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COMMENTS ON THE PROBLEM OF TURBULENCE IN AVIATION

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Since there has been aviation there has been a turbulence problem. The earliest aviators recognized several potentially turbulent situations such as strong low-level winds across rough terrain, convective turbulence due to solar heating and instability. They also had a great respect for the damaging turbulence associated with thunderstorms. Much of this knowledge was based on experience. It was not until the 1940's that much of the problem underwent scientific scrutiny. The Thunderstorm Project described the dynamics of the airmass thunderstorm, but as we now know, it did not address many of the ancillary characteristics that thunderstorms can generate. In the late 1950's the mountain wave was investigated and described.

With the advent of high-altitude jet aircraft in the 1950's, it was commonly thought that flight would be above all troublesome weather. The Air Force and, shortly thereafter, the airlines learned this was not so. A type of turbulence called CAT (Clear-Air Turbulence) reared its head and extended sharp claws. In February 1966 the joint military-civilian National Committee for Clear-Air Turbulence was established. This action, in part, led to a period of intensive research to both describe the phenomenon and to accurately forecast it.

In 1977, the downburst associated with thunderstorms was first described, and since that time there have been intensive efforts to identify the onset of this phenomenon and to give pilots a timely warning of the hazard.

In spite of all the efforts to improve the forecasting and detection of turbulence, the problem is still with us. Excerpts from the statistics of the most recent period of accident records compiled by the National Transportation Safety Board (NTSB) may give some insight into the magnitude of the problem.

Table 1 enumerates the accidents that occurred during the period from 1982 through 1984, the latest period that NTSB has complete records. It gives the total number of accidents for the three-year period for large commercial carriers--both scheduled and non-scheduled--operating under FAR Part 121, the commuter and air taxis operating under FAR Part 135, and general aviation, which includes corporate aircraft, operating under FAR Part 91. These accidents have, in turn, been subdivided into fatal and nonfatal accidents and subtotaled as weather-involved and, more specifically, as turbulence-involved accidents. The weather-involved accidents are accidents in which weather is listed as a cause or factor. Other casual factors such as those attributable to pilot actions or maintenance problems may have been assigned to the same accident.

More indicative of the magnitude of the weather hazard is Table 2 which gives the weather accidents as percentages of the total number of accidents and the turbulence-associated accidents as a percentage both of the total number of accidents and a percentage of weather-involved accidents. Most significant in these numbers is that the odds that an accident involving a large commercial carrier being in a weather accident are greater than for either the commuter and air taxi operations or for general aviation. This is probably due, at least in part, to the fact that the aircraft operated under FAR Part 121 are most sophisticated and more likely to have redundant systems than the smaller aircraft, and hence are less likely to suffer from catastrophic mechanical failure. Additionally, the pilots, as a group, have more experience and are less likely to become involved in situations attributable to operational errors. But based upon their scheduled operation, they do encounter all varieties of weather situations.

It is noteworthy that in all three operational categories, weather is a factor in a higher percentage of fatal accidents than it is in accidents overall, and in the case of FAR Part 121 operations, over half of all the fatal accidents are weather involved and they account for almost all of the fatalities. The common thread in this particular data sample is snow and/or ice, which was a factor in four of the five fatal accidents. Engine ice and ice and snow on the wings were major factors in the Air Florida accident in Washington, D.C., in January 1982 which killed 78 people. During the same month, two people were killed when a World Airways DC-10 ran off the runway into Boston harbor due to ice and snow on the runway. The other accidents were a Republic Airlines Convair 580 which ran into a snowbank in Brainerd, Minnesota, on January 9, 1983. A propeller disintegrated, fatally injuring a passenger. The other involved an Ozark Air Lines DC-9 which collided with a snow sweeper in Sioux Falls, South Dakota, on December 20, 1983, killing the sweeper operator. The fatal accident that was not involved with snow and/or ice was the wind shear encounter by Pan American Flight 759 on takeoff from New Orleans International Airport on July 9, 1982, which caused 153 fatalities.

