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Smooth Ride

Automated turbulence reports and enhanced turbulence radar aim to further reduce the risk of in-flight injury.

BY WAYNE ROSENKRANS

Several new technologies coming to fruition offer help in meeting the challenge of reducing and ultimately eliminating the unexpected encounters with in-flight turbulence that take a steady toll of injuries and occasional deaths. One is a new generation of turbulence detecting radars coming on the market; another is a new system now in limited use that automatically reports turbulence encounters to ground stations, with the promise that eventually the reports routinely will be data-linked into flight decks.

The best part for the airlines is the minimal initial and recurring cost of this reporting system that can save them so much not only in injuries to passengers and crew but in fuel, as well. But even as airlines step up to try these evolving tools, unresolved issues remain about how to integrate them into flight operations.

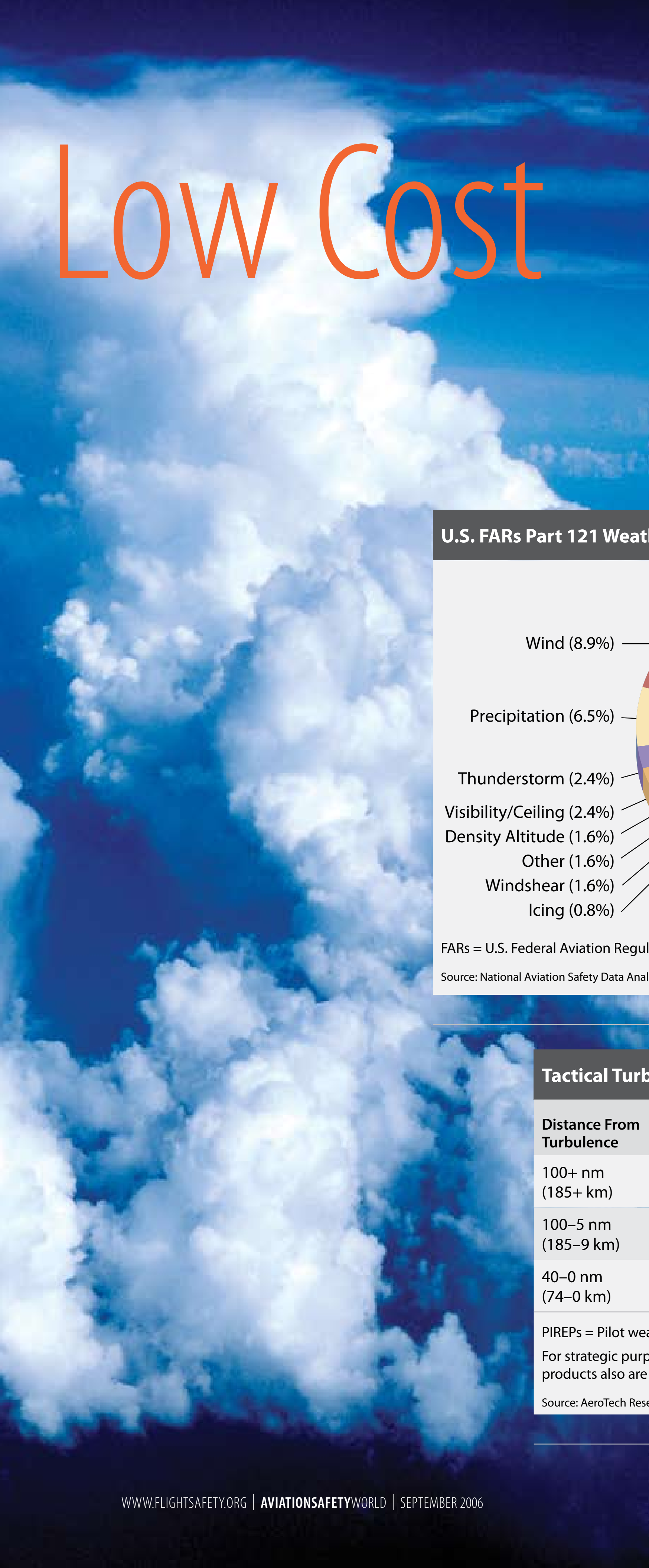
In 2005, the average number of occupant injuries caused by turbulence — if minor injuries are counted — was about three per day on U.S. Federal Aviation Regulations Part 121 air carriers, according to proprietary data, U.S. Federal Aviation Administration (FAA) data and U.S. Bureau of Transportation Statistics data, said Paul Robinson, Ph.D., president of AeroTech Research (USA), a contractor for the U.S. National Aeronautics and Space Administration (NASA). Figure 1 shows turbulence as a significant condition in weather-related accidents among U.S. air carriers.

