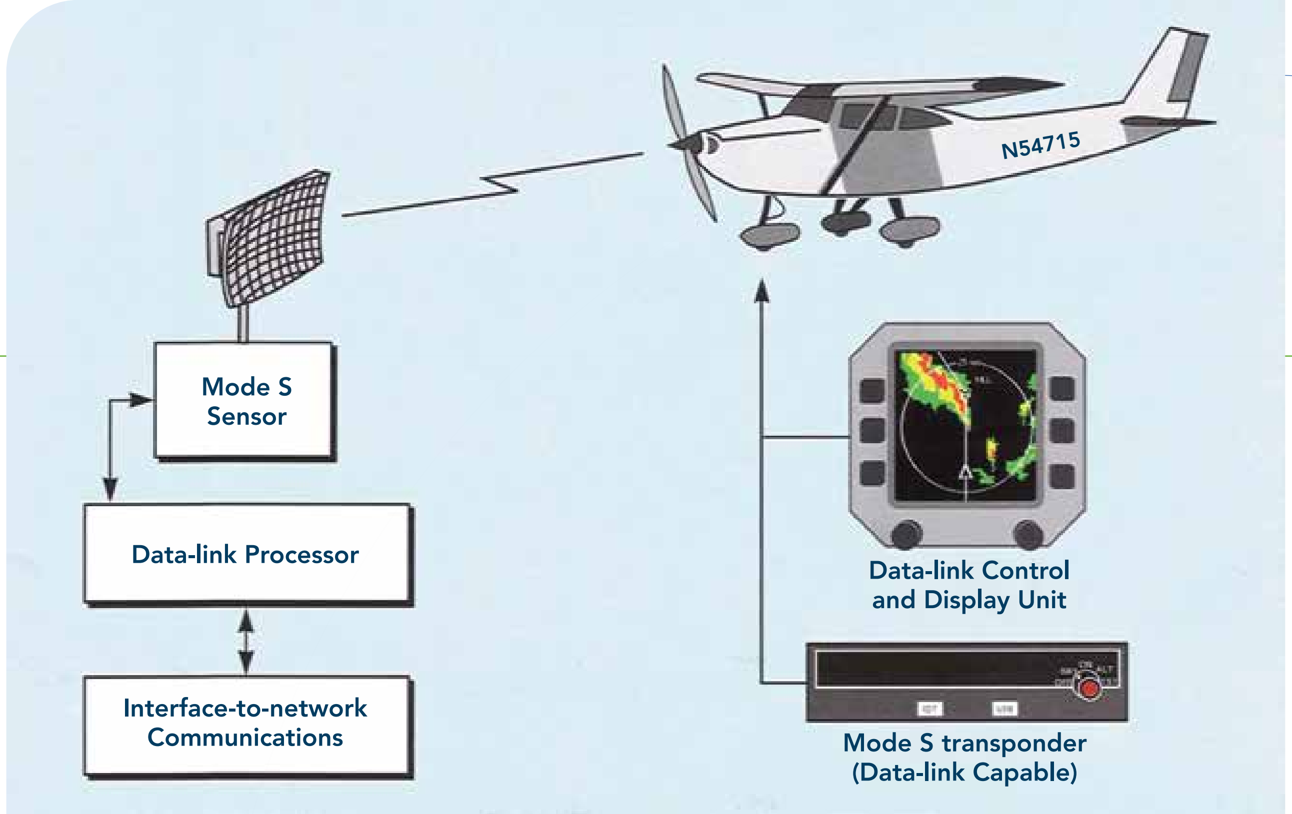
Moving Target Detector

In the mid-1970s, to address continuing challenges in detecting aircraft in high-clutter environments, the FAA initiated the Moving Target Detector (MTD) program. Under this program, Lincoln Laboratory developed one of the first parallel microprogrammed processors and demonstrated reductions in rain and ground clutter false target reports while providing a six-level storm intensity output that conformed to National Weather Service standards. To demonstrate robust performance of the MTD system, evaluation tests took place near Burlington, Vermont, at an Airport Surveillance Radar (ASR)-7 terminal site characterized by significant ground clutter.

1984

Mode S Beacon System

In 1984, the FAA awarded a contract for procurement of the nationwide network of 137 Mode Select (Mode S) radars in the United States. As a follow-on to the Discrete Address Beacon System (DABS), Lincoln Laboratory developed the capability to use the DABS data link for airborne surveillance. The Mode S surveillance system was developed to expand the capabilities of ATCRBS while retaining interoperability with legacy systems. The Mode S radar system includes both surveillance and data link functions. Surveillance is performed according to ATCRBS protocols and using a set of selective address protocols by which every aircraft equipped with a Mode S transponder is interrogated individually. Mode S has since been fully implemented into the U.S. National Airspace System and has been adopted as the worldwide secondary surveillance radar standard by the International Civil Aviation Organization.



1987

Airport and Terminal Area Automation System Programs

To improve the safety and operational efficiency of the area around and on the surface of major airports, Lincoln Laboratory initiated, with FAA support, two major new research initiatives: the Terminal Air Traffic Control Automation (TATCA) and the Airport Surface Traffic Automation (ASTA) programs. TATCA focused on the development of computer-based aids that allowed the air traffic controller to utilize new surveillance, communications, navigation, and control capabilities to increase the efficiency of terminal area operations. ASTA focused on airport surface operations and implemented improved surface surveillance and communications along with associated automation aids to enhance the safety and efficiency of these operations.

1988

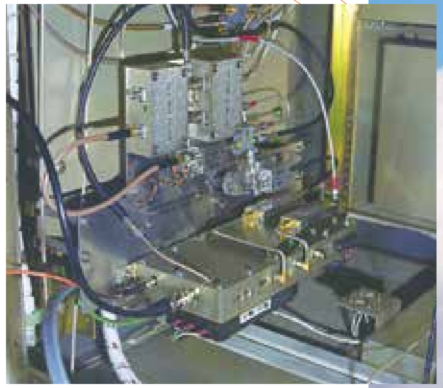
Terminal Doppler Weather Radar

In the mid-1980s, a series of commercial aircraft accidents associated with microbursts (powerful, thunderstorm-generated downdrafts and divergent surface wind shear) spurred the FAA to develop a Terminal Doppler Weather Radar (TDWR) to provide wind-shear detection and warning services at large U.S. airports. Lincoln Laboratory was tasked with developing a TDWR prototype and the signal processing and pattern recognition algorithms needed to provide highly reliable, fully automated detection of wind-shear phenomena. The prototype was used for operational TDWR demonstrations in Denver, Colorado; Kansas City, Missouri; and Orlando, Florida. These tests validated the technical and operational viability of the TDWR concept and provided valuable data on regional characteristics of wind shear, supporting detection algorithm optimization for different environments. Lincoln Laboratory's TDWR prototype activities resulted in the specification and procurement by the FAA of 45 TDWRs from the Raytheon Corporation. The TDWR network was fully deployed during the 1990s, and there has not been a major U.S. wind shear–related accident since 1994. Lincoln Laboratory has continued to support the FAA in optimizing the performance of TDWR wind-shear detection algorithms; modernizing the TDWR data-processing architecture; and implementing additional algorithms, including a thunderstorm tracking and motion-prediction function.

1989

Precision Runway Monitor

In 1989, Lincoln Laboratory installed and evaluated a Precision Runway Monitor (PRM) radar at Memphis International Airport in Tennessee. The PRM is an advanced radar-monitoring system that improves the arrival capacity of closely spaced parallel runways during poor weather conditions. At airports where runways are separated by less than 4,300 feet, once the cloud ceiling drops and/or the visibility to the runway reduces past defined levels (instrument meteorological conditions), the two streams of traffic must become dependent on each other and stagger their approaches with prescribed spacing. The PRM system aids controllers in avoiding delays by making it possible to safely conduct independent arrivals in instrument meteorological conditions to closely spaced parallel runways. Lincoln Laboratory's evaluations paved the way for the acquisition and deployment of PRM radars at selected airports in the United States.



1990

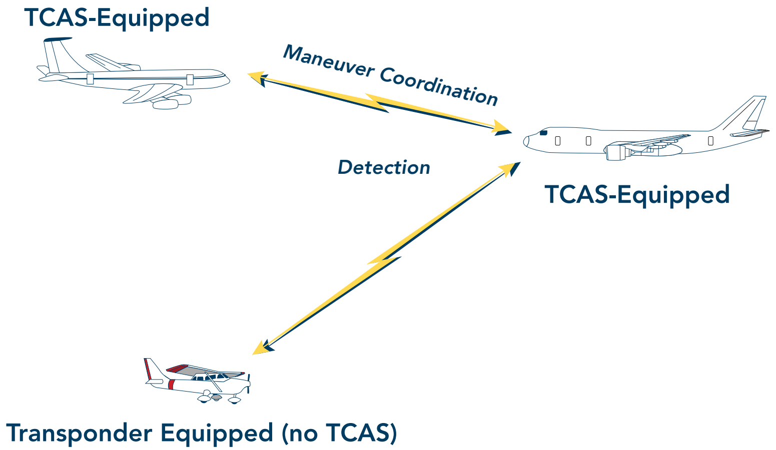
ASR Weather System Processor

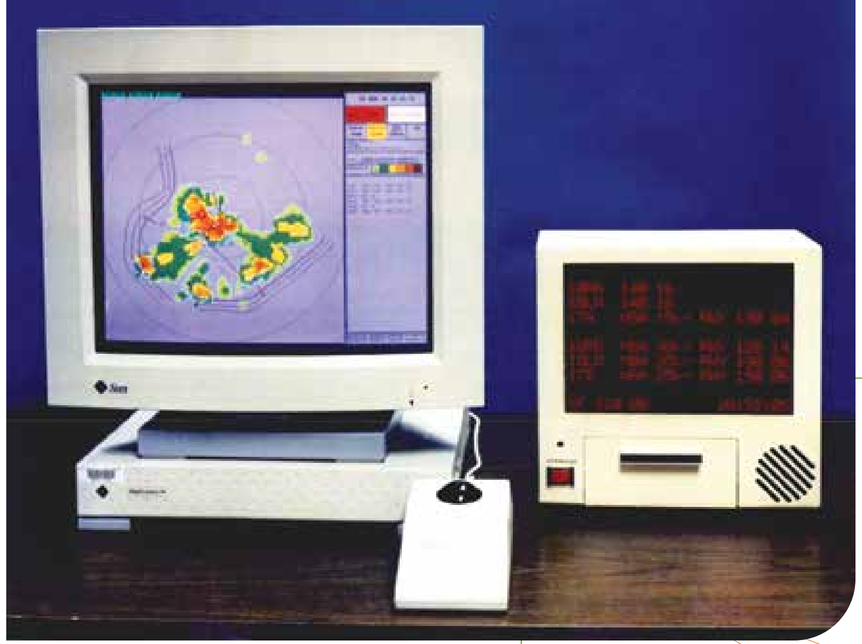
The acquisition and life-cycle maintenance costs of TDWR precluded its deployment at medium- and low-density U.S. airports. To provide wind-shear detection services at these smaller airports, Lincoln Laboratory developed a complementary Weather System Processor (WSP) augmentation for the ASR-9 radar. The WSP consists of microwave and timing signal interfaces, a high-capacity signal processing computer, innovative signal and image processing algorithms, and ATC displays that provide wind-shear warnings for relay to pilots via tower local controllers. Lincoln Laboratory developed a WSP prototype and validated its operational performance during field trials in Orlando, Florida; Albuquerque, New Mexico; and Austin, Texas. Northrop Grumman received the FAA contract for WSP's implementation and worked closely with Lincoln Laboratory staff to deploy the system at 34 U.S. airports during 2000–2003.

