This page intentionally left blank.

Surveillance

As automated weather radar systems appear on large commercial jets, pilot training on conventional systems may deserve another look.

BY WAYNE ROSENKRANS

Incident investigations, research studies and safety audits recently have challenged longstanding assumptions about how professional pilots — especially corporate and regional airline pilots — should become proficient in using airborne weather radar systems.[1] One assumption is that training only serves to introduce fundamental principles and/or methods of operating specific equipment. Another is that thousands of hours of flight experience must be invested for consistent success in avoiding cumulonimbus clouds and associated hail, severe turbulence, wind shear and other hazards.

Reconsidering such assumptions might be warranted for a number of reasons. First, technology for airborne surveillance and assessment of weather hazards has advanced significantly. Historically, failures to correctly use airborne weather radar have caused serious incidents, and pilots have been unsuccessful in interpreting simulated radar displays while being evaluated by researchers. Finally, some pilots have said that they would welcome recurrent training to validate or improve their practices.

The most widely used systems are conventional types, which require manually setting controls. Their color displays enable pilots to distinguish heavy precipitation from light precipitation, and, by observing the color gradient and shapes, to estimate the severity of convective weather hazards and make timely flight-path deviation decisions. In contrast, systems with fully automatic operating modes, sometimes called "next-generation" radar, have been introduced in the past five years.

Current discussions about training can be traced to serious incidents in Australia that prompted a series of studies sponsored by the Australian Transport Safety Bureau (ATSB) and to human factors research by Honeywell. The importance of training also has been emphasized in documents such as "Adverse Weather Operations: Optimum Use of the Weather Radar," published in 2004 by Airbus as part of its *Flight Operations Briefing Notes* series.

Without Surprises

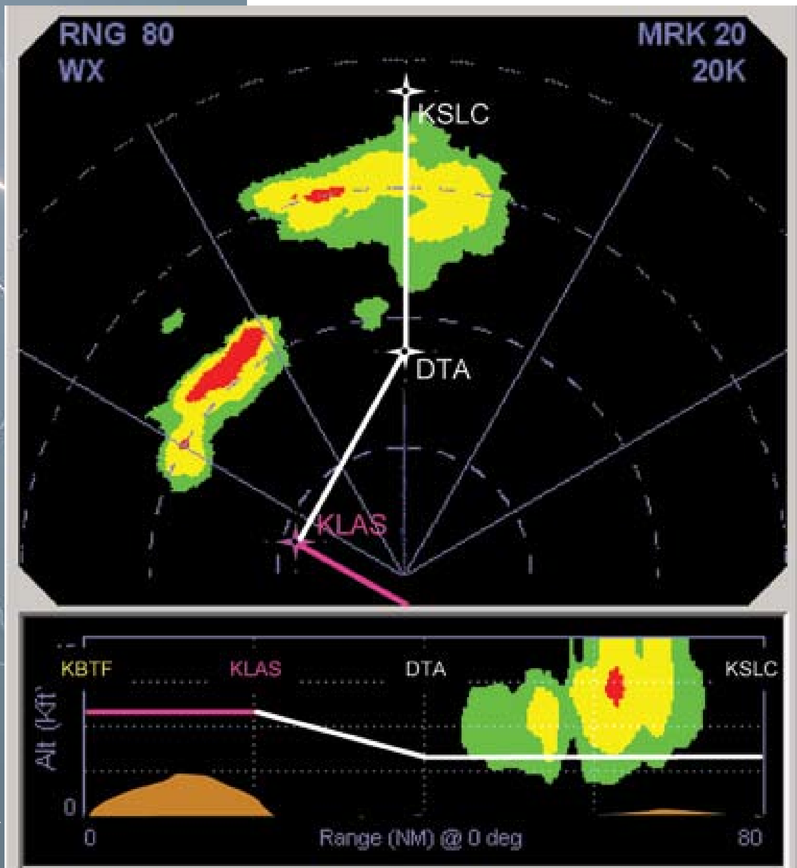
© Moritz von Hacht/iStockphoto

An incident from March 2002 illustrates the potential consequences of incorrect radar operation. A Saab 340A, equipped with a Collins WXR-200 conventional weather radar, was flown inadvertently into an area of severe convective weather activity during a diversion to Canberra, Australia. The aircraft was damaged but no injuries occurred.[2]