In January 2006, FAA published Advisory Circular (AC) 120–88A, *Preventing Injuries Caused by Turbulence,* updating its 1997 guidance to air carriers based on analyses and recommendations of the U.S. Commercial Aviation Safety Team (CAST) and the ongoing research and development in government, academia and industry. Table 1 shows some of the current and anticipated resources for tactical turbulence awareness.[1]

A prominent theme of the AC is the importance of constantly communicating turbulence information. The AC said, "In the past, the practice of rerouting has met with limited air carrier acceptance, primarily because of the inaccuracy of first generation turbulence forecast products, the subjectivity inherent in pilot weather reports (PIREPs), if available, and the operational costs of rerouting. … The most promising way to capture and convey [real-time] information is through a comprehensive program of reports from aircraft in flight. That program would be founded on automated turbulence reporting supplemented by human reports (PIREPs)."

Among its recommendations, the AC suggests that Part 121 operators "commit to the installation of the Turbulence Auto-PIREP System (TAPS)," developed by Robinson and his staff under NASA's Turbulence Prediction and Warning System (TPAWS) project, which concluded at the end of 2005. TAPS is software that uses the same vertical accelerometer that feeds the flight data recorder and ties into the aircraft's existing aircraft communications addressing and reporting system (ACARS).

The current International Civil Aviation Organization (ICAO) metric for automated turbulence reporting is eddy dissipation rate (EDR) data. The U.S. National Center for Atmospheric Research (NCAR) developed the EDR method for automated turbulence measurement in flight. Since 2001, in a separate program from TAPS, more than 100 airliners have been downlinking peak and average EDR turbulence readings.

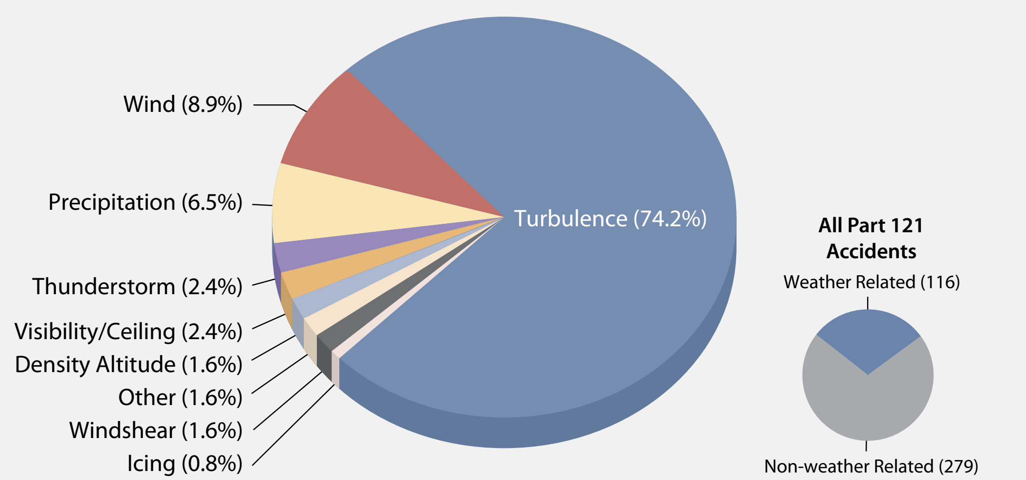


Low Cost

These efforts fill specialized niches at present, but to deliver their full benefit they will have to be integrated into commercial air transport operations. "To operate safely, everyone in the cockpit and on the ground has to be able to assimilate one big picture of turbulence and wrap that into the big picture of airspace and airspace usage," Robinson said. "All of the strategic and tactical products have to fit together — and I don't know if that answer is out there yet."

