MODIFIED DOPPLER DETECTS WIND SHEAR MORE RELIABLY

BRUCE D. NORDWALL/ORLANDO, FLA.

Joint NASA/FAA flight tests have shown that advanced, predictive sensor systems can provide airline crews up to 30-sec. warning of wind shears during the critical takeoff and landing phases of flight.

Of the three forward-looking sensors installed in NASA's Boeing 737-100 Transport Systems Research Vehicle, the modified Doppler weather radar is detecting wind shear consistently and at longer ranges than the light detection and ranging (LIDAR) or the infrared sensors. The radar is consistently providing 20-40-sec. warning before the aircraft encounters wind shear conditions. Michael S. Lewis, deputy manager for NASA's airborne wind shear sensors program, said.

Current equipment installed on commercial transports are reactive, and detect wind shear only after the aircraft has encountered it—not before. The ability to detect wind shear before entering a microburst should allow pilots to add power, clean up the aircraft, and fly safely through or avoid it effectively removing a hazard that has caused over 26 U.S. air carrier accidents since between 1964 and 1985.

Wind shear, usually caused by microbursts, is most dangerous to an aircraft during takeoff and landing because the aircraft is low, slow, and has a minimum of excess energy because of drag from the landing gear and high lift devices.

This second phase of the joint NASA/Federal Aviation Administration wind shear research program started in Denver this summer and recently concluded in Orlando (AWST Dec. 16/23, NASA Langley's Boeing 737-130, the pre-production prototype for the 737, prepares to launch to test airborne wind shear detection sensors.

Even a relatively small vertical cloud can create wind shear hazards during landing approach or takeoff, with the aircraft losing altitude and airspeed.
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AVIONICS

1991, p. 46). Bendix/King, Rockwell/ Collins and Westinghouse have also been conducting flights, to test modifications to existing radars and to work on new designs to spot wind shears.

This AVIATION WEEK & SPACE TECHNOLOGY reporter had the opportunity to fly with the NASA crew during recent tests in Orlando. A crew of 31 was on board the aircraft to gather the sensor and aircraft data. Over 500 parameters are recorded on a primary magnetic tape data system, and four cameras recorded the primary flight and navigation displays in the cockpit, the research flight deck and a view forward from the aircraft nose.

The flight crew briefed at noon, and then settled in to wait for the afternoon cumulus clouds to build. A call from the Terminal Doppler Weather Radar (TDWR) site that microbursts had been detected in the area triggered a scramble to the aircraft and launch at 5:37 P.M.

Access to TDWR information was one of the reasons Orlando and Denver were selected as test sites. Orlando has a prototype TDWR, and Denver has a research radar with similar capability operated by the National Center for Atmospheric Research. The FAA plans to install the powerful ground-based TDWRs at major terminal areas around the country to detect wind shear.

For the purposes of the NASA tests, the TDWR was looking for isolated cells—the kind that typically develop during late summer afternoons—rather than those embedded in storm fronts, because it would be easier for the test aircraft to correlate the data collection effort. There is also a safety issue. Relatively isolated storm cells can produce microbursts of the same strength as those in embedded cells, but pose less hazard to the NASA crew since the aircraft could always have a clear "escape" vector.

Flying around and seeking wind shears at low altitude is not inherently safe, but NASA had planned the tests very carefully. The 737 would fly between 750 ft. and 1,500 ft. agl. at speeds between 200 and 240 kt. With airspeeds considerably higher than normal approach speeds, and a clean aircraft, the NASA 737 would have enough

NASA's Boeing 737-130 is testing the ability of three sensors to detect and warn pilots before an aircraft encounters wind shear—a modified Doppler weather radar installed in the aircraft nose (top), an infrared sensor mounted on the left fuselage (center) and a belly-mounted Doppler laser system (bottom), also called light detecting and ranging (Lidar). Airborne Doppler weather radar displays the red "alert" to warn pilots of wind shear directly ahead of the aircraft at 5-km. range. F-Factor helps determine the severity of wind shear.
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excess energy for a significant safety margin.

These safety limits were established after analyzing the performance of four research pilots who flew the entire test sequence in a simulator under varying wind shear conditions.

