National Transportation Safety Board
Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-107 to -108

Honorable Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

About 1554 eastern standard time,[1] on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by COMAIR Airlines, Inc.,[2] as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Comair flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport (CVG), Covington, Kentucky, to Detroit Metropolitan/Wayne County Airport (DTW), Detroit, Michigan. The flight departed CVG about 1508, with 2 flightcrew members, 1 flight attendant, and 26 passengers on board. There were no survivors. The airplane was destroyed by ground impact forces and a postaccident fire. Instrument meteorological conditions prevailed at the time of the accident, and flight 3272 was operating on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the Federal Aviation Administration's (FAA) failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that a Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces.[3]

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[1] Unless otherwise indicated, all times are eastern standard time, based on a 24-hour clock.

[2] Within this safety recommendation letter, COMAIR Airlines, Inc., will be identified as Comair.

[3] National Transportation Safety Board. 1998. *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997.* Aircraft Accident Report NTSB/AAR-98/04. Washington, DC.

Summary of Accident Sequence

According to cockpit voice recorder (CVR) and air traffic control (ATC) information, during the 20 minutes preceding the accident, the pilots received a series of clearances from ATC that included descent, airspeed, and heading instructions. Flight data recorder (FDR) and radar data indicated that the airplane's descent from the en route cruise altitude of flight level 210 to 4,000 feet mean sea level (msl) was stable and controlled and was accomplished at airspeeds and headings consistent with those assigned by ATC. Meteorological information and pilot reports indicated that the airplane was probably intermittently in clouds as it descended between about 11,000 feet msl and 8,200 feet msl; below 8,200 feet msl, the airplane was probably operating predominantly in the clouds.

The pilots were operating with the autopilot engaged during the descent. They had completed the descent checklist (including the activation of the propeller deicing and windshield heat at the ice protection checklist prompt) and the first four of the six items on the approach checklist[4] before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down direction to counter the increasing left roll rate. FDR data indicated that, during the next 3 seconds, the left and right AOA vanes began to diverge, indicating a left sideslip/yaw condition, and the lateral acceleration values began to increase to the left while the autopilot increased the control wheel input to the right in an attempt to control the roll. Thus, by 1554:10, as the airspeed decreased through 155 knots, the airplane experienced the beginning of a significant asymmetry in the lift distribution between the right and left wings and an uncommanded yaw and roll to the left.[5] The roll and control wheel position parameters continued

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[4] According to several Comair EMB-120 pilots, the remaining approach checklist items—flight attendants, notified and flaps, 15/15/checked—would normally be accomplished later during the approach, as the airplane neared the destination airport.

[5] Evaluation of the FDR information revealed that a slight asymmetry of lift because of ice existed earlier in the flight; however, it became aerodynamically significant about 1554:10.

to trend in opposite directions, and the left and right AOA vanes continued to split for the next 14 seconds, until the autopilot disconnected at 1554:24.125.

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;[6] however, the airplane's airspeed continued to decrease. When the captain drew the first officer's attention to the low airspeed indication at 1554:20.8, the airplane's airspeed had decreased to 147 knots. During the next 2 seconds, the pilots more aggressively increased the engine power, and a significant torque split occurred; the torque values peaked at 108 percent on the left engine and 138 percent on the right engine. The Safety Board considered several possible reasons for the significant torque split, including uneven throttle movement by the pilots, ice ingestion by the left engine, a misrigged engine, or an improper engine trim adjustment on the newly installed right engine; however, it was not possible to positively determine the cause of the torque split. Postaccident simulations indicated that this torque split had a significant yaw-producing effect at a critical time in the upset event, exacerbating the airplane's excessive left roll tendency. The airplane's airspeed decreased further to 146 knots, the left roll angle increased beyond the autopilot's 45° limit, and (at 1554:24.1) the autopilot disconnect warning began to sound. One second later, the stick shaker activated. The sudden disengagement of the autopilot (at 1554:24.125) greatly accelerated the left rolling moment that had been developing, suddenly putting the airplane in an unusual attitude. Although the pilots were likely surprised by the upset event, interpretation of the FDR data indicated that the pilots responded with control wheel inputs to counter the left roll within 1 second of the autopilot disengagement and continued to apply control inputs in an apparent attempt to regain control of the airplane until the FDR recording ceased.

