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ABSTRACT

The hazards posed by low-level windshear are an important issue in commercial aviation. Extensive research into methods for coping with low-level windshear has been continuing for many years. This paper addresses the issues pertaining to low-level wind shear causes, impact on commercial aviation, and initiatives undertaken to prevent low-level windshear mishaps today and in the future.

INTRODUCTION

Normand "Rock" Sheeren heard jet engines screaming and knew the plane was in trouble. As the Boeing 727 cartwheeled into the ground and burst into flames, he heard people screaming, too. The crash, on July 9, 1982, killed all 146 people on Pan Am Flight 759 and eight more on the ground - two women in their 20s and six children. Jolted out of the air by a sudden, intense downdraft and ferocious crosswinds, the 95-ton airplane cartwheeled through two blocks of the close-knit neighborhood near New Orleans' international airport. Twenty years later, it remains the worst crash ever caused by wind shear. Thanks to better knowledge, training and equipment developed partly in response to that crash, the record might stand (Mconnaughey, 2002).

Flight 759 hit the ground during a storm so intense that within a short distance, the sounds of the banging, slamming, splintering wood and tearing metal merged into the booming thunder. John Lavarine, working at his insurance office five blocks away, didn't hear it. A phone call alerted Lavarine, a Jefferson Parish councilman who represented that area on the Kenner City Council. He went straight through rain so heavy that vision was drowned for blocks. All he could see was wreckage; all he could smell was jet fuel. The downpour probably kept the fire from spreading over about 110 city blocks, he said. As it was, eight homes were flattened, another seven too damaged to repair. The 154 deaths made it the nation's third-worst crash at that time. It remains the nation's worst accident caused by windshear (Mconnaughey, 2002).

What Is Low-Level Windshear?

Windshears are rapid changes in wind speed and/or direction in either the horizontal or vertical direction. We know that wind shears can cause significant turbulence. But low to the ground, windshears can be killers. Studies on windshear accidents have shown that pilots will only have from five to 15 seconds of time to react, and react correctly, to safely negotiate the hazards. The hazards are rapidly changing headwind and tailwind, strong side gusts and variable lift on the wings, all during a time when an aircraft is most vulnerable (Minor, 2000).

The causes of windshear are very well known. Convective weather with first gusts, downdrafts, microbursts, and gravity waves are the most significant forms of windshear. Terrain features like mountains, gullies, or other topography cause wind flows to change over short distances. Man-made obstacles, like a large hangar beside the runway, create a changing wind pattern. Fronts and storms can create vertical shearing in the atmosphere close to the ground. Windshear from each of these causes has made an impact on some airplane in the last few decades (Minor, 2000).

What is a Microburst?

A microburst is windshear that is the result of cool air pouring from the bottom of a thunderstorm cloud and onto the airplane, like an inverted mushroom of air. As a jet passes through the downdraft, it first encounters a strong headwind, which slows the plane's speed and gives it extra lift. But the head wind suddenly diminishes, followed by an equally strong tail wind, which causes the jet to lose lift and sink. If this occurs during landing or takeoff, when the airplane is only about 100 feet off the ground, a crash can result (Rozas, 2002).

Microbursts can occur anywhere, normally from spring through fall in the United States-thunderstorm season. They occur most frequently between 1200 and 1800 hours local time, with maximum occurrence between 1500 and 1700. Observations have shown that about five percent of all thunderstorms are capable of producing a microburst. Microbursts are typically only a few hundred to 3000 feet across. As a microburst contacts the ground, it usually fans out in a radial pattern, which can produce headwind to--tailwind speed differences greater than 50 knots. Because of their small size and rapidly changing wind conditions over very small distances, extreme wind shear conditions often exist. Most microburst winds intensify just after ground contact and typically dissipate in about 10 to 20 minutes (Lawyer, 2001).