Enhanced turbulence mode weather radar (E-Turb) and TAPS were the main technologies

U.S. FARs Part 121 Weather-Related Accidents by Weather Condition, 1994–2003



FARs = U.S. Federal Aviation Regulations

Source: National Aviation Safety Data Analysis Center, U.S. Federal Aviation Administration

Figure 1

Tactical Turbulence Awareness

Distance From Turbulence	Resources	
	Currently in Use	Under Development
100+ nm (185+ km)	Weather radar	Flight deck graphical weather and turbulence forecast products
100–5 nm (185–9 km)	PIREPs	Automated turbulence reports
40–0 nm (74–0 km)	Weather radar with turbulence mode	Enhanced turbulence mode weather radar

PIREPs = Pilot weather reports

For strategic purposes, typically up to six hours before departure, various turbulence forecast products also are in use and others are under development.

Source: AeroTech Research (USA)

Table 1

that came out of TPAWS, said Jim Watson, senior research engineer, Crew Systems and Aviation Operations Branch, and former TPAWS project manager for NASA's Aviation Safety and Security Program. NASA-authored technical reports about them are scheduled for presentation at the congress of the International Council of the Aeronautical Sciences in Hamburg, Germany, in September 2006. Robinson is a scheduled presenter at the Flight Safety Foundation International Air Safety Seminar in Paris in October 2006.

"NASA also is providing technical support directly to FAA during certification activities, particularly for E-Turb radar, and we fund ongoing technology development for cockpit display of TAPS information using a Class 2 electronic flight bag [EFB] with AeroTech Research and ARINC," Watson said.

E-Turb on Board

Turbulence detection algorithms historically were uncorrected for aircraft type and flight configuration. In comparison, E-Turb adds a hazard prediction algorithm that calculates g load — i.e., aircraft loading relative to the acceleration of gravity — for the airplane using factors such as altitude, true airspeed and weight and balance, and graphically displays results to pilots. Experiments in fall 2000 and spring 2002 using NASA's instrumented Boeing 757 demonstrated a detection range of 25 to 40 nm (46 to 74 km). When flight crews intentionally traversed an area of moderate or severe turbulence — which a commercial flight crew typically would not do — researchers found 80 to 85 percent accuracy in predicting the actual turbulence encountered, he said.

In 2004, one Delta Air Lines Boeing 737-800 was equipped with a prototype E-Turb mode in its WRT 2100 receiver/transmitter, part of a Rockwell Collins WXR-2100 Multiscan Radar system, and with TAPS software code. In this installation, the E-Turb mode adds a display of relative turbulence hazard overlaid on the thunderstorm reflectivity display. In addition to the solid magenta representations of moderate or greater turbulence, speckled magenta areas represent light turbulence. "The direction to pilots has been that seat belt signs should be illuminated before going through a speckled magenta area, and that seat belt signs should be on for any solid magenta area, which should be avoided if possible," Robinson said.

Data from the Delta 737-800 equipped with E-Turb show pilots approaching a solid magenta area and then deviating around it. There is a "strong correlation between radar-predicted loads and actual loads when avoidance is not possible," Robinson said. "There is not a whole lot of correlation between thunderstorm reflectivity and turbulence."

