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Turbulence and Its Impact on Commercial Aviation

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ABSTRACT

The hazards posed by turbulence remain an important issue in commercial aviation. Safety experts say turbulence is the leading cause of in-flight injury to passengers and airline employees, especially flight attendants. Extensive research into methods for alleviating this turbulence hazard has been continuing for many years. This paper addresses the issues pertaining to turbulence, including the causes, impact on commercial aviation, and initiatives undertaken to prevent turbulence-related mishaps today and in the future.

INTRODUCTION

" Flight attendant Kathy Boyers remembered little after the wave of turbulence hit. As she finished pouring soft drinks in the galley of Pan American Flight 165, Boyers felt the jet shake. Seconds later, she flew about the galley, shot toward the ceiling and crumpled to the floor when the jet leveled off. By the time the Boeing 727 emerged from clear-air turbulence, an eerie silence gave way to moaning and sobs throughout the cabin. Boyers lay unconscious at the back of the jet, her neck, a rib, her collarbone and shoulder blade broken" (Morrison, 2001, p.3).

Such encounters with turbulence costs in the millions of dollars each year--in insurance premiums, workers compensation and injury settlements--for the commercial airline industry. For unbelted passengers and flight attendants, these injuries are occasionally fatal. All the news is not bad, however. The probability that turbulence will cause a commercial airliner to crash is virtually zero. Still, the injury statistics support what some analysts fear. As record levels of air traffic increase, the result will be increasing numbers of encounters with turbulence, already the leading cause of injuries in non-fatal airline accidents. "As the skies get more and more crowded, it is going to be a bigger and bigger issue," warns Robert Massey, a pilot serving on a federal commission looking for ways to battle turbulence (Morrison, 2001, p. 2).

A number of agencies, including the Federal Aviation Administration (FAA) along with the airlines, are developing technology that could help pilots avoid turbulence encounters. Knowing that turbulence is ahead does not necessarily allow a pilot to avoid it; however, the information would alert passengers and flight attendants to fasten their seat belts. The FAA mostly funds such research (Perry, 2000). Regardless, most researchers admit that airlines are years from equipping jets with the technology needed to ensure smooth flights.

What Causes Turbulence?

Aviation experts describe turbulence as random, unpredictable motion that occurs between layers of air moving at different speeds. Just as the smooth flow of an ocean wave breaks up into swirls and eddies when it crashes on shore, uniformly moving layers of air that brush against each other fragment into vortices, and other small-scale disturbances (Cowen, 1998). Types of turbulence are summarized in table 1

Table 1. Summary of types of turbulence

Turbulence Type	Cause
Convective	Uneven heating of earth's surface
Mechanical	Obstructions disrupt airflow
Mountain-wave	Airflow disrupted by mountains
Wake	Aircraft wingtips produce vortices
Clear-air	Jet stream associated

Convective turbulence is caused by uneven heating of the earth's surface, which causes air in contact with the surface to warm at different rates; and therefore, to rise at different rates distorting the wind-flow pattern at higher altitudes and generating chaotic motion (Cowen, 1998). Convective turbulence often is linked to severe weather, such as thunderstorms (Spotts, 1997).

Mechanical turbulence occurs when air near the earth's surface becomes disrupted as it passes over obstructions such as buildings, trees, and irregular terrain. The higher the wind speed and the rougher the obstruction the greater is the turbulence (AFH 11-203).

Mountains cause turbulence as the wind tries to flow around and through them. When the wind flows over the top, it can set up waves of air known as gravity waves. These spread from their points of origin like ripples in a pond. Mountain-induced turbulence may be encountered more than 20,000 feet above a 12,000-foot range (Spotts, 1997).

In-flight aircraft create wake turbulence. When an aircraft generates lift, it produces a pair of counter-rotating cylindrical air masses, called wake vortices. Wake vortices are a potential hazard to following aircraft. Since a means to locate and track vortices does not exist, safety is currently ensured by imposing arrival and departure separations between aircraft in the terminal area (Volpe, 2001). The FAA requires six miles between planes to prevent crashes. Most times, that distance could be reduced considerably, but there is no operational system in place that can detect the few occasions when it cannot (Hamilton, 1999).