Different Types of Microbursts

There are basically two types of microbursts--wet and dry. The main distinguishing characteristic between the two is the prevailing environment in which they are produced. Dry microbursts, as the name implies, develop in an extremely dry environment in which moist convection is just barely possible. They often occur from the front range of the Rocky Mountains to the Western Plateau region. The atmosphere is moist at high altitudes, but at lower altitudes conditions are exceedingly dry. The process of a dry microburst begins when the updrafts in a convective-type cloud can no longer support the weight of the ice and water particles. As the particles begin to fall, they drag the air downward, causing a downdraft. This is the beginning of a precipitation-induced downdraft. Figure 1 illustrates the microburst (Rauber, 2002). The downward motions are strengthened when air from outside the cloud is mixed with saturated air of the cloud. As the moist air descends through the cloud and eventually below the cloud deck, evaporation of the water particles further cools the air and increases the downward motion. In addition, snow melts at lower elevations, contributing to the cooling of the air and the strength of the downdraft. If the cloud bases are high enough and the air beneath the cloud dry enough, rapid cooling takes place, resulting in strong, downward-rushing air. Because of the lack of abundant moisture, much of the precipitation evaporates before it reaches the ground (called virga). However, in the dry microburst, the air continues to rush downward, striking the ground at speeds approaching 25 knots-in some cases, wind speeds may approach 100 knots! The only evidence that a microburst may be occurring is blowing dust on the ground beneath the cloud. Once the air reaches the ground, the wind spreads outward radially and will often curl upward along its outer boundary. If the winds are strong enough, the air will curl upward and back over the outward rushing air. An aircraft that encounters a headwind of 40 knots with a microburst may expect a total shear of 80 knots across the entire microburst and the direction may reverse 180 degrees across the centerline of the microburst. Amazingly, the conditions just described, from the initial downdraft to the final dissipation of the microburst, can happen within 10 minutes. Unfortunately, with the speed at which microbursts occur, pilots have little time to react once their aircraft encounters that first gust (Lawyer, 2001).

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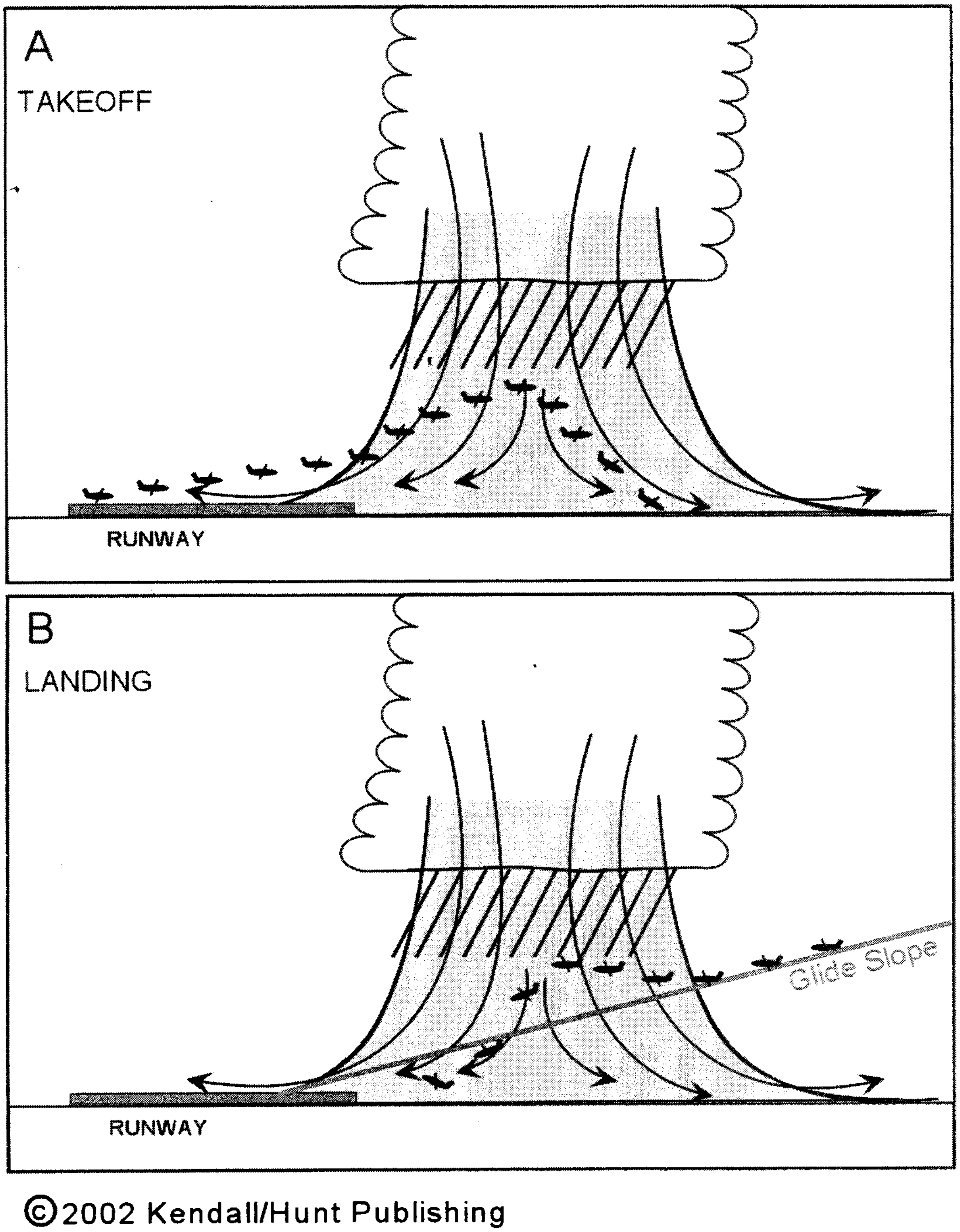

