FLIGHT SAFETY FOUNDATION

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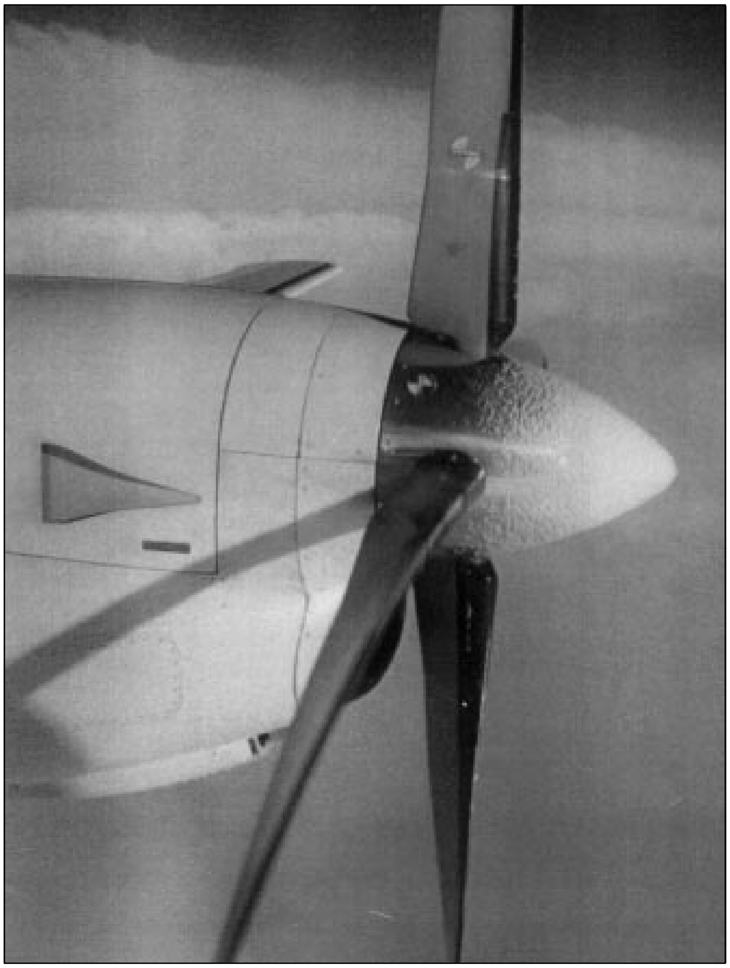
FLIGHT SAFETY
D I G E S T

Pilots Can Minimize the Likelihood of Roll Upset in Severe Icing



Flight Safety Digest

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In This Issue

Flight Safety Foundation is an international membership organization dedicated to the continuous improvement of flight safety. Nonprofit and independent, FSF was launched in 1945 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce positive influence on aviation safety. Today, the Foundation provides leadership to more than 660 member organizations in 77 countries.

Pilots Can Minimize the Likelihood of Aircraft Roll Upset in Severe Icing

Under unusual conditions associated with supercooled large droplets, roll upset can result from ice accretion on a sensitive area of the wing, aft of the deicing boots. Pilots must be sensitive to cues — visual, audible and tactile — that identify severe icing conditions, and then promptly exit the icing conditions before control of the airplane is degraded to a hazardous level.

John P. Dow Sr.
U.S. Federal Aviation Administration

On Oct. 31, 1994, an Avions de Transport Regionale (ATR) 72-212, operating as American Eagle Flight 4184, suffered a roll upset during descent after holding in severe icing conditions. The airplane crashed, killing all 64 passengers and the four crew members.

Although the U.S. National Transportation Safety Board (NTSB) has not announced its finding of probable cause for the American Eagle accident, the NTSB reported that "evidence from air traffic control (ATC) sources and the airplane's flight recorders have prompted the [NTSB's] concern that the loss of control leading to the steep dive might be attributed to the weather conditions encountered by the flight and the characteristics of the aerodynamic design and flight control systems of the airplane."

[The U.S. Federal Aviation Administration (FAA) on Dec. 9, 1994, prohibited ATR-42 and ATR-72 airplanes from flying in "known or forecast" icing conditions, a restriction that was withdrawn on Jan. 11, 1995, provided that new training and flight procedures were followed, and pending the fitting of the affected ATRs with deicing boots covering a larger wing area.]

Uncommanded and uncontrolled roll excursion, referred to as roll upset, is associated with severe in-flight icing. Roll upset can occur without the usual symptoms of ice or perceived aerodynamic stall. Roll upset can be caused by airflow separation (aerodynamic stall), inducing self-deflection of the ailerons and/or degradation of roll-handling characteristics. It is a little-known and infrequently occurring flight hazard that can affect airplanes of all sizes. Recent accidents, however, have focused attention on such hazards in relation to turboprop aircraft.

Despite the U.S. Federal Aviation Regulations (FARs) and the most current aircraft certification requirements, the American Eagle accident is evidence that icing conditions and their effects on airplanes are not completely understood. Simply put, pilots must not be overreliant on deicing/anti-icing equipment fitted aboard airplanes that have been certified for flight into icing conditions. Severe icing conditions can be outside the airplane-certification icing envelope, and each pilot must be vigilant to avoid conditions beyond an airplane's capabilities.

The U.S. *Aeronautical* (formerly *Airman's*) *Information Manual* (*AIM*) defines severe icing as, "the rate of accumulation is such that the deicing/anti-icing equipment fails to control the hazard. Immediate flight diversion is necessary."

Severity in the context of the *AIM* is associated with rapid growth of visible ice shapes, most often produced in conditions of high liquid water content (LWC) and other combinations of environmental and flight conditions. This kind of severe ice is often accompanied by aerodynamic degradation such as high drag, aerodynamic buffeting and premature stall.

Ice associated with freezing rain or freezing drizzle accreting beyond the limit of the ice-protection system is also described as severe. This kind of ice may not develop large shapes, and may not produce familiar aerodynamic degradation such as high drag, but nonetheless, may be hazardous. Freezing rain and freezing drizzle contain droplets larger than those considered in meeting certification requirements, and temperatures near freezing can produce this kind of severe icing.

As prescribed by FAA policy, a 40-micron (one micron is one thousandth of a millimeter) sized droplet diameter is normally used to determine the aft limit of ice-protection system coverage. Drizzle-size drops may be 10 times that diameter (400 microns), with 1,000 times the inertia, and approximately 100 times the drag, of the smaller droplets.

Drizzle drops not only impinge on the protected area of the airplane, but may impinge aft of the ice-protection system and accumulate as ice where it cannot be shed.

Freezing raindrops can be as large as 4,000 microns (four millimeters). Freezing rain, however, tends to form in a layer — sometimes coating an entire airplane.

Freezing drizzle tends to form with less extensive coverage than freezing rain, but with higher ridges. It also forms ice fingers or feathers, ice shapes perpendicular to the surface of the airfoil. For some airfoils, freezing drizzle appears to be far more adverse than freezing rain to stall angle, maximum lift, drag and pitching moment.

A little-known form of freezing drizzle aloft — also described as supercooled drizzle drops (SCDD) — appears to have been a factor in the American Eagle ATR-72's roll upset.

SCDD Is New Challenge

SCDD is a new challenge. The physics of ice formation and altitude vs. temperature profiles differ between freezing drizzle and SCDD, but for the discussion of ice accretion only, freezing drizzle and SCDD may be considered synonymous. Droplets of supercooled liquid water at temperatures below 0 degrees C (32 degrees F) having diameters of 40 microns to 400 microns are found in both freezing drizzle and SCDD.

Like freezing rain and freezing drizzle, SCDD conditions tend to be limited in horizontal and/or vertical extent. These conditions are reported in AIRMETs but are not usually reported in SIGMETs, which report on conditions in areas of less than 3,000 square miles (7,770 square kilometers).

Language used in AIRMETs and SIGMETs to indicate the potential for freezing rain or freezing drizzle would be "moderate," "severe clear" or "mixed icing in cloud in precipitation." Amplifying terminology in abbreviated form (ZL/ZR ALF) indicating freezing rain or freezing drizzle aloft may be found in the remarks section.

[AIRMETs are in-flight weather advisories issued only to amend the area forecast concerning weather phenomena of operational interest to all aircraft and hazardous to aircraft whose capability is limited by lack of equipment, instrumentation or pilot qualifications. According to the *AIM*, AIRMETs "cover moderate icing, moderate turbulence, sustained winds of 30 knots or more at the surface, widespread areas of ceiling less than 1,000 feet [305 meters] and/or visibility less than three miles [4.8 kilometers] and extensive mountain obscurement." SIGMETs are advisories concerning weather significant to all aircraft, including severe icing, severe and extreme turbulence and widespread dust or sandstorms that reduce visibility to less than three miles (4.8 kilometers)].

No aircraft is certificated for flight in supercooled-large-droplet (SLD) conditions.

During the American Eagle accident investigation, the FAA found additional accidents and incidents involving other types of airplanes in freezing rain, freezing drizzle and SCDD. Collectively these icing conditions are referred to as supercooled large droplets (SLD).

Ice can form aft of the ice-protection system in SLD conditions where the droplets strike and freeze aft of the boots. Ice formation may be rapid in large-droplet and near-freezing conditions where ice accretes aft of the boots because of the direct impingement of the large droplets and because temperatures do not allow rapid heat transfer from the droplets that strike the leading edge. The droplets do not freeze immediately, but flow aft to the spanwise ice formation and then freeze.