Clear-air turbulence is associated with the jet stream, a river of air moving at speeds as fast as 170 miles per hour at altitudes of 30,000 to 45,000 feet (Spotts, 1997). A plane entirely immersed in the jet stream moves at a steady, uniform rate. At the boundaries of the stream, however, where it moves over slower air, wind shear can generate severe turbulence. Such turbulence is more common in winter, when the stream lies at lower altitudes and latitudes (Cowen, 1998).

Categories of turbulence

The aviation community, in order to provide a standard for reporting and describing turbulence, has classified turbulence into intensities according to its effect on aircraft and occupants as follows:

Light: Displaces loose objects, but there is no difficulty walking about the cabin.

Moderate: Strong enough to make walking difficult. Drinks splash, and passengers strain against their seat belts.

Severe: Passengers are pushed violently against their seat belts, walking is impossible and loose objects are thrown about (Morrison, 2001).

Extreme: Aircraft is violently tossed about and is practically impossible to control (AFH 11-203, 1997).

Impact of Turbulence on Commercial Aviation

Areas of turbulence affect a jet much the same as potholes affect a car. The wings of the jet, shaped to provide lift and enable a jet to fly, interact with the air as a car's tires interact with a road. When winds are steady, the air provides a smooth, constant lift. When the airflow is disturbed, the amount of lift varies and causes the plane to shake (Morrison, 2001).

"Turbulence, as a passenger, is probably one of the most unsettling things you can go through. Unless you're just really into roller coasters, it really is a frightening experience," Robert Massey, a pilot serving on a federal commission looking for ways to battle turbulence, says. "But if you're properly belted in there, that's all it will be is frightening. You really do not have to worry about the wings getting ripped off the airplane"(Morrison, 2001, p. A.01).

Airliner encounters with turbulence represent one of the industries most costly safety concerns, yet they seldom produce much publicity (Spotts, 1997). During the past 15 years, such incidents have resulted in three deaths and 850 injuries , 70 serious injuries. The cost to airlines in compensation claims, aircraft damage and accident investigations has been estimated to be at least $100 million each year (Anonymous, 1999). Some passengers are terrified as a result of their experience and they swear to never fly again. The problem is persistent and leads to lawsuits, workers' compensation claims, and sometimes-lengthy absences as crewmembers recuperate from injuries. "This is a silent problem of the industry," says Larry Cornman, an atmospheric scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado and one of the researchers involved in a federal research effort (Spotts, 1997, p.3). " At one major United States carrier during 1997, over 230 flight attendants suffered turbulence-related injuries, resulting in more than 2,800 lost workdays," said Jill Gallagher, spokeswoman for the Association of Flight Attendants (Leib, 1998, p.1). This union represents 43,000 flight attendants at 27 United States carriers (Leib, 1998).

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Among the latest high-profile incidents of turbulence was one occurring during December 1997 involving United Airlines Flight 826, flying from Tokyo to Honolulu. The plane encountered severe turbulence over the Pacific Ocean and quickly dropped 1000 feet. The descent was so rapid and jarring that it tossed unbelted passengers, flight attendants and equipment around the interior of the Boeing 747's cabin. One passenger was killed and 93 passengers and nine flight attendants were injured. Most of those interviewed attributed the event to clear air turbulence (Leib, 1999).

The Federal Aviation Administration (FAA) provides the following statistics:

- In-flight turbulence is the leading cause of injuries to airline passengers and flight attendants in non-fatal accidents.
- Each year, 58 airline passengers in the United States are injured by turbulence while not wearing their seat belts.
- From 1981 through December 1997, 342 reports of turbulence affected major air carriers. Three passengers died, 80 suffered serious injuries and 769 received minor injuries.
- At least two of the three fatalities involved passengers not wearing their seat belts while the seat belt sign was illuminated.
- Of the 80 passengers seriously injured, 73 were not wearing seat belts while the seat belt sign was illuminated.
- Two-thirds of turbulence-related accidents occur at or above 30,000 feet. In 1997, half of the accidents occurred above 30,000 feet (FAA, 1997).

PREVENTING TURBULENCE-RELATED MISHAPS TODAY

Aviation Weather Center

The Aviation Weather Center (AWC), located in Kansas City, MO, is a component of the National Weather Service. The AWC issues accurate warnings, forecasts and analyses of hazardous weather for aviation interests. The Center identifies existing or imminent weather hazards to aircraft in flight and creates warnings for transmission to the aviation community. The Center also originates operational forecasts of weather conditions that will affect domestic and international aviation interests out to two days. Warnings of flight hazards, such as turbulence, remain most critical for the protection of life and property over the United States from the earth's surface up to 24,000 feet. Above 24,000 feet, the AWC provides warnings of dangerous turbulence for the Northern Hemisphere from the middle of the Pacific Ocean eastward to the middle of the Atlantic Ocean. Additionally, above 24,000 feet, the AWC forecasts turbulence for the Northern Hemisphere from the east coast of Asia eastward to the west coast of Europe and Africa (AWC, 2000).