Meteorological Factors

Although Comair flight 3272 was operating in winter weather conditions throughout its flight from the Cincinnati area to Detroit, CVR and weather information indicated that the airplane was operating above the cloud tops at its cruise altitude of 21,000 feet msl. Further, the temperatures at the altitudes flown during the en route phase of the flight were too cold to be conducive to airframe ice accretion, and examination of the FDR data did not reflect degraded airplane performance until later in the airplane's descent. Therefore, the Safety Board concludes that the airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

A study conducted by the National Center for Atmospheric Research (NCAR) indicated that there was strong evidence for the existence of icing conditions in the clouds along the accident airplane's descent path below 11,000 feet msl. In addition, weather radar data showed generally light precipitation intensities in the area west of Detroit, with weather echoes of increasing intensity below 11,000 feet msl along the airplane's descent path. The weather radar

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[6] An engine torque split manifested itself during this application of power—at 1554:17, the FDR recorded torque values of 33.3 percent and 39.3 percent on the left and right engines, respectively. The engine torque split ranged from 6 to 10 percent between 1554:17 and 1554:22, when torque values (and the range of the torque split) began to increase abruptly. Simulator test flights that replicated the accident scenario demonstrated that the initial 6 to 10 percent torque split did not have a large aerodynamic effect on the airplane's left roll; however, the larger torque split that occurred later in the accident sequence had a significant aerodynamic effect.

data indicated that the highest precipitation intensities likely existed between 4,100 feet msl and 3,900 feet msl.

The NCAR research meteorologists reported that the average liquid water content (LWC) in the clouds near the accident site likely varied from 0.025 to 0.4 grams per cubic meter when averaged over the cloud depth. However, according to an NCAR research meteorologist, droplet size and LWC are rarely evenly distributed through the depth of a cloud; he stated that, in a typical cloud distribution, the larger droplet sizes with corresponding lower LWC would likely exist near the cloud bases, whereas smaller droplet sizes with higher LWC would typically exist near the cloud tops. He stated that the accident airplane might have encountered higher LWC values (0.5-0.8 grams per cubic meter) with smaller droplets (non-supercooled large droplets (SLD), 10-30 microns) near the cloud tops and lower LWC values (0.025 to 0.4 grams per cubic meter) with larger droplets (larger than 30 microns) near the cloud bases (consistent with the previously discussed weather radar data). Further, the NCAR research meteorologist stated, "if any SLD existed…it would have been more likely to be lower in the cloud…be mixed with smaller drops…the larger drops in the spectrum of those that may have existed there would have been in the 200-400 micron…range."

In addition, the accident airplane's descent path passed through an area of relatively low radar reflectivity during the 4 to 5 minutes before the accident. According to the NCAR report, the area of reduced reflectivity indicated that "the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist." Postaccident statements obtained from the other pilots who were operating along the accident airplane's flightpath (and passed through the area of low reflectivity) near the time of the accident indicated that they encountered widely variable conditions. For example, the pilots of Cactus 50 reported moderate rime icing with the possibility of freezing drizzle, the pilots of Northwest Airlines (NW) flight 272 encountered moderate-to-severe rime icing as soon as they leveled off at 4,000 feet msl, and the pilots of NW flight 483 reported no icing.

Comparison of data from the airplanes indicates that the differences in airframe ice accretion reported by the pilots can be attributed to slight differences in timing, altitude, location (ground track), airspeed, and icing exposure time (and time within the area of reduced reflectivity) of the airplanes. Based on weather radar information and pilot statements, the Safety Board concludes that the weather conditions near the accident site were highly variable and were conducive to the formation of rime or mixed ice at various altitudes and in various amounts, rates, and types of accumulation; if SLD icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet msl.