Normal Symptoms May Be Absent

SLD conditions may challenge contemporary understanding of the hazards of icing. Moreover, an airplane may not exhibit the usual symptoms (warnings) associated with severe icing prior to loss or degradation of performance, stability or control characteristics. *No aircraft is certificated for flight in SLD conditions.*

The American Eagle accident airplane was operating in a complex icing environment that likely contained supercooled droplets having an LWC estimated to be as high as 0.7 grams per cubic meter and a temperature near freezing. Estimates

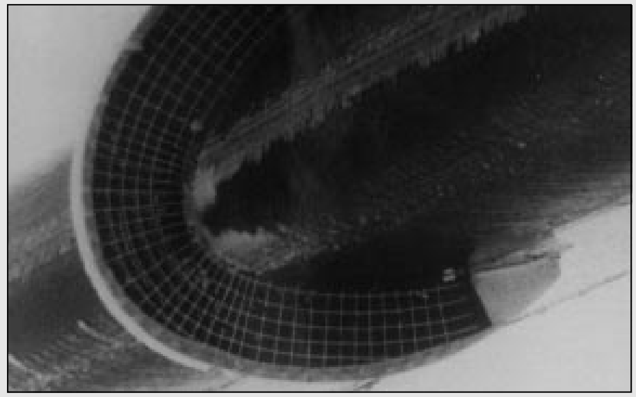
Measuring Temperature

Static air temperature (SAT) is what would be measured from a balloon, and is the temperature given in a forecast or report. It is also referred to as outside air temperature (OAT).

Total air temperature (TAT) is obtained by a probe having velocity with respect to the air. Because of kinetic heating on the upstream side of the probe, TAT is warmer than SAT. SAT is computed from TAT and other flight conditions by an air data computer for dry air. There is less kinetic heating in saturated air than in dry air.

Indicated outside air temperature (IOAT) is measured by a simple sensor in the airstream — essentially a thermometer. Typically, IOAT values will be SAT or OAT plus approximately 80 percent of the difference between SAT and TAT.

Surface temperature varies with air pressure along the airfoil. At the leading edge, where pressure is the highest, the surface temperature will also be higher than farther aft. If the local surface temperature on the airfoil is warmer than freezing, no ice will form. Infrared measurements of a typical airfoil in the icing tunnel at a true air speed of 150 knots show that there can be a decrease in temperature of more than 1.9 degrees C (3.5 degrees F) along the airfoil. At temperatures close to freezing, there may be no ice on the leading edge, but ice can form farther aft because of the lower temperatures. Because there is liquid runback, any ice formation aft of the leading edge tends to act like a dam, making ice growth more rapid.



Source: U.S. National Transportation Safety Board

Supercooled drops are at tempertures below freezing, yet still in a liquid phase. To change to solid, heat (called the "heat of fusion") must be removed from the liquid. Ice-free area shows that temperature at the leading edge is too warm to remove heat of fusion from the supercooled drops, but the temperature is colder on upper and lower surfaces.

of the droplet diameter vary significantly depending on the estimating methodology, but the droplets with the most severe adverse consequences appear to be in the range of 100 microns to 400 microns, or up to 10 times larger than the droplets upon which normal certification requirements are based.

The severe icing conditions caused ice to form on, and aft of, the deicing boots while the accident airplane was holding with the flaps extended. The ice aft of the boots could not be shed, because the ice was not affected by the deicing boots, which were functioning normally. When the flaps were retracted while the aircraft's airspeed remained constant, the airplane suffered a roll upset.

Although the crew of the accident airplane may not have been aware that they were holding in severe icing conditions, the cockpit voice recorder indicated that they were aware of ice accretion on their aircraft. Up to the time of the upset, the autopilot was controlling the airplane, and the pilot was not feeling physical changes in control-wheel forces that related to accumulation of ice on the aircraft.

Airfoil Sensitivity Varies

Although ice can accrete on many airplane surfaces, concern is focused on wing-airfoil icing. Some airfoil designs tend to be less sensitive to lift loss with contamination than other, more efficient, airfoils. Traditionally, the industry has relied on the infrequency of occurrence, limited extent of coverage, forecasting and reporting to avoid freezing rain and freezing drizzle, and recognition to exit the conditions.

An infinite variety of shapes, thicknesses and textures of ice can accrete at various locations on the airfoil. Each ice shape essentially produces a new airfoil with unique lift, drag, stall angle and pitching moment characteristics that are different from the wing's own airfoil, and from other ice shapes.

These shapes create a range of effects. Some effects are relatively benign and are almost indistinguishable from the wing's airfoil. Others may alter the aerodynamic characteristics so drastically that all or part of the airfoil stalls suddenly and without warning. Sometimes the difference in ice accretion between a benign shape and a more hazardous shape appears insignificant.

The effects of severe icing are often exclusively associated with ice thickness. For example, it is reasonable, in a given set of conditions, to believe that a specific three-inch (7.6-centimeter) shape would be more adverse than a similar 1.5 inch (3.8-centimeter) shape in the same place. Contrary to that one criterion, however, a five-inch (12.7-centimeter) ice shape on one specific airfoil is not as adverse as a one-inch (2.54-centimeter) ice ridge located farther aft on the chord. In another example, a layer of ice having substantial chordwise extent is more adverse than a three-inch ice accretion having upper and lower horn-shaped ridges (double horn).

Ice can contribute to partial or total wing stall followed by roll, aileron snatch or reduced aileron effectiveness.

Wing stall is a common consequence of ice accretion. Ice from freezing drizzle can form sharp-edged roughness elements approximately 0.5-centimeter to one-centimeter (0.2-inch to 0.4-inch) high over a large chordwise expanse of the wings' lower surfaces (perhaps covering 30 percent to 50 percent) and fuselage, increasing drag dramatically, thereby reducing speed. Correcting for this demands increased power, increased angle-of-attack (AOA) or both to maintain altitude. Ultimately, such unmitigated adjustments lead to exceedance of the stall angle and a conventional stall, likely followed by a roll.

Aileron snatch is a condition that results from an imbalance in the sum of the product of aerodynamic forces at an AOA that may be less than wing stall, and that tends to deflect the aileron from the neutral position. On unpowered controls, it is felt as a change in control-wheel force. Instead of requiring force to deflect the aileron, force is required to return the aileron to the neutral position. With all else equal, smaller ailerons would have smaller snatch forces. Aileron instability sensed as an oscillation, vibration or buffeting in the control wheel is another tactile cue that the flow field over the ailerons is disturbed.

Although flight testing using simulated ice shapes on the ATR-72 (intending to simulate the conditions at the crash location) demonstrated that these forces were less than the 60-pound certification limit for temporary application in the roll axis, the forces' sudden onset and potential to cause a rapid and steep roll attitude excursion were unacceptable. FAA investigation has revealed similar roll attitude excursions affecting other aircraft types that are equally unacceptable.

Ailerons that exhibit the snatch phenomenon have control-wheel forces that deviate from their normal relationship with aileron position. Nevertheless, the ailerons may be substantially effective when they are deflected.

Flow Disruption Handicaps Ailerons

Degradation of roll control effectiveness results from flow disruption over the wing ahead of the ailerons, and the controls do not produce the rolling moments associated with a given deflection and airspeed.

Degradation of aileron control caused by ice may or may not be accompanied by abnormal control forces. If, for example, the airplane is displaced in roll attitude, through partial stall caused by ice, the pilot's efforts to correct the attitude by aileron deflection are defeated by the ailerons' lack of effectiveness.

Ice tends to accrete on airfoils in different ways, depending on the airfoil, the AOA and other aircraft variables, and of course the atmospheric variables controlling the size, density, temperature, etc. of the water droplets. Similarly, the ice has differing effects on the airfoils.

The implications can be illustrated with a wing. The airfoil at the tip is in all probability a different airfoil than at the root. It is probably thinner, may have a different camber, be of shorter chord, and there are likely two degrees or three degrees of twist or washout relative to the root section.

Stall May Begin at Wing Tip

Twist or washout helps to ensure that the symmetric stall starts inboard, and spreads progressively, so that roll control is not lost. Greater ice accretion has probably occurred at the tip, leaving it more impaired aerodynamically than the inboard wing section. Stall, instead of starting inboard, may start at the tip.

Because the tip section may have a sharper nose radius and probably has a shorter chord, it is a more efficient ice collector. As a result, ice accretion at the wing tip may be thicker, extend farther aft and have a greater adverse effect than ice at the root.

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Even if the ice does build up at the root to nearly the same thickness as that at the tip, ice still tends to affect the smaller chord section, such as the wing tip, more adversely.

Power effects can aggravate tip-stall. The effect of the propeller is to reduce the AOA of the section of the wing behind it. At high-power settings, stall on the inner wing tends to be delayed by propeller wash. But the outer wing does not benefit from the same flow field, so the outer wing tends to stall sooner.

Finally, because of its greater distance from the flight deck to the outer wings, the crew may have difficulty in assessing ice there.

This means that at some AOAs, the outer wings maybe undergoing partial aerodynamic stall, while normal flow conditions still prevail over the inner parts of the wing. If such a stall occurs, there may be no pronounced break and the pilot may not sense the stall, so the stall is insidious. This partial stall condition also accounts for a degree of degradation of aileron effectiveness.

Where ice builds up on a given airfoil depends on the AOA, airspeed and icing variables. For example, the ATR accident flight testing included flying in drizzle-size drops. At the test airspeed, ice would predominantly build on the upper surfaces of the wings with the flaps extended to 15 degrees (resulting in a smaller AOA) and predominantly on the lower surfaces of the wings with the flaps retracted (resulting in a larger AOA).

