The Case for Better Microburst Detection

Improvements upon the present low-level windshear advisory system (LLWAS) are suggested by the author.

by
Master Chief Stephen A. Stoll, U.S. Coast Guard
Adjunct Professor, Embry-Riddle Aeronautical University

Hazardous weather, particularly windshear, has been a subject of safety research in aviation for the past two decades. Windshear's most deadly manifestation is the microburst. Under the U.S. National Airspace System (NAS) plan, 65 airports were designated to receive an improved Low-Level Windshear Alert System (LLWAS). These airports are currently using this equipment as the primary means of detecting microburst at the surface and aloft (above individual wind sensors, i.e., where the wind from a microburst has not yet reached the anemometer wind sensor). It is the system air traffic controllers and pilots rely upon.

Although improvements have been made, LLWAS is not foolproof in the detection of microburst activity. There are a number of factors that reduce the system's performance such as sensor resolution, surface obstructions and blind spots. This paper focuses on these factors that reduce system performance and their effects on system reliability. Recommendations are offered to enhance system performance and flight safety.

Factors Reduce LLWAS Detection of Microbursts

Windshear may arise from a change in horizontal wind velocity along the flightpath or from the existence of a vertical wind component (Hopkins, 1984). Significant wind speed or directional changes cause the velocity of air moving across the wings of an aircraft to change rapidly. For example, the sudden replacement of a strong headwind by a tailwind can cause significant reduction in lift and may lead to an aerodynamic stall.

Windshear is most hazardous when encountered in close proximity to the ground during takeoff and landing. It is frequently caused by microbursts, which are small-scale downdrafts (diameters of less than 4 kilometers, 2.5 miles) that are produced by convective clouds, typically thunderstorms (Fujita, 1985). These downdrafts induce surges of winds that spread out horizontally when they reach the ground. The highly divergent nature of the microburst makes it a producer of deadly windshear. Figure 1 represents a dangerous situation to an aircraft flying through windshear produced by microburst.

A high concentration of accidents and incidents attributed to windshear occur in the United States. This does not mean that microbursts occur more frequently in this part of the world, but rather, reflects both an awareness of the phenomena and high traffic levels. This high

Graphic not available

Figure 1

incidence of reports is a result of the high frequency of takeoffs and landings in this country. Also, more cases are documented because of the methods of accident investigation in the United States which are based upon a well-established knowledge of windshear and microburst; accident investigators recognize it as an important cause factor to be addressed in analyzing accidents and incidents during takeoff and landing operations.

Low-Level Windshear Alert System Reviewed

The LLWAS was initially conceived to be an interim windshear detection system. However, it has matured into a fully sponsored U.S. Federal Aviation Administration (FAA) flight safety program within the National Airspace System. An initial cost-benefit analysis was completed in 1978, and 110 sites were identified by the FAA for system installations. Site selection was based upon the number of passengers using the terminal, the number of takeoffs and landings, and frequency of significant weather events occurring (Nilsen, 1990).

The basic six-sensor LLWAS has been the principle windshear detection system for the past 12 years. Since 1982, four serious microburst-related incidents have occurred where this detection system was in operation. Accident investigations by the U.S. National Transportation Safety Board (NTSB) and the FAA revealed that two major system inadequacies existed. First, the anemometers did not detect the microbursts aloft due to the sensors' close proximity to the ground (Figure 2). These downbursts were detected while an aircraft was in a critical phase of flight. Second, the microbursts were encountered outside the perimeter of the sensor network (GAO/RCED-87-208).

Efforts were made to design a more accurate windshear detection system to provide adequate warnings to pilots. Upgrading this basic system to the "improved" six-sensor LLWAS has been ongoing and was completed in June 1991.

The improved LLWAS incorporated modifications to the system software that improved its capability to detect windshear. Specifically, the installation of an increased capacity processor and the introduction of an improved algorithm (a new mathematical method of computing wind divergence) have both enhanced microburst-detection performance. Although the system detection has improved, it still cannot forewarn the presence of microburst aloft. Fur-

Microbursts — A Worldwide Concern

Scientists and the aviation world know that microbursts and low-level windshear historically have been primary factors in the majority of U.S. weather-related accidents/incidents. The phenomena occur throughout the world as well, but their frequency is not well known because of lower air traffic densities and weather observing systems that may not detect such small-scale, but severe, hazards.

Dr. T. Theodore Fujita (*The Downburst*, 1985) states that "not until knowledge of microburst-related windshear becomes known widely to international aviation communities will microburst-induced windshear be recognized as an important cause of worldwide accidents/incidents during takeoff and landing operations." He notes that the earliest verified microburst-related accident took place on June 24, 1956, not in the United States, but in Kano, Nigeria. Of 45 passengers and crew, 32 were killed.

Microbursts outside the United States prior to 1985 have been documented in American Samoa, Australia, Bahrain, Qatar, India and Mexico. Recently, at an international aviation weather conference, Japanese scientists reported on a microburst that occurred on July 19, 1990, in Menuma Town, Japan — microbursts were thought to be rare in Japan. Doppler radar was used to observe a microburst near Chitose Airport in Japan on September 22, 1988, that was spawned by a severe thunderstorm which also produced a tornado and gust front.

Until two years ago, microbursts in Australia were not well detected and therefore scarce. The Bureau of Meteorology examined 15 days of Doppler radar data collected in February 1989 at Darwin and discovered a surprisingly high incidence of microbursts — an average of five per day during the period.

Worldwide, countries are modernizing aviation weather systems. For example, France developed an integrated meteorological observing system for runways, which has been installed in Morocco and soon will be installed at Paris-Orly airport. France is also conducting comparative radar studies for detecting low-level windshear at airports. Sweden is several years into its MET90 project, launched in the late 1980s, which will modernize its aviation weather system. Radars similar to the FAA's Terminal Doppler Weather Radar likely will be installed in Japan and Hong Kong. A Doppler weather radar is situated near C.K.S. Airport in Taipei, Taiwan, to detect low-level windshear. Many other international airports are considering the installation of the new Phase III Low-Level Windshear Alert System.

Within a few years, onboard in situ devices that warn pilots of windshear will be required on all U.S. air carriers. Some of these systems will also provide recovery guidance that includes increasing pitch to optimum angle and applying maximum available thrust. In addition, several radar and avionics manufacturers are developing onboard, forward-looking microwave and LIDAR (Light Detection and Ranging) radar systems that are designed to look ahead of the aircraft to provide advanced warning of microburst conditions. Aircraft so equipped will not depend on ground-based aviation weather systems. So far, there is no evidence that countries other than the United States will be required to have similar onboard devices. As worldwide air traffic increases, the likelihood of microburst encounters will also increase without adequate sensing and warning systems and pilot training.

Deborah Davis, Special Assistant
U.S. National Center for Atmospheric Research
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thermore, the probability of detecting microburst is significantly impaired due to the limited area of coverage that the six-sensor field provides. This includes the critical approach and takeoff corridors.