Figure 1. **The Microburst Model**

Impact of Low-Level Windshear on Commercial Aviation

Wind shear! Now that's a subject that we can all look at again. It's been the number one weather killer in aviation. In the last twenty years, over 650 deaths took place in commercial aviation alone, due to wind shears (Miner, 2000). U.S. commercial aviation deaths associated with wind shear accidents have dropped as a result of training pilots to handle wind shear and the installation of the first operational Doppler radar in 1992. Commercial airline deaths associated with wind shear are summarized in table 1(Rozas, 2002).

But making the decision to take off or land in spite of a wind shear alert is left up to the pilot in command. That was the case in Little Rock, Ark., in June 1999, when an American Airlines crew decided to land despite two wind shear warnings given by air traffic controllers. The plane, which was carrying 139 passengers and six crewmembers, skidded off the runway, broke apart and caught fire. Eleven people died, and 87 were injured. The airport did not have a Doppler radar system, but the NTSB determined that although wind shear was a factor, pilot error caused the accident. Many airlines now mandate their pilots not land or take off when a wind shear advisory is issued. Pilots today will often delay a flight's takeoff to wait out wind shear, which usually lasts between five and 15 minutes, or will circle the airport until the danger has passed (Rozas, 2002).

Table 1. Summary of deaths associated with windshear

Years	Deaths
1970-74	138
1975-79	112
1980-84	152
1985-89	134
1990-94	37
1995-99	0

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PREVENTING LOW-LEVEL WINDSHEAR MISHAPS

Low-Level Windshear Alert System(LLWAS)

Although pilots had for years described encounters with sudden downdrafts and quick-changing head winds and tail winds during even light thunderstorms, the term wind shear was not attributed to a major airplane crash until 1975. Even then, researchers were far from an understanding of its true danger. That year, Eastern Airlines Flight 66 crashed while landing during a thunderstorm at John F. Kennedy International Airport in New York, killing 112 people. The flight had taken off from New Orleans. Meteorologists studying the crash determined that a previously unknown phenomenon had pushed the Boeing 727 out of the sky. They named it wind shear. Still, scientists didn't know how to detect or avoid wind shear (Rozas, 2002).

After the 1975 crash, the Federal Aviation Administration began developing equipment to signal changes in wind, the first of which was called Low-Level Wind Shear Alert System, or LLWAS. The first technological breakthrough in windshear sensing occurred in 1976 with the Low Level Windshear Alerting System (LLWAS). The LLWAS was installed at 110 FAA towered airports between 1977 and 1987(Meyer, 1999). This system of anemometers is placed around the airport with a computer comparing the wind speed and direction of all the anemometers every second. When different values of direction or speed are sensed, the tower is notified automatically for voice dissemination to aircrews. The first generation of LLWAS had six sensors, but that was found to be inadequate since microbursts slipped in-between the wind gauges. Wind differences of 13 knots from one sensor to another triggered an alert to air traffic controllers, who then relayed the information to pilots in arrival and departure phases of flight. The next two generations increased the number of sensors and their location. The latest version has up to sixteen wind sensors at the airports. Forty-one airports in the CONUS use this system including Colorado Springs, Omaha, Shreveport, and other joint-use fields (Miner, 2000).