In their 2005 analysis of 554 E-Turb radar events, researchers found that in 55 events, 9.9 percent, there was no predicted turbulence on the radar display, little or no reflectivity in the vicinity, and yet the airplane's vertical accelerometer data confirmed turbulence; 204 events, 36.8 percent, there was a radar display of an area of predicted turbulence the aircraft did not enter and turbulence was not detected by the vertical accelerometer; and 295 events (53.2 percent) involved radar displays of predicted turbulence, the aircraft traversing the affected area and the turbulence recorded by the vertical accelerometer.

Wayne Rosenkrans (FSF)

Robinson

Genesis of TAPS

"In fiscal year 2002, the NASA 757 also transmitted the first turbulence encounter reports to Glenn Research Center in Cleveland to validate the technology that became TAPS," Watson said. "The accelerometer we use … is loads-based," Robinson said, "so it focuses on how badly the aircraft is getting shaken up by continually calculating a turbulence hazard metric — the same as we use in E-Turb radar. When the hazard metric exceeds a threshold, a report is made." Figure 2 shows elements of the TAPS architecture.

On Delta airplanes, TAPS software resides in the aircraft condition monitoring system (ACMS), a partition of the digital flight data acquisition unit (DFDAU) that continuously monitors airplane data buses. Air-ground communication automatically is handled by the existing ACARS VHF/satellite link. "When the hazard metric exceeds a threshold, the automatic turbulence report is a very small data packet that comes down to the ground through the communications infrastructure," Robinson said. "Because it's event-driven, there can be entire flights where you don't hear from the system."

Delta offered to install TAPS software for NASA's in-service evaluations.

In addition to the E-Turb–equipped airplane, TAPS software was replicated on 70 other 737-800s. The same software code also currently sends reports from 52 airplanes in Delta's 767-300/400 fleet.

TAPS reports are displayed using ARINC's Web Aircraft Situation Display (WebASD), a commercial system that uses "push" technology to update data via the Internet on any computer's Web browser, including NEXRAD radar overlays and infrared satellite imagery. Delta's dispatchers have password-protected access to the TAPS reports from their fleet.

Each TAPS report appears on WebASD displays as one of three symbols distinguishable by shape and color: a green icon for light turbulence, an amber icon for moderate turbulence and a red icon for severe turbulence. When the user clicks a mouse pointer on any icon, a pop-up window appears, showing the aircraft identification (flight number); coordinated universal time of event; flight level; wind speed and direction; temperature; plus/minus peak load around 1 g (such as "1.2G/0.7G") and the hazard metric (such as "0.101"), called "RMS g" because it uses root mean square to express deviation from 1 g; maintenance flag (MFO, maintenance required); and weight/speed values (such as "263/22 kt," representing 263,000 pounds [119,296 kg] and 220 kt).

TAPS displays are available to Delta's entire dispatch team for evaluation but have not been built into daily procedures, according to Neil Stronach, vice president of the Delta Operations Control Center. "While wide adoption by authorities and industry is still being figured out, we continue to evaluate it, provide feedback and participate in industry activities driving toward a conclusion and utilization of either TAPS or EDR, or both," Stronach said. "We are going to be given a nudge toward adopting a standard so that we can get industrywide coverage."[2]

Delta pilots do not know when their airplane transmits a TAPS report. "We've seen in discussions between pilots and dispatchers — either voice or with ACARS — that pilots ask dispatchers if their aircraft has made any TAPS reports," Robinson said.