On the upper surfaces, there was little drag increase until separation. On the lower surfaces, the expanse of rough ice was accompanied by a substantial drag increase.

In an icing environment, the propeller wash also tends to influence icing impingement on the airfoil. Unless the propellers are counter-rotating, the flow field is asymmetric over the wings, and ice impingement tends to be slightly asymmetric as well.

After aerodynamic stall occurs, reattaching flow generally requires a marked reduction of AOA and then refraining from increasing the AOA to the stall angle for that part of the wing. This characteristic is configuration-dependent, and is not limited to just one airplane type.

For example, in two different airplane types studied in detail, the stall angle for the outer wings was about five degrees with ice accretion forward of the ailerons on the upper wing surface aft of the deicing boots. The normal stall angle was near 20 degrees with no ice accretion. In both aircraft, reattachment of flow occurred when the AOA was reduced to substantially less than the stall angle. Applying power and maintaining attitude may not be most effective in recovering from an outer wing stall, because the reduction in AOA does not occur as rapidly.

To avoid ambiguity, meaningful terminology must be well-defined.

In recent years, reports of roll excursions associated with icing appear to have increased in frequency, especially among turboprop airplanes used in regional airline commuter operations. One possible reason for this increase is that exposure to icing conditions in general has dramatically increased.

In 1975, the number of annual departures for all U.S. major airlines was 4.74 million. In 1994, almost two decades later, the regional segment alone has grown to 4.60 million annual departures.

Regional Airlines Have Higher Icing Exposure

Annual regional airline exposure to icing may be double that of jet aircraft, which service the longer routes and tend to operate above most icing conditions at higher altitudes for a greater percentage of their flight time.

The increase in operations suggests increased exposure to all icing conditions, so a commensurate increase in the number of flights involving SLD could be expected. For whatever reasons, exposure to these hazardous conditions appears to be more frequent than was previously believed.

Substantial effort is being placed into improving forecasts for all SLD. Since fall 1995, there have been preliminary changes to mathematical models used to forecast these conditions. The models will be reviewed and updated periodically, based on correlation with observations and pilot reports (PIREPs).

Pilots are best situated to submit a real-time report of actual icing conditions. But there is no assurance that another airplane will transit that small volume of the sky containing SLD. If it does, there must be some way for the pilot to identify that the icing is caused by SLD and then submit the PIREP. Not all pilots may be sensitive to what SLD icing looks like on their airplane, and PIREPs are a low priority during periods of high cockpit workload.

In-flight meteorological conditions reported by the crew of one airplane may not reflect the hazards of that same airspace for other airplanes, because of the many variables involved.

The variables include the size and type of the airplane's airfoil, configuration, speed, AOA, etc. If the reporting airplane was a large transport, the effect of icing may have been unnoticed and unreported, but the conditions could be a problem for a smaller airplane.

PIREPs from an identical-model airplane are most likely to be more useful, but even the identical-model airplane climbing through an icing layer would likely result in a different ice accretion than one descending.

Ice accreted beyond ice-protection system coverage will not be shed and will continue to accrete until the airplane exits the icing conditions. Remaining in such icing conditions cannot improve the situation.

Severity indices of trace, light, moderate and severe vary among airplanes for the same cloud and tend to be subjective. Not too far from the American Eagle ATR accident site at about the same time, a jet airplane experienced a rapid ice accretion. The jet airplane's captain said that he had never experienced such a fast ice build-up. One inch (2.54 centimeters) of milky ice accumulated on a thin rod-shaped projection from the center windshield post in one to two minutes. The captain reported the buildup as light rime. In these extraordinary conditions, does "light" icing convey a message to others suggesting vigilance or complacency?

Descriptions Not Always Accurate

Extent of accretion, shape, roughness and height of ice are the most important factors affecting an airfoil. Unfortunately, operational descriptors of rime, clear or mixed ice are not adequate to convey nuances of the icing environment and the hazards of SLD. Ice forming aft of the boots may be white, milky or clear. Nonhazardous ice may also be described using the same terms. In the same cloud, one airplane may accrete rime ice, while another airplane — at a higher speed — accretes mixed ice. To avoid ambiguity, meaningful terminology must be well-defined.

PIREPs are very useful in establishing a heightened sense of awareness to a possible icing condition and to aid forecasters in correlating forecast meteorological data with actual ice. Although a forecast projects what may be, and a PIREP chronicles what was, the most important issue is: What is the icing condition right now?

Cues that can be seen, felt or heard signal the potential for ice to form, the presence of ice accretion or icing severity. Cues may vary somewhat among airplane types but typically cues include:

- Temperature below freezing combined with visible moisture;
- Ice on the windshield-wiper arm or other projections, such as engine-drain tubes;
- Ice on engine-inlet lips or propeller spinners;
- Decreasing airspeed at constant power and altitude; or,
- Ice-detector annunciation.

For example, experienced pilots rely on visual cues to determine the presence of SLD. After confirming SLD, they reroute to exit immediately from the SLD conditions. Because SLD conditions tend to be localized, the procedure has proved to be practical and safe. Using cues requires alertness to existing conditions and a very clear understanding of the airplane and its systems. Pilots should have an equally clear understanding of aviation weather and know what the temperatures and conditions are likely to be to the left, right, ahead, behind, above and below the route of flight, and how to recognize severe icing.

Tactile cues such as vibration, buffeting or changes in handling characteristics normally trigger a mental warning that ice has already accreted to a perceptible, and perhaps detrimental, level. Typically, as ice increases in thickness, cues become more prominent.

Using meaningful cues, pilots are trained to activate the various elements of airplane ice-protection systems, and when necessary, to exit the conditions.

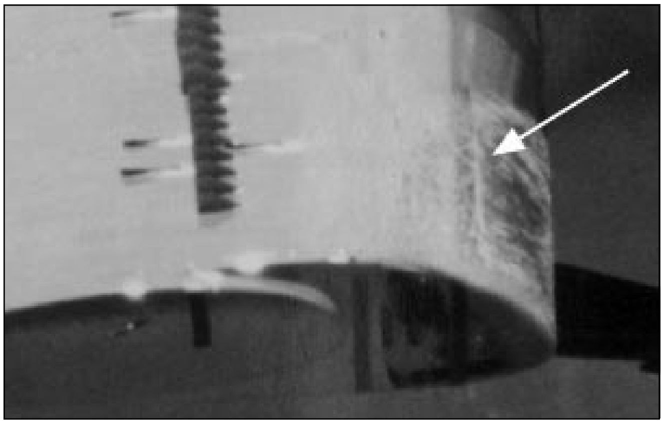
Experience suggests that it has been impractical to protect airplanes for prolonged exposure to SLD icing because at its extreme — it tends to cover large areas of the airplane. A conventional pneumatic ice-protection system able to deal with such extensive ice accretion would likely affect airfoil performance as much as the ice, would be expensive and would be heavy. Conventional electrothermal systems would require extraordinary amounts of power.

Because of the broad range of environmental conditions, limited data available and various airplane configurations, the manufacturer's pilot's operating manual should be consulted for guidance on a specific airplane type. The suggestions below are not intended to prolong exposure to icing conditions, but are a warning to exit the conditions immediately.

- **Ice visible on the upper or lower surface of the wing aft of the active part of the deicing boots.** It may be helpful to look for irregular or jagged lines or pieces of ice that are self-shedding. For contrast, a portion of the wing may be painted a dark color with a matte finish, different than the color of the boots. The matte finish can help identify initial formation of SLD ice, which may be shiny. All areas to be observed need adequate illumination for night operation.
- **Ice accretion on the propeller spinner.** Unheated propeller spinners are useful devices for sorting droplets by size. Like a white wing, a polished spinner may not provide adequate visual contrast to detect SLD ice. If necessary, a dark matte circumferential band may be painted around the spinner as a guide.
- **Granular dispersed ice crystals, or total translucent or opaque coverage of the unheated portions of the front or side windows.** These may be accompanied by other ice patterns, such as ridges, on the windows. After exposure to SLD conditions, these patterns may occur within a few seconds to approximately one minute.
- **Unusually extensive coverage of ice, visible ice fingers or ice feathers.** Such ice can occur on parts of the airframe not normally covered by ice.

At temperatures near freezing, other details take on new significance:

- **Visible rain** (which consists of very large water droplets). In reduced visibility, occasionally select taxi/aircraft landing lights ON. Rain may also be detected by the sound of impact.
- **Droplets splashing or splattering on impact with the windshield.** Droplets covered by the icing certification envelopes are so small that they are usually below the threshold of detectability. The largest size of the drizzle drops is about the diameter of an 0.002-inch (0.05-centimeter) pencil lead.



Source: Avions de Transport Regional (ATR)

Ice tends to accrete more on the upper surface (arrow) at low angle-of-attack associated with higher speeds or flap extension.

- **Water droplets or rivulets streaming on the heated or unheated windows.** These may be an indication of high LWC of any size droplet.

- **Weather radar returns showing precipitation.** These suggest that increased vigilance is warranted for all of the severe icing cues. Evaluation of the radar display may provide alternative routing possibilities.

Preventive and remedial measures include the following.

Before takeoff:

- **Know the PIREPs and the forecast** — where potential icing conditions are located in relation to the planned route, and which altitudes and directions are likely to be warmer and colder. About 25 percent of SLD icing conditions are found in stratiform clouds colder than 0 degrees C (32 degrees F) at all levels, with a layer of wind shear at the cloud top. There need not be a warm melting layer above the cloud top.