Commercial Airlines

Currently, forecasts are based on weather conditions, as well as reports from pilots already airborne. Yet turbulence can be short-lived and difficult to forecast. Transcontinental flights have the benefit of a dense network of weather stations on the ground, as well as heavily traveled air lanes to provide information. By contrast, transoceanic flights are notoriously data sparse (Spotts, 1997). The most valuable information comes from pilots, especially those who stray into turbulence and then radio warnings to others (Morrison, 2001).

Many commercial airlines have in-house meteorology departments to relay the latest information to the carrier's flight crews. Northwest Airlines, widely recognized as the largest and one of the most successful at avoiding turbulence, employs 29 meteorologists. They plot turbulence patterns around the clock as part of their copyrighted Turbulence Plot System. More than half of the staff has at least 10 years experience at the airline (Anonymous, 2000). Meteorologist Tom Fahey says, "his staff looks at airflow patterns, searching for spots where the atmosphere buckles and where the most concentrated areas of energy -- jet streams – are" (Morrison, 2001, p. 5). Turbulence will most likely occur where the largest changes in wind speed occur over the shortest distances. Northwest meteorologists, dispatchers, and flight crews have achieved an outstanding turbulence avoidance record. According to the records, the carrier had far fewer turbulence incidents than its five largest rivals. In fact, Northwest experienced only one turbulence accident between January 1980 and December 1999 (Anonymous, 2000). Fahey acknowledges that the forecasts aren't perfect. However, Northwest's prognostic measures are the envy of the other airlines. Five -- including Alaska and Continental airlines-- have contracts to use Northwest's service (Morrison, 2001). Northwest Airlines earned the 1998 Laurel citation from Aviation Week & Space Technology's editorial team for making substantial contributions to the field of aerospace by its commitment to avoiding turbulence

(Editors, 1999).

New Software For Flight Computers

Research sponsored by the FAA is focusing on the critical task of obtaining accurate information on in-flight turbulence. As United Airlines jet liners go back in service after routine maintenance checks, they are carrying something new. Instructions in their flight computers convert the airliners' sophisticated navigation systems into flying turbulence detectors by measuring wind velocities in raindrops or other precipitation. United installed the software as part of a federal effort to help commercial pilots avoid potentially fatal encounters with turbulence. The new software provides an objective measure of turbulence, which will be transmitted once a minute from each aircraft to a data collection center. Eventually, other major carriers are expected to follow (Spotts, 1997).

These instruments don't give advance warning of turbulence to crews, but instead confirm incidents of shearing winds when they strike the plane. By requiring hundreds of planes to record and transmit such incidents to forecasters on the ground in real time, a map can be created showing areas of turbulence across the country. The pilots, who've just flown through it, won't be helped by the information, but other flight crews will be able to pull up the map electronically on their cockpit weather displays and use the information to avoid turbulence (Leib, 1998). The in-flight information not only will be of interest to researchers, but also will feed into the computer programs the National Weather Service uses to forecast weather. The goal is to make the data available to forecast models designed to give pilots estimates of where turbulence will be one to three hours in advance (Spotts, 1997).

Federal Aviation Administration (FAA) Regulations and Cabin Safety

FAA regulations require passengers to be seated with their seat belts fastened:

- When the aircraft departs the gate and until it climbs after takeoff
- During landing until aircraft comes to a complete stop at the gate
- When the seat belt sign is illuminated during flight (FAA, 1997)

After two serious turbulence events in June 1995, the FAA issued a public advisory to airlines urging the use of seat belts at all times when passengers are seated. The FAA concluded that seat belt rules did not require strengthening but that a public education initiative was necessary to encourage the use of seat belts (FAA, 1997).