1993

Traffic Alert and Collision Avoidance System

As the aviation industry grew and traffic increased, the need to mitigate the risk of mid-air collisions became a critical public need. Building on the original BCAS program, the FAA initiated development of the Traffic Alert and Collision Avoidance System (TCAS) in 1980. TCAS uses active interrogation and response to detect and track nearby aircraft. Threat logic provides pilots with guidance to maneuver vertically if action is required to mitigate the risk of a mid-air collision. Lincoln Laboratory was primarily responsible for the development of surveillance and tracking algorithms and maneuver coordination. Spurred by a San Diego, California, mid-air collision in 1978 and a Cerritos, California, collision in 1986, Congress passed legislation requiring TCAS equipage by 1993 for turbine-powered transport aircraft with more than 30 passenger seats. This mandate followed decades of research, development, flight testing, and validation. TCAS has since been mandated by the International Civil Aviation Organization and is now installed on more than 30,000 transport category aircraft worldwide.

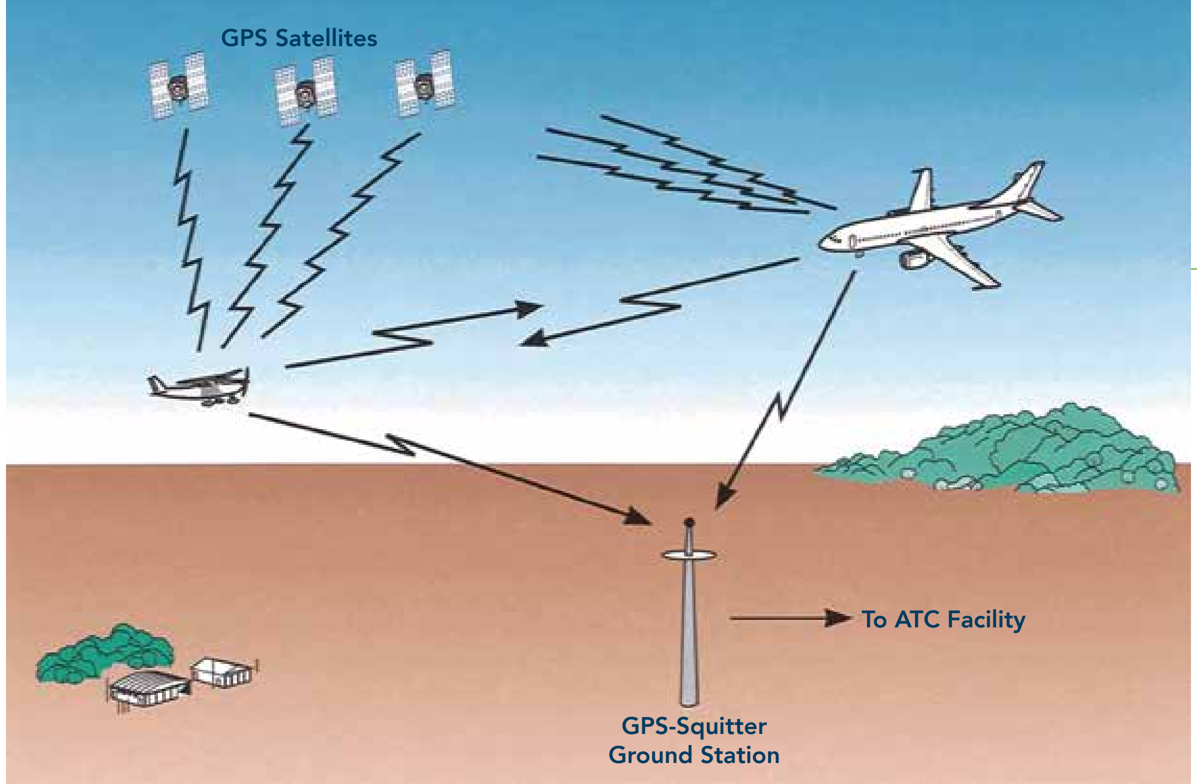




1994

Integrated Terminal Weather System

Working with an innovative team of controllers at the TDWR field site in Orlando, Florida, the Laboratory recognized the opportunity to leverage broad-area weather surveillance and associated decision support capabilities to address surging weather-related delays at U.S. airports. The resulting Integrated Terminal Weather System (ITWS) prototypes operated for more than 16 years and led to the creation of a suite of new products that exploit the benefits of multi-sensor integration, extending the scope well beyond what was possible from the TDWR alone. The TDWR still provided basic data for wind-shear detection, but additional sources were used to add a microburst-prediction capability, the extension of high-resolution precipitation coverage beyond the limited terminal domain, and a one-hour convective-weather forecast. Thus, the ITWS was born, with additional prototypes deployed to Memphis, Tennessee (to support independent testing at a non-development location), and Dallas/Fort Worth, Texas (to represent different climatic and traffic conditions). Operation of these prototypes continued until 2007. Lincoln Laboratory contributed the high-level specification for the system and the detailed specifications for each of the 27 algorithms that were to be part of the initial procurement. Through technical involvement with Raytheon, Laboratory staff assisted in the FAA's acquisition of ITWS. Additional testing and refinement of the ITWS products and concept of usage were accomplished in New York between 1998 and 2004 under a partnership with the Port Authority of New York and New Jersey. The Laboratory developed and operated a demonstration ITWS with user displays at the towers of the four major airports serving New York City, the New York Terminal Radar Approach Control, the New York Air Route Traffic Control Center, and the FAA's ATC System Command Center. The functional capability of the system was subsequently modified to reflect feedback from the operational users and the results of data analyses by Laboratory staff.



1996

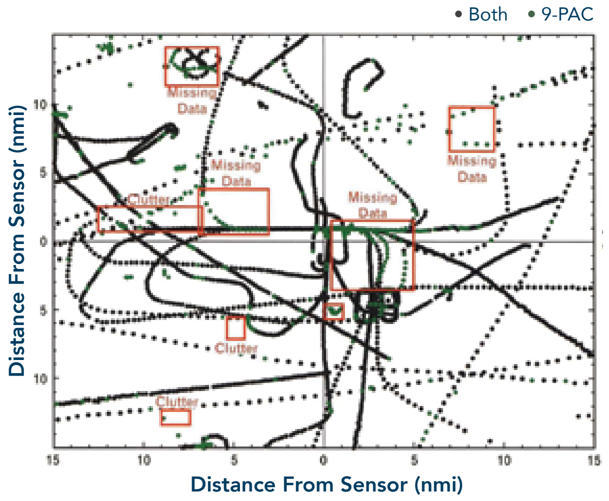
Automatic Dependent Surveillance–Broadcast

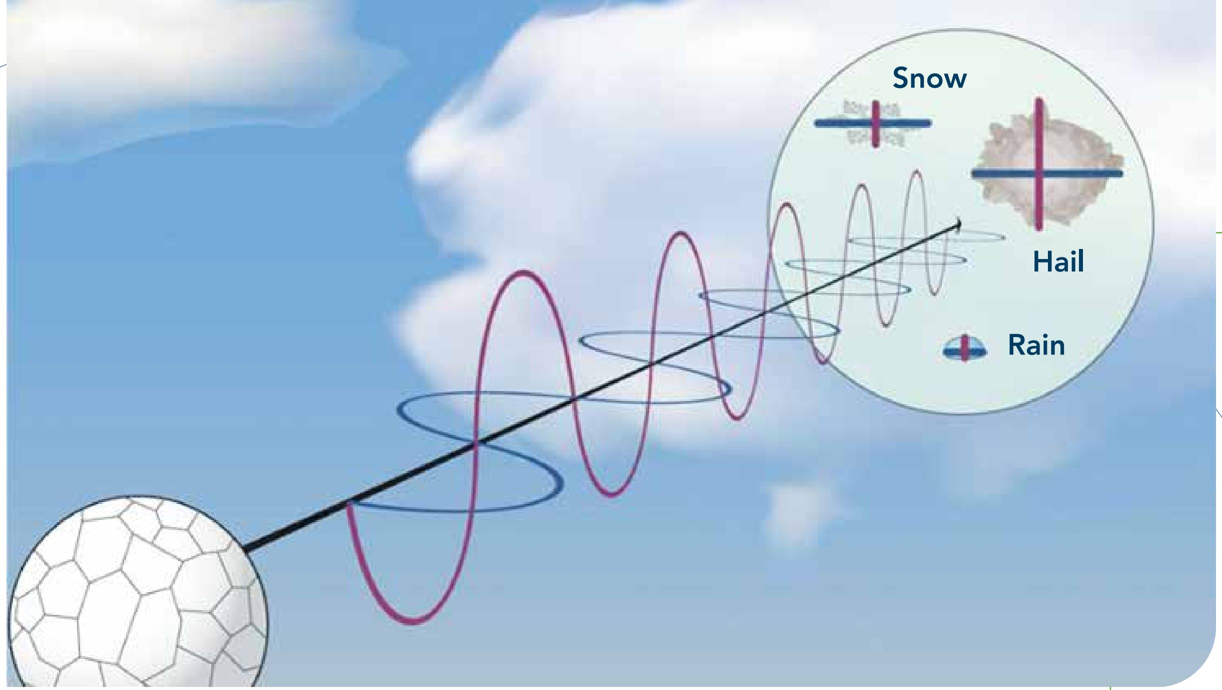
Starting in the late 1970s, the Department of Transportation undertook an examination of the use of satellite-based ATC systems for communications, navigation, and surveillance. Lincoln Laboratory participated in this effort by exploring the application of satellites to each of these principal ATC functions. In particular, Automatic Dependent Surveillance–Broadcast (ADS-B) was conceived as a system with which each aircraft automatically broadcasts its position, intent, and status information once each second. This broadcast position information can be received by other aircraft and by ground stations, providing robust air-to-ground and air-to-air surveillance. The ADS-B concept, leveraging the communications protocols developed for the Mode S system, was patented by Lincoln Laboratory in 1996 and was awarded the 2007 Robert J. Collier Trophy, a national aviation award. The ADS-B ground infrastructure has been fully deployed in the United States, and installation of ADS-B avionics was mandated in most controlled airspace beginning in 2020. Today, ADS-B surveillance is used to support aircraft separation in many portions of the world that lack a ground-based radar surveillance network.