In flight:

- **Stay aware of outside temperature.** Know the freezing level (0 degrees C static air temperature [SAT]). Be especially alert for severe ice formation at a total air temperature (TAT) near 0 degrees C or warmer (when the SAT is 0 degrees or colder). Many icing events have been reported at these temperatures.

- **Avoid exposure to SLD icing conditions** (usually warmer than -10 degrees C [14 degrees F] SAT, but possible to -18 degrees C [-0.4 degrees F] SAT). Normally temperature decreases with each 1,000-foot (305-meter) increase in altitude between approximately 1.5 degrees C (2.5 degrees F) for saturated air, to 2.75 degrees C (5 degrees F) for dry air. In an inversion, temperature may increase with altitude.

When exposed to severe icing conditions:

- **Disengage the autopilot and hand-fly the airplane.** The autopilot may mask important handling cues, or may self-disconnect and present unusual attitudes or control conditions.

- **Advise air traffic control, and promptly exit the icing conditions.** Use control inputs as smooth and as small as possible.

- **Change heading, altitude or both.** Find an area that is warmer than freezing, or substantially colder than the current ambient temperature, or clear of clouds. In colder temperatures, ice adhering to the airfoil may not be completely shed. It may be hazardous to make a rapid descent close to the ground to avoid severe icing conditions.

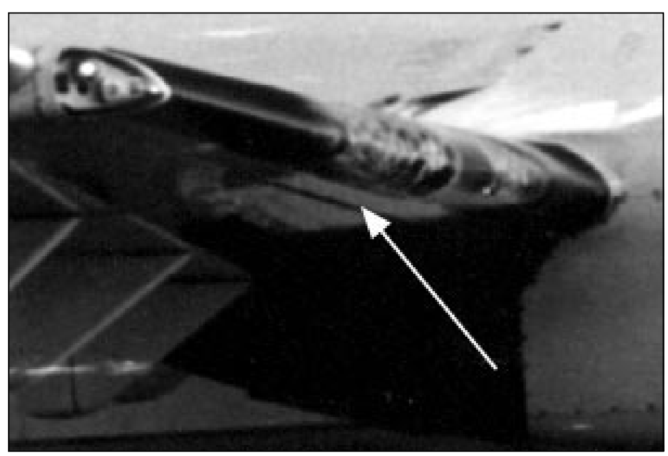
- **Reporting severe icing conditions may assist other crews in maintaining vigilance.** Submit a PIREP of the observed icing conditions. It is important not to understate the conditions or effects.

If roll control anomaly occurs:

- **Reduce AOA** by increasing airspeed or extending wing flaps to the first setting if at or below the flaps-extend speed (V_{FE}). If in a turn, roll wings level.

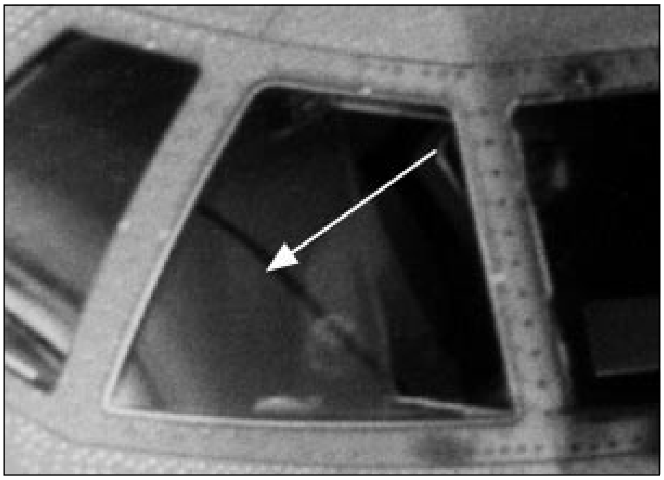
- **Set appropriate power and monitor airspeed/AOA.** A controlled descent is vastly better than an uncontrolled descent.

- **If flaps are extended, do not retract them unless it can be determined that the upper surface of the airfoil is clear of ice.** Retracting the flaps will increase the AOA at a given airspeed.



Source: Avions de Transport Regional (ATR)

Ice tends to accrete more on the lower surface (arrow) at higher angle-of-attack (slower air speed).



Source: Avions de Transport Regional (ATR)

Granular pattern on the unheated portion of a window (arrow) indicates freezing drizzle drops.

- **Verify that wing ice protection is functioning normally and symmetrically.** Verify by visual observation of the left and right wings. If the ice-protection system is dysfunctional, follow the manufacturer's instructions.

Although there is ongoing atmospheric research, the SLD environment has not been extensively measured or statistically characterized. There are no regulatory standards for SLD conditions, and only limited means to analyze, test or otherwise confidently assess the effects of portions of the SLD environment.

Ice shape–prediction computer codes currently do not reliably predict larger ice shapes at temperatures near freezing because of complex thermodynamics.

Near freezing seems to be where SLD conditions are most often — but not exclusively — reported. Further research using specially instrumented airplanes will be necessary to accurately characterize the SLD environment.

In addition to energy balance problems, there are other challenges not addressed by computer codes, such as the shape (and therefore drag) of large droplets as they are influenced by the local flow field; fragmentation of drops; and the effect of drops splashing as they collide with the airfoil. Ice shedding and residual ice are not currently accounted for, either.

The U.S. National Aeronautics and Space Administration (NASA) and others are working on these computational tasks and simultaneously pursuing validation of icing tunnels to simulate SLD conditions. Those efforts will require comparison against measured natural conditions, but there is no universally accepted standard on how to process or accurately characterize data collected in the natural icing environment. Clearly, until these tasks are complete, more specific certification issues cannot be resolved.

Assuming that a natural SLD icing environment data base is developed, that the icing envelope is amended and that test means are modified and are validated to adequately evaluate aircraft in all, or part, of the SLD environment: What then?

Three-phase Program Established

To minimize the hazard of SLD, the FAA established a three-phase program:

- Phase I — remedy problems in the accident airplane type;
- Phase II — screen other airplane types similar to the ATR-42 and ATR-72 for susceptibility to roll upset in severe icing and correct susceptible airplanes; and,
- Phase III — re-examine all aspects of icing certification, including the large-droplet environment, weather forecasting, crew training and aircraft operation.

Phase I is complete. All ATR-42 and ATR-72 airplanes are now equipped with extended deicing boots that approximately double the coverage on the upper surface of the outer wings. The increased coverage of the ATR boots is intended to minimize the hazard during inadvertent exposure to drizzle-size drops while the crew takes steps to exit the icing condition.

Phase II examined types of turboprop airplanes used in scheduled passenger service with unboosted controls and pneumatic boots for susceptibility to roll upset in freezing rain or freezing drizzle.

In January 1996, the FAA issued 17 notices of proposed rulemaking (NPRMs) for these airplanes, to require revising the airplane flight manuals (AFM) to specify procedures that would prohibit flight in freezing rain or freezing drizzle (as determined by certain visual cues), limit or prohibit the use of various flight control devices, and provide the flight crews with recognition cues for, and procedures for exiting from, severe icing.

The proposals were prompted by results of a review of the requirements for certification of the airplane in icing conditions, new information on the icing environment and icing data provided currently to the flight crews.

Phase III response will encompass all aircraft and the freezing rain/freezing drizzle icing environment. Included will be a re-examination of the adequacy of current aircraft certification regulations, and requirements for training, forecasting and flight in operations of aircraft in icing. Phase III will commence with an FAA-sponsored international conference scheduled for May 6–8, 1996, in Springfield, Virginia, U.S.

Two new technologies offer promise for SLD detection and protection systems. There are improvements in the ability of ice detection systems to recognize ice. Increasingly sophisticated designs of such systems appear able to measure the effect of ice on aerodynamic parameters.

Surface ice detectors sense the presence of contamination on the detector surface. Some distinguish among ice, slush, water, freezing point depressants and snow. Strip and area detectors are capable of detecting the thickness of ice on a deicing boot.

A recent design innovation measures the stall angle and other aerodynamic parameters of a contaminated airfoil. This could be a valuable tool for pilots because ice thickness is not the only determining factor. Location, roughness and shape are important too. For example, on one airfoil, an 0.5-inch (1.3-centimeter) step on the upper surface of the airfoil at 4 percent chord reduces maximum lift by more than 50 percent. Yet the same shape at 20 percent chord decreases maximum lift by only 15 percent. On another airfoil, distributed sandpaper-like roughness elements on the upper wing may decrease lift by 35 percent.

These new aerodynamic performance monitors also claim a somewhat predictive function, not just warning of airflow stall as it occurs, but before stall occurs.

For detectors to reduce the hazard of SLD conditions, sufficient detection and warning time for the crew to safely exit the condition must be shown. The FAA has generally preferred preventing or removing the formation of ice on a critical surface rather than advising of its presence.

Recent advancements in ice-protection systems include a high-pressure pulsed pneumatic system with a conformal metallic or composite leading edge that could replace the familiar black rubber boot. The system uses a 600 pounds per square inch (PSI) pulse of air to reliably clear ice in the range of 0.02-inch (0.05-centimeter) thickness. Current pneumatic systems generally are operated when ice is allowed to build to 0.25-inch to 0.5-inch (0.6-centimeter to 1.3-centimeter) thickness.