Proper use of an approved child restraint system (CRS) on an aircraft enhances child safety in the event of turbulence. The FAA strongly recommends that all children who fly, regardless of age, use the appropriate restraint based on their size and weight. What about the child on your lap under two years old. Regulations say children do not have to be buckled up (Irwin, 1999). The FAA recommends that a child weighing:

- Less than 20 pounds be placed in a rear-facing CRS.
- From 20 to 40 pounds use a forward-facing CRS.
- Over 40 pounds may safely use an aircraft seat belt (FAA, 1997).

PREVENTING TURBULENCE-RELATED MISHAPS IN THE FUTURE

A number of groups, including NASA, FAA and the airlines are working to develop onboard turbulence detection and display systems which are expected to enter service in the future and will provide pilots with a direct indication of the severity of turbulence ahead of their aircraft. Table 2 summarizes these systems.

Table 2. Summary of Turbulence Sensor/Display Systems Capabilities

Sensor/Display Systems	Capability
(On-Board) Radar Algorithm	Directly detects convective turbulence
SOCRATES	Detects wake turbulence and clear air turbulence
LIDAR	Detects clear air turbulence
Airborne Doppler Radar	Detects convective turbulence in areas of low reflectivity
Wake Vortex Warning and Display	Displays wake vortices on cockpit screen

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(On-Board) Radar Algorithm Research

Researchers are investigating whether radar could detect convective turbulence directly by tracking the motion of rain or ice particles embedded in a turbulent region. "This would be a new use for (on-board) radar," says Kenneth Leonard of the FAA. "If we can develop an algorithm that will help us determine where turbulence is or where it might develop, based on something reflecting off the radar beam, that would improve both detection and forecast of turbulence," says Leonard (Cowen, 1998, p.3). First, notes meteorologist David Pace of General Sciences Corp. in Laurel, Md., "we have to determine exactly what the signature of different types of turbulence looks like"(Cowen, 1998, p. 3). Pace observes, for example, that if ice or rain particles are moving at wildly different speeds and directions—a sign of turbulence—the frequency of the reflected radio wave will move to higher or lower values, resulting in a wider spread in the frequencies of the reflected spectra (Cowen, 1998).

SOCRATES

Another detection strategy relies on turbulence producing traveling sound waves that can be detected by a plane miles away. Project SOCRATES (Sensor for Optically Characterizing Remote Turbulence Emanating Sound) addresses the development of sensors for detection, location, and tracking of aircraft-generated wake turbulence and clear air turbulence. (AAR, 1999). Radar cannot detect these phenomena because they do not contain rain or hail which radar requires for tracking (Baus, 1999). SOCRATES uses low-powered laser light that travels just a short distance, over a set path, before being reflected back to its source. The speed of the laser light, and hence its travel time, vary with changes in atmospheric pressure induced by the sound waves. Sound waves generated by turbulence spread through the atmosphere and have unique characteristics that can be detected, classified, localized, and tracked, states Sam Kovat, chief executive officer of Flight Safety Technologies, a New London, Connecticut company that designed the experimental laser system. (Cowen, 1998).

Air traffic controllers currently separate aircraft on approach by as much as six miles to allow wake turbulence time to dissipate. This separation distance is based on a "worst case"" scenario. Project Socrates is intended to create a reliable, accurate and real-time wake vortex sensing and warning system. If successful, it could allow closer spacing for landing aircraft while continuously monitoring for potentially hazardous conditions (Proctor, 2000). By 2003, Kovnat expects the system to be certified by the FAA for installation at thirty major hub airports. This is a $500 million project (Hamilton, 1999). It will be several more years before the SOCRATES system can be tested in the cockpit (Cowen, 1998).

Light Detection and Ranging (LIDAR)

Larry Cornman, a leading weather scientist at the National Center for Atmospheric Research (NCAR), is working on projects to help pilots by forecasting, detecting and measuring turbulence. One project NCAR is working on is with Coherent Technologies Inc., a Lafayette company that has developed a prototype laser system for detecting turbulence in clear air (Leib, 1998) up to 8 nautical miles (Nordwall, 1999). The laser device is called LIDAR, which stands for light detection and ranging. LIDAR works much like radar - "radio detection and ranging" - except that LIDAR sends out a wave of infrared light while radar sends out radio waves for detection. LIDAR works best in clear weather, where it detects dust particles, or aerosols, in the atmosphere ahead of the plane. The laser determines wind velocity at selected points along its beam by analyzing the frequency of reflected light off the aerosols. Highly variable velocity of the particles indicates the presence of turbulence ahead (Leib, 1998). This technology will require installation of a transmitter-receiver in the nose of a plane that will fire laser pulses through a small window. The LIDAR's infrared waves detect turbulence in clear air by measuring the movement of dust particles in the atmosphere ahead of the plane (Leib, 1999). About $2.4 million has been designated for developing and testing the laser device. "Experiments 'reinforced our intuition' that it will work," Cornman said about laser detection (Leib, 1998, p. j-01).