The airplane operating manual provided information about pilot control of displayed range; antenna tilt angle, the angle between the center of the radar beam and the horizon; adjustment of gain, the sensitivity of the receiver; and normal interpretation problems that occur when a radar beam is reflected by objects on the ground or by areas of heavy precipitation and hail. Transmitted microwave energy was reflected back to the antenna by precipitation in front of the aircraft, and depending on the type of precipitation and its intensity, typically was displayed as "black (no precipitation), green (minimum detectable moisture), yellow (medium moisture level), to red (strong to extreme moisture level)," the report said.

Heavy precipitation and hail caused attenuation of the radar beam. Before penetrating the thunderstorm cell, the flight crew also had selected maximum gain, with the tilt angle set at approximately three to four degrees up and range set at either the 25 or 50 nm [46 to 93 km] setting. "[The tilt angle used] would have resulted in the radar beam scanning above the level at which the aircraft was flying, and into an area that was above the freezing level," the report said. "It is likely that above that level, the hail was dry. As such, it would have provided a low reflectivity target for the weather radar [the captain saw only green areas and an occasional yellow radar return]."

Mark Wiggins, Ph.D., an associate professor at the University of Western Sydney, published in April 2005 a study based on accident and incident reports, interviews with five professional pilots and a survey of 109 pilots from several world regions. He asked pilots to interpret color images of 12 simulated radar displays, estimate and explain their confidence about proceeding at the same track and altitude for 80 nm [148



© Honeywell

A vertical view — positioned below the conventional plan view — shows the elevation of weather along the selected azimuth from the aircraft nose to the selected display-range distance of the Honeywell RDR-4000 weather radar system.

km] and rank the level of expected turbulence, updrafts and downdrafts.[3]

"One of the most significant themes that emerged as a result of the interviews was the apparent lack of operational training and experience in the use and interpretation of weather radar," Wiggins said. Sixty percent of these pilots said that they had experienced situations in which the weather radar display appeared to be incorrect, and 53 percent said that during the previous six months, they had detected flight crew errors in use of an airborne weather radar system.

When a human factors specialist at Honeywell studied related issues around the same time, results were similar. Ratan Khatwa, Ph.D., senior fellow of flight deck and flight safety human factors, was surprised by knowledge/performance gaps among 46 professional pilots who interpreted simulated displays of conventional and advanced systems, the pilots' dissatisfaction with their radar training and their desire for recurrent training.

"In some incident reports reviewed prior to the Honeywell study, what we saw was that the pilots' interpretation of some of the weather radar displays and their use of the tilt control were not optimal — that's a fair way to put it," Khatwa said. "In many cases, this was directly a consequence of a lack of appropriate weather training. We decided to conduct a survey, a true-false questionnaire, on weather radar fundamentals to include every pilot who came into our human factors evaluation. We included a good cross section of pilots from around the world currently flying and active in corporate, regional and large airline operations, and using weather radar. One very simple question was: 'Was your weather radar training sufficient?' Sixty-eight percent of these pilots stated 'no.'"

Pilots from only one airline had recurrent training dedicated to weather radar. "What came out of the interviews was a bit of a disturbing picture for me," Khatwa said. "The message was that very little basic or recurrent weather radar training was being provided in this group. A lot of the pilots said, 'I believe that my system knowledge, including limitations of how weather radar works, is not optimal. This is something I need to have.'" Two subjects that repeatedly came up during the interviews were appropriate uses of the tilt and gain controls. Problematic principles included understanding the airspace that the radar beam actually covers; manually adjusting tilt for radar beam coverage that compensates for Earth's curvature; interpretation of weather radar during high-altitude cruise; and calibrated weather and associated range.