Electrothermal systems consisting of metal-coated fibers embedded within the paint system are being tested. One device boasts a low power consumption between 0.5 watt to more than six watts per square inch, depending on the ambient temperature. Conventional systems consume 10 watts to 15 watts per square inch. Hybrid systems that combine conventional pneumatic boots and advanced electrothermal ice protection are also being explored.

Other low-energy innovations are electro-impulsive/expulsive deicing systems (EIDI/EEDS) that rapidly discharge electrical energy stored in a capacitor through a coil or conductive ribbons. Eddy currents or magnetic repulsion forces cause the iced surface to move at extremely high acceleration, but small distance, to shed ice in the 0.02-inch thickness range or larger.

Another proposed feature of emerging systems is a closed-loop operation where a detector signals that ice has accreted, actuates the system and then waits for another build-up. This feature would allow surfaces to be individually operated at optimum ice thickness.

These systems are in various stages of maturity and testing. As with any system, testing must be successfully completed before there can be assurance that the system will perform its intended function reliably in the entire icing certification envelope — whatever that may be ultimately.♦

About the Author

John P. Dow Sr. is an aviation safety engineer with the U.S. Federal Aviation Administration (FAA) in Kansas City, Missouri, U.S. He was the icing specialist on the FAA team investigating the susceptibility of turboprop airplanes to roll upset in freezing rain and freezing drizzle. Dow was a codeveloper of an international program to identify and remedy ice-induced tailplane stall.

Dow participated in the U.S. National Transportation Safety Board (NTSB) Performance Group and Special Certification Review Team for the American Eagle ATR-72 accident. He has coordinated design approval of non-U.S.-manufactured airplanes among the FAA, other airworthiness authorities and manufacturers. He also has a commercial pilot certificate with multi-engine and instrument ratings.

Aviation Statistics

Approach-and-landing Accidents Accounted for Majority of Commercial Jet Hull Losses, 1959–1994

The flight crew was the primary causal factor in the largest number of commercial jet hull-loss accidents, according to Boeing statistics.

Editorial Staff Report

More than half — 55.8 percent — of hull-loss accidents in worldwide commercial jet operations occurred during the approach-and-landing phase between 1959 and 1994, according to Boeing Commercial Airplane Group statistics.

Figures for hull-loss accidents, covering the period approximately from the introduction of jet transports through 1994, are contained in *Statistical Summary of Commercial Jet Aircraft Accidents: Worldwide Operations, 1959–1994.* Hull-loss accidents are defined as "airplane damage which is substantial and beyond economic repair." The summary is based on totals of 536 hull losses in the full period and 187 hull losses in the 10-year period 1985 through 1994.

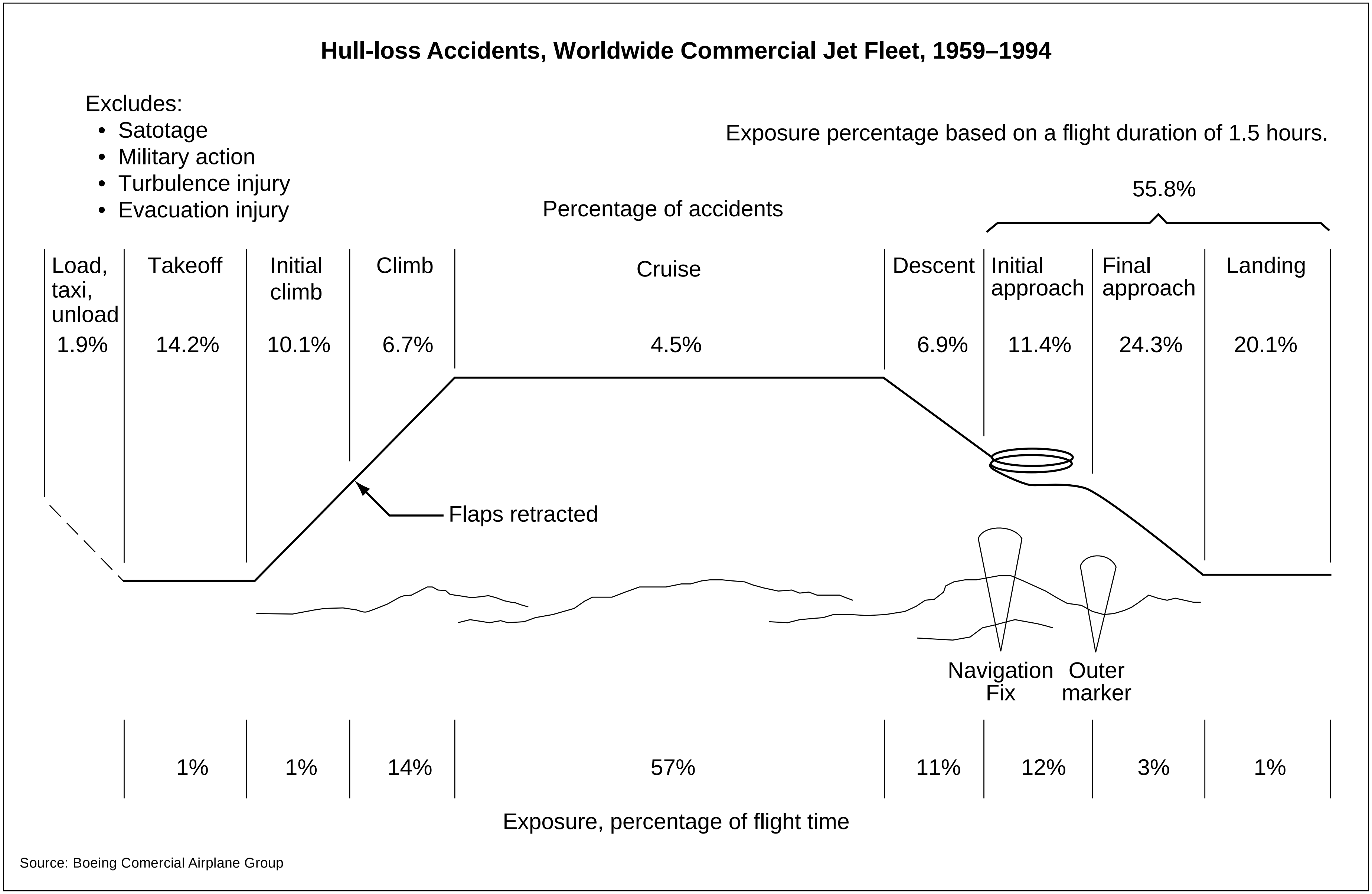
Among the 536 full-period hull losses were 143 to U.S. operators (27 percent), including 101 during passenger operations, 27 during all-cargo operations and 15 during testing, training, demonstration or ferrying. The 187 hull losses recorded in the 1985–1994 period included 37 to U.S. operators (20 percent), of which 26 occurred during passenger operations, nine during all-cargo operations and two during testing, training, demonstration or ferrying.

Hull-loss accidents for worldwide commercial jet operations, 1959–1994, were analyzed according to the phase of flight in which they occurred (Figure 1, page 11). After the combined approach-and-landing phases, the next greatest number of hull-loss accidents occurred in the combined phases from loading through initial climb (26.2 percent). Cruise, which accounts for about 57 percent of flight time in a 1.5-hour flight, occasioned only 4.5 percent of hull-loss accidents.

The summary also considered primary cause factors for commercial-operations hull-loss accidents, both in the 1959–1994 and 1985-1994 periods (Figure 2, page 12). For accidents with known causes, flight crews were considered the primary cause in the great majority of accidents — 73.3 percent over the whole period and 69.7 percent for 1985–1994.

Those primary causal factors also were correlated with phase of flight for the 1959–1994 period (Figure 3, page 13). Flight crews were the predominant cause of hull-loss accidents occurring in every phase of flight except climb, in which airplane malfunctions and flight crew problems each accounted for 10 hull losses, and taxi/loading, where each was responsible for two accidents. But whereas the second most common overall primary cause, airplane malfunction, was the primary cause in one-third of the accidents in climb with known causes, in 30 percent of takeoff accidents with known causes and 18 percent of cruise-phase accidents with known causes, airplane malfunction represented a much smaller proportion of accidents in later phases from descent through landing.

Boeing's accident data exclude turboprop aircraft as well as those with maximum gross weight of 60,000 pounds (27,216 kilograms) or less; Soviet Union and Commonwealth of Independent States accidents; and accidents resulting from sabotage, hijacking, suicide and military action.♦