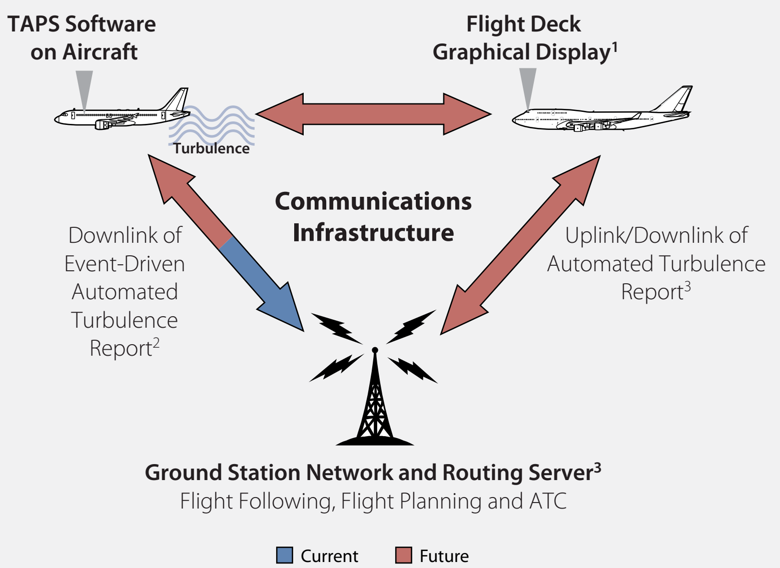
A fundamental capability of E-Turb and TAPS is data scaling, translating turbulence hazard metrics so that they have practical value to flight crews and others. Any very turbulent environment increases the workload for pilots and dispatchers. "Delta's dispatchers can run WebASD in the background of their separate flight-following application, and if one of the aircraft they're following has its flight path threatened by a TAPS report of moderate or severe turbulence, a little pop-up window will appear to alert them to maximize the window to assess the situation and communicate with flight crews." Ideally, TAPS information would be integrated with Delta's primary flight-following software, Robinson said, but that could not be done for cost and time reasons.

In one 96-hour observation period, 345 TAPS reports were sent from 737-800s while their crews made 47 turbulence PIREPs. From June 10, 2004,

Wayne Rosenkrans (FSF)

Watson

TAPS Architecture



TAPS = Turbulence Auto-PIREP System   ATC = Air traffic control

Notes:

1. Future uplink/downlink and air-to-air communication of automated turbulence reports would include onboard report interpretation and generation of a receipt to the sender.
2. The report includes data such as turbulence hazard metric, weight/airspeed, time, location and altitude.
3. TAPS currently uses ARINC's aircraft communications addressing and reporting system (ACARS) and Web Aircraft Situation Display (WebASD).

Source: AeroTech Research (USA)

Figure 2

through Aug. 31, 2005, Delta dispatchers received 35,656 TAPS reports from 15,510 flights, including 1,047 TAPS reports of moderate turbulence and 89 TAPS reports of severe turbulence.

Pilots today make the decision whether their airplane has experienced turbulence severe enough that it needs to be inspected. "What we'd be able to do with TAPS in the future is make measurements, and if the loads have exceeded the severe-loads thresholds in the maintenance manual, a TAPS maintenance flag would advise the air carrier to inspect that airplane," Robinson said.