NCAR's researchers and Coherent's executives have different views on how soon laser-driven turbulence detection systems will be routine on commercial aircraft. Cornman said it may be 5 to 10 years before the devices can win FAA certification and be small enough, light enough and cheap enough to be acquired in large numbers by commercial carriers. But executives of Coherent Technologies believe the time required can be compressed and the LIDAR units placed in cockpits of commercial jets within about three years. The laser prototype now fits in a container that resembles a milk crate, nearly a cubic yard in size (Leib, 1998).

Hal Bagley, Coherent's director of commercial development, acknowledges that the company eventually must make a more powerful laser for turbulence detection that fits it in a case roughly the size of a shoebox. Coherent also must reduce the price of the laser to about $100,000 a unit. Airlines already have shown interest in the LIDAR if the price gets that low. With thousands of planes flying the skies for commercial airlines around the world, the financial reward for Coherent is potentially huge if it can be the first to market a laser-based turbulence detector to the industry. The market is estimated at between $500 million and $1 billion (Leib, 1998).

Officials of United, Delta and American airlines say the carriers are aware of the research into turbulence detection using lasers and there is great interest. United will assess the requirements for the turbulence system, such as size, weight, power, where it should be located and how much visual and aural warning should be given to the flight crew. In addition, United will suggest procedures that could be used to take full advantage of the benefit of the warning time provided. If the system proves effective, United eventually could install the sensor in all of its 580-plus aircraft (Moorman, 1999).

Now, scientists at NCAR must develop more precise measurements for mapping incidents of turbulence, and they must translate data gleaned by the laser into a form of information that can be used instantly by pilots. The plan is to integrate turbulence data received by the laser sensor with other information that pilots already get now on their cockpit weather displays. Ideally, Coherent will be able to add a turbulence indicator to the current weather display. It might be an oval on the screen that would show as green during smooth flight, switch automatically to yellow as the laser detected light-to-moderate turbulence and finally switch to red if the plane approached severe turbulence. Inside the oval, a number would signal the time, in seconds, that the plane had before it hit the turbulence. Coherent's plan is to develop and deliver a detection laser to airlines that could give flight crews between 30 seconds and one minute of warning before an encounter with severe turbulence. A minute's warning ought to give flight attendants time to stow carts and get passengers and themselves belted, officials say (Leib, 1998).

The Severe Clear Air Turbulence--Colliding with Air Traffic (SCATCAT)

The SCATCAT project, a series of reconnaissance flights in the middle of the Pacific Ocean, may improve National Oceanic and Atmospheric Administration (NOAA) researcher's understanding of air turbulence. Scientists are flying into rough air near the jet stream looking for the meteorological features that cause air turbulence. They want to learn why some airplanes fly through regions where turbulence is expected without difficulty, while others experience major problems (Anonymous, 2001).

Jim Weyman, meteorologist in charge of the Honolulu Forecast Office, stated, "Clear air turbulence has had major impacts on flights in and out of Hawaii. In the last few years, several flights have encountered severe turbulence resulting in significant injuries to passengers. If we can improve our knowledge of turbulence, we will not only save lives but also thousands of dollars lost in fuel, flight rerouting, and delays"(Anonymous, 2001, p. 1026). Jack May, acting director of the Aviation Weather Center in Kansas City, Missouri, welcomed the research results. He stated, "new findings from this type of research will greatly improve the forecasts of turbulence over the continental United States and large oceanic areas that the center has responsibility for and where thousands of flights every day have the potential of encountering turbulence" (Anonymous, 2001, p. 1026).

Selecting an area to fly a reconnaissance mission into is based on the area having conditions favorable for turbulence. Satellite images, aviation weather models, and air turbulence forecasts are analyzed to determine the most probable area for turbulence to occur. Upon arriving at the selected research area, dropsondes are released from the plane at high altitude. As these instrumentation packages descend, they send back data to the plane. These data spot areas of turbulence below the aircraft, allowing the pilots to descend and purposefully fly there for the experiment. Comparing the actual atmosphere to the model prediction is the solution to improving aviation models that are used by commercial, civil, and military pilots for flight safety (Anonymous, 2001).