Although sensor relocation and a revised algorithm have increased windshear detection, the effectivity number (measurement of the system's ability to detect microbursts) remains a low 48 percent. This value can decrease or increase depending on the geometry and number of sensors.

Further research and development have lead to still another LLWAS version. The primary objectives for the development of this "enhanced" LLWAS were to increase the number of sensors and to establish an effective sensor location geometry to improve detection of mi-

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Figure 2

croburst events, and provide a means of identifying the runway affected by windshear. Currently, there are two sites which have the enhanced LLWAS network expansion. These prototype systems are located at Denver's Stapleton International Airport and New Orleans Moisant International Airport.

The enhanced LLWAS has 11 or more sensors nominally spaced 2.5 kilometers (1.5 miles) apart to give runway-specific alarms. This has provided a significant increase in resolution from the basic system's four-kilometer (2.5-mile) resolution. The new siting guidelines (FAA Order 6560.21A) address the placement of the sensors geometrically to achieve the proper location density for detecting microbursts. They also address placement requirements in order to avoid wind measuring error which might be introduced by placing anemometers too close to man-made or natural obstructions. The sensor spacing provides optimum probability of microburst detection relative to system implementation cost. The Stapleton network includes 16 anemometers and has an extended feature which can detect microbursts 4.8 kilometers (three miles) from the end of the runway. The test installation at New Orleans has 11 sensors and monitors one mile along the approach path. An evaluation of the enhanced 11-sensor LLWAS was conducted in the summer of 1987 at Stapleton. It was superior to the improved six-sensor network, mainly because of the increased system resolution. Although the network expansion, much like the one used at New Orleans, has been greatly improved, it still has a low effectivity number (in the low 60 percent range). The extended network expansion at Stapleton monitors three miles along the approach path and has an effectivity number in the low 90 percent range, a very significant advancement.

On July 8, 1989, there was an incident at Stapleton involving a Boeing 737-200. An extended network enhanced LLWAS accurately indicated the presence of winds associated with a microburst that could cause a 95-knot headwind loss to the aircraft (Hughes, 1990). The 10 additional sensors used in this version, particularity the sensors located on the approach path, were responsible for detecting this microburst. As a result of this incident, the NTSB in June 1990 called for all airports not scheduled to have installation of Terminal Doppler Radar to be upgraded to the enhanced 11-sensor version (*Aviation Week and Space Technology*, July 23, 1990). This identical upgrade had been previously recommended by the FAA in May 1989 but currently, funding is far short of the amount needed for this transition. Regardless of this upgrade, the system would not be as effective as Denver's enhanced 16-sensor system because the problem of detecting windshear aloft has not been resolved.

Factors That Reduce System Performance Explored

During this research project, many factors that reduce LLWAS system performance were explored. They include: A. deficient sensors, B. system resolution, C. system siting, D. logistical constraints, E. sheltering, F. microburst asymmetry and G. blind spots. The effects of these factors can be minimized, but they will always have some impact on system performance.

A. *Deficient Sensors*. During the operational test and evaluation of the enhancements to the 11-sensor LLWAS at Stapleton, two stations reported very light winds during a microburst incident. Windrose analyses (use of a compass diagram designed to show the frequency, direction and speed range of winds for a given location) for these stations and a center field station were performed. The windroses showed that these stations performed poorly when compared with the center field station. It was determined that the stations required maintenance or were severely shielded in all directions (Smythe, 1989). The consequence of this abnormality was that the system did not detect the microburst. In order for the system to work with any degree of reliability, all the sensors must be geometrically positioned to maximize detection coverage and be in good working order, or the system's performance will be dramatically degraded.

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B. *System Resolution*. The six-sensor, improved system had microburst detection capabilities in the immediate vicinity of the airport. However, the absence of LLWAS sensors on the approach and departure paths beyond airport boundaries has resulted in missed or incomplete detection of events in the regions where aircraft are most vulnerable to windshears from microbursts (Richmond, 1986).

NTSB reports have indicated that four of the last five fatal accidents were located off the airport property along the approach path (Kessler, 1990). During departure, an aircraft usually leaves the ground well before the departure threshold is attained and operates nearly at full power which, in itself, provides an increased measure of safety. Thus the approach path is potentially the most critical phase of flight. Currently, only two airports have the "extended" feature which covers the glideslope for the arrival and the departure routes. Off-airport anemometry is scheduled for deployment at seven additional airports by 1992.

C. *System Siting*. The effectiveness of LLWAS is dependent not only upon the reliability of the electronic equipment, but also upon the location of the wind sensors. Improper siting of these will create false alarms, or decrease sensing of correct alarms, which can significantly degrade the performance of the windshear algorithm. The methodology in designing this windshear system at an airport for optimum performance must include maintaining the required geometry of the sensor array and adhering to spacing requirements (FAA Order 6560.21A, 1989).

Requirements for this system were calculated from siting criteria gathered during a number of scientific studies, and were developed by the U.S. National Center for Atmospheric Research (NCAR) and Cermak, Peterka, Petersen (CPP), Inc. (FAA Order 6560.21A, 1989). To obtain accurate runway wind component estimates, there is less freedom in the design of the station geometry, especially with the distance of the stations from the runway centerline. If the stations are placed 750 meters to 900 meters (2,500 feet to 3,000 feet) on either side of the runway path, then runway wind components can be reasonably estimated. Examples of station placement, relative to runway orientation, are shown in Figure 3 (a) and (b).

The radius of the strong outflow of a microburst can be as small as 1,500 meters (5,000 feet). Therefore, if the stations are placed too far apart, it is possible for a microburst to occur between them and not be observed until the microburst outflow reaches a station. If the station spacing is no greater than 26,000 meters (8,500 feet), then most microbursts that occur in the network will be promptly detected (Chan and Nyberg, 1989). Occasionally, situations exist where a small individual microburst may occur between sensors and may or may not show strong enough divergence to be detected.

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Figure 3

Another siting consideration is local wind circulations produced by coastal or mountainous terrain. These local features must be understood in choosing a specific sensor site to optimize the system's siting effectiveness. According to J. Peterka, chief scientist and co-author of the FAA siting guidelines (Order 6560.21A), each airport should be more closely studied for local peculiarities and adjusted accordingly, rather than using generalized guidelines for them (Peterka, 1991). A recently completed wind tunnel study, which evaluated sensor sites at Greater Pittsburgh International Airport, Pa., U.S., suggests that the influences from terrain, climatology and atmospheric stability play an important role in the sensor placement to maximize system performance. This implies that the FAA's siting guidelines are not site specific, which may cause a reduction in the system's ability to detect microbursts.

D. *Logistical Constraints*. Increasing the network station density to optimize microburst detection has led to several significant logistical concerns. To achieve high system effectivity, sensors should be moved from the runway centerline, which imposes a requirement to acquire off-airport locations for sensors. A sensor site occupies approximately 37 square meters (400 square feet). Negotiation of a lease or purchase price with property owners, or possibly property condemnation, is time consuming, expensive and labor intensive. The LLWAS Project Office in Washington, D.C., U.S., recognized this problem and began a lease/acquisition process.