Aerodynamic Effect of the Ice Accretion

To help assess the type, amount, and effect of the ice that might have been accumulated by Comair flight 3272 during its descent, the Safety Board reviewed the available icing and wind tunnel research data, conducted additional airplane performance studies/simulations, and requested the National Aeronautics and Space Administration's (NASA's) assistance in conducting icing research tunnel (IRT) tests and computational studies. In addition, the Safety

Board reviewed wind tunnel test data obtained during research conducted by the FAA at the University of Illinois at Urbana/Champaign (UIUC).

The Safety Board's study of the accident airplane's aerodynamic performance indicated that it began to degrade from ice accumulation[7] about 4½ to 5 minutes before the autopilot disengaged, as the airplane descended through 7,000 feet msl; the amount of degradation increased gradually as the airplane descended to 4,000 feet msl. Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,[8] and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the 14 CFR Part 25 appendix C envelope[9] and/or the lower portion of the SLD icing range during its descent to 4,000 feet msl. Thus, the postaccident icing tunnel tests were performed using LWCs between 0.52 and 0.85 grams per cubic meter and water droplet sizes between 20 microns and 270 microns. Total air temperatures (TAT) used in the icing tunnel tests ranged between 26° F and 31° F (-3° C and -0.5° C),[10] consistent with the static air temperature (SAT) values recorded by the FDR during the airplane's descent from 7,000 to 4,000 feet msl. The exposure time used in the icing tunnel tests was 5 minutes; additional runs were conducted under some test conditions to determine the effect that deicing boot activation had on cleaning the leading edge and on subsequent ice accretions.

The icing tunnel tests did not result in thick ice accumulation under any test condition (including SLD droplets); rather, the tests consistently resulted in a thin (0.25 inch accumulation or less), rough "sandpaper-type" ice coverage over a large portion of the airfoil's leading edge deicing boot surface area (and aft of the deicing boot on the lower wing surface in some test conditions). In addition, in many IRT test conditions, small (½ inch) ice ridges accreted along the leading edge deicing boot seams. According to NASA and Safety Board IRT test observers, the thin, rough ice coverages (and ice ridges, where applicable) that accreted on the EMB-120 wing were somewhat translucent and were often difficult to perceive from the observation window. The IRT observers further noted that IRT lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation, making it difficult to perceive the ice accumulation during the icing exposure periods. Scientists at NASA's Lewis Research Center described the IRT ice accretions as mostly "glaze" ice, like mixed or clear ice in nature, although it looked slightly like rime ice when the IRT was brightly lighted for photographic documentation of the ice accretions because of its roughness. The Safety Board notes that it is possible that such an accumulation would be difficult for pilots to perceive visually during flight, particularly in low

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[7] Although the Safety Board considered other possible sources for the aerodynamic degradation (such as a mechanical malfunction), the physical evidence did not support a system or structural failure, and the FDR data indicated a gradual, steadily increasing performance degradation that was consistent with degradation observed by the Safety Board in data from events in which icing was a known factor.

[8] All pilot reports indicated moderate or less ice accretions, except the pilots of NW flight 272, who reported that they encountered a trace of rime ice during the descent, then encountered moderate-to-severe icing at 4,000 feet msl about 2 minutes after the accident.

[9] The Part 25 appendix C icing envelope specifies the water drop mean effective diameter, the LWC, and the temperatures at which the airplane must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing.

[10] These TATs are equivalent to SATs of 21° F (-6° C) to 25.5° F (-3° C).

light conditions. This type of accumulation would be consistent with the accident airplane's CVR, which did not record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.[11]

The density of the rough ice coverage also varied, depending on the exposure time; a sparse layer of rough ice usually accreted on the entire impingement area during the first 30 seconds to 1 minute of exposure, and the layer became thicker and more dense as exposure time increased. The NASA-Lewis and FAA/UIUC tests indicated that thin, rough ice accretions located on the leading edge and lower surface of the airfoil primarily resulted in increases in drag, while thin, rough ice accretions located on the leading edge and upper wing surface had an adverse effect on both lift and drag; this is consistent with information that has been obtained during National Advisory Committee for Aeronautics/NASA icing research conducted since the late 1930s. Data from research conducted in the 1940s and 1950s indicate that an airfoil's performance can be significantly affected by even a relatively small amount of ice accumulated on the leading edge area, if that accumulation has a rough, sandpaper-type surface.

