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How Much Is Too Much Wing Ice?

What may appear to be a minor coating of ice on an aircraft wing may be sufficient to impair lift to the point that safe flight is not possible.

by
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U.S. Federal Aviation Regulations (FARs) are very specific about whether and how airplanes can be operated when icing conditions exist. FAR Part 91.209, *Operating in Icing Conditions*, states that no pilot may take off an airplane that has:

- Frost, snow or ice adhering to any propeller, windshield, or powerplant installation or to any airspeed, altimeter, rate of climb, or flight attitude instrument system;
- Snow or ice adhering to the wings or to the stabilizing and control surfaces; or,
- Any frost adhering to the wings or to the stabilizing and control surfaces, unless that frost has been polished to make it smooth.

Regarding air carriers, FAR Part 121.629 states that:

- No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher (U.S. domestic and flag carriers only), icing conditions are expected or are met that might adversely affect the safety of the flight; and,
- No person may take off an aircraft when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.

After a spate of icing-related takeoff accidents involving both air carrier and general aviation airplanes, the U.S. Federal Aviation Administration (FAA) issued Advisory Circular (AC) 20-117 in December 1982 that provided extensive guidance on wing contamination. The AC states that the only way to ensure that an airplane is free from surface contaminants is through close visual inspection prior to takeoff.

Yet, icing-related takeoff accidents continue to occur and much of the responsibility for those accidents has been placed with the flight crews, many of whom may not be

aware of how much wing ice is too much and that visual — and even touch — inspections are absolutely necessary. The following accident discussion illustrates the problem, the danger and the tragic result in failing to take the necessary precautions.

The U.S. National Transportation Safety Board (NTSB) issued Aircraft Accident Report, PB91-910410, NTSB/AAR-91-09, adopted Nov. 16, 1991, which delves into the circumstances involving a DC-9-15 aircraft that crashed while taking off from Cleveland Hopkins Airport, Cleveland, Ohio, U.S., at approximately 0019 hours, Feb. 17, 1991. The following information is taken from that report.

History of the Flight Reviewed

The DC-9-15 was operated by Ryan International Airlines as Ryan 590 on a contract to carry mail for the U.S. Postal Service with a flight crew of two pilots. The aircraft crashed while taking off. Both pilots were fatally injured and the airplane was destroyed.

Ryan 590 originated at Greater Buffalo International Airport (BUF), N.Y., at 2255, Feb. 16, with a stop at Cleveland (CLE) before going on to its final destination of Indianapolis International Airport (IND), Ind.

At 2329:58, prior to landing at Cleveland, approach control advised Ryan 590, "two pilot reports, moderate rime icing reported 7,000 feet on to the surface during the descent, that was by a 727, and also moderate chop turbulence from 4,000 feet to the surface." The crew of Ryan 590 acknowledged receipt while they were executing an instrument approach to Cleveland.

Ryan 590 landed at 2344 and taxied to the mail ramp for cargo transfer. The pilots reportedly remained in the cockpit. Snow, reported as dry and blowing, fell throughout the approximately 35 minutes that Ryan 590 was on the ground. Neither Ryan 590 nor any other flight that took off from the airport during the evening or early morning hours of Feb. 16-17, 1991, requested or received de-icing service.

A departure clearance was issued at 0006:38 and, at 0018:17, Ryan 590 was cleared for takeoff. Some witnesses described seeing the airplane lift off from the runway, saying that at 50 to 100 feet above ground level it rolled to the right, followed by a severe roll to the left, past the 90-degree position relative to the horizon and crashed. Other witnesses described the first unusual movement as a slight roll to the left, followed by a substantial roll to the right, with an increase in pitch attitude, and a more severe roll to the left before impact.

The tower controller saw the roll sequence differently, stating that after the airplane lifted off and gained a height of approximately 100 feet, it made a quick bank to the left, followed by a quick bank to the right. He then observed a fireball come out of the rear of the airplane. He stated that these actions were "all together, real quick," in that sequence. After the fireball, he saw the airplane bank farther right to 90 degrees, increase pitch attitude, continue to roll past the 90-degree point to an inverted position and impact with the ground.