Flight tests started with a limit of 0.10 F-factor, as measured by the TDWR. As the data was collected and confidence in equipment increased, the limit was increased to 0.15 when I was flying with the crew.

Pilots Kenneth R. (Dick) Yenni and Michael Phillips manned the front cockpit. Lee H. Person would be flying the wind shear penetrations from the left seat in the research cockpit installed in the passenger compartment area with flight test project engineer Michael S. Lewis in the right seat. I occupied the jump seat behind Person, and program manager Roland Bowes was behind Lewis. The area to the rear carried researchers and test equipment.

We took off in weather that was generally hazy, with scattered clouds at 3,000 ft., surface winds from 190 at 5 kt., and a north/south line of cells developing 30 km. (18 mi.) to the east.

We would operate within the 25-nautical-mile-radius radar coverage of the TDWR—located just 10 km. south of the airport—to get collaborating data. The TDWR data-linked alerts that were displayed in the aft research cockpit provided vectors to the next wind shear over the radio—since the ground-based radar has much greater range than the airborne system.

Flying between 750 and 1,000 ft., a sense of urgency prevailed in the cockpit when a vector was received. Person banked aggressively to pick up the vector to each cell—because wind shear usually reaches its peak outflow within 5 min. of TDWR detection. A wind shear is short lived, and only lasts for the 5-10 min. life of a microburst.

We could see the nose camera view of the approaching cell displayed in the research cockpit. On another display we could see the TDWR view of our 120-deg. sector, which helped find the most appropriate wind shear. Switching the display from nose camera view to our airborne radar, the display showed a sector out to 1.5 km. Its colors depicted different wind velocities vividly. Dark blue indicated performance enhancing headwinds, and dark red indicated the more hazardous tailwinds.

Between 4 and 8 km, from a location TDWR had identified, our airborne radar would consistently warn the crew with "ALERT," and a box marking the wind shear location would appear on the display. Even with our 210-kt. plus speed, which is much faster than typical ap-

'F-FACTOR’ TO WARN PILOTS OF WIND SHEAR SEVERITY

ORLANDO, FLA.

NASA’s Langley Research Center has coined a new term that is likely to become widely used in the aviation community. "F-factor" is a number that indicates the danger of a specific wind shear.

In tests here NASA pilots receive wind shear alerts from the 3 in-flight sensors and the ground-based Terminal Doppler Weather Radar in terms of F-factor. This measure of wind shear severity is proving so useful that it is likely to become a standard in aviation. Its actual scale may be simplified, however, when the transition is made from research to general use.

The F-factor is a dimensionless number that indicates how much climb performance an aircraft will lose in a specific wind shear—the higher the number, the greater the hazard [AVI 1991, p. 46]. Each aircraft type would have a corresponding number that indicates equivalent specific excess thrust, which determines its ability to climb.

By comparing this aircraft performance number with the F-factor for a specific wind shear, a pilot could tell if a microburst exceeds the capability of his aircraft and should absolutely be avoided. For example, a typical twin turbojet transport might have an excess thrust at maximum gross weight of 0.17. A sustained wind shear of more than 0.17 would cause the aircraft to lose airspeed or altitude or both, no matter what the pilot, NASA pilot Kenneth R. (Dick) Yenni said.

Wind shears can be caused by gust fronts but are usually generated by microbursts, according to NASA's flight test project engineer, Michael S. Lewis. A microburst is formed when a column of air at high altitude quickly cools due to evaporation of ice, snow or rain and, becoming denser, falls rapidly to the ground.

Upon nearing the ground, downward moving air spreads rapidly in all directions away from the descending core. An aircraft flying into a microburst will experience a performance-enhancing headwind followed by a decreasing headwind, downburst and tail wind. Windspeed changes in excess of 80 kt. over 4 km. have been recorded, Lewis said.

The hazard of wind shear is most severe during takeoff and landing. Aircraft are at low altitude and airspeed, and have minimum excess energy because of the drag from the landing gear and high lift devices.

Under those conditions a safety hazard exists if the energy loss from wind shear (decreasing headwind, downdraft or increasing tailwind) saps aircraft energy faster than the engine thrust can replace it.