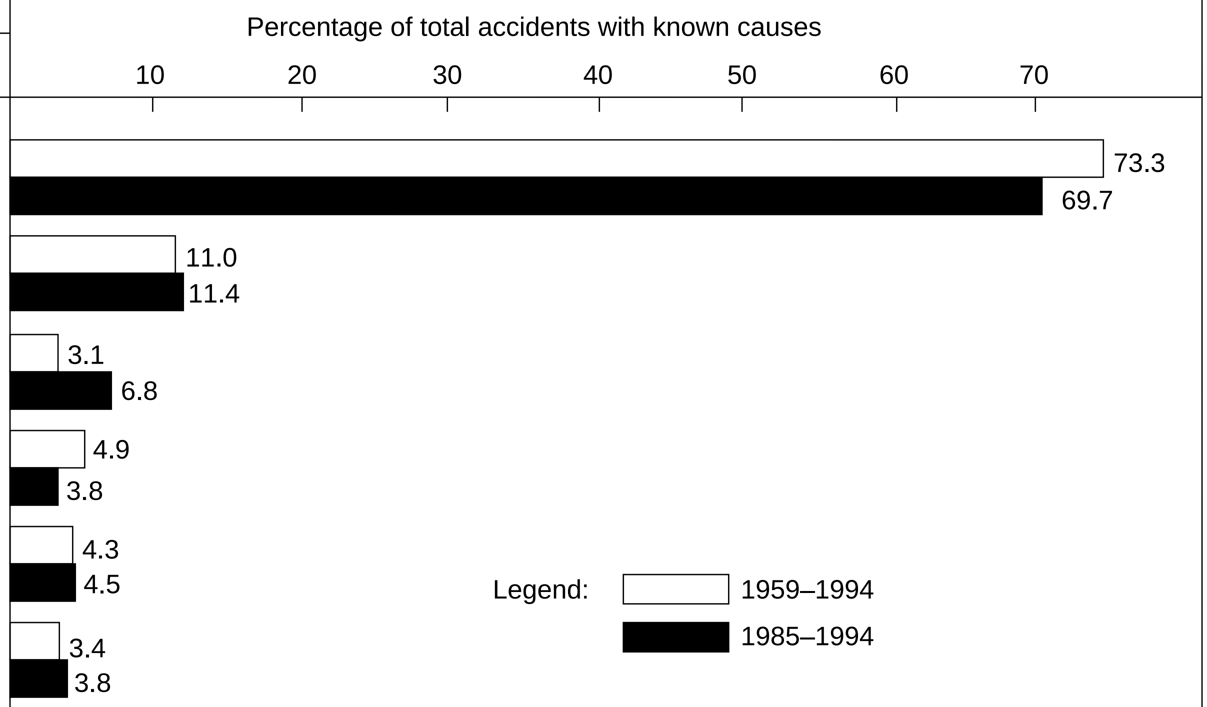


Hull-loss Accidents, Worldwide Commercial Jet Fleet, 1959–1994
Excludes:
• Satotage
• Military action
• Turbulence injury
• Evacuation injury
Exposure percentage based on a flight duration of 1.5 hours.
55.8%
Percentage of accidents
Load, taxi, unload
Takeoff
Initial climb
Climb
Cruise
Descent
Initial approach
Final approach
Landing
1.9%
14.2%
10.1%
6.7%
4.5%
6.9%
11.4%
24.3%
20.1%
Flaps retracted
Navigation Fix
Outer marker
1%
1%
14%
57%
11%
12%
3%
1%
Exposure, percentage of flight time
Source: Boeing Comercial Airplane Group

Figure 1

Primary Cause Factors — Hull-loss Accidents, Worldwide Jet Fleet, 1959–1994

Primary factor	Number of accidents: Total	Number of accidents: Last 10 years
Flightcrew	327	92
Airplane	49	15
Maintenance	14	9
Weather	22	5
Airport/Air traffic control	19	6
Miscellaneous/Other	15	5
Total with known causes	446	132
Unknown or awaiting reports	90	54
Total	536	189



Excludes:
- Sabotage
- Military action

Source: Boeing Comercial Airplane Group

Figure 2

Hull-loss Accidents, Primary Cause Factors vs. Flight Phase — Worldwide Commercial Jet Fleet, 1959–1994

Primary Factors	Boeing / Non-Boeing	Number of Accidents								
	Total	Takeoff	Initial Climb	Climb	Cruise	Descent	Initial Approach	Final Approach	Landing	Taxi Load
Flightcrew	157 / 170	16 / 15	15 / 22	7 / 3	4 / 2	13 / 13	25 / 24	48 / 58	31 / 31	0 / 2
Airplane	17 / 32	6 / 12	0 / 3	4 / 6	0 / 3	1 / 1	0 / 0	3 / 0	2 / 6	1 / 1
Maintenance	5 / 9	0 / 4	0 / 1	2 / 2	2 / 0	0 / 0	0 / 0	0 / 1	0 / 1	1 / 0
Weather	8 / 14	0 / 0	2 / 1	2 / 0	0 / 2	0 / 1	0 / 1	3 / 4	1 / 5	0 / 0
Airport/Air traffic control	6 / 13	3 / 0	0 / 1	1 / 1	0 / 2	0 / 0	1 / 1	0 / 2	2 / 3	0 / 1
Miscellaneous	9 / 5	1 / 3	0 / 2	2 / 0	2 / 0	1 / 1	0 / 0	1 / 0	0 / 0	2 / 0
Unknown	35 / 55	4 / 12	6 / 3	3 / 3	6 / 1	1 / 3	4 / 6	4 / 6	5 / 21	2 / 0
Total 536	237 / 299	30 / 46	21 / 33	21 / 15	14 / 10	16 / 21	29 / 32	59 / 71	41 / 67	6 / 4

Excludes
- Sabotage
- Military Action

	Hull Losses	Flight Time	Departures
Boeing	44%	58%	55%
Non-Boeing	56%	42%	45%

Source: Boeing Comercial Airplane Group

Figure 3

Publications Received at FSF Jerry Lederer Aviation Safety Library

Report Disputes Commission's Findings on Mt. Erebus Accident

Book offers guidance on successful corporate aviation management.

Editorial Staff

Advisory Circulars (ACs)

Export Airworthiness Approval Procedures. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) no. 21-2H. Sept. 6, 1995. 132 pp. Available through GPO.*

This AC contains general information on procedures for the certification and export of aeronautical products in compliance with the U.S. Federal Aviation Regulations (FARs) Part 21, *Certification Procedures for Products and Parts.* Although this AC primarily addresses Class I products, it also provides guidance for export airworthiness certification application for Class II and Class III products. This AC cancels AC no. 21-2G, *Export Airworthiness Approval Procedures*, dated July 9, 1992.

Appendix 1 provides sample application forms and certificates. Appendix 2 contains special requirements submitted to the U.S. Federal Aviation Administration (FAA) by the governments of importing countries. Since 1992, special requirements have been added for the Bahamas, Barbados, China, Malawi and the Commonwealth of Independent States. Revisions have been made in the special requirements for Argentina, Bangladesh, Brazil, Germany, Ireland, Malaysia, Norway, Pakistan, Portugal, Saudi Arabia, South Africa, Spain, Sweden and Taiwan. Appendix 3 lists FAA Aircraft Certification Offices responsible for civil aviation matters in other countries. Appendix 4 lists International Civil Aviation Organization (ICAO) member states and territories.

Announcement of Availability — National Plan of Integrated Airport Systems (NPIAS) 1993–1997. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) no. 150/5000-14. Sept. 12, 1995. 1 p. Available through GPO.*

This AC announces the availability of the National Plan of Integrated Airport Systems (NPIAS) for 1993–1997. The NPIAS estimates the costs related to the establishment of a system of airports capable of meeting the needs of civil aviation as well as supporting the U.S. Department of Defense and the U.S. Postal Service. The estimates represent the total cost of airport development eligible for Federal aid under the Airport and Airway Improvement Act of 1982.

Designated Engineering Representatives. U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) no. 183.29-1DD. Sept. 12, 1995. 84 pp. Available through GPO.*

This AC is the updated directory of designated engineering representatives (DERs) available for work as consultants. DERs are authorized to approve engineering or flight test information that complies with U.S. Federal Aviation Regulations (FARs) within particular categories. The directory is arranged according to DER specialties: acoustical, engines, flammability testing, flight analysts, flight test pilots, power plant, propellers, radio, structures, systems and equipment, and special administrative.

Nationally Scheduled Federal Aviation Administration (FAA)-Approved Industry-Conducted Flight Instructor Refresher Clinics (FIRCs). U.S. Federal Aviation Administration (FAA) Advisory Circular (AC) no. 61-83D. Sept. 20, 1995. 13 pp. Appendices. Available through GPO.*

This AC provides guidance for the preparation and approval of training course outlines for flight instructor refresher clinics (FIRCs). FIRC training programs approved by the U.S. Federal Aviation Administration (FAA) allow certified flight instructors to renew their certificates and enable participants to meet the instructional requirements to maintain qualification as chief flight instructors for pilot schools under U.S. Federal Aviation Regulations (FARs) Part 141.

Topics addressed in this AC include application for FAA-approved FIRC programs, training course outline (TCO) structure and contents, testing procedures, authorized training aids, graduation certification issuance, scheduling and application and approval of an airman certification representative (ACR) solely employed by a FIRC sponsor. Appendix 1 outlines required subjects for FAA-approved TCO curricula. Appendix 2 provides a sample sequence of TCO construction.

Reports

The Erebus Enquiry: A Tragic Miscarriage of Justice. L'Estrange, C.H.N. The Air Safety League of New Zealand, Inc. August 1995. 101 pp.

This report disputes the findings of the Royal Commission of Enquiry on the Air New Zealand McDonnell Douglas DC-10 crash into Mt. Erebus on Antarctica in 1979. The Commission, presided over by the Honorable Justice P.T. Mahon, exonerated the flight crew of all responsibility for the accident and placed the blame on officers in the flight operations division of Air New Zealand.

Because of "white-out" conditions, in which ice and snow confound visual perceptions, instrument flight rules (IFR) flight plans were programmed in advance on Air New Zealand tour flights over Antarctica so that, regardless of the weather, the pilot did not need to rely on visual cues to avoid high ground. The Commission concluded that flight operations personnel had supplied incorrect data, which the flight crew had no power to alter.

Justice Mahon's findings stated: "[The] aircraft was now programmed to fly on a collision course with Mt. Erebus." In addition, the Commission accused 10 senior officers who gave testimony of conducting a "predetermined plan of deception" to cover up this error. The New Zealand Court of Appeal later rejected the accusation.