Establishing sensor operations in remote locations could involve building roads, installing power lines or using boats where sensors would be deployed over water. Site vandalism and the time required for immediate maintenance due to poor accessibility are two additional concerns that could affect system performance.

In many cases, locating sensors outside the airport boundary presents problems such as trees, buildings or terrain irregularities. To measure representative wind over such rough surface areas, very tall masts, nine meters to 45 meters (30 feet to 150 feet) above ground level (agl) would have to be used. There are cases where airspace regulations prevent a shielded sensor from being raised to this prescribed height. The siting team has recommended that such sensors be relocated to sites where airspace regulations would not limit height.

To obtain a high degree of microburst detection probability, the system must stay within siting guideline requirements. There may be a degradation of detection capability, or an increase in warning lead time, if siting guidelines or height requirements are not precisely followed.

E. *Sheltering*. Air traffic controllers and pilots have reported occasional nuisance windshear advisories, which can lead to mistrust of the system. Sheltering has caused some false microburst and windshear alarms. These types of false alarms can occur when one sensor indicates a considerably lower wind speed than the others because of sheltering. Recent collections of data from the LLWAS in New Orleans (Marks and Jaffe, 1984), Denver (Barab et al., 1985; Barab et al., 1988) and many other U.S. locations have revealed a loss in performance due to sheltering at many sensor locations caused by surrounding obstructions (Jaffe, 1989). Since the time when the system was first installed, trees have grown and buildings have been constructed in the vicinity of many sensors, thus inducing even greater sheltering effects.

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Recently, more detailed information on the siting of anemometers has been provided to the FAA by CPP. This information describes the sheltering effects of forests, tree lines, buildings, hills and ridges, which are divided into the following categories: three-dimensional, two dimensional, forest canopies, terrain features and changes in roughness (FAA Order 6560.21A, 1989).

Estimations of terrain roughness and barrier obstructions have been determined for sensor sites. Because of this appraisal, a CPP siting evaluation team has recommended minimum sensor heights which would limit shielding error to 20 percent to 30 percent, an acceptable level of error. Additionally, some allowances have been made for future tree growth around sensors in wooded areas, but when sensor relocation is necessary, it may cause a decrease in system effectiveness due to a variance from siting guidelines.

F. *Microburst Asymmetry*. A microburst tends to move asymmetrically along an axis in the direction of its movement; it does not spread out evenly as does the ripple when a pebble is dropped into a pool of water. The asymmetry of microburst outflows is a factor in the detection of microburst in the airport vicinity, as well as for the estimation of windshear along runway flight paths within a microburst (Eilts, 1989).

The improved and enhanced LLWAS uses a new microburst algorithm that has stations (sensors), triangles (lines) and triangle edges referred to as elements and uses a symmetric microburst model. This model, on some occasions, is likely to misrepresent the wind field due to the asymmetry of microburst (Figure

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Figure 4

4). However, due to asymmetry, there is still the possibility of a microburst occurring near an element (line or edge), which will cause a time delay in the issuance of a warning to the pilots.

G. *Blind Spots*. An impacting microburst creates an effective "blind spot" (sometimes referred to as a dead spot) in the wind field within a disc of approximately 0.3 kilometers (0.18 miles) in radius, or approximately one-eighth the distance to the nearby stations. For example, when the sensors are 2,400 meters (8,000 feet) apart, the "blind spots" affect the detection of microburst. Furthermore, the arrangement and number of dead spots lowers the percentage of area of network coverage (Figure 3). Blind spots make up approximately 50 percent of the total area covered by the six-sensor system, whereas the 11-sensor enhanced system has only a 15 percent blind spot area. Experimentally, a combined 42-station anemometer mesonet (intermediate-size network) has eliminated some blind spots by the dense overlapping of the triangle and edge detection area. To reduce the potential risk from a divergent wind hazard along the runway corridor, stations should be located so that the regions of lower detectability (blind spots) are not near the runways (Cornman and Wilson, 1989). However, as in the case of asymmetry, the blind spots are an inherent problem with the present system and cause a time delay in the issuance of a warning to the pilots.

Results of Research Presented

From the information researched, the following conclusions can be drawn:

- The system improvements have not resulted in the ability of the system to detect microburst activity aloft.

- Given the current parameters and cost limitations, it is doubtful whether the improved LLWAS will achieve optimum performance in the detection of microburst due to sensor error created by shielding, subjective estimations of surface roughness, and limited site studies evaluating the impact of local wind circulation and atmospheric stability.

- Although the six-sensor system has been improved by using Doppler radar to validate microburst activity, there have been incidents where the system either did not detect, or was late in detecting, windshear. This has been attributed to blind spot areas or limited system resolutions.

- To date, no formal study has been conducted on the improved six-sensor system which is the primary detection system for 65 major airports.

The extended LLWAS expansion network has superior reliability in the detection of surface microburst. This prototype system, which is installed at Stapleton, has 16 sensors that are geometrically positioned. Furthermore, this system has limited blind spot areas and experiences minimal effects from surface obstructions. This tends to increase system performance with lower false alarm rates. This ground system reflects the state-of-the-art in microburst detection technology and affords adequate protection in the terminal area. Conclusions from experiments done at Denver have been applied to the improved and enhanced systems located in various airports throughout the country, each of which has unique local features. To account for local differences, alterations may have to be made to the prescribed guidelines to prevent degradation of system performance.

Recommendations suggested by the author include:

- The microburst detection problem can be offset, to some degree, by the combined use of the extended LLWAS and Terminal Doppler Weather Radar (TDWR), which will eventually be located at 45 selected airports in the United States. The integration of these two systems is appropriate because technical deficiencies in one system sometimes become technical attributes in the other. The Microwave Doppler system can detect the precursors of microburst aloft, and can be an excellent short-range forecasting tool. Also, LLWAS coverage is limited by the geographical extent of its network, whereas the TWDR has a much larger range of coverage, particularly along approach and departure paths. Although the cost of this combined system is currently prohibitive, it would provide the minimum level of protection for advance warning of dangerous windshear conditions.

- A cost-effective solution to improve the detection of microburst aloft was advocated by Alfred Bedard of the U.S. National Oceanographic and Atmospheric Administration (NOAA). He has suggested the use of pressure sensors to measure the "pressure nose" which is a sharp increase in pressure build-up in advance of microburst downdraft (Gannon 1987). These pressure sensors would detect a pressure jump before the descending plume of the microburst arrives at the surface. Airports could be instrumented with an array of pressure sensors that accompany the extended LLWAS. These arrays should be spaced no more than 800 meters (0.5 miles) apart. The output from these instruments would be processed by computer into forms that can be displayed visually to control tower personnel (Fujita and Caracena, 1977). This would increase the lead time afforded to the pilot to plan for evasive action when confronted with microburst activity and, therefore, may increase the margin of flight safety.