1996

ASR-9 Processor Augmentation Card

The ASR-9, which featured moving target detector algorithms, dramatically improved primary radar performance and was greatly appreciated by air traffic controllers. However, operational use of the system revealed several performance issues attributed to the system's improved sensitivity levels. Ground clutter and flocks of birds could overwhelm the system with false tracks, and limitations in digital processing could lead to aircraft positions being merged into a single location. In response to these issues, Lincoln Laboratory developed a replacement board for the ASR-9: the ASR-9 Processor Augmentation Card (9-PAC). The new board allowed for C-programmable processors and the use of flash cards for updating clutter maps. The processors supported advanced tracking and centroiding algorithms, and allowed for improved processing of ATCRBS secondary data to address reflections in crowded environments. With the 9-PAC, the ASR-9 became easier to customize for each site and to update, and provided improved radar system performance at numerous challenging locations around the nation.





2001

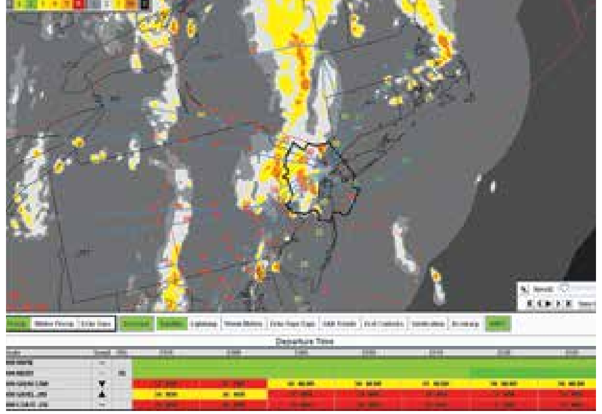
Next-Generation Weather Radar Algorithm Enhancements

The FAA is a supporting partner of the nation's tri-agency Next-Generation Weather Radar (NEXRAD) network. Since 2001, Lincoln Laboratory's NEXRAD Algorithm Enhancements program has provided operational algorithm products supporting FAA weather systems. Fundamental products include all-season precipitation intensity and echo-top storm heights created by automated algorithms that meet FAA data-quality needs. Lincoln Laboratory has also provided NEXRAD wind-shear products for gust front and microburst detection for tri-agency use. Algorithm development and real-time NEXRAD data ingest at the Laboratory are bolstered by extensions to NEXRAD's Open Radar Product Generator Common Operations Development Environment. The NEXRAD dual-polarization upgrade of the early 2010s moved the algorithm development focus to the detection of icing and hail aviation hazards and improved data quality. Lincoln Laboratory directed first-of-their-kind inflight icing field campaigns with partners from the National Research Council of Canada and Environment and Climate Change Canada. These studies validated the presence of an icing hazard and hydrometeor verification within NEXRAD's scanning range. Those studies and other research have led to operational algorithm products for aviation icing hazard, hail hazard, and chaff detection for use in future systems, such as the Next-Generation (NextGen) Weather System.

2002

Wake Turbulence Mitigation

In 2002, Lincoln Laboratory conducted an assessment of technologies and procedures that could be employed to reduce in-trail separation between aircraft when favorable wind conditions transport hazardous wake turbulence away from following aircraft (wake turbulence is a disturbance in the air that forms behind a moving aircraft). As a result of that study, Lincoln Laboratory was tasked with developing a wind-forecast algorithm to enable wake turbulence mitigation for departures (WTMD) procedures. With WTMD, the potential three-minute wait between departures at an airport could be reduced when persistent crosswinds are present to remove the wake turbulence from the runway. Because of the safety-critical nature of aircraft operations, a high degree of confidence in the wind forecast was required to enable the procedure. The solution was developed by implementing a two-stage forecast: a statistical model for rapidly changing surface winds and a low-altitude wind forecast leveraging National Oceanic and Atmospheric Administration (NOAA) numerical models. Successful operational evaluations of WTMD were held at San Francisco International Airport in California; George Bush Intercontinental Airport in Houston, Texas; and Memphis International Airport in Tennessee, beginning in 2013.



2003

Corridor Integrated Weather System

The New York Integrated Terminal Weather System provided the impetus for studies of the extent to which delays at airports were avoidable and highlighted the importance of controllers being aware of severe storms at significant distances from the airports. In response to the findings of these studies, Lincoln Laboratory developed a fully automated weather analysis and forecasting system called the Corridor Integrated Weather System (CIWS) to support the development and execution of tactical (0- to 2-hour) plans for mitigating the impact of convective weather on congested en route airspace. CIWS combines data from dozens of weather radars with satellite data, surface observations, and numerical weather models. These models dramatically improve the accuracy and timeliness of information on storm severity and provide accurate, automated, high-resolution, three-dimensional 0- to 2-hour forecasts of storms, including explicit detection of storm growth and decay. Weather information from CIWS, operated at Lincoln Laboratory, is disseminated to the FAA's Traffic Flow Management System and is available to airlines and other stakeholders through web interfaces. Real-time observations of the FAA decision-making process during convective weather have shown that CIWS enables FAA users to achieve more efficient tactical use of the airspace, lessening traffic managers' workload and significantly reducing flight delays.

2003

Route Availability Planning Tool

Field experiences with CIWS gave Lincoln Laboratory researchers insights into how controllers were required to mentally project the weather onto the routes around an airport region and how such projections presented a challenge to determine where and when specific routes would be impacted by weather. The Route Availability Planning Tool (RAPT) was developed to help tactical air traffic controllers with this task. RAPT uses CIWS precipitation intensity and storm-height forecasts, together with models of airspace usage and storm height, to forecast storm impacts for specific departure routes. The system assigns a level of impact based on precipitation intensity, storm height, and expected pilot behavior. Timelines are generated for each route, showing the anticipated level of impact for five-minute intervals out to 30 minutes into the future. RAPT was developed by Lincoln Laboratory and prototyped for the FAA in the New York and Chicago, Illinois, regions between 2003 and 2013. Subsequently, it became an FAA operational capability, and RAPT status data are now available for the New York; Chicago; Philadelphia, Pennsylvania; and Washington, D.C. regions via traffic situation displays.

This technology won an R&D 100 Award.

2004

San Francisco Marine Stratus Forecast System

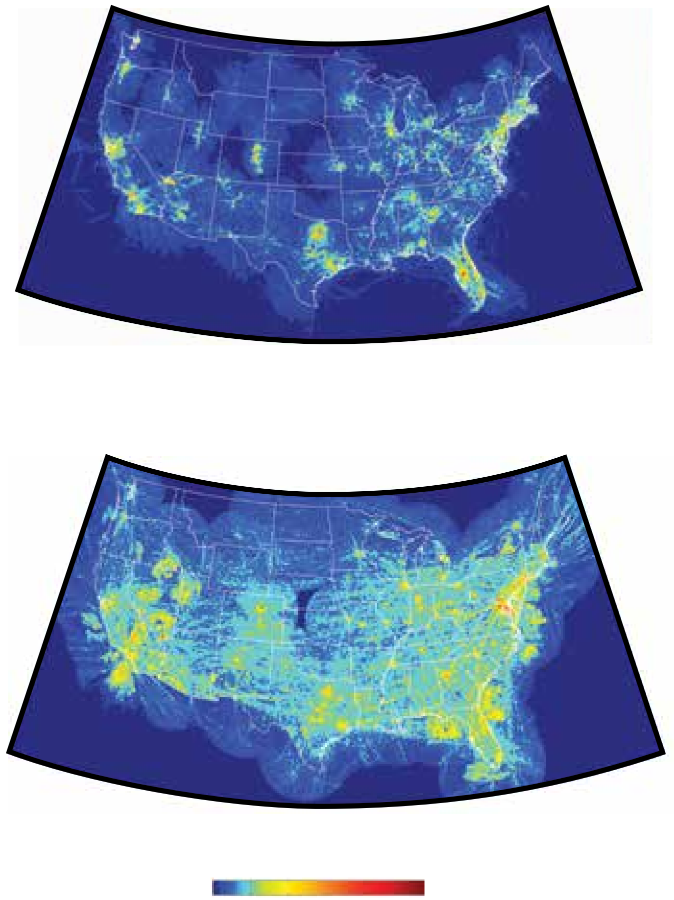
The frequent occurrence of summer marine stratus causes significant restrictions of arrival capacity at San Francisco International Airport. A low stratus cloud deck in the airport approach zone prohibits dual parallel approaches to closely spaced runways, cutting the arrival capacity in half. Lincoln Laboratory led a collaborative effort with the FAA and the National Weather Service to develop an automated system to predict the time of stratus clearing each morning. The system uses four forecast models that rely on a host of sensor measurements to capture the physical processes associated with cloud dissipation. These component models are combined to produce a performance-weighted consensus forecast that indicates the expected time of clearing in the approach zone and is updated hourly throughout the morning. The model forecasts and a display of sensor observations are provided to operational users via a web browser interface. Operation and maintenance of the prototype system was transferred to the National Weather Service, where it is used by forecasters.

2005

Runway Status Lights

Preventing runway incursions, or the incorrect presence of vehicles or people on a runway, is a continuing priority for the FAA. To help prevent impending incursions, Lincoln Laboratory developed the Runway Status Lights (RWSL) system, a highly automated system that directly alerts pilots and vehicle operators of potential incursion risks. The RWSL system alerts pilots when a runway is unsafe by turning on special red lights, embedded in the runway pavement, that are fully visible to pilots and nearby personnel. The lights are controlled by safety logic that automatically processes surveillance information at the airport. The system serves as an independent backup to the clearances issued by air traffic controllers, issuing alerts rapidly to all vehicles approaching an intersection when a collision may be imminent. In 2005, a prototype system was installed at Dallas/Fort Worth International Airport in Texas for an operational evaluation to ensure the alerting was operationally suitable. Subsequent prototypes were deployed to San Diego and Los Angeles, California, and Boston, Massachusetts, for final system validation and refinement. Since 2005, the FAA has installed RWSL at 20 airports in the United States, and two systems are in operation in Europe.

This technology won an R&D 100 Award.



2007

Airspace Encounter Models for Safety Assessment

During the initial development of TCAS, Lincoln Laboratory, the MITRE Corporation, and the FAA had developed simulation and analysis tools to assess the performance of the threat logic under a limited set of conditions. This work was greatly expanded in the mid-2000s when Lincoln Laboratory developed a series of updated and expanded aircraft encounter models based on data from more than 130 radars across the United States. These models allowed for realistic three-dimensional intruder maneuvers and captured a wide range of aircraft types and encounter situations. The Collision Avoidance System Safety Assessment Tool (CASSATT), a flexible, fast-time Monte Carlo simulation capable of running in the Lincoln Laboratory Supercomputing Center, was also developed to simulate millions of encounters and generate statistical performance metrics for a range of collision avoidance concepts. CASSATT was subsequently used to approve enhancements to the TCAS threat logic and to develop future collision avoidance concepts.