The cockpit voice recorder (CVR) tape indicated that the first officer was flying the airplane, because the captain made the following callouts during the takeoff sequence: "Vee one," at 0018:44; "rotate" at 0018:45; "Vee two," at 0018:48; "plus ten," at 0018:49; and "positive rate" at 0018:50. The captain then warned the first officer three times in quick succession to "watch out," beginning at 0018:51 and ending about one second later. At 0018:52, immediately after the last call to "watch out," the CVR recorded sounds similar to engine compressor surges, and at 0018:53, the sounds of a stick shaker. The sound of the first impact occurred at 0018:57.

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The airplane's left wing struck the grass to the right of the takeoff runway. After leaving an approximately 1,600-foot path of wreckage along the right side of the runway, the airplane came to rest, inverted, on the runway about 6,500 feet from the threshold.

Flight Crew Qualifications Reviewed

The captain held an Airline Transport Pilot (ATP) certificate and was rated in the Cessna 500 corporate jet, the McDonnell Douglas DC-8 and DC-9, and the Boeing 727, 737 and 747. He had accumulated approximately 10,505 total flight hours, of which 505 were in the DC-9 series 10. In addition, he flew the DC-9-30 for approximately three years in the U.S. Air Force.

The captain flew six successive night flights on the Buffalo-Cleveland-Indianapolis and return route the week before the accident. He then flew another six successive nights with the same first officer each night, including the night of the accident. The captain had one day off before the last six flights. All of these flights were on the same route from Buffalo to Cleveland to Indianapolis and return to Buffalo through Cleveland. The total flight time for the six successive nights, which included the

night of the accident flight, was 19.6 hours.

Both the airline's chief pilot at Indianapolis and the director of hub operations at Dayton, Ohio, said that the captain might have suffered from a cold the week before the accident. A hotel employee stated that the captain was coughing on the evening of Saturday, Feb. 16. (The CVR tape recorded several coughing episodes by a crew member just before the accident). The captain had bought cough drops before he departed on the accident trip. However, three other witnesses stated that he did not appear to have a cold.

Following the accident, non-prescription cold medications were found in the captain's possessions in the cockpit. They were Actifed Plus tablets, Sudafed 12-hour sustained action nasal decongestant tablets, Halls throat lozenges and Vicks cough drops.

While the aircraft was on the ground in Cleveland, the operations supervisor for Emery Worldwide, a company that contracted with the airline, took paperwork to the cockpit. He said that the flight crew remained in the cockpit and stated that crew members normally leave the airplane for a walkaround, or at least to check the outside cargo door latch. He described the captain, whom he met briefly, as quiet and expressionless.

NTSB noted, but apparently did not emphasize the fact that, according to FAA records, the captain was subject to possible certificate action for a runway incursion incident he was involved in on Nov. 4, 1989. According to the NTSB report, he had taxied a DC-9 aircraft onto a runway at Greater Cincinnati Airport in Ohio without clearance and powered backwards off the runway using powerplant reversing systems to avoid conflict with an aircraft that had initiated takeoff. Action was pending by the FAA at the time of the accident to suspend his ATP certificate for 30 days.

The first officer held an ATP certificate and had accumulated approximately 3,820 total flying hours, of which 510 were in the DC-9. However, only about 30 hours were in the DC-09-10 with Ryan International. He joined that company on Jan. 29, 1991, and completed 60 hours of ground school training on Feb. 2, 1991, which satisfied the requirements for both initial and recurrent ground school. He completed a proficiency check in the DC-9 series 10 aircraft on Feb. 8, 1991. His seven-day total of flight hours prior to the accident was 19.6 hours and was accumulated during six successive nights, including the night of the accident flight, accompanied by the same captain on the same flight schedule.