- Airborne atmospheric sensing through equipment installed in aircraft may offer the best alternative when assessing windshear aloft at airports not protected by TDWR. Furthermore, it could be the primary means for microburst detection, both aloft and on the ground, for approximately 290 towered airports throughout the country which have little or no detection capability at the present time. The U.S. National Aeronautics and Space Administration (NASA), the FAA and the private sector are now engaged in developing airborne sensors that will detect hazardous windshears and provide cockpit crew members sufficient lead time to avoid windshear produced by downburst. These airborne sensors include Doppler radar, LIDAR and passive infrared sensing. This existing state of on-board detection of adverse atmospheric phenomena could be significantly enhanced by the inclusion of some or all of these sensing systems, particularly when flying in areas with limited or no ground detection capability.

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About the Author

Master Chief Stoll is a marine science technician in the U.S. Coast Guard, stationed at the Yorktown Training Center in Virginia, where he is on his second tour in the Marine Safety Branch. Previously, he served as a qualified weather forecaster at three Coast Guard air stations which include Cape Cod, Mass., Kodiak, Alaska and Elizabeth City, N.C. and also aboard the icebreaker USCGC Glacier, *which traveled to Antarctica.*

Stoll is an adjunct professor at Embry-Riddle Aeronautical University and teaches meteorology. Presently, he holds a master of aeronautical science degree from Embry-Riddle and a bachelor of science degree in physical science with a concentration in meteorology from Old Dominion University.

Aviation Statistics

Trends of Worldwide Bird Strikes Calendar Years 1984-1989

by
Shung C. Huang
Statistical Consultant

During the period 1984 through 1989, the International Civil Aviation Organization (ICAO), under its ICAO Bird Strike Information System (IBIS), received more than 27,390 bird strike reports, an average of 5,480 per year. However, only about 100 of the 164 ICAO contracting states participated each year.

An analysis of the annual bird strikes by bird species, location, phase of flight, aircraft damage and effect on flight reveals that there were few changes in the annual patterns. A great majority of the strikes occurred on or near airports; more than half of the strikes occurred during the approach for landing and landing roll; and, 40 percent occurred during takeoff run and initial climb. The damage to the aircraft involved was evenly distributed to wing, engine, windshield, fuselage (random locations) and nose, and about 90 percent of the strikes had no effect on flight. Of the known species of the birds involved, the majority were gulls, terns and perching birds (i.e., sparrows, thrushes and warblers).

Table 1 shows the annual bird strikes by bird species and Figure 1 shows the percentage distribution. Note that in nearly every year the species of approximately 40 percent of the birds involved in the strikes was unknown. Of the known

Table 1
Bird Strikes by Bird Species

Bird Species	1984	1985	1986	1987	1988	1989	Total
Gulls/Terns	785	806	784	899	978	998	5,250
Perching Birds	527	617	711	682	717	981	4,235
Hawks/Eagles etc.	304	309	330	357	397	394	2,091
Lapwings/Plovers	358	255	237	214	196	252	1,512
Pigeons/Doves	132	131	141	154	177	109	844
Other	278	283	330	341	326	325	1,883
Unknown	1,439	1,644	1,916	2,412	2,453	1,718	11,582

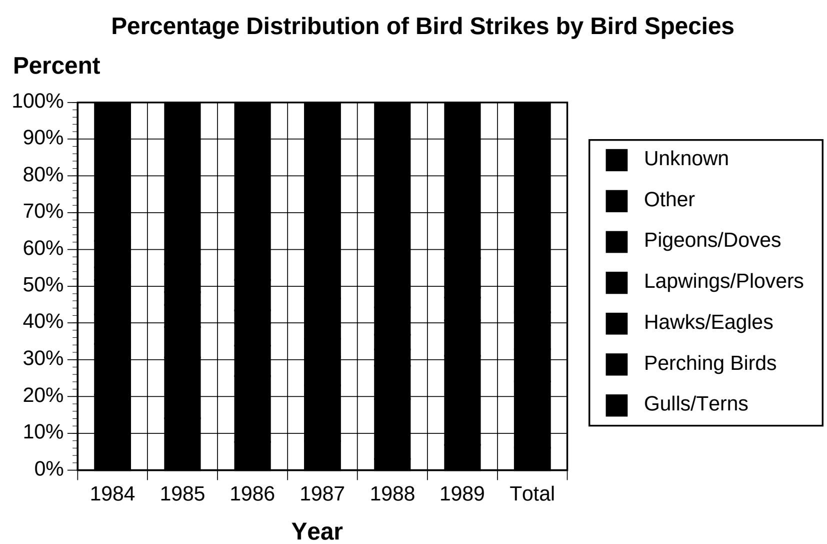


Figure 1

bird species involved, the majority were small birds, such as gulls, terns, pigeons and doves or perching birds. Only eight percent were large birds such as hawks and eagles.

Table 2 shows annual bird strikes by the phase of flight of the aircraft involved, and Figure 2 shows the percentage distribution. Approximately 95 percent of the strikes occurred during descent/approach, landing, takeoff or climb. The phase of flight of the remaining few occurrences were unknown. Almost all strikes occurred on airports and near airports, and Table 3 shows the annual bird strikes by location; Figure 3 shows the percentage distribution. Note that "on airport" strikes were those which occurred at or below 200 feet above ground level (agl) during approach or 500 feet agl during climb, or during the parked, taxi, takeoff run or landing roll phase. "Near airport" strikes were strikes which occurred between 201 feet agl and 1,000 feet agl during approach or between 501 feet agl and 1,500 feet agl during climb. The percentage distribution of the strikes shows little change during the period; annually, strikes occurring at airports account for 66 percent; strikes near airport and off airport each account for seven percent; and, locations for the remaining 18 percent were unknown.

Figure 4 shows the damage to aircraft by location of the strikes. The aircraft engine appears to be struck slightly more often than other parts of the aircraft. In terms of annual distribution, the chance of aircraft engine, nose, wings, windshield,

Table 2
Bird Strikes by Phase of Flight

Phase of Flight	1984	1985	1986	1987	1988	1989	Total
Approach	1,076	1,160	1,400	1,487	1,414	1,551	8,088
Take-off run	1,015	1,090	1,102	1,229	1,335	1,136	6,907
Landing roll	770	829	846	971	1,177	895	5,488
Climb	539	582	642	728	645	739	3,875
Other	107	106	135	174	188	179	889

Percentage Distribution of Bird Strikes by Phase of Flight

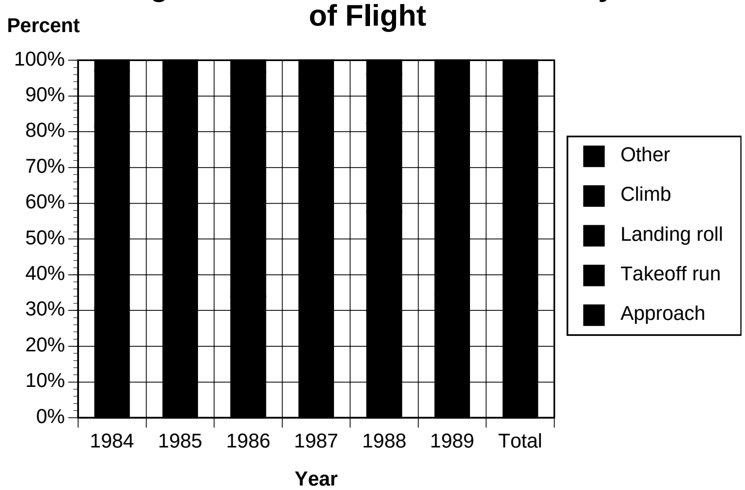


Figure 2

Table 3
Bird Strikes by Location

Location	1984	1985	1986	1987	1988	1989	Total
On Airport	2,704	2,844	3,003	3,205	3,282	3,143	18,181
Near Airport	274	335	379	415	398	467	2,268
Off Airport	223	287	342	356	395	513	2,116
Unknown	622	579	725	1,083	1,169	654	4,832