But the system had flaws. It could not predict wind shear, but merely told pilots when it was detected. It also had a high rate of false alarms, experts say. Few pilots were convinced that wind shear was something always to be avoided. "I can remember back in the old days, the pilots would just bore straight ahead and go through it," says Leonard Parmley, the New Orleans International Airport tower control chief. "There was some talk in magazines and among the pilots about wind shear, but it wasn't something that kept the pilots from going through." In 1982, only 60 of the nation's 500 commercial airports employed the LLWAS devices. Most airfields still relied on simple wind cones to measure wind direction or anemometers to measure wind speed. At the time of the Pan Am crash, New Orleans International had LLWAS, the most current equipment available. But in its investigation of the crash, the National Transportation Safety Board determined that the LLWAS was not advanced enough to detect the microburst that brought the Pan Am flight down. "The probable cause of the accident was the airplane's encounter during the liftoff and initial climb phase of flight with a microburst-induced wind shear, ... the effects of which the pilot would have had difficulty recognizing and reacting to in time," the NTSB report said. "Contributing to the accident was the limited capability of current ground-based, low-level wind shear detection technology to provide definitive guidance for controllers and pilots for use in avoiding low-level wind shear encounters." The Pan Am crash generated momentum for an attack on the wind shear problem (Rozas, 2002).

The FAA turned to researchers with the National Center for Atmospheric Research, which had been conducting wind shear experiments. "At that point, the FAA jumped in (in) a major way," says Dr. John McCarthy, one of the primary researchers on the project. He is now manager of science and technical development at the Naval Research Laboratory. Researchers tweaked the LLWAS, adding more detectors and increasing the probability of detection of wind shear (Rozas, 2002).

Today modern Vaisala's MIDAS IV LLWAS (low-level windshear alert system) allows air traffic control (ATC) personnel at airports to warn pilots when low-level windshear penetrates the runway corridors so that appropriate evasive action can be taken, improving safety and operating efficiency. The ground-based system simultaneously detects low-level windshear and microburst events in the runway corridors and gives audio and visual alerts to ATC and other airport personnel. MIDAS IV LLWAS constantly collects wind data from sensors placed along the runway. A typical LLWAS sensor suite will include a Vaisala Wind Transmitter, a Vaisala Ultrasonic Wind Sensor, and also will include a central display unit (CDU) and workstation displays. Using the CDU, the MIDAS IV LLWAS processes wind data using the Phase-3 windshear algorithm, developed for the FAA by the National Center for Atmospheric Research (NCAR). If windshear and microburst threshold values are exceeded, the system generates alerts and warnings to workstations used by air traffic controllers, weather observers/forecasters and maintenance personnel. The MIDAS IV LLWAS gives ATC personnel enough advance warning to adjust patterns and taxiing queues, estimates headwind loss or gain, accurately determines where wind shear will be encountered and cuts down the probability of false alerts to under 10% (Vaisala's MIDAS IV LLWAS, 2003).

Next Generation Radar (NEXRAD)

Still, experts knew the aviation industry needed more than just state-of-the-art weather sensors. They needed a tool to predict the conditions that create wind shear. Researchers turned to a weather observation system being used by the National Weather Service since the 1970s called NEXRAD, for Next Generation Radar. "We had a hunch that we could use that equipment to detect wind shear," McCarthy says. The radar, renamed Terminal Doppler Weather Radar, and often referred to simply as Doppler, reads an echo from dust particles in storm clouds to determine the speed and direction of wind. Scientists began testing it at Denver's Stapleton International Airport and found they were able to detect 98 percent of wind shears, McCarthy says. But it would be another decade before the system would be deployed at major airports. Delays in the development and federal financing of the project, as well as hiccups in land ownership and questions in some communities about the environmental impact of the radars, which must be placed at least five miles from the airport, slowed the process. The first prototype Doppler system was tested in 1988 at the National Center for Atmospheric Research's facility in Denver. Later that year, the government awarded a $180 million contract to Raytheon Co. for the installation of 47 Doppler radars. The number was later changed to 46. The first operational Doppler was installed at the FAA Technical Facility in Atlantic City, N.J., in 1992. New Orleans received the TDWR, as the system is known, in 1996. The cost of the radars, about $8 million per airport, made them too expensive to be placed at all airports, FAA officials said. Roland Herwig, spokesman for the FAA, said cost-benefit analysis is used to determine which airports get TDWR. The analysis involves many variables, including airport location, weather environment, and number of landings and takeoffs per year and the cost of the TDWR (Rozas, 2002).