NTSB Analyzed the Accident

The NTSB found no evidence that the flight crew had adverse medical histories, and the analysis of toxicological specimens did not detect any alcohol or other drugs. The board did consider, however, that the flight crew's performance may have been affected by fatigue.

NTSB found no evidence of any pre-existing faults in the airplane's structure, systems or engines that contributed to the accident. The engine compressor surges that were noted by witnesses and evident on the CVR during the attempted takeoff occurred as the airplane's stall warning stick shaker sounded. Flight tests previously conducted by the manufacturer, and investigations of other DC-9-10 takeoff accidents, have shown that engine compressor surges occur when the airplane is flown into a stall angle of attack (AOA) condition. The surges are attributed to the disruption of air flow aft of the airplane's wing at the engine inlet. The NTSB concluded that the compressor surges were an effect of disrupted airflow and were not a cause factor in this accident.

The abrupt decrease in the airplane's normal acceleration, the entry of the airplane into a steep roll attitude, the sounding of the stall warning stick shaker, and the occurrence of engine compressor surges at an airspeed 27 knots above the theoretical stall speed for the given conditions clearly indicated to the NTSB that the aerodynamic lift-producing capability of the wings had been degraded. The board cited the possible reasons for a loss of aerodynamic efficiency as improper takeoff configuration, extension of wing spoilers and contamination or roughness of the airfoil surface.

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Because the evidence did not support either an improper takeoff configuration or an extension of wing spoilers, the NTSB focused on the possibility that some amount of ice or frozen snow was present on the wing leading edge or upper surface and that this contamination affected the airplane's flight characteristics.

The NTSB believed the most likely possibility of explaining the formation of ice on the wing surface is that the flight crew used the wing anti-ice system during the approach to Cleveland and that the falling dry snow melted and refroze while the airplane was on the ground. This scenario was possible because the wing would be hot upon touchdown (when the air/ground relay automatically deactivates the anti-ice system) and that blowing dry snow can melt on the wing and refreeze as the wing temperature cools to below freezing.

Wing Contamination Affects Performance

Flight Data Recorder (FDR) information indicated that liftoff occurred at a slightly higher-than-normal AOA and that the airplane began to climb. However, when reaching about 100 feet, the airplane rolled steeply. The evidence supported the finding that the airplane's left wing struck the ground first. Four previous accidents investigated by NTSB determined that the DC-9 series 10 aircraft have encountered nearly identical flight control difficulties during takeoff in conditions conducive to the accumulation of wing airfoil ice contamination.

The NTSB's investigation of this accident provided substantial evidence that the rapid roll and descent after liftoff were the result of an aerodynamic stall. As in previous accidents, the airplane was able to lift off and climb initially because of the influence of ground effect on the aerodynamic characteristics of the wing. When an airplane is close to the ground plane, said NTSB, the direction of the airflow over the wing is altered. The result is that the wing will produce more lift at the same airspeed and AOA than it will when the airplane is in free air. This enhanced aerodynamic performance diminishes as the airplane climbs, and becomes almost negligible at a height equal to the airplane's wing span, 87 feet for the DC-9-15.

The NTSB determined that the aircraft reached a combination of airspeed and AOA at which a vertical lift was developed that exceeded the airplane's gross weight. On previous takeoffs of this airplane, the FDR showed that a positive (greater than 1.0 G) normal acceleration was sustained for approximately five seconds with peak values between 1.2 G and 1.3 G as the airplane transitioned to the climbing flight angle. During the accident flight, however, the normal acceleration abruptly decreased after only two seconds, reaching a maximum of about 1.17 G. At the same time, the captain called "Watch out" and one second later the airplane's heading deviated abruptly to the left and the engine compressor surges began. The NTSB noted that this combination of events was consistent with an abrupt and asymmetrical aerodynamic stall of the wings as the airplane reached a height where it lost the aerodynamic performance advantage of ground effect.

