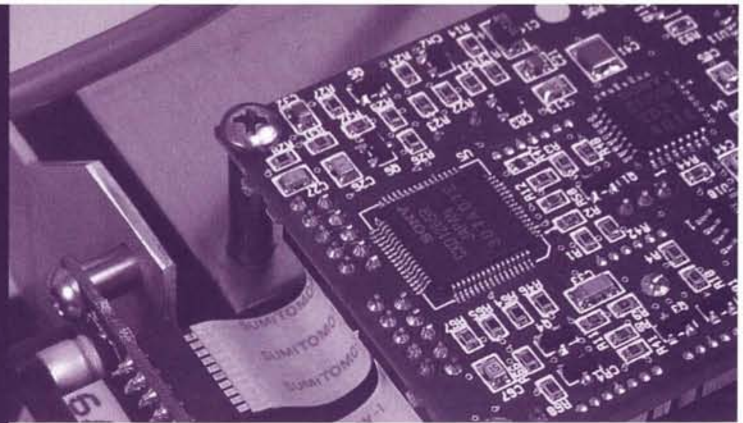

**A dramatic advance in aviation hazard prediction heads a selection of technology transfers for improved public safety**

On November 30, 1994, Continental Airlines Flight 1637, a Boeing 737-300 jetliner, took off from Washington (D.C.) National Airport bound for Cleveland. It was a routine, regularly scheduled flight — but to aviation safety officials all over the world it was something more; it was a historic moment that marked the introduction to commercial airline service of an instrument for detecting and predicting windshear, a leading cause of aircraft accidents.

The instrument was the Bendix RDR-4B airborne weather radar developed by AlliedSignal Commercial Avionic Systems, Fort Lauderdale, Florida. The first such system to be certified by the Federal Aviation Administration (FAA), the RDR-4B forward-looking radar is the product of a decade-long FAA/NASA/industry/academia research program spearheaded by Langley Research Center, which developed the technology base that enabled commercial manufacture of the AlliedSignal and other windshear detection/prediction systems.

Windshear is a sudden shift in wind direction and velocity. Its most violent characteristic is the microburst, a column of air which cools rapidly in a thunderstorm and generates intense downdrafts that create a maelstrom of powerful, swirling wind currents near ground level. Low and slow aircraft, such as airliners landing or taking off, are particularly vulnerable to the microburst, which can cause an airplane to lose aerodynamic lift and flight speed, and to plunge into the ground before the flight crew can take corrective action. That has happened on numerous occasions; windshear has been identified as the cause of more than 30 major aircraft accidents and the loss of hundreds of lives.

One of those accidents occurred at Dallas-Fort Worth Airport on August 2, 1985, when a powerful microburst caused the crash of a Delta Airlines Lockheed L-1011 jetliner with 137 fatalities. That accident triggered a Congressional mandate to the FAA to initiate a research/training effort toward curbing the windshear hazard.

In 1986, the FAA and NASA launched a joint program to develop the essential technology for detecting and avoiding microbursts. The FAA undertook an aircrew training program that focused on windshear recognition and procedures for recovering from its effects. FAA also led the development of ground-based windshear detection instruments, including the Terminal Doppler Weather Radar (TDWR) now being installed at 45 major U.S. airports; developed by Raytheon Corporation, the TDWR can accurately measure wind velocities in terminal areas and generate real-time aircraft hazard displays that are updated every minute.

NASA's Langley Research Center focused on development of airborne systems capable of predicting windshear. Another type of system, the reactive system, processes data from standard aircraft instruments to determine the presence of windshear. The reactive system only advises a pilot that he is in a windshear event, allowing him to increase engine power and possibly escape the hazard; however, the airplane might not be capable of recovering from a severe windshear at that point. Langley concentrated on a predictive system in the cockpit that would provide 10 to 40 seconds of warning, thereby enabling the pilot to determine the proper maneuver, add power for flight stability or avoid the windshear area altogether.

*AlliedSignal's company research aircraft awaits buildup of thunderstorm activity at Fort Lauderdale, Florida to test a radar instrument that provides flight crews up to two minutes warning of hazardous windshear.* ***Below,*** *company engineers analyze computer-processed windshear data during a flight test. Derived from NASA technology, the AlliedSignal Bendix RDR-4B became — in 1994 — the first predictive weather radar certified for airline operations.*

Augmented by technology application experts from Research Triangle Institute, Research Triangle Park, North Carolina, the Langley team initiated development of three different types of microburst sensors. The one that ultimately became the first in airline service is the Doppler microwave radar, which sends a radio wave ahead of the aircraft to "bounce" off raindrops in the thunderstorm and return to the instrument; computerized measurement of the Doppler shift (the difference in wavelength frequency between the outbound wave and the returning signal) provides an indication of windshear velocity.