2007

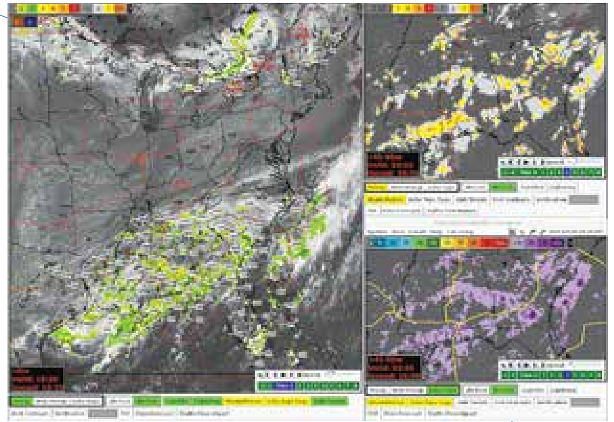
ADS-B Team Receives Robert J. Collier Trophy

Lincoln Laboratory and the broader government/industry Automatic Dependent Surveillance–Broadcast (ADS-B) development team were recognized with the National Aeronautic Association's 2007 Robert J. Collier Trophy for "conceptualizing, developing, and initially implementing the next generation performance-based air-ground, ground-air, and air-air surveillance system."

2009

Next-Generation Airborne Collision Avoidance System

To improve flight safety and enable the extension of an airborne collision avoidance capability to new vehicle types and operations, Lincoln Laboratory developed a novel approach to mitigate the risk of mid-air collisions: the next-generation Airborne Collision Avoidance System (ACAS X). Using advanced computer science techniques, such as dynamic programming and partially observable Markov decision processes, ACAS X treats collision avoidance as a large-scale optimization problem. A decoupled surveillance and tracking functionality allows for the use of active surveillance, Automatic Dependent Surveillance–Broadcast, airborne radar, or ground-based surveillance systems. The threat logic is created through an automated computer optimization process that results in a compact footprint that can be installed in airborne avionics. Using the Lincoln Laboratory Supercomputing Center, researchers designed the ACAS X system in approximately 50 percent of the time that was required to develop TCAS. Simulations predict that ACAS X can provide a 20% improvement over TCAS in safety while reducing nuisance alerts by 65%. Following an internally funded research program in 2008, the FAA began funding ACAS X in 2009, and the manned aircraft variant, ACAS Xa, was completed in 2018.



2010

Consolidated Storm Prediction for Aviation

Achieving the high-quality 0- to 2-hour forecast capability available from CIWS enabled traffic flow managers to truly do business differently—planning for reroutes, opening closed routes sooner, etc. But the larger problem of strategic traffic flow management—estimating future storm impacts on the airspace capacity—requires a longer lead-time forecast. The Consolidated Storm Prediction for Aviation (CoSPA) program built an aviation-oriented 2- to 12-hour forecast product, in collaboration with the numerical model developers at NOAA and other scientists at the National Center for Atmospheric Research, NASA, and several universities (MIT, the University of Wisconsin, and the University of Alabama). This nationwide forecast product, with a 3-kilometer resolution and new model runs every hour, is unprecedented in the United States. The first nationwide demonstration of this technology took place in 2010, and the product continues as an operational prototype with regular refinements and enhancements deployed and used by airlines and FAA personnel.

2011

Terminal Flight Data Manager and Staffed NextGen Tower

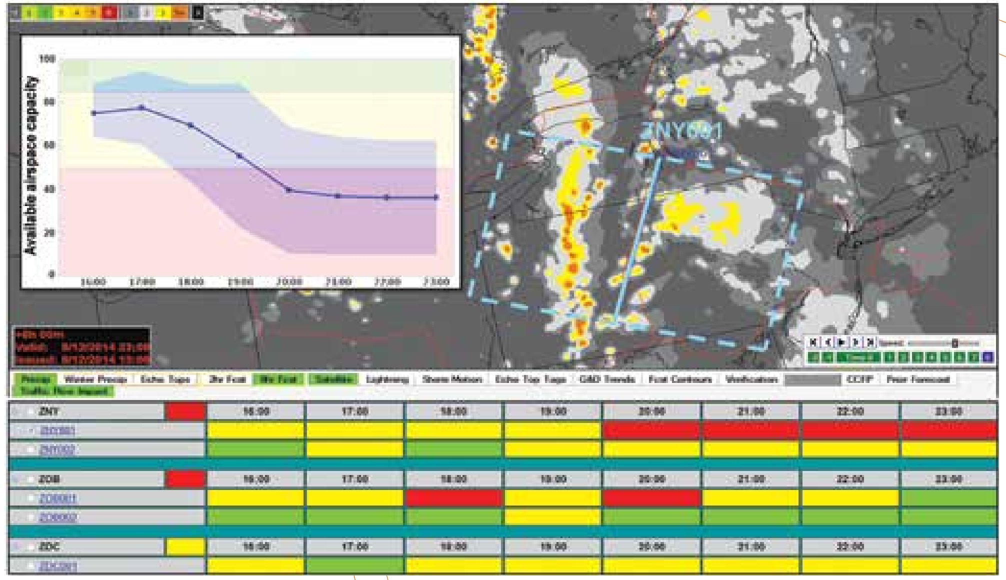
The FAA sought to develop an advanced automation platform for air traffic controllers to safely and efficiently manage aircraft operations on the airport surface and in the terminal area. This automation system became the Terminal Flight Data Manager (TFDM). In 2009, Lincoln Laboratory was asked to develop a prototype of the TFDM system to help define requirements and demonstrate proofs of concept of relevant capabilities. An enhanced surface-situation display, an electronic flight-data system, and a suite of decision support tools were developed to help manage safe and efficient operations. In concert with TFDM, Lincoln Laboratory developed the capability to integrate technologies for surveillance, displays, electronic flight data, decision support, and visual augmentation in the Staffed NextGen Tower (SNT) program. SNT enabled a range of uses from supplemental support for current tower tasks to the future capability for remote tower operations. A TFDM/SNT prototype was deployed to Dallas/Fort Worth International Airport for testing with controllers in 2010 and 2011 to gain operational user feedback for further refining the system. The prototype technology was transferred to the FAA to support the development of the operational system, which at the time of this writing is undergoing deployment to many major airports in the United States.

2015

Traffic Flow Impact Tool

The Traffic Flow Impact (TFI) tool was developed to provide a revolutionary approach to traffic management by integrating multiple weather forecast products with extensive historical analyses of forecast accuracy and traffic flows. The resulting system provides an objective display of airspace capacity and sustainable flow rates for key locations in the United States. TFI is based on the operational Convective Weather Avoidance Model, developed by Lincoln Laboratory and used in RAPT, and is augmented by modern machine learning algorithms. TFI's display shows the permeability of airspace regions as a function of forecasted weather impacts in the region. Additionally, TFI can compute the traffic flow rate that can be sustained under those weather conditions. With TFI, the FAA and airlines can view a common picture of the statistical distribution of airspace capacity reduction up to 12 hours in advance to best manage traffic flows.

This technology won an R&D 100 Award.

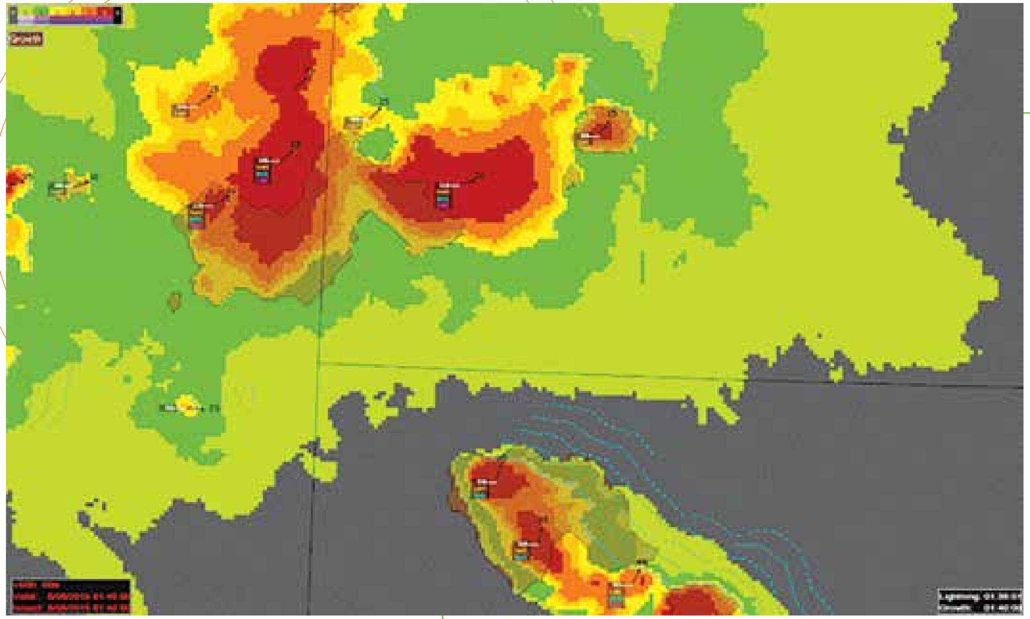


2016

Ground-Based Sense-and-Avoid System

The Department of Defense has a requirement to fly unmanned aircraft systems (UAS) in the national airspace for crew training, humanitarian response, and other missions of national importance. This requirement demands a technological means to comply with the regulation that pilots must be able to "see and avoid" other air traffic. Beginning in 2010, Lincoln Laboratory, in partnership with U.S. Army Program Manager Unmanned Aircraft Systems, SRC Inc., and Kutta Technologies, developed a ground-based sense-and-avoid (GBSAA) system for the U.S. Army that utilized FAA and SRC radars coupled to data fusion and conflict detection and avoidance logic developed by the Laboratory. Following a successful prototype demonstration at the U.S. Army Dugway Proving Ground in Utah in 2012, the Army began an acquisition program for six airfields throughout the country. The first production system began operations in 2016 at Fort Hood, Texas, making it the first sense-and-avoid system in the United States to gain an FAA Certificate of Authorization. The GBSAA system has subsequently been deployed to external customers, including the U.S. Air National Guard, and is operational at nine sites across the country with four additional sites under development.

This technology won an R&D 100 Award.



