National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply to refer to: A-98-88 through -106

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

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]

[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^{o}, 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^{o}. 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^{o} (moving toward the autopilot's command limit in the heading mode of 25^{o}, +/- 2.5^{o}). 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 (RWD) 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 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.

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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.

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

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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.

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 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.

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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).

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 (NACA)/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.

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.

[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 ice 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.

During tests conducted at a TAT of 26^{o} 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 FAA Order 7110.10L, "Flight Services," contains a definition of "trace" ice accumulations, that states, in part, "A trace of ice is when ice becomes perceptible….It is not hazardous even though deicing/anti-icing equipment is not utilized unless encountered for an extended period of time [over 1 hour]." Information obtained during this investigation, which echoed the results of research conducted in the 1930s and 1940s, indicated that thin, rough amounts of ice, even in trace amounts can result in hazardous flight conditions. The Safety Board concludes that the suggestion in current FAA publications that "trace" icing is "not hazardous" can mislead pilots and operators about the adverse effects of thin, rough ice accretions. Therefore, the Safety Board believes that the FAA should amend the definition of trace ice contained in FAA Order 7110.10L, "Flight Services," (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous.

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 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^{o} 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

[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.

[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.

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.

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 (AEG) 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 (OB) 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

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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.

"Winter Operating Tips," and the October 1996 flight standards bulletin (FSB) 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 (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.

The Safety Board concludes that had the pilots of Comair flight 3272 been aware of the specific airspeed, configuration, and icing circumstances of the six previous EMB-120 icing-related events and of the information contained in OB 120-002/96 and revision 43 to the EMB-120 AFM, it is possible that they would have operated the airplane more conservatively with regard to airspeed and flap configuration or activated the deicing boots when they knew they were in icing conditions. Therefore, the Safety Board believes that the FAA should require principal operations inspectors (POIs) to discuss the information contained in AFM revisions and/or manufacturers' OBs with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes.

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 the FAA should (with NASA 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 the FAA and NASA to expedite this training effort. Further, because ice bridging is not a concern in modern turbopropeller-driven airplanes and because thin amounts of rough ice can be extremely hazardous, the Safety Board believes that the FAA should require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions.

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.

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 the FAA should (with NASA 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.

The Safety Board considers it likely that future ice detection/protection systems will decrease the hazards associated with icing by incorporating ice detection and protection (automatic activation of deicing boots or anti-icing systems) for individual surfaces, including the horizontal stabilizers, of all airplanes certificated for flight in icing conditions. However, because ice accretions and their effects are not yet fully understood, the Safety Board concludes that

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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.

current ice detection/protection requirements and application of technology (particularly deice boots) may not provide adequate protection for a variety of ice accumulation scenarios (tailplane, SLD, thin, rough ice accumulations, etc.). Therefore, the Safety Board believes that the FAA should actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then, require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions.

Comair's Airspeed Guidance

During postaccident interviews, some of Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, and Comair's EMB-120 Program Manager told Safety Board investigators that 170 knots is the only airspeed the company supports for operating with the landing gear and flaps retracted. Although the Safety Board's review of the airspeed guidance contained in Comair's EMB-120 FSM revealed that it did not contain specific minimum maneuvering airspeeds for flight in icing conditions and for various airplane configurations, it did contain general airspeed information in descriptions of normal and non-normal procedures and maneuvers. For example, the technique outlined in Comair's FSM for an instrument landing system (ILS) approach associated the base leg vector position (which was the accident airplane's approximate position on the approach before the upset, albeit still about 20 miles from the destination airport) with 170 knots and the flaps 15 configuration. Additional guidance for the ILS approach procedure associated 150 knots airspeed with the selection of 25^{o} of flaps. (This guidance did not constitute minimum airspeed guidance, but it did represent how Comair intended the airplane to be flown and configured on an ILS approach.)