To be a hazard a wind shear must not only be of sufficient magnitude but also affect an aircraft for a significant time—at least 15 sec., NASA research pilot Lee H. Person said. Wind changes over a shorter time should be characterized as turbulence, which may affect aircraft control but do not pose the energy depleting danger of wind shears.

Roland Bowes, who manages the wind shear program, said that the F-factor can also be visualized in terms of a reduction in climb angle achieved by an aircraft.

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proach speeds, the span between alert and actual penetration would have been more than sufficient for an aircraft to clean up and accelerate through the microburst. For safety and data collection purposes the NASA aircraft remained clean and level and attempted to maintain a constant airspeed.

The pilots in the front cockpit were not just along for the ride. Yenni had the ultimate responsibility for safety and could veto going into a microburst if he did not like the looks of a particular cell.

The Doppler Light Detection and Ranging (Lidar) laser system is less mature than the radar technology, and would not be expected to perform as well in the high Florida humidity because its 10-micron-wavelength laser is absorbed by moisture, Lidar research engineer Paul Robinson said. With the Florida relative humidity at 78%, Lidar has had a wind shear detection range of 3 to 3.5 km. However, on the day that I flew the humidity was 41%, and Lidar was detecting wind shear at 4 km.

Right now Lidar is big, occupying about 3 cu. ft., but Robinson believes it could get considerably smaller as the technology matures. There are other possibilities for Lidar technology. Data about the wind field 4 to 6 km. ahead of the aircraft could be fed into the automatic flight control system, thus damping out excursions and leading to a smoother ride.

The infrared (IR) sensor developed by Turbulence Prediction Systems of Boulder, Colo., searches for the column of descending cold air that is a microburst. The difference in temperature can range from 2 to 10C, according to H. Patrick Adamson, general partner, Turbulence Prediction Systems.

There are two IR system sensors, one looking in the horizontal plane and the other up about 4 deg. The system senses temperature out to about 2 km., takes into account the adiabatic lapse rate for the upward field of view, and sends an alert to the cockpit if it detects wind shear.

The IR system could be used at 2,500 ft., but is intended for use at less than 1,500 ft. agl. During my flight the IR system provided its first two wind shear alerts. The system shares a problem of degradation with Lidar in that IR signals are absorbed by moisture. Yet it also offers the potential benefit of detecting clear air microbursts which elude radar. Compared with the Lidar system, the IR is relatively simple, requires no cooling and only consumes 18 w. of power. Adamson said cost is targeted between $50,000-

GEC FERRANTI DEVELOPING LIGHTWEIGHT, MULTI-MODE RADAR
MILTON KEYNES/ENGLAND

GEC Ferranti Defence Systems is midway through development of a new low-cost, lightweight radar designed for the light combat aircraft market, both new and retrofit.

The new multi-mode pulse Doppler radar, called Blue Hawk, already is assembled and undergoing system proving at the company’s Milton Keynes factory and would be available in about three-four years after a customer order is received. While a lot of work has been done over the last three years in the company-funded program, additional work would be required to tailor the baseline “generic” model to a specific aircraft, a GEC Ferranti official said. Antenna configuration is customer-specific.

Officials said the company sees a total potential market of several thousand radars in this class—for both new-generation light combat aircraft and retrofit of existing aircraft—over ten years for GEC Ferranti and its competitors.

Customers for Blue Hawk are expected to come primarily from the export market, rather than the United Kingdom. Aircraft installation schemes already are mapped out for new British Aerospace Hawk 200s, as well as customers retrofitting Northrop F-5, McDonnell Douglas A-4, MIG-21 BIS, Chengdu Super-7 and Shenyang F-8 II aircraft.

In developing the new radar, low cost was put “at the top of the list” of requirements, according to one official. The radar, which has a primary air-to-air role and a secondary air-to-ground/sea surface role, is expected to be about half the

price of previously available multi-mode radars. Company officials contend that Blue Hawk has the edge over U.S. competitors—which it says are higher in cost and subject to export restrictions—and over European radars—which it rates as immature products with low credibility.

Key features of the new radar system include high-, medium- and low-pulse repetition frequency; full transmitter power availability in all modes; programmable signal, data and display processors; automation for reduced pilot workload with control by hands on throttle and stick (HOTAS), and growth potential for later upgrades.