2016

NextGen Weather Processor

The fully automated NextGen Weather Processor (NWP) rapidly identifies aviation weather safety hazards and enhances air traffic efficiency by providing the translated weather information needed to predict route blockage and airspace capacity constraints up to eight hours in advance. NWP combines Doppler weather radar, environmental satellite, lightning, meteorological observations (from surface stations and aircraft), and NOAA numerical forecast model outputs to generate improved products for all FAA users across significantly expanded grids relative to today's weather products. NWP accomplishes these capability enhancements by harnessing massive computing power, unprecedented advances in numerical weather forecasting, and modernized information management services. These services include the NextGen Weather Common Support Services–Weather framework, which is the single provider of weather data, products, and imagery using standards-based weather dissemination via System Wide Information Management. NextGen Weather also consolidates many of today's FAA weather products (e.g., CIWS and CoSPA) into a single aviation weather display that provides consistent weather information at a glance for en route and terminal users. NextGen Weather is being transitioned to industry partners Raytheon Technologies and L3Harris for planned operational deployment of the baseline NWP capabilities in the next few years.

This technology won an R&D 100 Award.

2016

Aviation Cyber Assessments

Defined as critical national infrastructure by the Department of Homeland Security, the national civil aviation ecosystem is a widely distributed, complex system of systems that is increasingly interconnected in cyberspace as information technology advances. Responsibility for securing this ecosystem is also widely distributed among various government agencies and industry entities. Increased network connectivity has raised concerns about the security of aviation systems, especially with respect to ensuring the safety of flight. In 2016, the FAA Aircraft Systems Information Security/Protection research program tasked Lincoln Laboratory with developing and demonstrating a structured methodology that the FAA and its industry partners could use to assess and mitigate safety risks posed by potential cyberattacks as part of the airworthiness certification process. Lincoln Laboratory leveraged MIT's System Theoretic Process Analysis model to identify and evaluate cyber scenarios that could potentially result in safety hazards, and demonstrated the efficacy of the assessment approach through evaluations of several aircraft avionics and air-to-ground communication systems. In addition, Lincoln Laboratory tested select commercial avionics to identify potential vulnerabilities. The Laboratory then worked with the FAA and the Aerospace Industries Association to promote the use of this systems analysis approach by aircraft original equipment manufacturers. Through a partnership with the MIT Department of Aeronautics and Astronautics, the assessment framework has also been applied to assess requirements for a future Army rotary winged aircraft.

2017

Offshore Precipitation Capability and Global Synthetic Weather Radar

Although weather radar coverage is available throughout the continental United States, other regions do not have accurate and timely weather radar information. Aircraft can unexpectedly encounter storms and turbulence in these areas, sometimes resulting in serious injuries to passengers and crews. Lincoln Laboratory developed the Offshore Precipitation Capability (OPC) to provide real-time radar-like imagery for offshore and other radar-deficient regions to help mitigate these encounters and to improve the safety and efficiency of air traffic operations. OPC applies modern machine learning algorithms to use non-radar sources to generate real-time maps of precipitation intensity and storm heights. OPC development started in 2015, and an initial prototype was deployed in 2017 as an experimental system covering the Gulf of Mexico, Caribbean Sea, and portions of the western Atlantic Ocean. Since then, a global product called the Global Synthetic Weather Radar has been developed under Air Force funding and has been deployed to a cloud computing environment.

This technology won an R&D 100 Award.

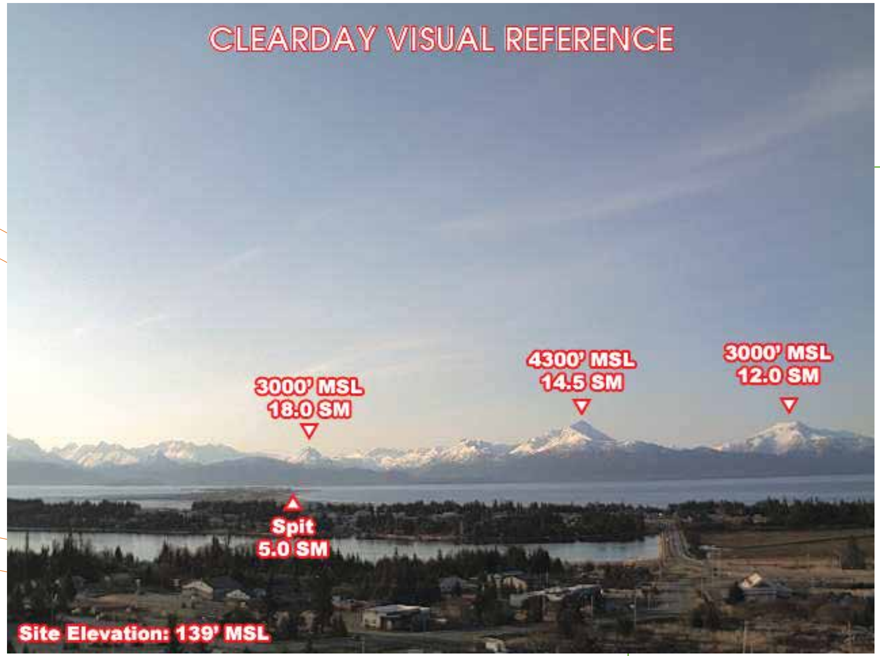
2018

Dual-Polarization Phased-Array Radar Advanced Technology Demonstrator

Beginning in 2006, Lincoln Laboratory worked with the FAA and NOAA to develop a detailed concept for an integrated U.S. aircraft and weather surveillance architecture that leverages dual-polarization phased-array radar technology. In 2014, these agencies asked Lincoln Laboratory to develop a phased-array radar prototype to demonstrate that a common, scalable radar architecture could serve as a basis for future modernization of both the ASR and NEXRAD Weather Surveillance Radar (WSR-88D) networks. Phased-array technology was chosen to enable the reconfigurable beam shapes and scan patterns needed for the multiple different missions.

Lincoln Laboratory developed the resulting Advanced Technology Demonstrator (ATD) in partnership with engineers at General Dynamics and the NOAA National Severe Storms Laboratory (NSSL) in Norman, Oklahoma. The ATD was deployed at NSSL in summer 2018. The radar will use rapid-update volumetric scan patterns as it serves as NSSL's primary tool for scientific studies of severe storms, and the ATD will be used to demonstrate operational improvements to NWS warning and forecast products. In addition, the ATD can support evaluation of the potential to use phased-array radar to enhance aircraft surveillance and wind-shear observations near airports.

This technology won an R&D 100 Award.



2019

Visibility Estimation through Image Analytics

The transportation systems of local communities in Alaska are highly dependent upon small aircraft for everyday travel. For many, flying is the only means to get children to/from school activities; transport service providers such as healthcare workers; and supply communities with groceries, fuel, and mail. Traditional weather observations from Alaska's widely dispersed network inadequately forewarn of weather likely to be encountered along routes between observation stations, through hazardous mountain passes, and at non-instrumented locations. The FAA recognized this lack of available weather information as a contributing factor to Alaska's high aircraft accident rate relative to other parts of the United States and identified a need for pictorial views of current weather conditions. Thus, the FAA installed cameras at hundreds of locations to aid the Visual Flight Rule pilots operating in Alaska. In support of this effort, Lincoln Laboratory developed the Visibility Estimation through Image Analytics (VEIA) algorithm that applies image processing techniques to process this extensive network of rapidly updating images and to provide the aviation and meteorological communities with automatically generated visibility estimates. VEIA can be used to quickly assess current weather conditions at an individual location, provide alerts of rapidly changing conditions to those unaware of developing hazards, or summarize the visibility conditions across a broad region for inclusion in meteorological analysis or forecast models.

This technology won an R&D 100 Award.

2020

ACAS Xu, sXu, and Xr

The introduction of new vehicle types and operations, such as large and small UAS and advanced air mobility (AAM) aircraft, presents many technical challenges, including the need to detect and avoid other aircraft, terrain, and obstructions. These vehicles are often performance limited and need to avoid all other aircraft, including those not equipped with a transponder. Beginning in 2014, Lincoln Laboratory began extending the ACAS X foundation to support larger UAS through a variant called ACAS Xu. ACAS Xu provides both vertical and horizontal avoidance maneuvers and is capable of using an air-to-air radar to detect and avoid aircraft that are not equipped with an operable transponder. In 2017, the Laboratory began development of ACAS sXu for small UAS (also known as drones). Because of small UAS' size, weight, and power constraints, ACAS sXu can use ground-based surveillance data, and the logic itself can be located either on the vehicle or in the cloud. Finally, ACAS Xr is being developed to provide collision protection for AAM and manned rotorcraft. In 2020, the final ACAS Xu standard was published, the initial standard for ACAS sXu was completed, and development began for ACAS Xr.

This technology won an R&D 100 Award.

2020

Airport Capacity Evaluation and Prediction Tool

Airport capacity is a key factor that air traffic managers need to carefully consider as they develop daily plans for the aviation system. Lincoln Laboratory is partnering with NAV CANADA to develop the Airport Capacity Evaluation and Prediction Tool (ACEPT), which predicts airport capacity for 12 hours into the future. If constraints such as low visibility or high winds are not addressed at a major airport, airborne delays, holding, and diversions can propagate through the aviation system. By identifying well in advance periods when demand may exceed the expected capacity of an airport, delay programs can be initiated to address system constraints as efficiently as possible. In 2020, an initial prototype of ACEPT was deployed to Toronto Pearson International Airport, the largest airport in the Canadian system. Subsequent algorithmic enhancements are under development.

2021

Small Airport Surveillance Sensor

There are more than 500 airport control towers in the United States, most of which are at small airports that lack all-weather surveillance of aircraft on the surface and in the surrounding airspace. The Small Airport Surveillance Sensor (SASS) was developed at Lincoln Laboratory to provide this comprehensive surveillance capability to tower controllers at a relatively low cost. SASS uses a novel phased-array antenna design that allows the angle of arrival of Mode S and ATCRBS replies to be measured with high accuracy. SASS provides surveillance accuracy up to 30 feet on the surface and airborne surveillance out to 20 nautical miles. A SASS test bed consisting of two sensors, an interrogator, and a master unit was installed and tested at Hanscom Field in Bedford, Massachusetts. On the basis of demonstrations of the SASS surveillance capabilities in this environment, the FAA is exploring transition of the system into operation through industry partners.

This technology won an R&D 100 Award.

EMERGING AREAS

As the demand for air transportation continues to grow, the need to mitigate aviation's impact on the environment and to safely integrate new operations, such as urban air mobility, is becoming more important. Lincoln Laboratory is working with the FAA, NASA, other government agencies, industry, and academia to develop and transition new technologies to enable a safe, efficient, and exciting future air transportation system.