Training The Pilots

Every year, about 11,000 airline pilots hone their skills in 35 simulators that cost up to $17 million each and represent the greatest collection of advanced airline training equipment in the world. Military pilots, including the crew from the president's Air Force One, also practice at Denver's virtual airport. The flight conditions are as varied as the world's airports and weather. The simulators are exact replicas of every jet cockpit, with computerized images and sounds that match what pilots will experience on the ground and in the air. Sophisticated hydraulics create the sensation of real flight. Hit a devastating wind shear and you feel the series of jolts and change in air speed as the computer calls out "Wind shear! Wind shear!" If a landing gear collapses, the cockpit drops. "The scenarios we use in the simulators represent 6 million possible combinations of events and conditions," said J.D. Whitlatch, vice president of pilot standards and training for United Airlines. There is no way we could train flight crews for that many experiences in a real airplane."(Williamson, 1998, p. 2) "The scenarios we show are not fictional; they actually happened somewhere," said Lew Kosich, a B777 fleet captain (Williamson, 1998, p. 2). For example, the microburst that downed a Delta Airlines Lockheed L-1011 in Dallas / Fort Worth in 1985 is among the scenarios. By practicing flying through the simulated storm, pilots learn how to respond to conditions that have claimed the lives of others. At roughly half the price of a Boeing 737 jet, the simulators are "expensive to buy but cheaper than planes to operate. Still, an hour in a 777 simulator is far from cheap, roughly $1,200 (Williamson, 1998).

After the Pan Am crash in 1982, the FAA studied how pilots were trained to handle wind shear. After the Dallas crash, the U.S. Department of Transportation awarded a $1.8 million contract to Boeing Co. to develop a training program to help pilots cope with wind shear, and the FAA required all commercial airlines pilots to master the program. "Pilots are trained to look for and anticipate possible wind shear conditions, something that was unheard of before the Pan Am crash," says John Mazer, spokesman for the Air Line Pilots Association (Rozas, 2002, p. 5). "We'd go back for training twice a year, and at the end of the training we'll just practice wind shears over and over again," says Zander, a retired United Airlines pilot. "With the proper technique, most are survivable. Some are just not. I can tell you it was nice sometimes to be in a simulator that's bolted to the ground"(Rozas, 2002, p. 5). The decision to take off or land in spite of a wind shear alert is left up to the pilot. Many airlines now require that their pilots not land or take off when a wind shear advisory is issued. Pilots today will often delay a flight's takeoff to wait out wind shear, which usually lasts between five and 15 minutes, or will circle the airport until the danger has passed (Rozas, 2002).

Future Technology

The FAA is focusing its future aviation technology on integrating the equipment airports and airlines already use, in order to better predict not only wind shears but also all potentially dangerous weather. Weather accounted for 31 percent of the nation's airline carrier crashes between 1989 and 1999, according to the NTSB (Rozas, 2002).

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The Integrated Terminal Weather System is a Federal Aviation Administration (FAA) system that brings together meteorological data from a wide variety of previously deployed sensors. The ITWS, available at eight airports, processes these data and provides highly distilled automated weather products to increase airport safety and efficiency. Primarily FAA personnel who control aircraft or plan traffic flow use the resulting weather information. Secondarily, the information is used by airline dispatchers and by meteorologists at the center weather service units. The ITWS was developed at MIT/Lincoln Laboratory and currently is in full-scale development ,by Raytheon. MIT/Lincoln Laboratory operates functional prototype ITWS systems at Orlando, Memphis, Dallas/Fort Worth, and New York City, providing real-time weather support. The FAA plans to install a total of 34 ITWS systems during the next two years to service 45 major airports (Cole, 2000). The ITWS uses the Terminal Doppler Weather Radar (TDWR) and the latest version of the LLWAS working together to provide automatic alerts to aircraft (Miner, 2000). Examples of the products provided by the initial deployment are microburst detections and predictions, gust front detections and wind shifts (Cole, 2000).