A second type of system — LIDAR, for Light Detection and Ranging — operates under the same Doppler shift principle but employs a laser beam instead of a radio wave. A third type, a passive infrared sensor, is based on the fact that a microburst is usually cooler than the surrounding air, thus can be detected by infrared measurement of the temperature differential ahead of the airplane. The infrared system is no longer in development; the LIDAR is still being investigated for possible use as a component of a future hybrid system or a multifunction weather/turbulence detection system.

Langley's task was essentially to build a technology base that would enable manufacturers to develop their own commercially viable, proprietary systems. The enormous job began with characterizing the windshear hazard and determining the warning time required. Extensive computational simulations, using computer models thoroughly validated by actual observations, documented the structure, strength and evolution of microbursts from the smallest to the largest (about four kilometers). This work established the basic specifications for sensors and enabled development of algorithms for rejecting ground "clutter" that could confuse sensor signals. Langley also developed the all-important "F-Factor," an index that relates atmospheric motions to aircraft performance capability and assesses the degree of hazard to an airplane in a microburst encounter.

All of this knowledge gave manufacturers a broad knowledge base on how to extract windshear information from a sensor signal, how to process the data against hazard criteria, and how to alert flight crews to valid threats while rejecting "nuisance" indicators.

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*In the 737's windowless research cockpit, aft of the regular flight deck, researchers study the special informational displays generated by ground and airborne windshear detectors.*

By 1991, five years into Langley Research Center's windshear sensor development program, the technology had advanced to the point where validation of the sensors required actual flight tests in windshear conditions. For that job, Langley outfitted its unique flying laboratory with three types of sensors: the Doppler radar, the Doppler LIDAR and the infrared remote temperature sensor.

Formally known as the Transport Systems Research Vehicle (TSRV), the airplane was a preproduction model of the Boeing 737-100 jetliner equipped with a research cockpit in what would have been the forward section of the passenger cabin. Most of the sensor testing was conducted from this windowless "second cockpit," which was fitted with a full suite of flight controls and aircraft instrumentation, plus the sensor-related displays and data recording equipment. The TSRV's dual-cockpit configuration was designed to allow testing of new equipment and technologies in a safe environment (the pilots in the standard forward cockpit could take control of the aircraft should a malfunction occur in the research cockpit's instruments or equipment).

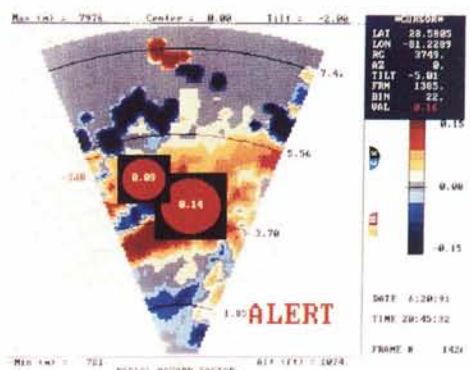
Langley selected two atmospherically-different field sites for the joint NASA/FAA flight test program: one at Orlando, Florida, the other at Denver, Colorado; both areas were noted for frequent microbursts in summertime. The flight test plan was simple: when ground radars detected windshear, the Langley crew would scramble, take off, fly directly toward and into the microburst, observe and record the sensors' findings, then validate them by cross-checking with ground radar data and with data from an airborne reactive system for measuring windshear velocities in situ. Orlando flights were supported by a Terminal Doppler Weather Radar (TDWR) operated by Massachusetts Institute of Technology's Lincoln Laboratory; at Denver, a research radar of similar capability was operated by the National Center for Atmospheric Research. For safety purposes, the TSRV was flown into windshear at speeds higher than those of a normal jetliner approach and at altitudes greater than takeoff/landing levels, speeds of 240-260 miles per hour and altitudes of 750 to 1,500 feet.


*Langley Research Center's Boeing 737 research aircraft is fitted with a Doppler radar windshear detection system (antenna shown) that sends a beam well ahead of the airplane to detect microbursts, evidenced by sudden large changes in raindrop velocities.*

Over the summers of 1991 and 1992, the Langley team conducted 130 flights and experienced 75 windshear events. The test program demonstrated that Doppler radar systems

*This view from a tail-mounted camera shows Langley's 737, vectored by a ground radar, heading into a thunderstorm that may harbor microbursts. In a two-year program, the Langley team conducted 130 such flights and encountered 75 microbursts, testing the ability of NASA-developed sensors to accurately measure windshear velocities and provide 20-40 seconds of warning.* ***Below*** *is a closeup of a sensor alert showing potentially hazardous microbursts 2-3 miles ahead of the plane; the 737's position is at the bottom of the cone, dark red areas indicate greatest shear intensity.*

offered the greatest promise for early introduction to airline service. The NASA forward-looking Doppler radar detected windshear consistently and at longer ranges than other systems, and it was able to provide 20-40 seconds warning of upcoming microbursts. The predictive sensors showed good correlation with data from ground radars and the on-board reactive systems.