Researchers have identified vertical layers 1000 ft thick or less in which turbulence is widespread, helping to explain why one plane is impacted and another is not. Additionally, vertical waves have been revealed inside the jet stream exhibiting the character of ocean swells, which break and crash like ocean waves. Researchers are able to replicate breaking waves and incorporate the measurements into experimental forecast modeling. This new information will be used to improve operational forecasts (Anonymous, 2001).

Wake Vortex Warning and Display System

A wake vortex warning and display system is one of several new cockpit safety technologies being studied at Honeywell Commercial Electronic Systems. As envisioned, airspace ahead of the aircraft expected to contain threatening wake vortices would be graphically displayed and annotated in yellow on an appropriate cockpit screen. The warnings would be compiled using an onboard database of aircraft wake vortex profiles, local wind information from onboard or off board sources and data contained in nearby aircraft's broadcasts. This technology also could improve airport capacity by allowing more closely spaced landing of aircraft when flight crews confirm wake vortices not to be a threat. Honeywell also is testing a low-cost storm cell tracking upgrade for onboard weather radars. It would add dashed white lines to radar or navigation displays to depict projected storm cell movements over the next 3-5 minutes, allowing pilots to change course to avoid penetration (Proctor, 2000).

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Airborne Doppler Radar

The Colorado Turbulence Research Experiment Program goals include a demonstration of the reliability of Doppler systems to distinguish turbulence associated with thunderstorms. It also includes possible software refinements to increase the detection range and accuracy of future radar systems. The test program is studying areas within thunderstorm activity in which airborne Doppler system returns show relatively low reflectivity. Larry Cornman, an NCAR scientist, said, "pilots may fly through these areas while trying to avoid regions that show a high level of reflectivity--which indicate severe weather conditions such as hail or heavy rain--on radar displays. He added, however, that severe turbulence can also be encountered in areas of low reflectivity and an objective of the program is to provide flight crews with additional guidance through these regions" (Smith, 1999, p. 52). Airborne Doppler radars may be able to detect turbulence 6-9 miles ahead of the aircraft, depending on reflectivity strength. At typical cruise conditions, this would give pilots an advance warning time of about one minute. Program officials said Doppler radar systems with improved software capabilities to better detect convective turbulence could begin to be available to commercial aircraft operators in as little as a year or two (Smith, 1999).

FAA Aviation Weather Research Program

AWRP efforts are organized into Product Development Teams (PDTs). Each PDT plans and coordinates the efforts of multiple laboratories and agencies working toward a common goal. This approach serves to eliminate redundant efforts, helps assure that all necessary issues are addressed, and promotes cooperation and leverage among the multiple agencies. The Turbulence PDT is engaged in addressing the fact that commercial and general aviation aircraft continue to encounter unexpected turbulence, which requires immediate changes in flight paths or is hazardous to the aircraft and passengers. Current information is not accurate enough to identify the location, timeliness and intensity of turbulence. The mission of the Turbulence PDT is to produce timelier and more accurate analyses and forecasts of turbulence and develop user-friendly turbulence products (FAA, 2001).

The Turbulence PDT has developed an algorithm to provide objective, aircraft-type independent turbulence data, down linked in real time from commercial air carriers. Its sensor is the accelerometer suite already resident on the aircraft. The Turbulence PDT has also developed an algorithm to forecast turbulence. This algorithm models jet stream, mountain induced, and convective induced turbulence. It is currently only available in an experimental mode (FAA, 2001).

The FAA is devising new ways to display weather products on the Aviation Digital Data Service Web page to gather pilot feedback. The pilot uses the mouse to draw a route on a map of the United States. The view of the route displays weather data including turbulence. The data is not considered official since it is still experimental (Dornheim, 1999).

THE BUREAUCRACY AND POTENTIAL DELAYS

The Federal Aviation Administration (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, manufacturers and others. According to records and interviews, the result can be delays in addressing safety problems and more accidents related to them (Brazil, 1994).

After FAA admitted in July, 1994 that it may have mishandled reports on turbulence problems associated with Boeing 757 jetliners, the Los Angeles Times reviewed hundreds of airline crashes and thousands of government documents obtained under the Freedom of Information Act. Scores of past and present FAA officials, members of Congress, airline industry sources and safety experts were interviewed. What emerged was a portrait of an agency that many times has been slow to address safety problems. This was particularly true when the problems were controversial or costly to correct. 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).