The tower is still the primary means of communicating windshear warnings at civilian airports. Controllers have a display in the tower which shows the windshear and microburst warnings for specific runways. The warnings are generated automatically. If there is a limitation to these systems, it is that the tower controller is the only source of the information for the pilot. Terminal controllers do not have access to the information. For the last three years, airlines have been using a VHF data-linking program to have text and graphic information of the terminal area broadcast directly from the TDWR, and ITWS systems to the flight deck. The textual description of the weather within 5 NM of the airport is automatically updated every minute. The radar can produce a graphic (using letters and numbers) every five minutes. Direct interface between the sensors and the flight deck looks to be the future when it comes to sensing windshear (Miner, 2000).

The system is designed to give highly accurate forecasts of expected weather conditions for a 200-mile radius, for up to 20 minutes into the future. The FAA plans to buy 37 such systems to cover the airports that have Doppler and would install them between now and 2007, but those dates depend on congressional financing (Rozas, 2002).

Airlines

The FAA required airliners' radar to include windshear alert systems by the end of 1995 (Mconnaughey, 2002). American Airlines has selected Honeywell to provide predictive windshear radar systems for installation on selected current and future American Airlines aircraft (Coventry, 2001).

To give pilots advance warning of windshear, 71 airlines around the world have installed AlliedSignal's RDR-4B windshear radar system in its 4,016 aircraft (Melymuka, 1998). AlliedSignal's system is a predictive radar, which detects windshear up to five miles in front of the aircraft and warns flight crews before the aircraft enters a potentially dangerous windshear event. The system gives flight crews 30 to 60 seconds of warning time before encountering potentially damaging windshear. In contrast, most radar systems are reactive systems that tell the pilot when the plane has encountered windshear - the warning can be as little as a few seconds. Here's how the system works: A Doppler radar antenna in the nose of the airplane sends out signals that measure the motion of raindrops moving toward and away from the aircraft. Those signals bounce back to a receiver in the plane, which interprets the data and displays the green, yellow and red weather patterns on a monitor in the cockpit. The monitor allows pilots to see the location and size of hazardous windshear and storms (Lorek, 1994).

THE BUREAUCRACY AND DELAYS

The FAA provides oversight for the largest, busiest and most complex aviation system in the world. As part of its mission, the FAA and its staff of 49,000 operate and maintain our nation's air traffic system, orchestrating the take-off, landing and routing of 93,000 aircraft a day. The FAA also regulates aviation safety and security, which entails standard setting for, and oversight of, commercial airlines, private aircraft, aircraft manufacturers and the air traffic system (U.S. Newswire, 2000).

Why does it sometimes take disaster or the passage of years for the FAA to take significant action? It is embedded in the conflicted nature of the FAA. Serving two masters, the agency not only is charged with nurturing the aviation industry but also must ensure the safety of the flying public. Whenever the FAA considers changes in safety and equipment regulations, the agency must balance safety against the cost to airlines. According to records and interviews, the result can be delays in addressing safety problems and more accidents related to them. Deadly delays have occurred in part because a law requires the FAA to justify the cost of implementing proposed safety measures by showing that enough lives will be saved (Brazil, 1994).

Joe Cox, a scientist who directed the FAA's $4 million windshear project, said the equipment could have been developed for use by 1982 at a cost of about $48 million. He blamed the FAA's abandonment of the in-cockpit systems in part on resistance from the Air Transport Association, an industry group representing major airlines (Boeing Co. to install windshear equipment in jetliners, 1986).

A four-month Los Angeles Times review of government documents revealed that in some cases years have passed and lives have been lost before the FAA acted on safety problems, although the agency had long been aware of the hazards (Brazil, 1994).

CONCLUSION

The Pan Am Flight 759 on July 9, 1982 remains the nation's worst accident caused by windshear, partly because it focused attention on the problem, said John McCarthy of the Naval Research Laboratory in Monterey, California (Mconnaughey, 2002 p. 2).