The start of the stick shaker one second after the stall indicated that the stall occurred at an AOA of about 12 degrees and an airspeed of about 150 knots. Under normal conditions, with this combination of AOA and airspeed, the airplane should have been developing a normal acceleration (or load factor) greater than 1.4 G. The NTSB concluded that the lift coefficient for the wing of the accident airplane was nearly 30 percent less than the theoretical lift coefficient for a DC-9 series 10 wing. According to the manufacturer, *a wing upper surface contamination that is only .014 inch thick, about equal to the roughness of 80-grade sandpaper* [emphasis added] can produce a 25 percent loss of wing lift. The NTSB concluded that the decrease in the aerodynamic lift-producing ability of the accident airplane was caused by an ice or snow accumulation on the wing that "may have been less than .02 inch thick and barely perceptible from visual observation."

Preventive Information and Procedures Were Absent

Ryan International acquired the accident DC-9 in 1989 and, according to the NTSB, was reportedly not aware of the accident history or related documentation concerning the series 10 aircraft's vulnerability to control loss during takeoff with minute amounts of contamination on the wing. Although a wealth of information on the subject had been developed by McDonnell Douglas dating as far back as January 1969, the NTSB said it was unlikely that the manufacturer's publications were sent to Ryan because that company did not operate Douglas airplanes at the time of distribution. Consequently, no specific information regarding the DC-9 icing history or special precautions relating to ground de-icing was given to the line pilots who were ultimately responsible for the safe operation of the aircraft.

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Ryan developed its DC-9 operations manuals from the airplane's previous owner's operations manuals and, according to the NTSB, certain purported Ryan practices were not incorporated into them. *The requirement to conduct an exterior inspection of the aircraft at intermediate stops was one of those practices not incorporated.*[emphasis added] The NTSB said that the preflight inspection requirement in the Ryan DC-9 manual clearly indicated that exterior inspections were required only on originating flights or after the airplane had been left unattended.

Witness testimony convinced NTSB that neither of the flight crew members conducted a walkaround inspection or a close observation of the wing surface. This did not violate written Ryan policy. Although the flight crew may have observed the wing leading edge from the cargo loading door or the cockpit windows, the NTSB felt that under the existing light conditions and distance, the detection of a critical, *but minute* [emphasis added] amount