Aviation Environmental Impact Reduction

Aviation impacts on the environment include noise, air-quality degradation, and greenhouse gas emissions that affect the climate. Mitigating these impacts while maintaining operational safety and efficiency can be challenging. Lincoln Laboratory has been working with the FAA, MIT, and other stakeholders to develop techniques for managing airport surface congestion. For example, a technique called N-Control departure metering was tested at Boston Logan International Airport in Massachusetts and Dallas/Fort Worth International Airport and was analyzed to determine the potential to reduce fuel burn and emissions. The resulting airport surface queueing models are now being leveraged to enhance the FAA's Aviation Environmental Design Tool, which is the industry-standard tool to undertake aviation environmental impact assessments. The Laboratory has also helped develop improved flight procedures that reduce fuel burn and emissions in different flight phases. The Cruise Altitude and Speed Optimization and Delayed Deceleration Approach procedures jointly developed with the MIT Department of Aeronautics and Astronautics are now becoming operational. Lincoln Laboratory is continuing to explore other areas in which its expertise could be leveraged to help analyze and mitigate environmental impacts, such as in aircraft condensation trail avoidance, management of impacts from emerging new airspace users (such as urban air mobility and commercial space operations), and other transportation modes.

Urban Air Mobility

Urban air mobility (UAM) is an evolving concept that uses small piloted or autonomous electric vertical-takeoff and landing vehicles to transport up to four people in an urban environment. This exciting vision could revolutionize urban transportation options and significantly reduce road congestion. However, a number of technical challenges must be addressed before UAM becomes a reality, including vehicle design, infrastructure development, system network design and scheduling, air traffic control, collision avoidance, high-resolution weather sensing and forecasting, certification, regulation, and interoperability issues between platforms. Lincoln Laboratory has a long history in many of these areas in conventional aviation and is working with federal agencies, private industry, and stakeholders to assist in realizing safe, efficient UAM.

Aircraft-Derived Observations

As aircraft fly through the atmosphere, their sensors can make observations of properties such as wind speed/direction, temperature, and humidity at very high update rates. Such aircraft-derived observations (ADOs) of the atmosphere have been shown to be valuable for numerical weather prediction models used to develop forecasts and for real-time use to enable new aircraft operating paradigms, such as time-based separation. Lincoln Laboratory is involved in several key activities to enhance ADO use, including demonstrating opportunities via existing Mode S enhanced surveillance systems; developing prototype low-cost, portable aircraft interrogation systems to increase the extraction and availability of ADOs; establishing new standards (e.g., via ADS-B Weather Out) to expand ADO access in the future; and developing new weather forecast systems and ATC procedures enabled by enhanced ADO access.

Commercial Space Operations

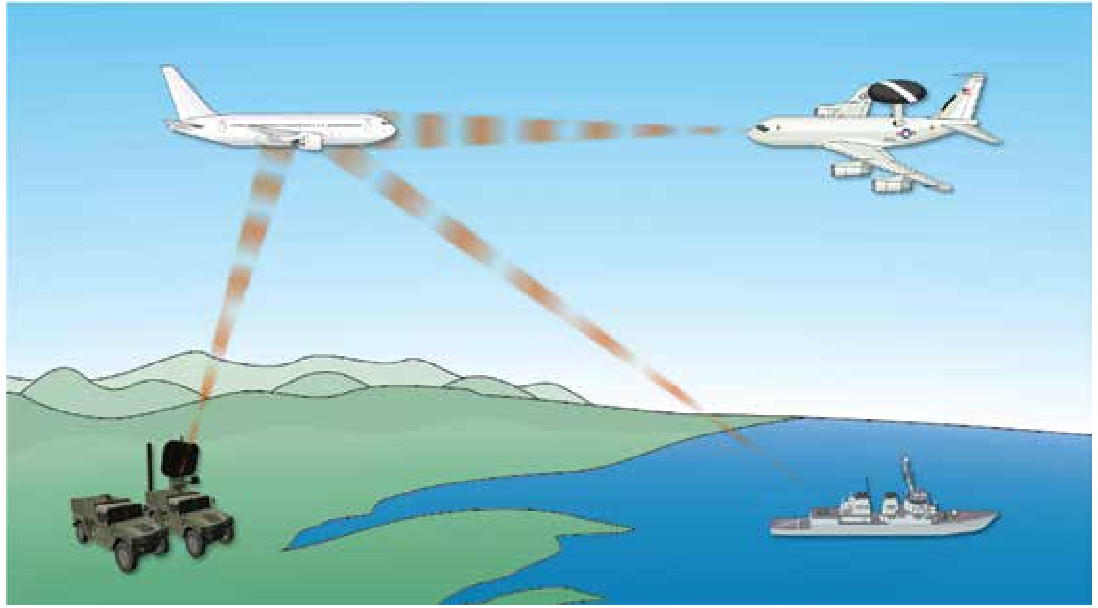
The increase in the number of commercial space operations is expected to continue. Newly operational launch and reentry sites will increase the potential extent and frequency of activation of restricted aircraft hazard areas. Other airspace users need to avoid these areas, but doing so often causes increased delays, flight times, and emissions for impacted airline flights. There is a need to develop tools to safely, efficiently, and equitably coordinate air and space operations. The FAA is pursuing various technologies to provide real-time space operation information exchange and decision support to key FAA facilities and other stakeholders. Lincoln Laboratory's prior experience in complex system architectures, technical modeling, prototype development, and investment analysis activities for the FAA is being leveraged to facilitate the continued development of relevant concepts and prototype decision support tools. One such tool, the MIT Integrated Risk Analysis Tool, is being used as an exemplar system by the FAA to determine appropriate aircraft hazard regions during commercial launch and reentry operations that balance safety and efficiency across all airspace users.

Trajectory-Based Operations

Trajectory-based operations (TBO) is a cornerstone concept for strategically planning, managing, and optimizing flights by using time-based management, information exchange between air and ground systems, and the aircraft's ability to fly precise paths in time and space. Lincoln Laboratory is playing a key role in the development of TBO-enabling technologies, including System-Wide Information Management data architectures and enhancements to automation systems. A particular focus of the Laboratory's work is on enhancing TBO performance in complex wind and convective weather environments. A TBO weather test bed is being developed as a joint FAA/Lincoln Laboratory facility with operational versions of automation systems to enable integration of enhanced weather information for testing and validation. Use of the test bed includes ingesting high-fidelity wind fields and exploring modifications to trajectory-prediction algorithms to more accurately capture aircraft dynamics and pilots' avoidance behaviors in the presence of weather events.

Aviation Spectrum Assessment and System Development

New airspace entrants, such as small UAS and AAM, may operate in numbers and densities that exceed the capacity of the existing radio frequency spectrum allocated to surveillance for manned aircraft (1030/1090 megahertz and 978 megahertz). Beyond spectrum capacity, given the higher level of autonomy associated with these new entrants, there are additional requirements to improve the security of the information transmitted on the vehicle-to-vehicle link and mitigate the risk of spoofing and jamming. A new vehicle-to-vehicle link will be required to support detect-and-avoid capabilities and a means to provide surveillance information for sUAS and AAM operations. Research and development activities include developing message sets, message security requirements, and onboard avionics requirements.



Small Unmanned Aircraft Systems

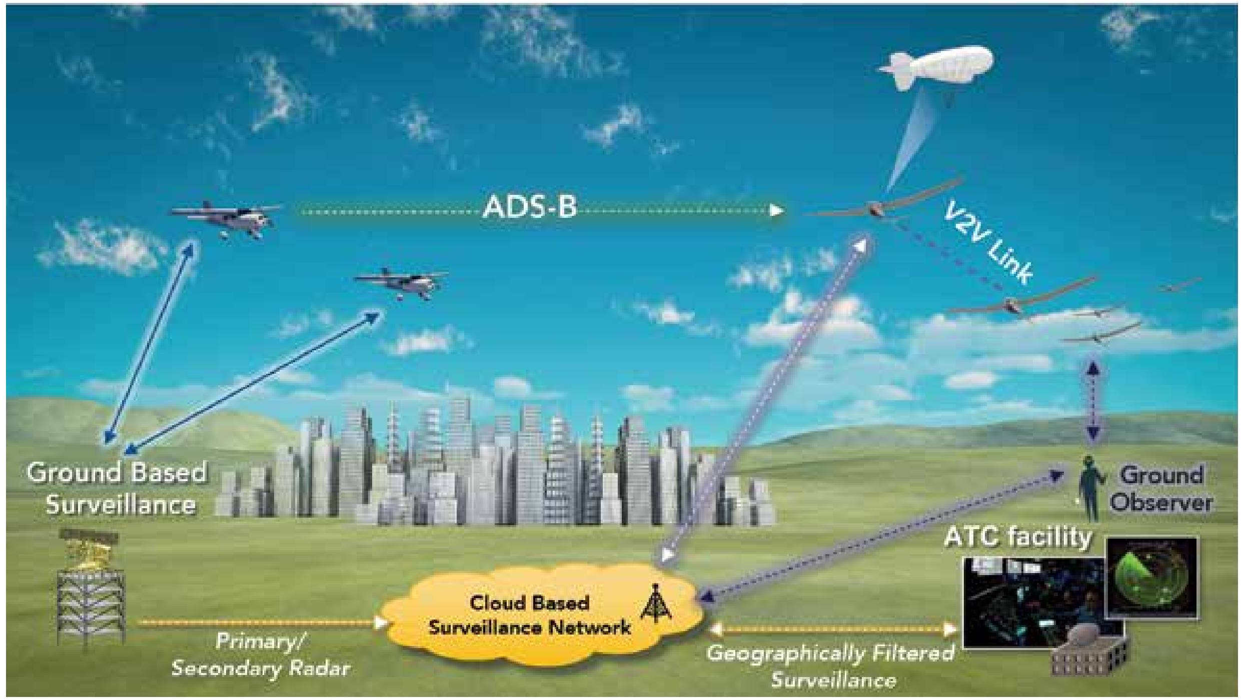
Small unmanned aircraft systems (sUAS), often called drones by the general public, are envisioned to provide a significant public benefit by performing a wide variety of missions at lower cost with increased flexibilty compared to traditional methods. Example applications include package delivery, infrastructure inspection, aerial photography, agriculture, and surveillance missions. Because these vehicles are highly autonomous with very limited size, weight, and power to support surveillance and other systems, significant research and development are required to safely integrate these vehicles into the airspace. Major research areas include conflict detection and resolution for airborne and ground hazards, air traffic management algorithms, safety assessment, surveillance requirements for ground and airborne sensors, and UAS traffic management requirements. To facilitate this research, Lincoln Laboratory has developed an sUAS test bed to explore prototypes, develop concepts, and collect data. Using this facility, the Laboratory is working with a wide variety of government and industry partners to facilitate safe, efficient integration of sUAS into the airspace.