The Federal Aviation Administration already was studying windshear. The crash got everyone--government, business and science--working hard together to find ways to avoid similar accidents, McCarthy said. "We thought we could decrease the number of windshear accidents by 60 percent," he said (Mconnaughey, 2002 p. 2). Instead, windshear has downed only two airlines since then: the Delta Air Lines crash that killed 137 on Aug. 2, 1985, at Dallas-Fort Worth Airport and the July 2, 1994, USAir crash in Charlotte, N.C, which killed 37. We've gone from a hazard that caused hundreds of deaths in the '70s and '80s to essentially, knock on wood, we're not having them anymore," McCarthy says (Rozas, 2002, p. 6). "At the time we started this work, we never dreamed it would be as successful as it has been. "We obviously can't say that there won't be another wind-shear accident, but we've gotten a whole lot better than we ever imagined, "McCarthy said (Mconnaughey, 2002 p. 2). Wind shear has continued to cause dozens of accidents and incidents; it is mentioned in an average of 25 National Transportation Safety Board reports a year from 1983 through 2001. But the vast majority were nonfatal. They also are mostly small, private planes (Mconnaughey, 2002).

Many lives have been saved because of the reduction, if not elimination, of potential airline crashes caused by dangerous wind shear conditions on takeoff and landings. These saved lives are the result of training pilots on the dangers of microbursts and the installation of Doppler radars and LLWAS at major airports across the United States to warn pilots when microbursts are present. Just as important is the airlines predictive radar, which gives flight crews 30 to 60 seconds of warning time. In the future it is critical that pilot training programs continue and that there is a progressive oversight activity to monitor the performance of the TDWRs and the operational microburst detection and forecast algorithms (Wilson, 2001).

Congressional officials have suggested that the nation's skies would be safer and more efficient if the day-to-day air traffic control operations were taken away from the FAA so it can focus on airline safety issues. At the heart of the issue lies FAA's conflicting mandates: to ensure the welfare of the flying public but also to nurture the economic welfare of the aviation industry (Brazil, 1994).

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DOI: https://doi.org/10.15394/jaaer.2005.1530

REFERENCES

Aerospace Technology, Vol. 71, Issue 4, 329.Airports Find New Weather Technology Tools Help Reduce Delays. (2001, May 22). World Airport Week, Vol. 8, Issue 19, 1.

American Airlines Chooses Rockwell Collins Avionics for New Boeing 737 and 777 Aircraft. (1997, Dec 11). PR Newswire, 1.

Associated Press. (1997, Jan 29). Crew of fatal flight 1016 made errors, pilot testifies. ATC Market Report, Vol. 10, Issue 24, 9

AWI to begin installing display system in Boston. (2003, Apr 25). ATC Market Report, Vol. 1, Issue 12, 4.

Bell, T. (1986, Aug 25). Windshear detectors already in place, but research into phenomenon goes on. Houston Chronicle, 9 Boeing Co. to install windshear equipment in jetliners. (1986, Feb11). Seattle Times, C 4.

Brazil. (1994, December 12). FAA must strike balance between safety, cost issues. Los Angeles Times, A-1.

Broadston, B. (1999, May). Meeting a microburst. Flying Safety, Vol. 55, Issue 5, 21.

Business Brief -- AlliedSignal Inc.: Windshear Detection System Ordered by Continental Air. (1993, May 27). Wallstreet Journal, 1.

Case bears similarities to other landing accidents in foul weather. (1999, Jun 7). Air Safety Week, Vol. 13, Issue 23, 1.

Chatelain, K. (1992, Jul 5). Remembering the crash-Ten years later residents haunted by disaster. Times-Picayune, A1.

Clark, P. (1998, May 13). Eye on the sky. The Washington Post, HO3.

Cole, R. (2000, Aug). Improving RUC-1 wind estimates by incorporating near-real-time aircraft. Weather and Forecasting, Vol. 15, Issue 4, 447-460.

Crash Spurs Changes from Cockpit to Corporate Headquarters. (2000, May 22). Air Safety Week, Vol. 14, Issue 21, 1.

Croft, J. (2002, Aug 26). Taming Loss-of-Control: Solutions Are Elusive Industry and government reevaluate efforts to curb this major contributor to airline accidents and fatalities. Aviation Week & Space Technology, Vol. 157, Issue 9, 50-52.

Decision to Land in Thunderstorm Likely to be Central Point of Crash Investigation- Case bears similarities to other landing accidents in foul weather. (1999, Jun7). Air Safety Week, Vol. 13, Issue 23, 1.