L'Estrange disputes the Commission's findings by placing responsibility for the crash with the captain, who was the pilot-in-command. The author claims that although the flight plan did include an error relating to coordinates, it did not include a descent to 1,500 feet (457.5 meters), that is, below the top of Mt. Erebus. L'Estrange offers a transcript of the cockpit voice recorder as evidence that the pilot made the decision to descend below the minimum safe altitude on the basis that "we are [in] VMC [visual meteorological conditions]."

According to L'Estrange's reconstruction, " ... the pilot-in-command of the accident Flight 901 made his own decision to descend below the minimum safe altitude of 16,000 feet [4,880 meters] and this decision was based on his observation of the weather in the area in which he was flying." The booklet reports that, according to the cockpit voice recorder transcript, about one minute before the DC-10 disintegrated on impact with terrain the captain said: "Actually, these conditions don't look very good at all — do they?"

[This report is available from the Air Safety League of New Zealand Inc., 310 Hurstmere Road, Takapuna, New Zealand.]

Enhanced Warning and Intervention Strategies for the Protection of Rotor Speed Following Power Failure. Haddon, D.R.; Hughes, T. U.K. Civil Aviation Authority (CAA) Paper no. 95009. October 1995. 153 pp. Figures, tables, appendices. Available through CAA.***

In 1981 an accident involving a Wessex G-ASWI helicopter outside Bacton, Norfolk, England, killed all 13 people on board; in 1986, an AS355 Twin Squirrel helicopter accident near Banbury, Oxfordshire, England, resulted in the deaths of all six people on board. Both accidents resulted from a failure to enter autorotation following a power failure. While unexpected power failure is dangerous to any type of aircraft, a helicopter's ability to autorotate gives it an advantage over fixed-wing aircraft. If the helicopter pilot is immediately alerted to a power failure and takes swift, corrective action before the power loss results in diminished rotor speed, the pilot can achieve autorotation and maintain control of the rotor speed throughout descent and landing. The intervention time between the moment of power failure and the pilot's action to maintain control of rotor speed is therefore crucial.

In response to recommendations made by the U.K. Air Accidents Investigation Branch (AAIB) following the accidents described above, Westland Helicopters Ltd. (WHL) investigated the extent to which intervention time could be reduced. The primary objectives were to review the warning devices currently available and the emergency procedures adopted in civil helicopters for use during a power failure, which may contribute to autorotation failure.

WHL also studied possibilities for providing additional warnings and developing enhanced warning strategies; WHL's own Advanced Engineering Department's simulator facility assessed the performance of these enhanced strategies. The most promising systems to emerge from this study were the phase advance filter, the modulated tone warning, automated collective reduction and the automated flare system. The modulated tone was considered to offer the best short-term method of improving rotor speed warnings.

Drugs and Alcohol Found in Fatal Civil Aviation Accidents Between 1989 and 1993. Canfield, Dennis; Flemig, Jo; Hordinsky, Jerry; Birky, Merritt. A special report prepared for the U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. Report no. DOT/FAA/AM-95/28.

November 1995. 6 pp. Figures, tables, references. Available through NTIS.**

Keywords:
1. Aviation
2. Drugs
3. Alcohol

The U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine has conducted tests to determine the extent of drug and alcohol usage by pilots who were involved in aircraft accidents. The reports resulting from these toxicology tests are used by the FAA and the U.S. National Transportation Safety Board (NTSB) to assess the causes of aviation accidents and to evaluate current FAA regulations on drug and alcohol use.

To conduct these tests, the Office of Aviation Medicine Civil Aeromedical Institute (CAMI) collected biological specimens (e.g., blood, urine and organ tissues) from 1,845 pilots after fatal aircraft accidents between 1989 and 1993. Specimens were screened for the presence of drugs, alcohol, carbon monoxide and cyanide. All data were entered into a computer database, and then analyzed using a program developed by the Office of Aviation Medicine forensic toxicology research section. The data base was sorted based on the class of drug discovered in testing. Controlled dangerous substance (CDS) schedules I and II (marijuana, cocaine, PCP, barbiturates, opiates and synthetic opiates) were found in 74 of the 1,845 pilot specimens analyzed. CDS schedules III–V (i.e., benzodiazepines) were found in 28 cases. Prescription drugs were found in 110 pilots' specimens and over-the-counter drugs were discovered in 207. Alcohol at or above the level of 0.04 percent was found in 146 specimens.

This report concludes that over-the-counter and prescription drugs are the types of drugs most frequently involved in fatal aviation accidents. Many of these drugs or the medical conditions for which they are taken can impair the pilot's ability to fly an aircraft. The increased number of cases involving drugs during the five-year period in which samples were taken more likely indicates improved methods of analysis than increased drug usage, the report says. The report also notes that the low incidence of CDS schedules III–V may be a result of the difficulty in finding and identifying new benzodiazepines. The number of incidents involving CDS schedules I and II, however, appears to have decreased steadily over the five-year period.

Books

Tests of Character: Epic Flights by Legendary Test Pilots. Middleton, Donald. Warrendale, Pennsylvania, U.S.: Society of Automotive Engineers (SAE), Inc., 1995. 224 pp. Photographs, references, index.

This book reveals the problems test pilots have faced from aviation's earliest days, through a safer period between the two world wars and into the modern era of supersonic flight. The emphasis is primarily on British manufacturers. The book traces the development of military aircraft as the strategic advantages of a war fought from the air were recognized, and discusses the development of increasingly large passenger airplanes designed to accommodate an expanding civil market after World War II.

The dangers of flying experimental aircraft are described with regard to the men who tested them. Featured test pilots include Maj. James Cordes, Harald Penrose, Capt. Eric Brown and Geoffrey de Havilland. The book relates the efforts of the Royal Aircraft Establishment at Farnborough, England, to design an aircraft capable of maintaining supersonic speeds, then follows the U.S. National Advisory Committee for Aeronautics (NACA) and Capt. Chuck Yeager through eight successive sorties in the XS-1, each nearer to Mach 1 (the speed of sound), before the "sound barrier" was broken on the ninth flight. *Tests of Character* is a collection of tales of bailouts, crash landings and inspiring acts of bravery. Disasters are reported as well as triumphs.

A variety of classic prototypes are examined: the Hurricane, the Spitfire, the Mosquito, the Victor, the Lightning, the Boeing 307 and 707 and the Bell X series supersonic aircraft. One chapter is dedicated to the development of vertical/short takeoff and landing (V/STOL) aircraft. Many black-and-white photographs of the prototypes are featured throughout the book.

Beyond Aviation Human Factors: Safety in High Technology Systems. Maurino, Daniel E.; Reason, James; Johnston, Neil; Lee, Rob B. Brookfield, Vermont, U.S.: Ashgate Publishing Co., 1995. 169 pp. Figures, tables, references, index.

This book provides an alternative approach to traditional human factors studies. Rather than focus on the clinical and psychological factors contributing to individual human error, the authors propose the proactive management of human error from an organizational, systematic point of view. They urge a shift in aviation-safety thinking from individual errors to the faults in the collective system that encourage human beings to err.

Examples illustrate that an accident is often not the result of one mistake, but the result of a series of errors, any one of which avoided or corrected might have averted the tragedy. The book considers several well-known aircraft accidents through this new perspective. One chapter, "Erebus and Beyond," discusses the radically divergent conclusions drawn by investigators following the 1979 Air New Zealand McDonnell Douglas DC-10 crash into Mt. Erebus on Antarctica. Another chapter, "Pathogens in the Snow: The Crash of Flight 1363," examines the flawed deicing procedures that led to the 1989 Air Ontario accident at Dryden, Ontario, Canada. Other chapter headings include: "Widening the Search for Accident Causes: A Theoretical Framework"; "The BAC-111 Windscreen Accident"; "The

Australian Airmiss Study"; and "Remedial Implications: Some Practical Applications of the Theory." Each chapter contains its own reference citations.

Corporate Aviation Management. Castro, Raoul. Carbondale, Illinois, U.S.: Southern Illinois, U.S. University Press, 1995. 328 pp. Photographs, figures, tables, references, appendices, index.

When Raoul Castro began his career in flight operations in 1947, he sought a single, basic source of information that covered the principles and functions of corporate aviation management. None was available. After four decades in corporate aviation, Castro has used his own experience as a pilot, manager and president of Aerospace International Management Systems Inc. (AIMS) to provide the information he sought. This book describes how to manage a successful corporate flight operation.

The book is divided into four sections. Part One, "Role, Development and Function of Corporate Aviation Management," defines corporate aviation. The evolution of corporate aviation technology, the responsibilities of the corporate aviation manager and aviation department structure are among the topics addressed. Part Two, "Economics," considers cost/benefit factors and tax implications of acquiring corporate aircraft. A chapter on selecting the appropriate aircraft is also included in this section. Part Three, "Operations — The Seven Key Factors," discusses the functions and importance of flight operations, maintenance, scheduling, passenger service, safety, security, emergency planning and training. In Part Four, "Conclusions," the author uses trends and forecasts to project the future of corporate aviation

Appendix A provides job descriptions, duties, responsibilities and training required for all positions in corporate aviation from aviation department manager to maintenance clerk. Appendices B and C are respectively a sample operations policy manual and an aviation department maintenance manual. Appendix D gives a brief history of corporate aviation.♦

* Superintendent of Documents
U.S. Government Printing Office
Washington, DC 20402 U.S.