Traffic Management Initiative Recommender Systems

Artificial intelligence and machine learning approaches open up huge potential to revolutionize air traffic management. Vast amounts of operational data can be mined to assess what strategies work best under different operating conditions. Such assessments could be especially beneficial in determining Traffic Management Initiatives (TMIs) that manage demand as challenging weather conditions move through the airspace. Lincoln Laboratory is developing TMI recommender systems that utilize operational data and fast-time simulations to run hundreds of parallel instances of potential operational scenarios. Artificial intelligence and machine learning are being used to assess a range of TMI techniques that could recommend a potential solution that accounts for the user's preference of operational criteria, such as minimizing airborne delay or maximizing the completion rate of flights. These approaches could lead to effective and actionable strategies to support air traffic management decision making in the future.

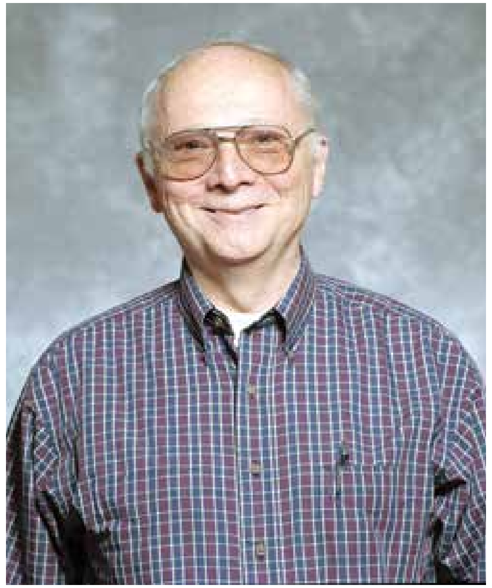
Vehicle-to-Vehicle Communications for New Entrants

Many highly critical civil and military aviation systems operate on the 1030-/1090-megahertz spectrum, including ATC secondary radar, ADS-B, Wide Area Multilateration, airborne collision avoidance systems, identification friend or foe, and military air defense interrogators. Research and development are required to improve the spectrum efficiency of existing systems and to evaluate and develop advanced algorithms for new systems to ensure safe, effective use of the 1030-/1090-megahertz spectrum. Lincoln Laboratory is working with the FAA, the Department of Defense, and industry partners to conduct modeling and simulation of existing and new systems and to develop new surveillance technologies that provide capabilities interoperable with current systems.



The foundation for Lincoln Laboratory's impact in developing air traffic control technology during the last 50 years has been centered on its exceptional people. Here, we provide brief highlights of just a few of the several hundred staff members who have been essential to the accomplishments described earlier in this booklet.

Staff Highlights



VINCENT ORLANDO

Dr. Vincent Orlando is arguably the person most responsible for the inception and international adoption of Mode S and ADS-B surveillance technologies. Vince joined Lincoln Laboratory in 1972, serving in key group leader positions until 1990 and then continuing as a senior staff member in the Surveillance Systems Group. Vince has played a significant role in the development and implementation of cooperative surveillance from the initial Discrete Address Beacon System (DABS, pre-Mode S) to the latest Mode S standards, which are the technical foundation upon which TCAS and ADS-B are based. His technical contributions have included definitions of the Mode S protocols and 1030/1090-megahertz frequency analyses.

Beyond making numerous technical contributions, Vince has been instrumental in ensuring cooperation between international teams and harmonization of cooperative surveillance systems worldwide. For the past 40 years, Vince has served as chair of the International Civil Aviation Organization (ICAO) technical group charged with the development and harmonization of international cooperative surveillance standards and recommended practices. His longstanding impact in this field was recently recognized when he received ICAO's 2021 Walter Binaghi Air Navigation Commission Laurel Award.

Over many decades, Vince has provided technical expertise, gracious leadership, unflagging energy, and remarkable consensus-building skills, allowing worldwide groups with diverse backgrounds and goals to produce exacting standards for safety-critical systems. Vince's ability to obtain high levels of international consensus has been critical for the successful adoption of foundational surveillance technologies around the world.

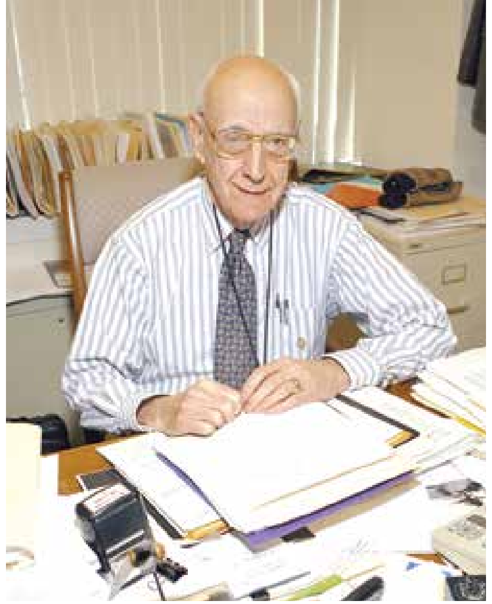
Vince received a BS degree in electrical engineering from the University of Cincinnati, an MS degree in statistics from Stanford University, and a PhD degree in systems and information science from Syracuse University. Before joining the Laboratory, he spent 10 years working on the development of military command-and-control systems.

MARILYN WOLFSON

The majority of Lincoln Laboratory's weather forecasting and display technologies trace their origins to the visionary leadership of Dr. Marilyn Wolfson. She joined the Laboratory in 1983, and her career began with understanding the hazards to aviation caused by thunderstorms and microbursts, working with national experts and contributing to the FAA's TDWR and ITWS algorithms. From 1998 to 2010, as the leader of the FAA's multi-laboratory Convective Weather Product Development Team, she developed automated short-term storm forecasts for air traffic management applications and prototyped them for operational use. Marilyn's energy and enthusiasm were the driving forces behind the successful development of CIWS and the NextGen Weather Processor systems. Her ingenuity led to a range of innovative algorithms and processing methods that produce accurate, rapidly updating weather information for aviation.

Marilyn served as a senior staff member and an associate group leader of the Weather Sensing Group at Lincoln Laboratory, and she was named a Laboratory Fellow in 2013. She received several honors and awards during her career, including being elected as a Fellow of the American Meteorological Society in 2012 for her "outstanding contributions to the atmospheric or related oceanic or hydrologic sciences, or their applications, during a substantial period of years." She also received the MIT Lincoln Laboratory Technical Excellence Award in 2005 for "her work in the application of meteorology to the problem of improving air traffic control and for her national-level role in the application of advanced convection weather forecasts for use in the aviation community."

Marilyn holds a BS degree (honors) in atmospheric and oceanic science from the University of Michigan, and SM and PhD degrees in meteorology from MIT, where she was named an Ida M. Green Fellow. She applied her thesis work in developing a real-time microburst prediction algorithm that is currently operational in the FAA's ITWS. She has served on National Academy of Sciences committees and has written numerous scientific papers and journal articles.

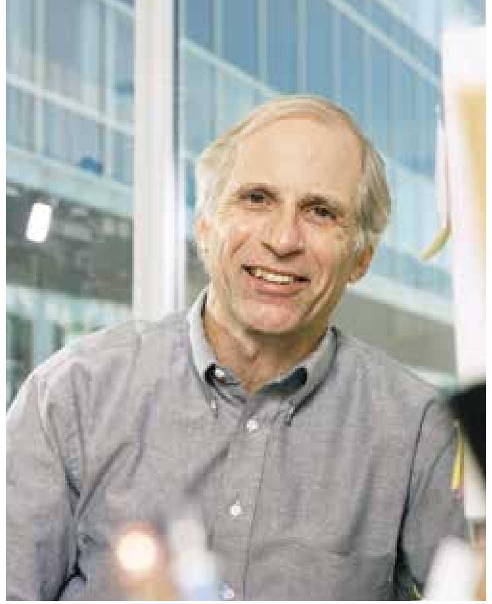


MEL STONE

Mel Stone's career at Lincoln Laboratory spanned almost 70 years, during which he made significant contributions to the air traffic control program and many important Laboratory technologies. Prior to joining the Laboratory, Mel served in the U.S. Army Air Corps from 1941 to 1943, then attended MIT radar school from 1943 to 1947. From 1948 to 1951, he participated in the development of weather radar techniques as a staff member in the MIT Department of Meteorology Weather Radar Laboratory. After completing his BS degree in electrical engineering at MIT, he joined the Laboratory in 1951 and rapidly rose to serve in group offices for almost 25 years. He then served as a senior staff member until retiring in December 2020.

Mel's technical skills and leadership were responsible for many key contributions to radar technologies and their associated applications for improving aviation safety, including the MTD, ASR-9, and 9-PAC. Mel was also instrumental in initiating weather radar development activities arising from the NEXRAD programs, including TDWR, WSP, and other applications such as low-level wind-shear and microburst detection.

Mel had a significant role in many other Laboratory programs beyond the air traffic control area. His interests and work areas included HF ground-wave radar, the lunar albedo UHF, auroral backscatter and propagation effects related to ballistic missile defense, and the perturbation of the ionosphere caused by missile exhaust. He played a key role in system engineering during the construction of the Haystack radar facility and in the development of the 500-kilowatt average power X-band radar used in the fourth test of general relativity. Mel was the leader of the group responsible for the testing and demonstration of the developmental air-to-ground radar that employed the displaced phase center concept. This radar was the progenitor of the U.S. Air Force/Army Joint Standoff Target Attack Radar System. Mel passed away in November 2021, and his seven decades of technical leadership and contributions in radar technology and applications have greatly benefited aviation safety.



JAMES EVANS

Lincoln Laboratory's aviation weather program was launched by Dr. James Evans, whose vision has been key to technical and operational achievements over four decades. Jim's leadership in aviation weather began in response to a government request to evaluate the NEXRAD radar system being procured by the FAA, National Weather Service, and Department of Defense. Jim attracted and cultivated a highly capable cadre of engineers and scientists to assess aviation-specific requirements, such as robust clutter and interference suppression to assure high data quality for non-meteorologist users.

When a series of fatal air carrier accidents was caused by microburst wind shear, Jim and his team were able to quickly address the challenge to air safety posed by microbursts. Under Jim's leadership, Lincoln Laboratory built a transportable TDWR prototype and, in collaboration with the National Center for Atmospheric Research, developed the algorithms and concepts of operation that enabled fully automated microburst warning for air traffic controllers and pilots. Jim also recognized the urgent need for improved decision support to reduce the impact of storms on flight delays, leading to the development of ITWS and CIWS.

Jim's sustained energy and commitment, recognized through a 2002 MIT Lincoln Laboratory Technical Excellence Award, have been driving factors in the Laboratory's development of ground-breaking meteorological processing algorithms and expansion into new areas, such as air traffic operations analysis and human-machine engineering. Through his experience transitioning prototype systems to operational deployment, Jim's energy and commitment have continued to inspire a new generation of aviation weather researchers.

Jim is a senior staff member in the Air Traffic Control Systems Group. In 2019, he received the third annual Aviation and Space Operations Weather Prize for his significant contributions to the sensing, warning, and mitigation of the hazards of convective weather at major airports and along airways around the United States.