Minimal Bandwidth

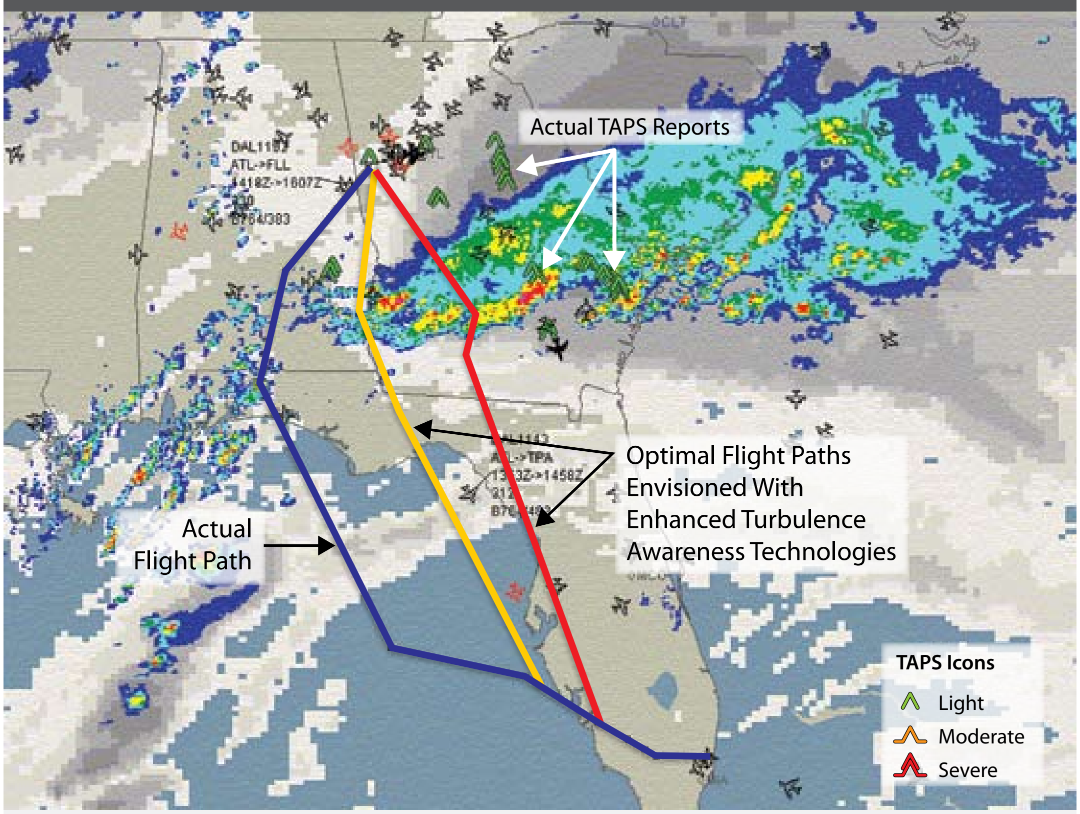
To date, AeroTech Research has uplinked a few TAPS reports to selected aircraft and verified that reports were received (though not displayed on the flight deck), and has developed software to automatically select which aircraft in the airspace should receive specific TAPS reports. "We are just starting to look at communication and routing that would be required to get this data up to the airplanes," Robinson said. "Flight deck display is being done this fiscal year. TAPS plus E-Turb on the flight deck is a long-term solution."

Robinson also has studied examples of actual Delta flights in which long deviations around weather were taken based on the NEXRAD displays, yet TAPS reports showed that shorter routes through gaps in the weather were clear of turbulence threats. Figure 3 shows an actual flight path that theoretically could be shortened with enhanced turbulence awareness technologies.

One TAPS limitation is the fact that if a TAPS-equipped airplane doesn't fly into turbulence there are no reports available. Another limitation is the possibility of interrupted data communication, although there would be strong drive to quickly restore full communication.

By the end of 2005, 48,600 TAPS reports had been received and evaluated. Because TAPS is event-driven, however, its data communication requirements are extremely low compared with other aeronautical data communications. "Delta's TAPS-equipped airplanes make an average of 35 TAPS reports per month, and each report is less than a kilobit of data," Robinson said. "Communication requirements are minimal. In 2006, TAPS software continues to run on Delta airplanes with

Retrospective Visualization of Delta Air Lines Flight, Atlanta to Miami



TAPS = Turbulence Auto-PIREP System PIREP = Pilot weather report

Flight paths, figure labels and the legend are overlaid on an ARINC Web Aircraft Situation Display (WebASD) depicting air traffic, infrared satellite imagery, NEXRAD color weather radar imagery and a base map of the southeastern United States.

Source: AeroTech Research (USA)

Figure 3

no cost to anyone, except that ARINC has a little overhead cost for operating the ground station network and routing server." In development of the Class 2 EFB so far, developers have found no insurmountable issues of bandwidth required for uplinking TAPS report data to airplane flight decks from ground networks.