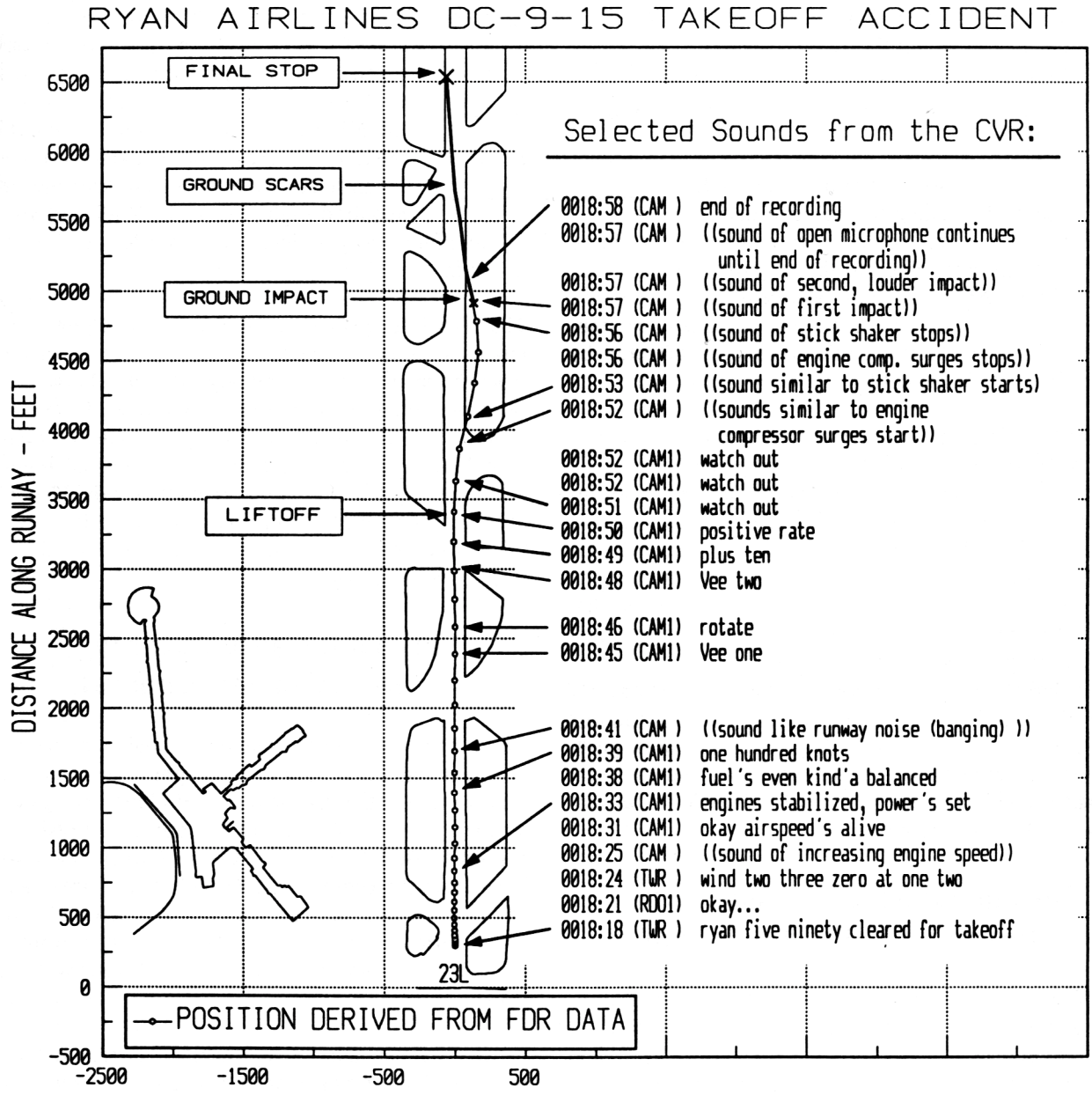
of ice would have been nearly impossible.

The NTSB enumerated several factors that may have influenced the decision of the pilots to remain in the cockpit.

- They may have believed that the air was too cold to contain liquid water that could freeze and stick to the wing surface. There was little information available regarding the possibility of ice forming during the melting/cool down period following the deactivation of wing anti-ice systems after landing.

- Both crew members' experience prior to flying with Ryan was in the DC-9 series 30 aircraft. Those models have wing leading-edge lift-enhancing devices and are not as vulnerable as the series 10 models to critical performance degradation from small amounts of wing contamination. Even if either crew member had encountered similar weather conditions prior to flying with Ryan, they most likely would not have encountered control problems, and their concerns about the hazard of wing ice contamination would probably have been lessened.

- Although deicing equipment had been standing by



Source: National Transportation Safety Board, Aircraft Accident Report, PB91-910410, NTSB.AAR-91/09

for approximately 1-1/2 hours and was immediately available, other operators had not called for the service. There was no evidence of fiscal or schedule pressures by Ryan that would have discouraged the crew from calling for the use of that equipment.

- Fatigue may have influenced the crew's judgment during ground operations at Cleveland and the decision not to conduct an exterior inspection. The crew had flown the same nighttime schedule for six days. The captain had flown the same route for six nights the week before the accident. The captain's schedule had recently intensified from one that called for flying for five days, followed by nine days off-duty time, and the increase could have induced fatigue.

- The captain was suffering from a cold, and the demanding duty schedule during the last 13 days could have made recovery more difficult and added to the negative effects of fatigue. Although there was insufficient evidence to reach a firm conclusion, the captain's decision-making capability could have been affected by fatigue and his cold.