Officials said the company would not proceed to production without customer funding, and it would need an order of “some magnitude.” The company has been talking to potential customers for about two years.

New lightweight multi-mode radar designed by GEC Ferranti for the medium-performance, new and retrofit fighter market is assembled and undergoing system proving.
FILTER CENTER

COMPiled by brUCE D. NORDwall

IBM CORP., SIEMENS AG AND TOSHIBA have allied to develop semiconductors and the manufacturing processes to build them starting with a 256-
million-bit dynamic random access memory (DRAM). An important part of
the effort will be to develop the ability to fabricate circuit features with 0.25
micron width. IBM is already working with Siemens to develop 64 Mb
DRAMs and with Toshiba for flash memory.

GEC-MARCONI HAS RECEIVED A $100 MILLION CONTRACT from United
Airlines to equip its new Boeing 777 fleet with interactive video systems for
passenger entertainment and retrofit systems into some of its Boeing 747
and 767 aircraft, with initial service in mid-1993. Color 5.6-in. diagonal
active matrix LCD screens will provide 12 channels of video. A single coaxial
channel will also deliver 24 channels of near-compact disk-quality stereo
audio. Video games will be available, downloaded to a processor at each
seat, and played with a hand controller. Telephone service, flight and tour-
ist information, aircraft position and credit card ordering of merchandise
will be possible. System weight will average 3.5 lb. per seat.

DEFENSE ADVANCED RESEARCH PROJECTS AGENCY plans to continue
spending a significant part of its budget for microelectronics research, de-
spite a published GAO report that the Pentagon will cut back its funding for
Sematech, the consortium of semiconductor manufacturers. The agency
wants to create the flexible tools to manufacture small quantities of a wide
variety of microelectronics, Arati Prabhakar, DARPA’s director of microelec-
tronics technology, said. Work with Sematech will continue because
DARPA and industry both need flexible manufacturing tools.

LITON, RAYTHEON AND TRACOR have formed an alliance to compete for
the world-wide electronic warfare market. By combining their expertise the
three intend to offer integrated systems tailored to each customer’s aircraft,
needs and available funding. A typical suite could include a Litton radar
warning receiver, Raytheon jammer and Tracor countermeasures dispens-
ing system. The team expects to offer to integrate a missile warning system,
and eventually a head-up display and towed decoy.

AIL SYSTEMS WILL BUILD AN UPGRADED EXCITER for the ALQ-99 tactical
jammer used on the Navy’s EA-6B aircraft. Under a $25-million Naval Air
Systems Command contract, AIl is to design, build and test the new device.
The universal exciter generates signal modulations in all bands to confuse
enemy radars and create false targets. More performance and reliability
are desired than offered by the current 1960s design.

MARCONI SYSTEMS TECHNOLOGY HAS DEVELOPED a software tool that
helps developers keep track of requirements and specifications for hard-
ware and software, and identifies the relationships of parts and require-
ments. When a change has to be made the Requirements & Traceability
Management (RTM) software immediately shows every part of the project
that will be affected, helping a manager assess the cost of the requested
change. RTM is designed to be compatible with industry standard computer
aided software engineering tools, and was used for the F-22 ATF.
they develop. G. Robin Sleight, assistant managing director for GEC Avionics Ltd., said that enhanced vision systems could be an important additional source of revenue for avionics companies. GEC has been supplying military aircraft with HUD systems since the 1970s, and these HUDs can display infrared images. But Sleight said it has only been in the past five years that infrared sensors have become affordable for commercial applications, due in part to the reduced costs of cooling systems.

Westinghouse will be exploring the optimal sensor suite for near-term applications, according to Gomer. This includes infrared sensors in the 3-5-micron as well as the 8-12-micron band.

Honeywell also has provided the FAA with a 35-GHz. millimeter-wave radar sensor that has been flown for 70 hr. on the Gulfstream 2 and may be flown for up to 80 hr. more. Burgess said the 35-GHz. sensor has worked well in penetrating dense fog at ranges of 2-3 mi. Pilots can switch between the millimeter-wave image on a GEC HUD in the aircraft and infrared imagery provided by an Eastman Kodak 3-5-micron platinum silicide camera. Burgess said this is a "wonderful sensor" with good resolution that works in clear air or haze and at night. Late last month the aircraft was cleared to operate below Category I ILS minimums for the first time down to 700 ft. RVR and 50 ft. decision height.