Turbulence accounts for 24 percent of the accidents involving large commercial carriers and 54 percent (over half) of the weather-involved accidents. Fortunately during the 1982 through 1984 time period, there were no fatalities caused by turbulence encounters. This is not unique to the period. There have been no fatal accidents involving large commercial aircraft directly attributable to turbulence since the crash of a Braniff Airways Lockheed Electra on May 3, 1968, in which 85 people were killed. In this case, the aircraft suffered structural failure recovering from an unusual attitude induced by a thunderstorm. There have been two fatal turbulence accidents since that time: a Fairchild F-27 in December 1968 and a Lockheed Hercules in May 1974. In both cases, the structural failure was attributed to fatigue or pre-existing cracks in the airframe. This is not to imply that turbulence is not a hazard. During the 1982 to 1984 time period, there were 81 injuries in FAR Part 121 operations, 24 of them listed as serious. This represents both considerable pain and suffering to those involved and a significant financial liability to the airlines. Those generally at greatest hazard by turbulence are flight attendants who often continue cabin services when the seat belt sign is on and are injured both by being thrown about the aircraft's interior and by service equipment, such as food and drink carts and galley equipment. An additional problem is the large amount of loose luggage and other objects that are carried aboard airliners and improperly stowed. These objects often become missiles in severe turbulence.

In the categories operating under FAR Parts 135 and 91, the turbulence accidents only account for 2 percent of the total accidents and 6 and 7 percent of the weather-related accidents, respectively. The difference between the smaller commuter, air taxi, and general aviation aircraft and the larger commercial carriers is that turbulence-related accidents with the smaller aircraft are much more likely to be fatal. The reason for the lower percentage of turbulence accidents is readily explainable. In the smaller aircraft, the passengers and crew remain strapped in and there are generally not the loose and potentially hazardous objects in the passenger spaces. Consequently, the turbulence--so long as control of the aircraft is maintained--is a discomfort. The serious problem is when control is not maintained. The large majority of fatal turbulence encounters are a result of the pilot losing control of the aircraft due to extreme accelerations or disorientation and either colliding with the ground while out of control or by overstressing the aircraft during an attempted recovery from an unusual attitude which results in an in-flight breakup of the aircraft.

The NTSB has investigated several turbulence accidents and has made recommendations to improve the system in those instances where the Board believed that changes in procedures might serve to alleviate the problem to some degree. Unfortunately, the NTSB does not have the resources to investigate all turbulence encounters. It is limited to investigating those classified as accidents by the Board's definition, which means that there was serious injury to passengers or crew members or sufficient damage to the aircraft that its airworthiness was affected. The following paragraphs are synopses of some of the accidents investigated by the NTSB which are examples of the problems associated with turbulence.

On May 19, 1980, a Gates Learjet Model 25D was enroute from West Palm Beach to New Orleans on J-58. The aircraft reached its cruise altitude of 43,000 feet just prior to reaching Clovia Intersection, about 104 miles west of Sarasota. Shortly after the pilot had reported leveling off the controller at the Jacksonville Center, monitoring the frequency used by the Learjet, heard an unusual staccato sound followed about 18 seconds later by a report from the co-pilot, "Can't get it up...it's in a spin." About 33 seconds after the first staccato sounds, radio and radar contact with the aircraft were lost. Floating debris was found in the water in the vicinity of Clovia Intersection, but the two pilots were missing and presumed to have been killed. There were no passengers on board.

Another Learjet was following about 16 minutes behind the accident aircraft at the same altitude. In the vicinity of Clovia Intersection the pilot reported that he encountered the most severe turbulence he had ever encountered in a Learjet.

An analysis of the weather conditions in the vicinity of the accident showed an upper front or vertical discontinuity at the approximate altitude where the aircraft encountered the turbulence. This discontinuity appeared on the sounding of Bootheville, Louisiana, and Appalachicala and Tampa Bay, Florida, the three stations nearest to the accident. Additionally, there were strong vertical and horizontal wind shears in the vicinity of the discontinuity.

It was determined that this upper front was most likely the cause of the turbulence that led to the accident. The NTSB believed that the indicators of potential CAT may have been available prior to the accident and recommended that the National Oceanic and Atmospheric Administration (NOAA):

> Define the relationship between clear-air turbulence and upper fronts as analyzed by soundings and develop forecasting techniques to utilize the information to improve clear-air turbulence forecasts.