ANN DRUMM

The fact that mid-air collisions between transport aircraft are now practically nonexistent is due in no small part to Ann Drumm's career focused on aviation safety. Ann received a BA degree in mathematics and computer science from Miami University in Ohio in 1969, and she joined Lincoln Laboratory that same year. Ann became a member of the Air Traffic Control Division when it was formed in 1970, and she was part of the teams that developed the Mode S sensor and ADS-B, two key technologies that have been critical for enhancing the ability to track aircraft. She also played essential roles in ensuring standardization between aircraft transponder systems for civil and Department of Defense applications. But Ann's real passion has been making flying safer through the development of TCAS, which she has worked on since it became a Lincoln Laboratory program in 1975.

Ann developed the protocols for TCAS air-to-air coordination, a process used worldwide to ensure that aircraft encountering one another select compatible avoidance maneuvers. She was also instrumental in developing methods to assess the performance of TCAS in the United States through the use of TCAS Resolution Advisory downlinks and fast-time simulations of aircraft encounters. Drawing from her experience working on TCAS, Ann helped outline a safety analysis process for unmanned aerial vehicles that could potentially be integrated into the civil airspace. Ann has made numerous technical contributions throughout her career, but she has also been a source of inspiration and cooperation by working closely with multiple government, industry, and international partners to reach agreements on the standards for collision avoidance systems and their improvement through successive enhancements.

Ann has been an essential part of the TCAS development process since its inception and continues to work with staff at Lincoln Laboratory to ensure the next-generation aircraft collision avoidance system, ACAS X, will be even safer and more effective than its predecessor. Many staff have benefited from her mentorship, leadership, and guidance during their careers.

RAYMOND LAFREY

Raymond LaFrey joined the Laboratory in 1969 at a time when revolutionary developments were happening in the advancement of digital radar systems. Ray's initial area of focus was bridging this work to the FAA's modernization of the national airspace system. Under Ray's leadership, capacity and safety enhancements were developed that enabled pilots and controllers to safely separate aircraft in high-density airspaces, especially in regions within and surrounding the busiest U.S. airports. Ray served as an assistant and associate group leader in the System Design and Evaluation Group. After his promotion to group leader of the newly formed Air Traffic Surveillance Group, he became an associate division head and leader of the Laboratory's Air Traffic Control program activities. He was also a member of the MIT Lincoln Laboratory Steering Committee.

One of Ray's most significant roles was to lead a program that evaluated the applicability of Mode S secondary surveillance radars for monitoring parallel runway approaches. The need for greater airport capacity had led to interest in new technologies that could support independent parallel approaches under instrument meteorological conditions at airports with runways spaced as closely as 3,000 feet. An operational evaluation of a back-to-back antenna system performed at Memphis International Airport helped guide the FAA's implementation decision and led to a better understanding of important human factor considerations for new displays and methods for automatic alerting.

During his last 10 years at the Laboratory, Ray was responsible for the Air Traffic Control mission area's FAA, NASA, and Department of Defense–sponsored research in radar, navigation, communications, and aviation weather systems. Many key technologies were developed under his leadership, including advancements to the FAA's primary and secondary radars and decision support systems to improve hazardous weather advisory and avoidance capabilities. The Mode S beacon system and TCAS, technologies that Ray worked on, became industry products that have been deployed internationally.

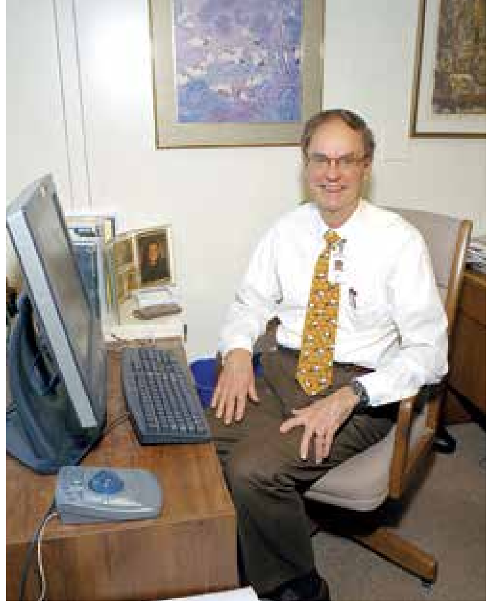
Ray retired from the Laboratory in 2003. Prior to joining the Laboratory, he served six years in the U.S. Army as a Signal Corps Officer. He received BSEE and MSEE degrees from Michigan State University.

ELIZABETH DUCOT

Elizabeth Ducot joined Lincoln Laboratory in 1988, and her research focused on large-scale distributed systems for weather sensing and decision support. During her career at the Laboratory, Beth served as both the project engineer and project manager for ITWS and CIWS. Her dedication to building operational prototype field-site demonstration systems validated the technical and operational viability of the ITWS concept. Her milestone contributions led to the successful transfer of the ITWS technology to Raytheon Corporation and its deployment to 45 locations across the United States.

Beth also led a critical re-engineering program using real-time data-fusion architecture models with massive compute infrastructure and software engineering solutions to deliver the national deployment of CIWS. In 2009, CIWS, which had only been a regional experiment until that point, expanded its coverage to encompass the entire continental United States and the southern part of Canada, allowing air traffic management personnel who had previously been outside of the area of CIWS's coverage to better assess how weather would impact their airspace. The re-engineered CIWS architecture has been running continuously at Lincoln Laboratory since 2011 and has been used by air traffic managers and airlines to mitigate weather impacts on flight delays. Following semiretirement from her role as an associate group leader in the Weather Sensing Group in 2008, Beth has continued to work as a strong software engineering mentor and inspiration to other technical staff members.

Beth received a BA degree in physics from Smith College. Her graduate studies in computer science were conducted at the University of California. Shortly after joining Lincoln Laboratory, she received the IEEE Control Systems Society Distinguished Member Award.



JERRY WELCH

Jerry D. Welch joined the Laboratory in 1961 and initially worked in the development of laser radars and microwave semiconductor receivers in support of the NASA Apollo program. In 1969, he assumed a lead role in the development of the Air Traffic Control Radar Beacon System. This work pioneered advancements in the ground interrogation equipment and the airborne transponder units necessary for reliably tracking commercial and military aircraft in high-density airspaces. Jerry's efforts then expanded to the development of the Mode S beacon system, which introduced advanced monopulse techniques and selectively addressable transponders to reduce spectrum congestion and to provide an air-to-ground data link.

After the Mode S design was completed in 1975, he led the Laboratory's development of reliable air-to-air beacon-based surveillance techniques for collision avoidance, which was key to the success of TCAS. In 1987, he became the leader of the joint FAA/NASA Terminal Air Traffic Control Automation Program that led to a successful demonstration of an automated traffic management advisory system for the FAA that is now operational nationwide. From 1990 to 1998, Jerry led the new Air Traffic Automation Group at Lincoln Laboratory. He developed and demonstrated a working model of an automatic runway status lights system to help prevent aircraft collisions on the ground at Boston's Logan International airport. After further research and development to refine surveillance and warning algorithms, the Laboratory transitioned the technology to the FAA in 2009. Today, runway status lights are helping to protect airliners at 20 U.S. airports and two airports in Europe.

Jerry is a senior staff member in the Surveillance Systems Group. He received SB and SM degrees in electrical engineering from MIT and a PhD degree in electrical engineering from Northeastern University.

DEDICATION

PAUL R. DROUILHET JR.

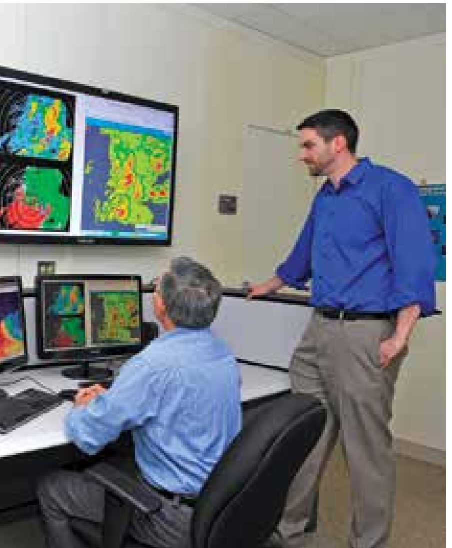
This pamphlet highlighting MIT Lincoln Laboratory's contributions to the national ATC system is dedicated to Paul Drouilhet Jr. Paul's brilliant technical vision and passion for the work in this area has led to many profound accomplishments and the most effective, efficient, and safe ATC system in the world.

Paul graduated from MIT, where he received BS (1954) and MS (1955) degrees in electrical engineering. After serving active duty in the U.S. Air Force, he joined Lincoln Laboratory as a member of the technical staff in 1959. For the next decade, he was active in the development of communication techniques for passive and active satellite systems and for very-low-frequency radio channels.

It was in 1970 that his efforts helped establish a program in the development of ATC technology for the FAA and led to his appointment as leader of the newly formed Air Traffic Control Group. His leadership was instrumental to the development of major new surveillance systems for the FAA: the Discrete Address Beacon System, now known as Mode S, and the Moving Target Detector Doppler radar processing system, which became the basis for the ASR-9. In 1972, Paul was appointed associate head of the Air Traffic Control Division, which pioneered new areas, such as the development of an airborne traffic alert and collision avoidance system and the Terminal Doppler Weather Radar to detect and identify severe weather phenomena, including microbursts.

For his contributions to ATC systems, Paul was elected a Fellow of the IEEE in 1986. He received the FAA Associate Administrator Award in 1993, the 1994 Air Traffic Control Association Walter A. Partenau Award for Outstanding Achievement in Air Traffic Control, and the 1996 Discover Award for Technical Innovation (Aviation and Aerospace category) for the development of the GPS Squitter concept which became the foundation of the Automatic Dependent Surveillance–Broadcast technology deployed by the FAA under the Next-Generation Air Traffic Control System.

Paul retired from Lincoln Laboratory as an associate director emeritus in 1996. However, his passion for work in ATC continued, and during this period, he continued to share his vision, contribute to strategic discussions, and mentor new management and staff. We are pleased that his legacy continues through the Laboratory's continued commitment and important contributions to advancing the state of the art in the nation's airspace system.



A note on R&D 100 Awards

Presented annually since 1962, the R&D 100 Awards recognize the 100 technology products judged by a panel of technical news editors and outside experts to be the most significance new developments of the year. The awards recognize diverse products developed by industry, research laboratories, and academic institutions worldwide.

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LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
244 Wood Street ▪ Lexington, Massachusetts 02421-6426

Communications and Community
Outreach Office

- 781-981-4204
- ccoo@ll.mit.edu

www.ll.mit.edu

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TECHNOLOGY IN SUPPORT OF NATIONAL SECURITY

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