Percentage Distribution of Bird Strikes by Location

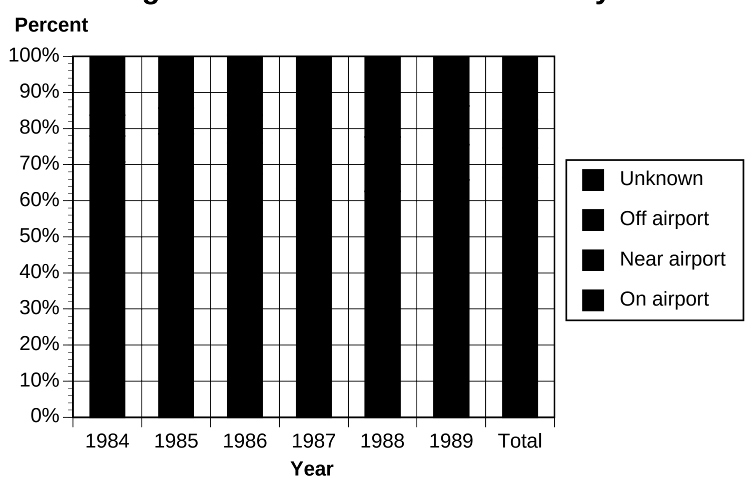


Figure 3

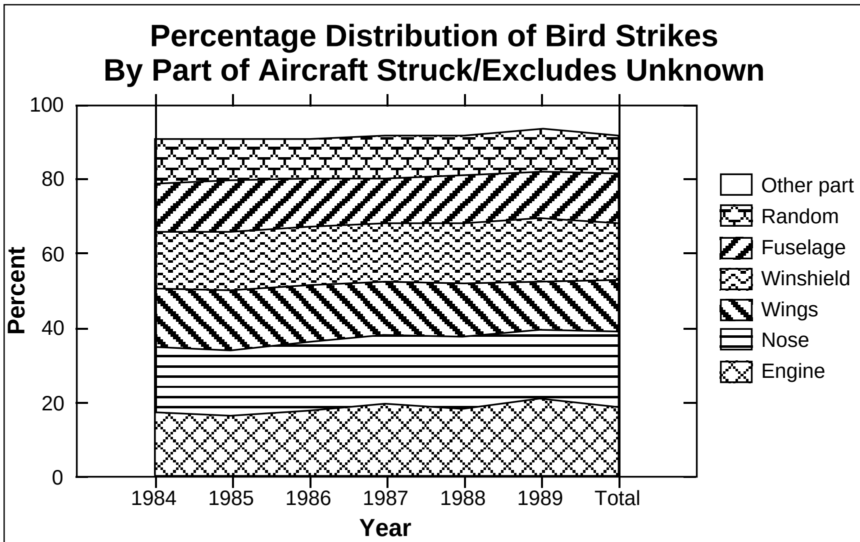


Figure 4

fuselage and random locations to be struck has been very constant. Of the type of engine to be struck, the damage ratio for turbine engines was much higher than for reciprocating engines (Figure 4A). Of all types of turbine engines, the damage ratio for turboshaft engines was the highest.

It is not known how many bird strikes worldwide result in aircraft accidents. During the 1984-1989 period, there were 26 bird strike accidents involved in U.S. general aviation flying, two of which were fatal. The ICAO bird strike statistics, however, did not identify the number of bird strikes that were the cause/factor of aircraft accidents. ICAO information shows that of the total strikes, more than 24,000, or almost 89 percent, had no effect on flight. Of the 1,500 bird strikes which had an effect on flight, (11 percent of the totals), 684 strikes or 45 percent, caused a precautionary landing, 35 percent resulted in an aborted takeoff, while 11 percent caused engine shutdown (Figure 5). ♦

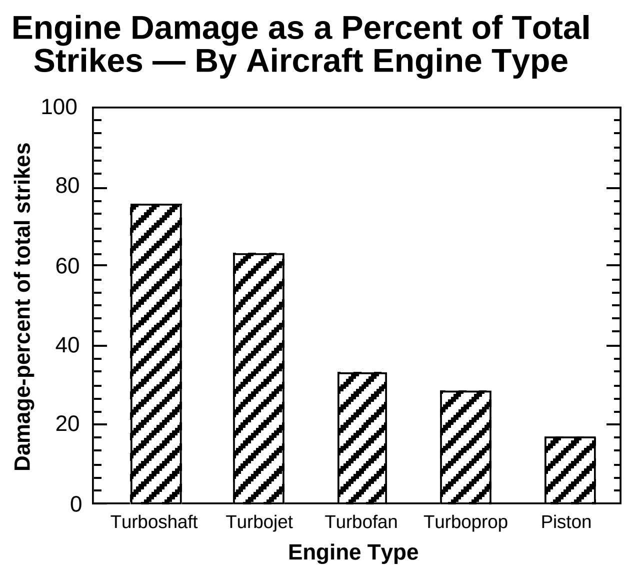


Figure 4A

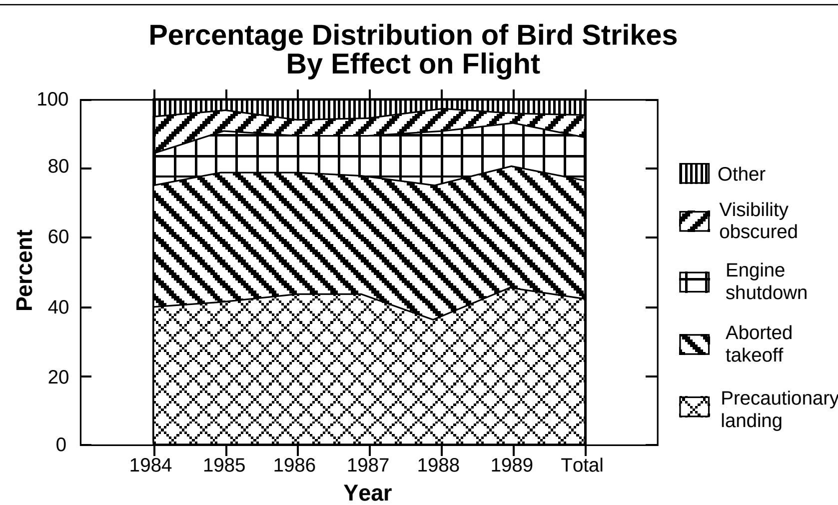


FIgure 5

Reports Received at FSF Jerry Lederer Aviation Safety Library

Updated Reference Materials (Advisory Circulars, U.S. Federal Aviation Administration - FAA):