Even FAA's harshest critics don't believe that the agency knowingly waits for accidents to happen. But because the FAA must justify changes that require expenditures by the aviation industry, the agency sometimes must use past accidents to help build its case. And once the agency decides to make safety-related changes, it can take years before new rules take effect because the agency must consider the effects on the airline industry. FAA is required by law to justify rules changes that cause financial burdens to government or private industry. Critics say that the FAA, in seeking changes in regulations, depends too heavily on accidents that have already occurred. The reason, they say, is that in an atmosphere of public outrage over a serious accident, it is easier to pass reforms through Congress. Before the FAA can act, the agency must calculate how a proposed safety rule will affect the aviation industry. The agency must consider everything from the public perceptions to the economic impact. Critics feel that sometimes safety is secondary to economic concerns (Brazil, 1994).

A four-month 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. 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).

CONCLUSION

Despite severe encounters that have damaged large jets, only one crash nearly 40 years ago has been attributed to turbulence, and that occurred because the pilots failed to handle the airliner properly. In addition, those wearing seat belts are seldom injured, and almost never seriously (Morrison, 2001).

A successful program to prevent turbulence-related mishaps must ensure that FAA toughens current in-flight safety regulations to include the airline seat belt policy. United States carriers encourage passengers to have their seat belts fastened whenever they are seated; however, the policy is not strictly enforced. If FAA were really serious about this issue, seats could be equipped with sensors that would alert the flight attendant when a passenger was seated without the seat belt fastened. Also, incentive programs could be initiated to encourage seat belt use. The cost to airlines in compensation claims and accident investigations has been estimated to be at least $100 million each year (Anonymous, 1999). An incentive program could operate on a small fraction of that cost. For example, a computer program could reward safe flyers (no seat belt infractions for a mileage prescribed by the airline) with a courtesy flight voucher. Not surprisingly, flight attendants are most likely to be hurt, primarily because they are not buckled into seats when the jet hits turbulence. Also vulnerable, are the few passengers who are not seated, for whatever reason, and the passengers who insist on not having their seat belts fastened even though they are seated. It should be apparent that seatbelts are not the total answer.

A successful program to prevent turbulence-related mishaps must also apply sensor technology to the problem. First, the dynamics of turbulence must be better understood and models improved to provide better forecasts. The benefit will be to assist pilots in preflight planning and in-flight strategies for avoiding turbulence. However, forecasts will never be perfect. Second, new sensor technologies capable of detecting various types of turbulence must continue to be explored. Third, prototype multi-sensor turbulence detection systems must integrate onboard radar for convective activity and lidar for clear air turbulence with data link for weather forecasts and pilot reports to warn pilots of the location and severity of turbulence. Fourth, the operational requirements necessary to fully realize the benefits of the turbulence sensor on the aircraft must be examined. The goal is to integrate turbulence sensor data with the cockpit display so that the pilot can refer to it and understand it instantly.

A successful program to prevent turbulence-related mishaps also must be approved by FAA. Two laws spell potential delay for installation of turbulence detection systems by our airlines. The FAA is required by law to balance safety against the financial burden to airlines and manufacturers whenever it considers changes in safety and equipment regulations. Cost could cause delay by adversely impacting the smaller airlines in a significant way. The lidar unit alone is expected to be about $100,000 with a market as much as $1 billion (Leib, 1998). Also FAA is required by law to justify the cost of implementing proposed safety measures by showing that enough lives will be saved (Brazil, 1994). This potentially could result in delay. Statistics reveal that from 1981 through December 1997, only three passengers died due to turbulence mishaps affecting major air carriers (FAA, 1997). Therefore, a realistic time frame that the lidar units can win FAA certification and be placed in cockpits of commercial jets is probably between 3 and 10 years (Leib, 1998).

Technology will eventually prevail in preventing turbulence mishaps by producing sensors to provide adequate warning. In the interim the commercial airlines industry should adopt the Turbulence Plot System used by Northwest Airlines and hire in-house meteorologists to monitor, forecast, and relay the latest turbulence information to the carrier's flight crews around the clock. This interim solution would certainly lead to a reduction in turbulence-related mishaps.

Finally, turbulence remains a major threat to flight safety and is a paramount concern to the aviation industry. I believe it's time to translate research into action!❑

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