** U.S. Department of Commerce
National Technical Information Service (NTIS)
Springfield, VA 221612 U.S.
Telephone: (703) 487-4780

*** U.K. Civil Aviation Authority
Printing and Publication Services
Greville House
37 Gratton Road
Cheltenham, GL50 2BN England

Updated U.S. Federal Aviation Administration (FAA) Regulations and Reference Materials

U.S. Federal Aviation Regulations (FARs)

Part	Date	Subject
91	9/20/95, 10/30/95	*General Operating and Flight Rules* (incorporates Amendment 91-244, "Notification to Air Traffic Control [ATC] of Deviations from ATC Clearances in Response to Traffic Alert and Collision Avoidance System," adopted 9/13/95; Special Federal Aviation Regulations [SFAR] 61-2, "Prohibition Against Certain Flights Between the United States and Iraq," effective 9/21/95; and SFAR 65-1, "Prohibition Against Certain Flights Between the United States and Libya," effective 9/20/95).

Advisory Circulars (ACs)

AC No.	Date	Title
150/5210-17	10/1/95	*Programs for Training of Aircraft Rescue and Fire-fighting Personnel* (updates Chapter 9, "Programs Available," dated 3/9/94).

Airbus A300 Crew Anticipates Clearance, Makes Unauthorized Takeoff

Helicopter strikes electrical wires, with two fatalities, during film shoot.

Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Confusion Leads To Takeoff Without Clearance

Airbus A300. No damage. No injuries.

The Airbus was in position on Runway 09R at a busy airport in the United Kingdom and began a daylight takeoff roll after receiving what the crew believed was takeoff clearance from air traffic control (ATC).

A few seconds later, while accelerating through 100 knots, the crew saw a taxiing Boeing 747 and two ground vehicles cross the runway. The crew determined that there was enough runway distance available to continue the takeoff safely. The aircraft passed above and behind the obstructions, which had cleared the runway. The flight crew then complained to ATC about the incident, but were informed by the tower that they had not been given takeoff clearance.

A review of an ATC recording of the incident confirmed that the crew had not been issued takeoff clearance. The last radio transmission from the tower informed the crew to maintain an altitude "not above, er, 4,000 feet [1,220 meters] till, er, correction 3,000 feet [915 meters] till advised by London Control." In that transmission, the controller misidentified the aircraft's flight number for the second time, but corrected it before issuing the altitude restriction.

An investigation determined that although the cockpit crew spoke and understood fluent English, "speed of delivery and the density of the [radio] traffic at this particularly busy time was such that total comprehension must have been difficult."

The investigation also noted the role of "expectation" in the incident. "Based on the order of the instructions given to the preceding aircraft (SID [standard instrument departure] amendment, then line-up, then takeoff), there was little reason for the ... crew to expect an altitude restriction if one had not already been given by the time their aircraft was lined up," the investigation summary said. The summary added: "They [the crew] therefore expected that, having lined up, their next instruction would be to take off. This expectation was aurally reinforced by the sequence of [radio] instructions ... and visually reinforced, by the sight of each aircraft ahead lining up and, almost immediately, taking off."

The captain had logged more than 13,000 flying hours, of which more than 2,500 hours were in type.

Air Taxi
Commuter

Commuter Loses Wheel After Takeoff

Fokker F50. Minor damage. No injuries.

The twin-turboprop F50 was on a positioning flight when the right inner mainwheel detached after takeoff. Fuel was burned off and the aircraft landed safely at the departure airport.

An investigation revealed that the inner bearing was still in place on the right inboard axle, that it was the correct type and that it appeared correctly installed. But after removal of the bearing it was determined that the bearing and reinforced seal had been prevented from "seating" correctly by an additional reinforced seal that should have been removed when the wheel was last replaced.

The aircraft's maintenance manual showed the wheel assembly and described the procedures for the removal and replacement of the main wheel. After removal of the wheel, the manual called for removal of the inner bearing, but it did not indicate that the reinforced seal was a separate item. That the bearing and seal were separate items was not indicated in the reassembly instructions or in the assembly diagram.

Corporate
Executive

Wake Turbulence Downs Twin

Cessna 310. Aircraft destroyed. Three fatalities.

The twin-engine Cessna departed an Asian airport about one minute after a McDonnell Douglas DC-10 took off from the same runway. The Cessna began its takeoff roll at an intersection about 2,700 feet (824 meters) from the departure end of the runway at about the same time as the DC-10 was lifting off.

Witnesses said the Cessna climbed to about 250 feet (76 meters), then banked 45 degrees to the right, corrected to about 30 degrees right bank, then snapped 120 degrees to the right. The aircraft descended out of control and struck the runway in an inverted attitude. The pilot and two passengers were killed. Daylight visual meteorological conditions were reported at the time of the accident.

Undershoot Follows Engine Failure, Go-around

Cessna 421. Aircraft destroyed. One serious injury.

The twin-engine Cessna departed in daylight visual meteorological conditions from a U.S. airport. Shortly after takeoff, the left engine began to run rough and the pilot shut it down. He advised air traffic control that he planned to continue the flight to its destination, 210 nautical miles (294 kilometers) away.

On short final to the destination airport, the pilot executed a go-around because he did not observe gear-down indications. In a second landing attempt, the aircraft struck the ground about 100 yards (91.4 meters) short of the runway, then collided with a ditch and a fence. It was later determined that there were three clear tire tracks from the touchdown point to the ditch, where the landing gear were sheared off. No problems were found with the landing-gear system. An examination of the engine determined that the left magneto failed because of lack of lubrication and wear, causing cylinder cross-firing. The pilot was not injured, but the only other occupant of the aircraft, a passenger, was seriously injured in the accident.

Other
General
Aviation

Scud Running Ends in Trees

Cessna 172. Aircraft destroyed. One serious injury.

The pilot of the single-engine Cessna reported experiencing navigational problems to air traffic control while flying at low altitude below cloud.

A few minutes later, the aircraft struck trees and came to rest nose down in the ground. The pilot, who was seriously injured, was rescued after the aircraft's emergency locator transmitter (ELT) activated.

Four Killed After Twin Stalls

Piper PA-34 Seneca. Aircraft destroyed. Four fatalities.

The Seneca had just departed a Canadian airport and climbed to about 200 feet (61 meters) above ground level (AGL) when it rolled to the left, pitched nose down and collided with the ground.

The pilot and three passengers were killed in the daylight crash. No mechanical failures were found.

Rotorcraft

Two Killed in Water Collision

Eurocopter AS350BA. Aircraft destroyed. Two fatalities.

The Eurocopter was flying at about 300 feet (91.5 meters) above the water when it began to descend slowly until it collided with the surface. Witnesses reported that the water was “glassy” at the time of the accident.

No unusual engine noises or erratic flight movements were observed before the accident. Weather at the time was reported as visual meteorological conditions, with clear skies and unlimited visibility. The pilot and a passenger were killed.

Wire Strike Brings Tragic End to Filming Mission

Bell 206B. Aircraft destroyed. Two fatalities.

The helicopter was being used in the filming of a motion picture in a U.S. national forest when it collided with electrical transmission wires and crashed. The pilot and a passenger were killed.

Witnesses reported that the helicopter made several low-level passes above a river at about 200 feet (61 meters) above ground level (AGL). During a final pass, at about 50 feet (15 meters) to 100 feet (31 meters) AGL, the aircraft struck the wires and spun violently several times before impacting terrain. The helicopter was not equipped with wire cutters and the transmission wires were not marked. Weather at the time of the accident was reported as visual meteorological conditions, with clear skies and 10 miles (16 kilometers) visibility.

Pilots Stay Dry, But Lose Main-rotor Blades

Enstrom 280C. Substantial damage. No injuries.

The helicopter had just completed an instructional flight with a student pilot and instructor on board. A light rain began to fall as the helicopter reached the pad near a hangar.

To avoid getting wet, the instructor elected to hover taxi the helicopter into the hangar. The aircraft was just inside the hangar when the main-rotor system impacted the ceiling structure of the hangar, destroying all three main-rotor blades. The instructor and the student pilot were not injured.

Helicopter Crashes on Rescue Mission

Bell 206B. Aircraft destroyed. One serious injury. One minor injury.

The Bell 206B was on a mission to rescue the pilot of a float-equipped, fixed-wing aircraft that had overturned on a lake. The helicopter located the pilot in the water and hovered near the accident site.

A passenger in the helicopter positioned himself in an external load basket attached to the right side of the aircraft and attempted to help the airplane pilot enter the helicopter. During the rescue, the helicopter tilted to the right. The pilot applied full left cyclic, but was not able to hold the helicopter level. The helicopter pilot then told the passenger and the airplane pilot to let go, but the helicopter continued tilting until the main rotor blades struck the water.

The helicopter crashed into the lake and sank. The helicopter pilot received minor injuries and the airplane pilot suffered serious injuries when he was struck by the helicopter’s landing gear. Weather at the time of the accident was reported as 3,000 feet (915 meters) scattered, 5,500 feet (1,678 meters) broken and visibility 30 miles.

Scud Running Cuts Short Medevac Flight

Bell 206L. Substantial damage. Three minor injuries.

The helicopter was en route to an accident scene when it inadvertently entered instrument meteorological conditions and struck terrain.

The pilot, flight nurse and medical technician on board suffered minor injuries in the accident. The aircraft was substantially damaged. Weather at the time of the accident was reported as visual meteorological conditions with 500 feet (153 meters) scattered, 1,900 feet (580 meters) overcast and visibility four miles (6.4 kilometers).♦

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FLIGHT SAFETY DIGEST

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