Hughes, D. (1999, Oct 25). Pilots see shrinking margin for error. Aviation week & Space Technology, Vol. 151, Issue 17. 73-74.

Grose, V. (1995, Apr). Your next airline flight: Worth the risk. Risk Management, Vol. 42, Issue 4, 47.

Gwinn, D. (2001, Aug). Going down. Plane and Pilot, Vol. 37, Issue 8, 60-65.

Hilkevitch, J. (1999, Jun 4). Fatigue studied in Little Rock crash investigators hunt reasons why pilot flew through storm. Chicago Tribune, 3.

Impact on Schedules of a Severe-Weather Avoidance Rule Largely Unknown, But Could be Determined. (2000, Mar 27). Air Safety Week, Vol. 14, Issue 12, 1.

Industry briefs. (2001, Sep 5). Airlines Industry Information, 1.

Johnson, G. (1999, Jun 3). Peril at ground level. Orange County Register, A09.

Lawyer D. (2001, Dec). Microburst. An aviator's worst nightmare. Flying Safety, Vol. 57, Issue 12, 4-9.

Legacy of Flight 759. (2002, Jul 8). Times-Picayune, B.04.

Lorek, L. (1994, Dec 1). Airlines get new windshear warning system. Times-Picayune, G14.

Mconnaughey, J. (2002, Jul 7). Wind-shear detection improves since deadly flight. Advocate, 3B.

Mammana, D. (1998, Jun 21). Weather Almanac. Newday, A47.

Melymuka, K. (1998, Jun 8). 10 years of heroes. Computerworld, Vol 32, Issue 23,71-74.

Mconnaughey, J. (2002, Jul 7). Wind-shear detection improves since deadly flight. Advocate, 3-B.

McWilliams, B. (2001, Aug 2). Aircraft's deadly new enemy is revealed. Irish Times, 32.

Meyer, D. (1999, January 10-15). Study of Network Expansion LLWAS (LLWAS-NE).

Paper presented at the American Meteorological Society79th Annual Conference, Dallas,Texas.

Minor, T. (2000, May). Judgement versus windshear: An epic poem with a heavy weather moral. Mobility Forum, Vol, 9, Issue 3, 27-33.

NTSB Wants Wind Unit Upgrade After MD-80 Runway Incident. (2001,Aug 7). Aviation Daily, Vol. 345, Issue 26, 2.

Probe of US Airways crash could lead to airline changes. (2003, Jan 12). Knight Ridder Tribune Business News, 1.

Raytheon Terminal Weather System Gets FAA Contractor Acceptance (2001, Nov 22).

Rauber, R. (2002). Severe Weather and Hazards.

Rozas, A. (2002, Jul 8). Twenty years after Pan Am crash, wind shear danger low. Newhouse News Service, 1-12.

Rozas, A. (2002, Jul 7). The Kenner Crash. Times-Picayune, A01.

Skilling, T. (2000, Mar 1) Ask Tom why. Chicago Tribune, 12.

United Flight simulators, largest training site in world. Rocky Mountain News, 1B.

U.S. Newswire. (2000,December 7). White House report on air traffic control reform.

Vaisala's MIDAS IV LLWAS. (2003, Mar 21). ATC Market Report, Vol. 1, Issue 7, 6.

Greensboro News Record, B2.

https://commons.erau.edu/jaaer/vol14/iss2/8
DOI: https://doi.org/10.15394/jaaer.2005.1530

Vincent, B. (2000, Feb 21). News Briefs. Air Safety Week, Vol. 14, Issue 7, 1.

Visser, H. (1999). Windshear recovery using thrust vectoring. Aircraft Engineering.

Weaver, B. (2001, Mar). In like a lion. Scientific Computing & Instrumentation, Vol. 18, Issue 4, 14.

Williamson, R. (1998, May 26). Denver's virtual aviators Stapleton Airport is home to Wilson, J. (2001, Jan). The discovery of the downburst: T. T. Fujita's contribution. Bulletin of the American Meteorological Society, Vol. 82, Issue 1, 49-62.

Windshear warnings preceded fatal crash Storm's winds hard to gauge. (1999, Jun 4). Colorado Springs Gazette, A1.