00-44CC	Aug 1991	Status of Federal Aviation Regulations
20-110G	Jun 1991	Index of Aviation Technical Standard Orders
20-126B	May 1991	Aircraft Certification Service Field Office Directory (Listing)
61-67B	May 1991	Stall and Spin Awareness Training
70/7460-1H	Aug 1991	Obstruction Marking and Lighting
70/7460-1H	Aug 1991	Change 1 to Obstruction Marking and Lighting
90-72B	Jun 1991	Minimum Safe Altitude Warning (MSAW) En Route Minimum Safe Altitude Warning (E-MSAW)
120-26H	Jun 1991	International Civil Aviation Organization Three-letter and Radiotelephone Designators
120-40B	Jul 1991	Airplane Simulator Qualification
135-14A	Jun 1991	Emergency Medical Services/Helicopter (EMS/H)
150-5000-3N	May 1991	Address List for Regional Airports Divisions and Airport District/Field Offices
150-5210-13A	May 1991	Water Rescue Plans, Facilities, and Equipment
150/5220-10A	Jul 1991	Guide Specification for Water/Foam Aircraft Rescue and Firefighting Vehicles
150/5300-13	Jun 1991	Change 1 to Airport Design
183.29-1Z	Jul 1991	Designated Engineering Representatives

Updated Reference Materials (Federal Aviation Regulations, U.S. FAA):

Part 108	Jul 1991	Change 9 to Part 108-Airplane Operator Security

Reference

Advisory Circular 61-89D, 02/21/91, Pilot Certificates: Aircraft Type Ratings. — Washington, D.C. : United States. Federal Aviation Administration, 1991, February 2. 40p. in various pagings.

AC 61-89C, dated March 6, 1990 is cancelled.

Key Words
1. Air Pilots — Certificates.
2. Air Pilots — Training.

Contents: Ground Instruction: Stage 1, General Operation Subjects, Lessons #1-5 — Stage 2, Airplane Systems and Components, Lessons #6 - 21 — Stage 3, Aircraft-Specific Emergency Training, Lessons #22-26 — Stage 4, Systems Integration Training, Lessons #27-34 — Stage 5, Flight Instruction, Lessons #35-38 — Pilot Certificate Aircraft Type Designations.

Summary: This advisory circular (AC) provides a generic type rating curriculum that may serve as a basis for schools to develop a training course outline (TCO) to meet the type rating training requirements of the U.S. Federal Aviation Regulations (FAR) Parts 61 and 141. This AC also provides pilot certificate designations adopted by the FAA for aircraft type ratings and standardizes aircraft designations placed on pilot certificates to show pilot type rating qualifications. [Purpose]

Advisory Circular 61-98A, 03/26/91, Currency and Additional Qualification Requirements for Certificated Pilots. — Washington, D.C. : United States. Federal Aviation Administration, 1991, March 26. 30p. in various pagings.

AC 61-98, "Scope and Content of Biennial Flight Reviews," dated September 1, 1987, is cancelled.

AC 60-12, "Availability of Industry Developed Guidelines for the Conduct of the Biennial Flight Review," dated February 11, 1976, is cancelled.

<u>Key Words</u>
1. Air Pilots — Certificates.
2. Air Pilots — Training.

Contents: Flight Review — Recent Flight Experience — Instrument Competency Check — Transition to Other Makes and Models of Airplanes.

Summary: This advisory circular (AC) provides information for certificated pilots and flight instructors to use in complying with the flight review required by the U.S. Federal Aviation Regulations (FAR). It also provides guidance regarding transition to other makes and models of aircraft. This AC is particularly directed to general aviation pilots holding recreational or higher grades of pilot certificates who wish to maintain currency in aircraft for which they are rated, or to transition to other makes and models and to certificated flight instructors (CFIs) who give flight instruction to support such activities. [Purpose, Focus]

Federal Aviation Regulations, Part 1 - Definitions and Abbreviations; Change 14. — Washington, D.C. : United States. Federal Aviation Administration, [1991].

Summary: This change incorporates Amendment 1-37, Small Airworthiness Review Program Amendment No. 2, adapted December 21, 1990, effective February 4, 1991, in U.S. Federal Aviation Regulation (FAR) Part 1.

Advisory Circular 23-10, 8/5/91, Auxiliary Fuel Systems for Reciprocating and Turbine Powered Part 23 Airplanes. — Washington, DC : U.S. Federal Aviation Administration, 1991. 39 p. in various pagings.

Summary: This advisory circular (AC) provides guidance and criteria for the installation of auxiliary fuel systems in U.S. Federal Aviation Regulations (FAR) Part 23 airplanes. It is intended to be used for auxiliary fuel system installations in aircraft including fuselage, wing or external configurations. Installations that involve changes to primary structure, aerodynamics, airspeed, mass distribution (those that could induce flutter changes), maximum weight or changes in center of gravity (CG) limits require additional substantiation that is beyond the scope of this AC. [Scope]

Advisory Circular 21-29, 8/6/91, Reporting Suspected Unapproved Parts. — Washington, D.C.: U.S. Federal Aviation Administration, 1991. 4 p. in various pagings.

Summary: This advisory circular (AC) provides information and guidance for use in reporting suspected unapproved aircraft parts and includes procedures for referral of such reports to the appropriate U.S. Federal Aviation Administration (FAA) office. It also introduces FAA Form 8120-11, "Suspected Unapproved Parts Notification," which provides a standardized method of reporting suspected unapproved parts to the FAA. [Purpose]

Advisory Circular 25.1529-1, 8/1/91, Instructions for Continued Airworthiness of Structural Repairs on Transport Airplanes. — Washington, D.C. : U.S. Federal Aviation Administration, 1991. 6 p.

Summary: This advisory circular (AC) provides instructions to ensure continued airworthiness of structural repairs on transport category airplanes. It addresses the approval procedures to follow when making structural repairs to structures certificated under the damage tolerance requirements of paragraph 25.571 of U.S. Federal Aviation Regulation (FAR) Amendment 25-45, and to type designs with supplemental inspection documents (SID) which were based on these criteria. The methods provided are not the only means acceptable for showing compliance; the FAA will consider other methods of compliance the applicant may elect to present. [Purpose]

Advisory Circular 91-67, 6/28/91, Minimum Equipment Requirements for General Aviation Operations Under FAR Part 91. — Washington, D.C. : U.S. Federal Aviation Administration, 1991. v, 31 p. in various pagings.

Summary: This advisory circular (AC) describes acceptable methods for the operation of aircraft under U.S. Federal Aviation Regulation (FAR) Part 91 with certain inoperative instruments and equipment which are not essential for safe flight. It also explains the process for obtaining U.S. Federal Aviation Administration (FAA) approval of a minimum equipment list (MEL). [Purpose]

Advisory Circular 150/5390-3, 5/31/91, Vertiport Design. — Washington, D.C. : U.S. Federal Aviation Administration, 1991. vi, 35p. in various pagings.