Next month the Honeywell sensor will be replaced by a 94-GHz. millimeter-wave sensor from Lear Astronics Corp., which will undergo 50 hr. of additional flight tests. Resolution is better at 94 GHz than 35 GHz as expected, but 94 GHz does not penetrate fog as well.

Rockwell-Collins also has formed a team to pursue HUD/EVS opportunities. The team includes Kaiser Electronics and Kodak. Shannon M. Murchison, vice president of marketing for the Collins Air Transport Div., said Kaiser has built 5,000 HUDs for use by the military, and the firm has considerable expertise in optics and combiners.

The Collins/Kaiser/Kodak team is interested in a building-block approach to an EVS system which would allow an airplane to select the sensors that would work for its operation. The system would start with a HUD and include an infrared camera as well as millimeter-wave and X-band radar. It might take five years of development for the team to complete a comprehensive enhanced situational awareness system.

This would "open up a lot of runways" by allowing crews to "land when they want to and where they want to without the huge expense of ground-based nav- aids," according to Murchison. The Collins division will be showing simulated enhanced vision approaches on a computer workstation at the Rockwell exhibit at the Farnborough air show.

Sextant Avionique also is working on EVS systems based on its long experience with HUDs on the A320 and, more recently, the A330 and A340 (AV&ST May 11, p. 46). Sextant pioneered the installation of HUDs in commercial aircraft in 1975 with Air Inter's Mercure 100 fleet, and these aircraft have logged 40,000 landings with HUDs. Air Inter's A320s have the Sextant HUDs, as will the airline's A330s. The Maryland laboratory Cessna 402 has the latest Sextant HUD coupled with an infrared camera and millimeter-wave radar.

Hughes Aircraft Co. also is pursuing the enhanced situational awareness system with Boeing along with its Flight Dynamics subsidiary and Smith Industries of the United Kingdom. Hughes also is continuing development of millimeter-wave radar for an enhanced vision system that will be ready for demonstration to customers next month, according to a Hughes official.

Meanwhile, avionics firms have not given up on electronic library systems. Rockwell-Collins, which was developing an electronic library system for the 777, is now working with several airlines on a reduced scale library that it calls an "electronic data management system." This system would perform an electronic maintenance logbook function and monitor fault correction, including when and how a discrepancy was fixed. The system would not computerize approach plates and charts, but it would downlink data to maintenance operations.

Rockwell-Collins officials believe this system will allow airlines to avoid 15-25% of maintenance delays. Such a data system could later be upgraded to a full electronic library. Honeywell also continues to explore electronic library possibilities with Boeing and United Airlines.

Several avionics companies also are pursuing predictive wind shear technology, including Allied Signal's Bendix King unit, Sextant, Rockwell-Collins and Westinghouse.

The Bendix King Air Transport Avionics Div. in Fort Lauderdale, Fla., plans to certify a modified version of its RDR-4A weather radar, named the RDR-4B, by the third quarter of this year. In retrofit installations the receiver/transmitter and control panel and indicator can be modified to add the predictive wind shear feature which can spot dangerous areas 5 mi. ahead of the aircraft and provide 30-60 sec. of warning.

Airlines have until 1993 to install some type of wind shear detection system, but customers who are investigating predictive systems have been granted extensions to the deadline.

Bendix King's equipment currently is being tested in a Continental Airlines A300 in revenue service and on a Convair 580 test aircraft at Denver, Colo., and Orlando, Fla. Prototypes of advanced ground-based weather radars for the FAA have been installed at these locations, and they are providing comparative data.

R. Bruce Duncan, marketing manager for MODAR radars at Westinghouse, said his company is developing a MODAR 4000 for the Lockheed C-130H and a MODAR 3000 for commercial transports. The MODAR 3000 in an ARINC 708 configuration is being developed and marketed together with Honeywell. It will have predictive wind shear capability. The new units build on Westinghouse's expertise in coherent pulse Doppler technology used in military sys-