Pathfinder Predicament

Accurate information about actual effects of turbulence on airplanes would help air traffic control to keep their blocked areas of airspace — shown as polygons on radar displays — at the minimum size required for safety. "Now, these polygons sometimes cover entire states," Watson said. "We need to bring TAPS into the air traffic management system, and we are continuing to discuss this with FAA's Air Traffic Organization."

Another suggested application for E-Turb and TAPS is the situation in which one flight crew could serve as the pathfinder for others. "After a certain time, ATC will want to reopen a route it has closed," Robinson said. "The forecast and satellite imagery have to define when the blocked area reopens, but in a performance-based operational concept, the preferred pathfinder would be a crew that is E-Turb-equipped and TAPS-equipped."

In addition to avoiding needless deviations, the technology also could save fuel by avoiding operations at nonoptimal altitudes while avoiding turbulence that is not hazardous. "To avoid excessive fuel burn, if the airplane only will be in light turbulence for 20 minutes, the crew does not have to descend 4,000 or 8,000 feet," Robinson said. "When one Delta flight crossed the United States west to east and experienced turbulence, its crew descended from FL 350 to FL 270 for half an hour. The TAPS report from another Delta aircraft passing through the same turbulence at the same time showed that there was only light turbulence. In the future, the crew that descended might not have to make that descent and take the fuel-burn hit."

Pending final reports on NASA's in-service evaluation, only a few U.S. airlines have inquired about details of installing TAPS software despite its minimal cost. Meanwhile, air traffic management involvement will be a critical enabler, Robinson said. "The federal government's multi-agency Joint Planning and Development Office [JPDO] is looking at this as part of network-enabled operations."

Delta's Experience

"TAPS technology is great in that it eliminates the lag time from traditional pilot reporting through ATC and then broadcast of PIREPs," Stronach said. "The EDR solution also seems well developed and provides input into forecast models that meteorologists use, so there is a very strong push in this industry toward an EDR solution."

Delta procedures specify that flight crews will make PIREPs if they encounter turbulence. Availability of TAPS reports has enabled some comparisons. "They demonstrate that there is a bias by the individual pilots — typically, they will have a tendency to report the turbulence as more severe than the TAPS RMS g loading would support," Stronach said. "We see the value in being more accurate and timely, but until we get a standard, we can't put TAPS into practical use." If a captain rates turbulence as severe, aircraft maintenance will treat the encounter as severe and conduct a severe-loads inspection.

"Future TAPS scenarios are very reasonable once TAPS is adopted and widely used; it's absolutely a viable technology," Stronach said. "We can foresee a time frame where turbulence PIREPs would not be necessary — the equipment would tell us everything. But a few hundred TAPS-equipped airplanes flying around within the airspace do not give the coverage necessary to get the footprint — the turbulence visibility — required to provide the widest safety net." Based on Delta's experience with E-Turb radar, he also expects that technology to be viable.

Robinson believes that the industry will be hard-pressed to meet the turbulence information needs of all user constituencies with one "silver bullet" among all the meteorological/engineered solutions in play.

"JPDO seems to be where all these [options] are coming together," Watson said. "E-Turb and TAPS are evolutionary technologies that will work their way into the Next Generation Air Transportation System [NGATS] being developed by the JPDO." ●

Notes

1. In May 2006, the U.S. Federal Aviation Administration (FAA) said the System-Wide Information Management (SWIM) system is being designed to connect networks that use or provide aviation-related information to create network-centric operations.
2. A 2003 federal law laid the groundwork for an integrated plan to transform the U.S. air transportation system to meet requirements of the year 2025. Called the Next Generation Air Transportation System (NGATS), the initiative is administered by the multi-agency Joint Planning and Development Office (JPDO). "Data link communications will replace voice communications between aircraft and air traffic management systems, improving the accuracy and timeliness of information exchange," JPDO said. "Aircraft will become mobile 'nodes' integral to this information network, not only using and providing information, but also capable of routing messages or information sent from another aircraft or a ground source." <www.jpdo.aero>