Summary: This advisory circular (AC) provides guidance to planners and communities interested in development of a civil vertiport or vertistop. The standards and recommendations contained in this AC are recommended by the U.S. Federal Aviation Administration (FAA) for use in the design of civil vertiports and vertistops. For vertiport projects receiving federal grant-in-aid assistance, the use of these standards is mandatory. At certificated vertiports, the standards may be used to satisfy specific requirements of Federal Aviation Regulation (FAR) Part 139, "Certification and Operations: Land Airports Serving Certain Air Carriers, Subpart D." [Application]

Reports

FAA Staffing: New Pay Act Offers Options to Bolster Maintenance Work Force. Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, House of Representatives / United States. General Accounting Office. — Washington, D.C. : U.S. General Accounting Office*, April, 1991. Report No. GAO/RCED-91-92; B-242887. 12 p.

Key Words
1. Air Traffic Control — Electronic Equipment — Maintenance.
2. Air Traffic Control — Officials & Employees — Salaries.
3. United States. Federal Aviation Administration — Officials & Employees — Salaries.
4. United States. Federal Aviation Administration — Personnel Management.

Summary: The U.S. General Accounting Office (GAO) was asked to follow up a 1987 report on the shortage of technicians for maintaining the air traffic control system by determining whether shortages in the maintenance technician work force have adversely affected air traffic control (ATC) operations and assessing plans of the U.S. Federal Aviation Administration (FAA) to increase its maintenance capability. GAO found that FAA has hired new staff, relied more on contractors to maintain new equipment, increased overtime usage and reduced maintenance coverage at some ATC facilities. The U.S. Congress has also authorized financial incentives under the Federal Employees Pay Comparability Act of 1990 that may help FAA bolster technician staffing.

"Flight Safety — An Endless Task," Proceedings of the 43rd Annual International Air Safety Seminar, November 19-22, 1990, Rome, Italy / Flight Safety Foundation. — Arlington, VA : Flight Safety Foundation (2200 Wilson Blvd., Suite 500, Arlington, VA 22201 U.S.), c. 1990. xx, 306 p., 26 p. ISSN: 0270-5176.

Key Words
1. Aeronautics — Safety Measures — Congresses.

2. Aeronautics — Human Factors — Congresses.
3. Airpilots — Training.
4. Airlines — Management.
5. Aeronautics — Accidents — Investigation.

Notes: Hosted by Alitalia Airlines; "Proceedings of the 43rd International Air Safety Seminar are dedicated to the memory of J.R. Riedmeyer 1928-1991."

Contents: Opening / Capt. Robert Weatherly — Welcome / Ing. Ferruccio Pavolini (Alitalia Airlines) — Response / Stuart Matthews — Your Flight Safety Foundation / John H. Enders — Keynote Address / Eng. Professor Federico Quaranta (Director General, Italian Civil Aviation). Session Headings: The Aviation Safety Posture — Training: Targeted at Aviation Safety — Operational Considerations for Safety Enhancement — How Management Views Aviation Safety: A Panel Discussion — International Aspects of Aircraft Accident Investigation: Cross-Border Coordination — Technology: Tool of Master? — Appendices.

Summary: "Fifty-four countries were represented by the more than 400 attendees. 'Flight Safety — An Endless Task,' the seminar's theme, is likely to remain timeless in our industry because safety demands never-ending vigilance, a point well-made in many of the presentations at this seminar." [Preface]

*National Technical Information Service (NTIS)
Springfield, VA 22161 U.S.
Telephone: (703) 487-4780

*U.S. General Accounting Office (GAO)
Post Office Box 6012
Gaithersburg, MD 20877 U.S.
Telephone: (202) 275-6241

Accident/Incident Briefs

This information is intended to provide an awareness of problem areas through which such occurrences may be prevented in the future. Accident/incident briefs are based upon preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be accurate.

Air Carrier

The Taxiway That Looked Like a Runway

British Aircraft Corp. BAC One-Eleven: No damage. No injuries

The pilot was flying the aircraft for a night landing on runway 8L in visual meteorological conditions (VMC) but the aircraft touched down on taxiway 2. The pilot stopped the aircraft slightly more than 600 feet short of a taxiing Boeing 737. The 737 pilot had seen the landing lights of the approaching aircraft and turned off the taxiway to avoid it. There was no damage or injuries, although the Boeing aircraft became stuck in soft ground.

The pilot of the BAC One-Eleven was confused by the lighting patterns on the ground and landed on the taxiway, but believing that he was on runway 8L, according to the accident report. Runway 8L was used both as a runway (it had edge lighting) and as a taxiway (it had center lighting). Another factor to confuse the crew was the red stop bar at the end of taxiway 2 that implied a runway threshold, leading the crew to believe that the taxiway was a poorly lit runway.

The flight crew had not briefed each other prior to the landing approach on the type of lighting they were expecting to see on the approach to runway 8L, and the pilot had, at first, properly lined up with the runway. After a well-intentioned question from the copilot about which runway was being approached, however, the pilot changed his interpretation of the visual cues and realigned the aircraft with the taxiway.

Landed Without Clearance

Boeing 737: No damage. No injuries.

The aircraft was being vectored to land at the high-density airport during a time of numerous arrivals. The first officer was flying the aircraft, which was cleared for the ILS (instrument landing system) approach and had been instructed to contact the control tower at the outer marker.

As the aircraft approached the outer marker, the first officer asked the captain for the current wind. After the aircraft landed and had cleared the active runway, the pilots realized that their radio was not tuned to the control tower frequency and that they had landed without a clearance.

Investigation of the incident revealed that, during training for that airline, the landing clearance is usually tied in with the wind report. In this instance, the first officer had assumed that the wind report the captain gave him came from the tower when the captain received landing clearance, when in fact the captain had read the wind from his horizontal situation indicator (HSI).

Part of the confusion may have related to the part played by fatigue, since the first officer who also had management duties, was assigned to the flight with short notice the evening before and scheduled for a late night deadhead trip to make the early morning departure.

Preventive suggestions include reinforcement during recurrent training of the need for situational awareness and the need for participation in ATC clearances by all crew members, and the need for crew members to be mentally and physically fit for flying assignments.

Check Ride Trick Backfires

Piper PA-31T Cheyenne: Aircraft destroyed. Fatal injuries to three.

The pilot was on a check ride to obtain a single pilot rating in the twin-engine turboprop executive aircraft. When the pilot declared a missed approach after an instrument landing system (ILS) approach, the check pilot surprised the pilot by rapidly reducing the power on the right engine as the pilot was retracting the gear and raising the nose. The aircraft turned to the right by more than 60 degrees in a steep bank angle.

In an attempt to regain control, the pilot levelled the wings and reduced power on the left engine, which resulted in a loss in speed and height. Power was reapplied, but the aircraft stalled and crashed with both engines at full power on a congested highway, colliding with a city bus and a restaurant.