Regardless of those factors, the NTSB stated that a preflight walkaround inspection of an airplane before each flight is a basic tenet for safe operations. Such an inspection, said the board, is necessary to detect serious defects, such as bad landing gear tires, hydraulic leaks, and loose or missing panels, as well as to observe the wing and empennage surfaces. NTSB concluded that this crew's failure to conduct a walkaround inspection was contrary to good practice. Further, the board believed that the crew's failure to detect and remove ice contamination from the wings was a causal factor in this accident. Factors that contributed to a lack of crew guidance on the importance of such inspections and the flight characteristics of the DC-9 series 10 aircraft, in particular, were also considered causal.

Dissemination of Airframe Icing Information Called Inadequate

The NTSB stated that written material, industry presentations and operator seminars available for more than 20 years should have eliminated any operational problem with icing on the DC-9. It concluded that efforts to educate line pilots of the DC-9 series 10 aircraft about its specific problems were not adequate.

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Line pilots apparently did not give the problem the attention it merits, said the NTSB, which noted, *Accumulations of ice as thin as .015 inch on the wings of a DC-9 can reduce the stall angle of attack below stall warning activation.* [emphasis added] NTSB investigators found that the vast majority of DC-9 series 10 pilots they questioned were either unaware of the facts or did not appreciate the critical danger of visually imperceptible amounts of wing contamination. The board was also concerned about the loss of "corporate memory," a failure to pass along complete documentation that could occur when aircraft are sold or when there are changes of pilots and instructors. Although the aircraft manufacturer had issued material and urged that the wing icing problem be incorporated into aircraft flight manuals, no positive action was taken to do so. By including the information in the approved aircraft flight manual, said the NTSB, it would be directly available to the line pilots and would be transferred when an aircraft is sold to a new operator. Ryan acquired eight DC-9s in 1989 and was unaware of the critical icing information until after the accident.

The NTSB suggested that any operator acquiring a new model aircraft in its fleet has an obligation to request from the manufacturer, and any other available sources, information unique to the safe operation of the aircraft. If Ryan had fulfilled this obligation, said the board, it would have become aware of the previous accidents involving wing contamination. Ryan then would have been able to provide the training and guidance to its crews that could have prevented this accident. NTSB also cited Ryan as a causal factor.

Probable Cause Points to Ice Detection and Removal

The NTSB determined that the probable cause of this accident was the failure of the flight crew to detect and remove ice contamination on the airplane's wings, which was largely a result of a lack of appropriate response by the FAA, Douglas Aircraft Co. and Ryan International Airlines to the known critical effect that a minute amount of contamination has on the stall characteristics of the DC-9 series 10 aircraft. The ice contamination led to wing stall and loss of control during the attempted takeoff.

NTSB Chairman James L. Kolstad filed a dissenting statement to the accident report that said, in part: "In my view, the probable cause of this accident was a failure of vigilance on the part of a cockpit crew and it is vitally important not to dilute or mask this message by scattering the

responsibility among impersonalized organizational structures, none of which had a direct hand in the decision-making in this cockpit.

"I think it is fair to say that each of these organizations might have performed better and that their failure contributed to the probability that an accident such as this might take place. But, it is misleading to suggest that the dangers of ice were surprising and that another piece of paper in the blizzard of information that pilots constantly receive would have prevented this accident. Under existing federal regulations it is unlawful to take off with ice adhering to wings. It is the responsibility of every pilot to adhere to this rule, not simply because it is a rule, but because the rule reflects the physics of flight. And it is important that this Board stress the responsibility of those in command of aircraft to stay in command, as it must go without saying that the proper execution of their duties is the single most important guarantor of safe flight."