NASA's technology development effort was essentially complete but the Langley group continued working in a consulting capacity on the matter of FAA certification. No certification standards existed; they had to be invented and the Langley researchers now represented the world's most knowledgeable body of windshear expertise. Langley worked with the FAA and industry to develop a set of standards for certification of windshear sensors; collectively, the standards define the hazard, the cockpit interface and alerts to be given to flight crews, a suggested methodology for certification, and the requisite sensor performance levels. The NASA research was the basis for most of the specifications.

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In 1990, the Federal Aviation Administration (FAA) ordered that all commercial carriers install windshear detection devices on their aircraft by yearend 1993. Reactive systems, which detect the presence of windshear without warnings, were being produced by several manufacturers and most airlines opted for that type of system. For those airlines who were already testing predictive systems and preferred to wait for their certification, the FAA offered an extended deadline of yearend 1995.

Meanwhile, NASA was trying to effect the broadest possible transfer to industry of the safety-enhancing predictive windshear technology. In addition to the usual practice of disseminating technical papers, NASA and FAA jointly sponsored well-attended windshear conferences and invited potential manufacturers to track the development of windshear detectors. Three major avionics manufacturers — AlliedSignal; Westinghouse Electronic Systems Group, Baltimore, Maryland; and Rockwell Collins Commercial Avionics, Cedar Rapids, Iowa — sent engineering teams to Langley to meet directly with NASA's radar engineering personnel and follow Langley's developmental effort step by step. The three companies each requested and were provided Langley's windshear simulations, which they used extensively in developing their own commercial systems.

*AlliedSignal's Bendix RDR-4B system includes the antenna (background), a receiver/transmitter (center) and a Planned Position Indicator (PPI). Shown in closeup* ***above,*** *the PPI displays the direction and distance of a windshear microburst in addition to the normal en route weather display.*

On September 1, 1994, AlliedSignal's Bendix RDR-4B became the first predictive windshear system to gain FAA certification for airline operations. Three major U.S. airlines selected the RDR-4B, United and Northwest in addition to Continental; collectively they ordered more than 1,000 units. The technology is also being extended to foreign airlines; among those who have purchased the RDR-4B are Swissair, Alitalia, Iberia, Gulf Air and Kuwait Airways.

Westinghouse, a leading manufacturer of radar systems for 50 years, is producing two windshear detection/prediction versions of its MODAR (Modular Aviation Radar). For commercial air transport service, Westinghouse and Honeywell Inc. are jointly marketing the MR-3000 forward-looking Doppler radar. The companion MR-4000, known in the Air Force as AN/APN-241, is designed for military tanker/transports and was initially produced for installation in the Air Force C-130 transport by Lockheed Aeronautical Systems Company. In addition

*Westinghouse Electronic Systems flew this BAC 1-11 transport through more than 200 windshear encounters to test the MODAR MR-3000 and MR-4000 predictive weather radars. The "black box" — the radar equipment* ***(left)*** *— is housed in the aircraft's bulbous nose.*

to general weather information and windshear prediction, the MR-4000 offers advanced mapping and navigational capabilities. The windshear detection elements of both the MR-3000 and the MR-4000 were derived from NASA technology.


Rockwell Collins' Air Transport Division was a participant in the Langley test program; under NASA contract, the company supplied the hardware for the Doppler radar tested, first flown in July 1990. Collins later developed its own algorithms and incorporated them into a modified version of the company's WXR-700 weather radar, known as the WXR-700WR forward-looking windshear radar. The predictive windshear system, tested aboard a Continental Airlines 737 and Collins' own Gulfstream I, is designed for installation in new aircraft or retrofit in aircraft already in service. Collins initiated system deliveries to airline customers in 1995.

It took almost a decade to bring the predictive windshear system from concept to commercial availability, but that, aviation experts say, was a remarkably brief period, considering the complexity of the phenomenon and the virtually non-existent knowledge base at the outset of the program. The program stands as a model of cooperative endeavor by a broad segment of the U.S. aviation community, including government agencies, aircraft manufacturers, sensor manufacturers, airlines, research organizations and academia.

*Engineers of Collins Commercial Avionics work on windshear displays in the company's laboratory mock cockpit facility. The product, Collins' WXR-700WR predictive windshear system, is shown* ***at right;*** *at bottom is the avionics box that houses the computer and above it is the radar disc, which is mounted on a movable arm in the nose of the airplane.*