Consistent with these data, NASA's drag calculations indicated that the thin, rough layer of sandpaper-type ice accumulation resulted in significant drag and lift degradation on the EMB-120 wing section. Further, the thin rough ice accumulation resulted in a decrease in stall AOA similar to that observed in wind tunnel tests with 3-inch ram's horn ice shapes on protected surfaces and frequently demonstrated a more drastic drop off/break at the stall AOA. FAA/UIUC conducted wind tunnel tests using generic shapes to represent the sandpaper-type roughness with ridges placed on the upper wing surface at 6 percent of the wing chord (farther aft than the ice ridges observed during NASA's IRT tests); these tests further demonstrated that the ridge type of ice accretion resulted in more adverse aerodynamic effect than the 3-inch ram's horn ice shapes.

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[11] According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel). However, the B.F. Goodrich impingement study (which predicts ice accretion impingement limits on an airfoil) and NASA's LEWICE computer program (which predicts the extent of ice accretion on the leading edges of airplane wings and impingement limits and ice thickness for specified conditions but cannot predict surface roughness features) also predicted a sparse, rough ice accretion aft of the deicing boot on the lower wing surface for some of the tested conditions. However, no ice accretion aft of the deicing boot was noticed during the natural icing certification tests. Although it is possible that some of the drag observed in the accident airplane's performance was the result of a sparse, rough ice accumulation aft of the deicing boot on the lower wing surface, it was not possible to positively determine whether the accident airplane's ice accretion extended beyond the deicing boot coverage.

As previously noted, NASA's IRT tests indicated that when an EMB-120 wing is exposed to conditions similar to those encountered by Comair flight 3272 before the accident, the airfoil tended to accrete a small ice ridge (or ridges) along the deicing boot tube segment stitchlines. During tests conducted at a TAT of 26° F, a small, but prominent (½ inch) ridge of ice frequently appeared on the forward portion (0.5 to 1 percent mean aerodynamic chord) of the leading edge deicing boot's upper surface.

The IRT test results were used in NASA's computational studies, which indicated that these pronounced ice ridges tended to act as stall strips, creating more disrupted airflow over the airfoil's upper surface, further decreasing the lift produced by the airfoil, and resulting in a lower stall AOA than the rough ice accretions alone. NASA's computational study data indicated that a thin, rough ice accretion with a small, prominent ice ridge can result in a lower stall AOA and a more dramatic drop off/break than the 3-inch ram's horn ice shape commonly used during initial icing certification testing.

The accident airplane's performance displayed evidence of adverse effects on both lift and drag during the airplane's descent to 4,000 feet msl. The degradation exhibited by the accident airplane was consistent with a combination of thin, rough ice accumulation on the impingement area (including both upper and lower wing leading edge surfaces), with possible ice ridge accumulation. Thus, based on its evaluation of the weather, radar, drag information, CVR, existing icing research data, and postaccident icing and wind tunnel test information, the Safety Board concludes that it is likely that Comair flight 3272 gradually accumulated a thin, rough glaze/mixed ice coverage on the leading edge deicing boot surfaces, possibly with ice ridge formation on the leading edge upper surface, as the airplane descended from 7,000 feet msl to 4,000 feet msl in icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

The Safety Board notes that in some icing exposure scenarios, pilots could become aware of the performance degradation without observing a significant accumulation of ice on the airplane by observing other cues, such as a decrease in airspeed, excessive pitch trim usage, a higher-than-normal amount of engine power needed to maintain a stabilized condition, and/or anomalous rates of climb or descent. However, the Safety Board concludes that because the pilots of Comair flight 3272 were operating the airplane with the autopilot engaged during a series of descents, right and left turns, power adjustments, and airspeed reductions, they might not have perceived the airplane's gradually deteriorating performance.