Susan Coughlin, NTSB vice chairman, filed the following statement:

"I have no difficulty in citing the crew's performance, in that I don't believe that this air crew took such actions to insure that their aircraft was free from ice contamination before departing the gate at Cleveland airport, regardless of the type of aircraft they were flying. At a minimum, The Ryan DC-9 Winter Operations Bulletin 89.4 should have prompted the crew in their preflight preparations to explore more fully the extent to which the weather may have been a negative factor with implications affecting the safety of their flight. While this crew may have had no specific training from the airline on icing conditions, they clearly had at least some cues that icing may be a factor on this particular night. Nevertheless, their collective resources didn't prompt them to inspect the aircraft from the outside either visually or tactually. …

"However, the most critical cue that was not provided to the crew on the night of the accident that was apparently readily available and known throughout much of the aviation community, that being the sensitivity and vulnerability of the DC-9 series 10 aircraft to minute amounts of ice contamination on the upper surfaces of the plane's wings. In my view, this lack of cohesive action by the aviation community at large to provide this critical information and guidance to line pilots of this specific aircraft type, left not only this air crew, but others preceding it, hopelessly ignorant of the situations they faced."

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Aircraft Manufacturer Emphasized Icing Precautions

The NTSB accident report contains a letter from the Douglas Aircraft Co., dated March 21, 1991, that states, in part:

"Ice contamination adversely affects (1) straight-wing aircraft such as the Nord 262, and numerous general aviation aircraft, (2) small turbojet aircraft with conventional airfoils (i.e., no leading edge high-lift devices) such as the Learjet, (3) larger aircraft with conventional airfoils such as the [Fokker] F-28, DC-9-10, and DC-8 and (4) aircraft with leading edge high-lift devices such as the [Boeing] 737. In most takeoff accidents, the ice contamination has not been large ice accretions on the leading edges or thick layers of snow adhering on top of the wings. Rather, dangerous reductions in handling qualities and stall margins can occur because of icing roughness equivalent to that of MEDIUM GRIT SANDPAPER. This seemingly modest amount of contamination can result in pitching moment changes during takeoff rotation that cause the airplane to increasingly behave as if it were mistrimmed in the nose-up direction. Following liftoff, degraded lateral stability requires larger and larger control wheel inputs to keep the airplane from abruptly rolling off, possibly followed by premature stall at lower than normal angles of attack. Additionally, the airflow into the engines may become disturbed causing compressor surges and momentary losses of power. …

"Scrupulously careful ice inspections shortly before takeoff are a must whenever atmospheric conditions make it prudent to do so. Even suspicious conditions justify inspection or precautionary de-icing. Crews should be encouraged to taxi back for a second de-icing if a delayed takeoff in freezing precipitation raises any question of wing condition. During descent, precautionary anti-ice application is also a wise investment."

Lessons Learned

A number of lessons may be learned from this accident, some of which follow:

- The aircrew bears the responsibility for compliance with applicable regulations regardless of other extenuating circumstances. Although the Ryan operations manual did not explicitly call for an

external walkaround inspection of the aircraft between flights, there was an implicit requirement to do so based upon the weather circumstances. Regardless of weather conditions, operations manuals should contain a requirement for a walkaround inspection of any type aircraft between flights. If there is any doubt about the aircraft's condition, it may be prudent to require that *both* pilots do the walkaround and use the combined judgment to make an appropriate decision.

- Ice contamination may be a problem for aircraft other than the DC-9. The Douglas letter names some specific aircraft but only refers to "numerous general aviation aircraft" that may have a similar problem. All aircraft operators might benefit from a review of the accident history of their aircraft to determine if there have been ice accretion causal factors and the best courses of action to ensure the safety of their flights.

- In addition to a visual inspection, touching and feeling the ice accretion may provide additional cues. Although it may not be possible to measure the thickness of ice accretion on the wings to determine how much is too much, the Douglas reference to "icing roughness equivalent to MEDIUM GRIT SANDPAPER" appears to be a practical guideline.

- To prevent the loss of "corporate memory" when acquiring previously used aircraft, it should be incumbent upon the seller to impart all information that may relate to the safety of flight in the particular aircraft being transferred. It should be incumbent upon the buyer to either demand the information from the seller and the aircraft manufacturer or to make an independent investigation of the accident history of the aircraft to determine what safety factors must be acknowledged.

That information should then be used to develop operations manual data and training programs for the air crews.

About the Author

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