The study used a part-task performance simulation with one of three plan-view displays. The first represented the RDR-4000 system — which has no manual tilt control — in automatic weather mode. The second was the same system in its manual weather–constant altitude mode with selectable range and gain. The third was the display and control panel of a conventional 4B weather radar system requiring pilots to select range, tilt and gain. The study required pilots to monitor instruments, make radar-control selections and tell researchers their weather-avoidance

© Alexander Zhiltosov/iStockphoto

decisions, without use of any aircraft flight controls, during eight operational scenarios.

Eighty percent of pilots in the group using the conventional system detected the simulated convective weather, which was hazardous. "But that means that in a fifth of these cases, they were unable to find the weather of interest," Khatwa said. "What became obvious from recordings of control panel input was that they were mismanaging tilt. Only about 70 percent of those who saw the convective weather made good weather-avoidance decisions while almost a third of the pilots ended up penetrating it." There was no statistically significant correlation among the participants between failure to see the weather cells of interest and the pilot's level of experience, he said.

Detection of significant weather and weather-avoidance strategies were superior among the pilot groups that used the automatic mode or the manual mode of the new system, which also had almost 90-percent pilot acceptance, he said. A fundamental issue for the other pilots was the removal of tilt control. "These pilots felt some uneasiness, that they were missing something that they had known since they started flying," Khatwa said. "But when we examined their performance data, it became clear that they detected all the weather cells of interest and made the right decisions more frequently and quickly than those who used conventional radar."

Specific next-generation capabilities vary among manufacturers; many are proprietary. For air transport aircraft, the RDR-4000 and a current Rockwell Collins system, the WXR-2100 MultiScan, offer capabilities such as continuous scanning vertically and horizontally of all space in front of the aircraft; storing and retrieving reflectivity data in a three-dimensional memory buffer for display of weather areas surrounding the aircraft; automatic compensation for Earth's curvature and aircraft movement; suppression of ground clutter; generation of vertical profile views; independent control of displays by each pilot; elimination of manual tilt or an optional manual tilt; analysis of storm growth rate and estimation of tops of cumulonimbus clouds; weather-assessment intelligence — based on algorithms, regional storm-model databases, calculations using atmospheric temperature, time of day and altitude; reference to the current flight path and flight management system flight path; and visual alerts to pilots when some precipitation becomes invisible because of beam attenuation.

"To address [limitations of earlier systems, we] decided to move weather radar operation from an experience-based skill to a technologically based capability," Rockwell Collins said in a 2006 technical paper. "The goal was to offer flight crews, with the exception of range selection, hands-free operation. In the automatic mode, the imbedded algorithms manage all aspects of radar operation. Tilt angle, gain and all other functions of radar operation occur without intervention by the pilots."[4]

Level Playing Field

One engineering goal has been to support flight crew decision making by simplifying and accelerating their acquisition of relevant data, according to Keith Stover, principal system marketing manager for weather radar at Rockwell Collins. "The biggest thing, from the training aspect, is that it allows pilots with varying degrees of experience and professional training to get a complete picture. The pilot may not know techniques that other pilots have acquired over many years but can get just as good a picture as any pilot with 25,000 hours."

Most questions received from pilots during training are about the automatic mode. "If they are not confident, we may ask them to try to duplicate in manual mode the picture seen in automatic mode, which is impossible because only the automatic mode has ground-clutter suppression," Stover said. "So then they leave the system in automatic mode, and they begin to feel comfortable. The Boeing 747 program manager of one non-U.S. air carrier uses this training technique."

For conventional systems, methods of pilot training have evolved in different directions for airlines versus corporate operators and regional airline operators. "The airlines all provide information in manuals on how the system works, and in many cases, they add information on gain and

tilt controls," Stover said. "The airline pilots' primary sources will be a classroom and/or training they get in the air. Most weather radar training — once you explain what switch does what — takes place in the airplane under the supervision of a line check airman or line check captain. A lot of subsequent weather radar operation is self-taught, using the system in real life. If corporate operators buy an airplane with our avionics, we speak with them directly or through FlightSafety International or a similar entity that does their recurrent training. We think there would be a big safety aspect to the MultiScan capability for corporate operators," Stover said. "In our research — which is promising for now — we're looking at how to translate this technology into smaller airplanes, at several ways to bridge the technology gap." Limitations of antenna size and radome shape have been among the performance challenges.