Further, although it is possible (based on the icing reported by the pilots of NW flight 272 and the NCAR scientist's estimation of the likely droplet size distribution in the clouds) that the accident flight encountered SLD icing[12] as it reached 4,000 feet msl, the airplane was only at that altitude for about 25 seconds before the upset occurred; during most of that 25 seconds, the FDR data showed that the autopilot was countering the increasing left roll tendency and a sideslip

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[12] Results from the SLD icing tanker tests suggest that the visual cues for SLD ice accumulations (unusually extensive ice accreted on the airframe in areas not normally observed to collect ice, accumulation of ice on the upper surface of the wing aft of the protected area, and on the propeller spinner farther aft than normally observed) would have been very apparent to the pilots and might have resulted in a comment.

condition was developing. However, even if the accident flight had accumulated ice at the rapid rate reported by the pilots of NW flight 272 (about ½ inch per minute), the accident flight could not have accumulated a large amount of ice during the brief period of time it spent at 4,000 feet before the autopilot disengaged and the loss of control occurred. Further, icing of the magnitude described by the pilots of NW flight 272 would have produced strong visual cues, and it is likely that the pilots would have commented on such a rapid accumulation, had it occurred. The accident airplane's CVR did not record any flightcrew comments about ice accumulation or the need to activate the leading edge deicing boots during the last 5 minutes of the accident flight; this is consistent with an ice accumulation that was either not observed by the pilots or that was observed but considered to be unremarkable.

Use of Deice/Anti-ice Equipment

The Safety Board attempted to determine whether the airplane's ice protection systems were operated during the accident airplane's descent and approach to DTW. CVR information showed that when the pilots performed the descent checklist at 1547, they confirmed that the airplane's "standard seven" anti-ice systems were activated and activated the windshield heat and the propeller deice system.[13] This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is +5° C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging]." Thus, at the time of the accident, Comair's (and most other EMB-120 operators') guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed ¼ inch to ½ inch ice accumulation, despite Embraer's FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation.

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[13] Although Embraer's nomenclature identifies the propeller ice protection mechanism as a deicing system, it functions as an anti-icing system because it is activated before ice accumulates on the airframe.

The pilots' activation of the propeller and windshield ice protection systems when the airplane entered the clouds would indicate that they were aware that the airplane was operating in icing conditions. If they had activated the leading edge deicing boots, at least some of the airplane's degraded performance would have been restored. However, even if the pilots observed any of the thin, rough ice accretion that likely existed before the loss of control, they probably would not have activated the deicing boots because Comair's guidance to its pilots advised against activating the deicing boots until they observed a thicker ice accumulation. Therefore, based on CVR information and on the steady degradation of airplane performance that was clearly uninterrupted by leading edge deicing boot activation, the Safety Board concludes that, consistent with Comair's procedures regarding ice protection systems, the pilots did not activate the leading edge deicing boots during their descent and approach to the Detroit area, likely because they did not perceive that the airplane was accreting significant (if any) structural ice.

During the postaccident (November 1997) Airplane Deicing Boot Ice Bridging Workshop, information regarding recent icing tunnel and flight test research into the ice bridging phenomenon was disseminated and discussed among industry personnel. The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.[14] However, in April 1996 when Embraer issued (FAA- and CTA-approved) revision 43 to the EMB-120 AFM, the procedure it recommended—activation of the leading edge deicing boots at the first sign of ice accretion—was not consistent with traditional industry concerns about ice bridging. According to the FAA's EMB-120 Aircraft Certification Program Manager, when the EMB-120 AFM revision was proposed by Embraer in late 1995, the deicing boot procedural change was very controversial and generated numerous discussions among FAA and industry personnel. The FAA's EMB-120 Aircraft Certification Program Manager stated that the aircraft evaluation group personnel involved in the discussions about the six EMB-120 icing-related events, the EMB-120 in-flight icing tanker tests, and the deicing boot procedural change were initially resistant to the deicing boot procedural change because of the perceived potential for ice bridging.