A CAT encounter by a United Airlines DC-10 over Morton, Wyoming, caused serious injuries to seven people and minor injuries to 19 others as well as causing damage to the aircraft, mostly to the interior from objects tossed about the aircraft.

A study of the weather data available showed that conditions were approaching those conducive to mountain wave development, but of several systems used to forecast the onset of a mountain wave only one would have forecast it and then only based upon the hourly data recorded about 2 minutes prior to the accident. Analysis also showed that there was a discontinuity below the tropopause with 10 kts of wind shear across it recorded at one sounding station. The conclusion was that the turbulence was caused by a combination of an incipient mountain wave and wind shear through an atmospheric discontinuity. It was also concluded that there were no known forecasting systems that would have predicted the turbulence.

There have been two accidents caused by turbulence that have been associated with strong upper level winds in the vicinity of intruding thunderstorms. These are the accidents involving a United Airlines DC-10 near Hannibal, Missouri, on April 3, 1981, and an Air Canada L-1011 about 60 miles south of Wilmington, North Carolina, over the Atlantic Ocean on November 24, 1983. In the United Airlines accident there were eight serious injuries, and in the Air Canada accident there were five serious injuries.

In both cases there were developed or developing thunderstorms in the vicinity of the jet stream, and the aircraft encountered the turbulence several miles downwind of the thunderstorm cell. The United pilot reported being in cirrus clouds, probably an anvil cloud. There have been several studies of these accidents with efforts to describe the atmospheric mechanics. Hopefully, these will lead to a better understanding of the phenomenon. In any event, the area downwind of a thunderstorm in a jet stream regime should be considered potentially turbulent. This is not a new idea. The Air Force has preached this gospel for many years and at least one airline recommends aircraft avoid thunderstorms downwind by at least one mile for every knot of wind speed at flight altitude.

As a result of its investigation of these two accidents, the NTSB recommended that NOAA:

Advise its weather forecasters to be alert for situations where there is a jet stream or strong upper level winds in association with lines of developing or developed thunderstorms which may produce an area of severe clear-air turbulence, and to issue appropriate warnings of this potential turbulence to pilots through area forecasts, SIGMET's, or other appropriate means of communication.

In spite of years of efforts, the problem is not solved and will probably never have a complete solution but improvements can be made. Instrumentation is being improved in quantum jumps and with this improvement will come better observations, a better understanding of the dynamics of turbulence, and in turn better forecasts with a better understanding of turbulence will come improved training helping pilots to recognize some turbulent situations and avoid them. This will help but will not be the total cure. The scale of some turbulence is too small for accurate forecasts. Here the answer may be on-board detectors that will give pilots a warning of turbulence ahead.

However, the problem is approached, the efforts of many scientists and engineers will be needed to help bring increased safety and comfort to those not always so-friendly skies.

TABLE 1. U.S. Civil Aviation Aircraft Accident Totals for the Time Period 1982 to 1984.

	Total accidents	Fatal accidents	Fatalities	Weather accidents	Fatal weather accidents	Weather fatalities	Turbulence accidents	Fatal turbulence accidents	Turbulence fatalities
FAR Part 121 large commercial	62	9	253	28	5	235	15	0	0
FAR Part 135 commuter and air taxi	485	96	260	154	43	106	9	5	17
FAR Part 91 general aviation	9,302	1,688	3,377	2,593	717	1,561	198	94	237

TABLE 2. U.S. Civil Aviation Weather Accident Percentages for the Time Period 1982 to 1984.

	Weather accidents, percent of all accidents	Fatal weather accidents, percent of all fatal accidents	Weather fatalities, percent of all fatalities	Turbulence accidents, percent of all accidents	Fatal turbulence accidents, percent of all fatal accidents	Turbulence fatalities, percent of all fatalities	Turbulence accidents, percent of all weather accidents	Fatal turbulence accidents, percent of all fatal weather accidents	Turbulence fatalities, percent of all weather fatalities
FAR Part 121 large commercial	45	56	93	24	0	0	54	0	0
FAR Part 135 commuter and air taxi	32	45	41	2	5	7	6	12	16
FAR part 91 general aviation	28	42	46	2	8	6	7	13	15