The Flight Safety Foundation (FSF) Audit Team also addresses training strategy, said Darol Holsman, FSF manager of aviation safety audits. "The vast majority of corporate operators are not providing initial and recurrent training on airborne weather radar, and in my estimation, only about 10 percent have provided any training on a consistent basis within the past three to five years," Holsman said. "I'm always amazed at how few companies have this as part of their initial orientation for new pilots. At least 50 percent of corporate operators seem to rely on radar-training video tapes that are 10 to 15 years old and do not contain current information about the newer color digital radar units."

A related finding involves the typical airplane operations manual that says, "Keep clear of thunderstorms." But Holsman responds, "What kind of guidance is 'keep clear'? It's no guidance. When I fly on the jump seat, I sometimes see new copilots … wait until they are five nm [nine km] away and make a steep turn to avoid going into the thunderstorm, but that is way too close. We say you should not come within 20 nm [37 km laterally or 5,000 feet vertically] of a buildup area — you should avoid it at all costs." Chief pilots who take radar courses almost invariably find them valuable, he added.

A Trainer's Perspective

Erik Eliel of Radar Training International said that trainers must convey accurately not only radar system capabilities but limitations that can conceal threats. He has been invited to make a 50-minute presentation on airborne weather radar at the 11th Safety Standdown to be sponsored by Bombardier, the U.S. Federal Aviation Administration and the U.S. National Business Aviation Association in fall 2007.

"Up-to-date, objective training is absolutely critical in reducing operational risks," Eliel said. "Without a solid academic foundation, proficiency is unattainable. Generally speaking, professional pilots are totally on their own when it comes to acquiring proficiency and the necessary knowledge about airborne weather radar."

Dedicated training is more likely to ensure that pilots understand why black areas on a display — commonly considered hazard-free — sometimes indicate the most serious threats, for example. "Dry hail, precipitation attenuation — also called radar shadow — and clear air turbulence are just three of many threats that can be present in areas of black," Eliel said. The relationship of geographic region to radar display interpretation also is essential background. "Every year, a few professional pilots encounter turbulence, dry hail or other hazards when they blunder through the frozen top of a thunderstorm and are confused about why nothing was displayed on the radar. The frozen tops of thunderstorms are virtually invisible to all X-band weather radar systems [8,000–12,500 MHz frequency range, the newer type with a flat antenna] regardless of antenna size or power output, for example."

Guidance via standard operating procedures and informal in-house training is preferable to no guidance on airborne weather radar, so long as aircraft operators do not assume that every professional pilot joining the company brings the same baseline background and proficiency. A knowledgeable, competent in-house trainer with adequate resources and authoritative materials can augment the initial classroom training so that pilots are not expected to "blindly follow techniques they don't fully understand," Eliel said. "Variations to the radar manufacturer's techniques should be backed up by operational experience and based on solid scientific data, consultation and study," he said.●

Notes

1. Khatwa, Ratan. "Human Factors Evaluation of Next Generation Weather Radar." A presentation to the Flight Safety Foundation European Aviation Safety Seminar in Athens, Greece. March 2006. "Pilot-in-the-Loop Evaluation of Next Generation Weather Radar Displays." A paper presented during ICAS 2006, the 25th International Congress of the Aeronautical Sciences in Hamburg, Germany. September 2006.

2. Australian Transport Safety Bureau. Aviation Safety Investigation Report no. 200201228. Dec. 19, 2002.

3. Wiggins, Mark. "The Interpretation and Use of Weather Radar Displays in Aviation: Final Report." University of Western Sydney, Australia. April 2005.

4. Rockwell Collins. *Rockwell Collins WXR-2100 MultiScan Weather Radar.* 2006.