The Safety Board notes that during the winter of 1995/1996, senior Comair personnel (and representatives from other EMB-120 operators) were involved in numerous meetings and discussions regarding the six preaccident icing-related events and that they subsequently received Embraer's Operational Bulletin 120-002/96 and revision 43 to the EMB-120 AFM, with its controversial deicing boot procedural change. Although these discussions and documents apparently heightened senior Comair personnel's awareness and concern about EMB-120 operations in icing conditions (as evidenced by the December 1995 interoffice memo, entitled "Winter Operating Tips," and the October 1996 flight standards bulletin 96-04, entitled "Winter Flying Tips"), until the (postaccident) ice bridging workshop, there was insufficient information available to allay the company's concerns regarding the perceived hazards of ice bridging. Because Comair management personnel were still concerned that ice bridging was a problem for modern turbopropeller-driven airplanes, at the time of the accident, the company's deicing boot activation procedures had not been revised in accordance with AFM revision 43. The Safety Board recognizes the concerns regarding ice bridging that Comair had at the time of the accident

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[14] It is important to note that ice bridging may still be a potential hazard for airplanes with older technology deicing boots that have slower inflation/deflation rates.

(before the ice bridging workshop) and notes that the FAA had not mandated incorporation of the procedural revision or engaged in discussions with EMB-120 operators/pilots regarding the merit of the procedural change. Apparently, Comair was not the only EMB-120 operator with concerns regarding the deicing boot procedural change because the air carriers' records indicated that at the time of the accident, only two of seven U.S.-based EMB-120 operators had incorporated the revision into its procedural guidance. However, the Board is concerned that Comair's EMB-120 pilots did not have access to the most current information regarding operating the EMB-120 in icing conditions.

According to EMB-120 pilots from Comair and the Air Line Pilots Association (ALPA), their discussions with other EMB-120 flightcrews indicate that the procedural change is still a controversial issue, despite the information revealed during this accident investigation and at the November 1997 Airplane Deicing Boot Ice Bridging Workshop. This illustrates how thoroughly ingrained the ice bridging concept was in pilots and operators and the importance of an ice bridging pilot education program. Therefore, a thin, yet performance-decreasing type of ice (similar to that likely accumulated by Comair flight 3272) can present a more hazardous situation than a 3-inch ram's horn ice accumulation because it would not necessarily prompt the activation of the boots. Based on this information, the Safety Board concludes that the current operating procedures recommending that pilots wait until ice accumulates to an observable thickness before activating leading edge deicing boots results in unnecessary exposure to a significant risk for turbopropeller-driven airplane flight operations. Based primarily on concerns about ice bridging, pilots continue to use procedures and practices that increase the likelihood of (potentially hazardous) degraded airplane performance resulting from small amounts of rough ice accumulated on the leading edges.

The Safety Board is aware that the FAA, NASA, and ALPA plan to organize an industry-wide air carrier pilot training campaign to increase pilots' understanding of the ice bridging phenomenon and safe operation of deicing boots. Unfortunately, according to NASA personnel, the training program has not yet begun because the FAA is still developing its position based on information from the Ice Bridging Workshop. The Safety Board appreciates the FAA's intention to initiate the development of ice bridging training and its desire to ensure that the training is as thorough and accurate as possible; however, the Board is concerned that the planned training is being delayed. Further, the planned training primarily targets air carrier pilots, and the Board considers it important that the information be disseminated to all affected pilots/operators. The Safety Board is concerned that if nonair carrier pilots and operators do not receive the training, they may operate turbopropeller-driven airplanes in icing conditions using deicing boot procedures that result in less safe flight operations. A training program that reaches only a limited part of the pilot population may not be sufficient to eliminate the pervasive beliefs regarding the potential for ice bridging in turbopropeller-driven airplanes.