The aircraft was destroyed. Both pilots and one person on the ground were killed. Five people on the ground were seriously injured and 22 received minor injuries.

Cited among causal factors were incorrect procedures by the pilot being checked. The check pilot was cited for excessive self-confidence, incorrect procedures and poor planning.

Ground Reference Lost In Whiteout

Cessna 185F (ski-equipped): Substantial damage. No injuries.

The pilot was flying three passengers into Thunder Bay, Ontario, Canada, on a midwinter afternoon. The weather conditions deteriorated en route, and the pilot decided to carry out a precautionary landing on a nearby frozen lake.

During the final portion of the approach, the pilot lost adequate visual clues and ground reference points because of whiteout conditions. The landing was harder than normal; both main gear collapsed, causing substantial damage to the propeller, wing struts and left ski. There were no injuries.

Corporate Executive

Out of Fuel and Practice

Cessna 421: Aircraft destroyed. Fatal injuries to one.

The pilot had recently been hired, but had not been checked out in the aircraft prior to the flight. He was on an evening solo familiarization flight. During the flight, the right engine failed because of fuel starvation. Subsequently, the aircraft's left engine failed, also from fuel starvation, within 10 miles of the home airport.

The aircraft struck the ground in a pasture with a slight left wing-low, nose-down attitude. Neither propeller was feathered, the landing gear was down and the flaps were fully extended. Fuel lines ruptured on impact and caused a post-impact fire that consumed one engine, the cabin and the left wing. The pilot suffered fatal injuries.

Power Lines in the Fog

Hawker Siddeley HS125: Aircraft destroyed. Fatal injuries to one.

The aircraft, with two crew members and six passengers, was cleared for an approach to runway 04 in instrument meteorological conditions (IMC). Weather included an indefinite ceiling in fog and the runway visual range (RVR) was 1,400 feet. The last contact with the aircraft was when the crew reported on the localizer inbound.

During the approach, the low-altitude alert was received in the control tower and the controller transmitted, "Low altitude alert. Check altimeter." The crew did not respond and air traffic control (ATC) observed the aircraft disappear from the radar display. The aircraft collided with power lines 6,500 feet short of the runway and was destroyed. One crew member was fatally injured and the other suffered serious injuries. Among the passengers, there were two serious injuries and four minor injuries.

Causal factors cited in the accident report included improper instrument flight rules (IFR) procedures and meteorological conditions below instrument approach minima.

Things That Go 'Bump' In the Cloud

Cessna F150L: Moderate damage. No injuries.

The recently licensed private pilot had just taken off for a solo flight to continue his training. After flying west for 10 miles at 1,100 feet, the pilot noted that the thin cloud base, previously at 1,200 feet, was dropping. The pilot turned the aircraft to the right and found himself in a cloud.

According to the accident report, the pilot became disoriented and realized he was losing altitude. He felt a bump and, after regaining control of the aircraft, he called air traffic control (ATC) and was able to return to the airport with radar assistance and made an uneventful approach to the runway.

When the aircraft touched down it came to rest on its nose. The pilot was not injured; however, the aircraft sustained damage to the lower front fuselage, propeller, engine and main landing gear. The report stated that the nosewheel assembly was presumed to have been separated from the aircraft by contact with the ground during the course of the flight; it was not recovered.

Concern About Slower Aircraft Unnerves Pilot

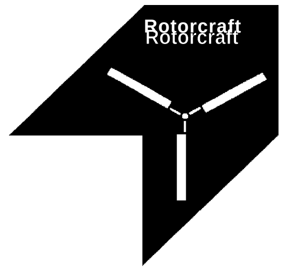
Piper PA-44-180 Seminole: Substantial damage. No injuries.

The pilot was returning during visual meteorological conditions (VMC) with an instructor from a training flight. He was a licensed commercial multi-engine pilot who was undergoing training for an IFR rating on multi-engine aircraft.

The aircraft had completed a very high frequency omnidirectional range (VOR) approach and was in the traffic pattern for runway 10. There was a slower, single-engine aircraft ahead, doing touch-and-go landings, and several other aircraft were elsewhere in the traffic pattern.

As the distance between the training aircraft and the aircraft doing touch-and-goes diminished during final approach, the pilots in the twin-engine aircraft became concerned whether they would overshoot the runway during landing. In the confusion, the pilot failed to move the landing gear lever down before landing, and the aircraft touched down on its underside and slid to a stop.

The two pilots exited the aircraft without injury, but the aircraft sustained substantial damage. Scuff marks and scrapes were visible on the aft exterior of the main nose gear doors and outboard side walls of the main tires, consistent with a wheels-up landing.



Too Little Sleep Kills

Bell 206B: Aircraft destroyed. Fatal injuries to one.

The pilot was flying a pipeline patrol from South Bend, Ind., U.S., to Montreal, Quebec, Canada. The pilot began flying that morning at 0605 hours eastern daylight time (EDT). He flew the first leg from South Bend to London, Ontario, Canada, cleared customs, and proceeded on the second leg of the flight to Kingston, Ontario, where he ate lunch and refueled the aircraft. Just after 1215 hours, the pilot departed for Montreal, on the final leg of the pipeline patrol.

At 1253 hours, the Ontario hydroelectric power company experienced a major power interruption in the area around Ottawa. A helicopter was dispatched to find the cause of the power outage. This search located the wreckage of the pipeline patrol helicopter that had departed Kingston earlier that day. Analysis of the accident site determined that the aircraft had gradually descended with a steep pull up over a group of trees 53 feet from the power lines that the aircraft hit. The helicopter collided with four of the six lines, severing two of them. The pilot was fatally injured in the accident.

The pipeline pilot had been employed with the company for 10 years. He held a commercial license with a valid instrument rating for helicopters and a helicopter instructor rating. He also was rated for multi-engine fixed-wing airplanes (land and sea). Three weeks prior to the accident he had completed a training flight that included emergency procedures and operational maneuvers. Also, the average flying time the pilot had flown during the last two and one-half days was 9.8 hours per day. The pipeline route inspection was scheduled during a five-day period, but the pilot wanted to complete it in three days to have two extra days off, according to the accident report.

The accident report stated that the pilot had been on duty an estimated 20 hours during the past two days and was known to be tired and did not have a second pilot or observer on board to help relieve the workload. The helicopter systems were examined and no evidence of malfunction was found. The report concluded that the aircraft probably struck the power lines and trees because of pilot fatigue. The pilot was not wearing protective headgear.

Powerlines Get in the Way

Messerschmitt Bölkow Blohm Bk117: Aircraft destroyed. Fatal injuries to one.

The aircraft was on a night mission in instrument meteorological conditions (IMC). The weather at the time was reported as low overcast ceiling, 0.25 to 1 mile visibility with rain, fog and thunderstorms. Prior to the flight, the pilot received three weather briefings.

While en route, the rotorcraft struck 70-foot-high power lines and crashed. The aircraft was destroyed by post-impact fire, and the pilot sustained fatal injuries.

Causal factors included the presence of poor weather, continued flight into adverse weather and inadequate operator and pilot training in emergency procedures. ♦