Therefore, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. The Safety Board encourages NASA and the FAA to expedite this training effort.

It is important to note that although leading edge deicing boots are useful in minimizing the adverse affects of ice accumulation on an airplane's protected surfaces, activation of deicing boots does not result in a completely clean boot surface; some residual ice remains on the deicing boot after it cycles, and intercycle ice accumulates between deicing boot cycles (on the EMB-120, during the 54-second or 174-second intervals, depending on the mode of boot operation selected). Icing tunnel tests indicate that when the deicing boots are activated early, the initial deicing boot cycle leaves a higher percentage of residual ice than it would with delayed deicing boot activation. However, when the deicing boots remained operating during the remainder of the ice encounter, subsequent deicing boot cycles resulted in a wing leading edge about as clean as would occur with delayed boot activation.

The FAA/UIUC wind tunnel tests revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) amount of rough ice accumulation over the leading edge deicing boot coverage area resulted in significant aerodynamic degradation. This information raises questions about the effectiveness of leading edge deicing boots when dealing with this type of ice accumulation, especially considering a B.F. Goodrich estimation that a good, effective deicing boot shed leaves about 20 percent of the accumulated ice on the boots. The sparse ice coverage observed during the first 30 to 60 seconds of exposure time in some of NASA's icing tunnel test conditions (and which could occur between deicing boot cycles) was estimated by observers to be about 10 percent. This combined research indicates that it is possible for a hazardous situation to occur even if pilots operate the deicing boots early and throughout the icing encounter. The Westair flight 7233 incident, in which uncommanded roll and pitch excursions occurred despite the fact that the pilots stated that they had activated the leading edge deicing boots and selected the heavy boot operation mode,[15] may be an example of such a hazardous situation.

In addition, a hazardous situation may develop even if deicing boots are operated throughout an icing encounter as a result of ice accretions on an airplane's unprotected surfaces, such as aft of the deicing boots. The B.F. Goodrich impingement study, NASA's LEWICE calculations, and NASA IRT tests indicated that a light accretion may occur on the unprotected lower wing surfaces aft of the deicing boot on the EMB-120. However, Embraer representatives stated that such an ice accretion would result in only a trace of ice accumulating aft of the deicing boots and would have a minimal aerodynamic penalty in drag only. Although there was no evidence of ice accretion aft of the deicing boot during the EMB-120 certification natural icing tests and it was not possible to determine whether the accident airplane's ice accretion extended aft of the deicing boot coverage, it is possible that ice accretion on the unprotected surface aft of the deicing boot could exacerbate a potentially hazardous icing situation.

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[15] According to the pilots of Westair flight 7233, they were aware that they were operating in "icing conditions;" they stated that they observed ice accumulating on the airplane and had activated the leading edge deicing boots when the airplane entered the clouds during their departure.

Based on icing and wind tunnel research and information from the Westair incident, the Safety Board concludes that it is possible that ice accretion on unprotected surfaces and intercycle ice accretions on protected surfaces can significantly and adversely affect the aerodynamic performance of an airplane even when leading edge deicing boots are activated and operating normally. Thus, pilots can minimize (but not always prevent) the adverse effects of ice accumulation on the airplane's leading edges by activating the leading edge deicing boots at the first sign of ice accretion. It is not clear what effect residual ice/ice accretions on unprotected nonleading edge airframe surfaces have on flight handling characteristics. Because not enough is known or understood about icing in general, and especially about the effects of intercycle and residual ice, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.

Therefore, the National Transportation Safety Board makes the following recommendations to the National Aeronautics and Space Administration:

> With the Federal Aviation Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-107)
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> With the Federal Aviation Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels. (A-98-108)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

[Original Signed]

By: Jim Hall
Chairman

Moffett/Blum (AS-70); 11/17/98 final
cc: C(2), GA, PA, AS-1, AS-10, AS-30, AS-40, AS-50, AS-70, RE-20, RE-40, RE-60
proofread by ________________