Comair's EMB-120 airspeed reference cards (readily available and used by the flightcrew in the cockpit) addressed a reference airspeed at an airplane gross weight of 24,000 pounds with gear and flaps retracted ($V_{ref}0$) of 147 knots, and a final segment airspeed (V_{fs})[16] of 143 knots (airspeeds varied, depending on the airplane's gross landing weight and temperatures). Comair's EMB-120 FSM addressed $V_{ref}0$ and V_{fs} airspeeds consistent with the cockpit airspeed reference cards. The FSM also contained guidance for a no-flaps approach and landing (a non-normal procedure) that specified a minimum airspeed of 160 knots while maneuvering on the approach, with a slight airspeed reduction (the amount varying with the weight of the airplane) once established on final approach. Further, the flap control fault (a non-normal procedure) checklist procedure advised pilots to add 35 knots to the reference airspeed for 45^{o} of flaps for the zero flaps configuration, resulting in airspeeds between 140 and 150 knots (again depending on the airplane's gross weight). The published stall airspeed for the EMB-120 at 24,000 pounds gross weight with landing gear and flaps retracted was 114 knots.

During the 13 months before the accident, Comair had issued an interoffice memorandum and an FSB that contained guidance advising EMB-120 pilots to maintain higher airspeeds than

[16] V_{fs} is the target airspeed for flap retraction after takeoff or during go-around.

normal when operating in icing conditions. The Comair interoffice memo, issued on December 8, 1995, advised pilots not to operate the EMB-120 at less than 160 knots in icing conditions and to use 170 knots for holding in icing conditions. According to Comair, this memo was distributed to all EMB-120 pilots through their company mailboxes and a 30-day pilot-read binder but was not incorporated into an FSB or a revision to the Comair EMB-120 FSM. The FSB, issued on October 18, 1996 (to be inserted at the back of the FSM), advised pilots to maintain a minimum airspeed of 170 knots when climbing on autopilot or holding in icing conditions, with no mention of a minimum airspeed for non-climbing/non-holding icing operations. Comair's October 1996 FSB did not support or repeat the interoffice memo's blanket 160-knot minimum airspeed for operating an EMB-120 in icing conditions. The Safety Board notes that the language used, the different airspeeds and criteria contained in the guidance, Comair's methods of distribution, and the company's failure to incorporate the guidance as a formal, permanent revision to the FSM might have caused pilots to be uncertain of the appropriate airspeeds for their circumstances.

Additional preaccident airspeed guidance was contained on the same page as revision 43 to Embraer's EMB-120 AFM (issued in April 1996), which stated that the manufacturer's recommended minimum airspeed for the EMB-120 in icing conditions with landing gear and flaps retracted was 160 knots. However, at the time of the accident, Comair had not incorporated the AFM revision 43 information into its EMB-120 FSM. Further, Comair had not incorporated long-standing AFM information into its FAA-approved EMB-120 FSM; specifically, Comair's FSM did not contain the note advising pilots to increase their approach airspeeds by 5 to 10 knots in icing conditions. (The Safety Board notes that this guidance had been included in Embraer's EMB-120 AFM at least since August 1991, and Comair's FAA POI had not required the company to incorporate the icing-related airspeed guidance into its FSM.) Because Comair's pilots used the company's Operations Manual and FSM as their primary sources of procedural guidance (rather than the EMB-120 AFM), it is likely that many Comair pilots were not aware that Embraer considered 160 knots to be the minimum airspeed for operating the EMB-120 in icing conditions. This is supported by the variations in the responses provided during postaccident interviews by the 16 Comair EMB-120 pilots (including line pilots, flight instructors, and line check airmen) when they were asked about the minimum airspeed for operating the EMB-120 without flaps extended in icing conditions.

Several of the pilots interviewed stated that they would not have been comfortable operating an EMB-120 in icing conditions at an airspeed of 150 knots without flaps extended, citing 160 knots or 170 knots as more acceptable airspeeds, based on previous bulletins and memos.[17] Other pilots indicated that there was no operational requirement to maintain a higher airspeed in icing conditions but cited a note in Comair's FSM that advised pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions. However, three Comair EMB-120 pilots made no special reference to icing conditions and told investigators that the minimum operating airspeed for the EMB-120 flaps up was below 150 knots. One Comair EMB-120 captain stated that he considered the absolute minimum airspeed for operating the airplane

[17] Although many of Comair's line pilots, flight instructors, and line check airmen appeared uncertain of the minimum airspeed for operating an EMB-120 in icing conditions without landing gear or flaps extended, most of the pilots interviewed were aware that Comair's FSB 96-04 stated that the minimum airspeed for holding in icing conditions was 170 knots.

without flaps [in nonicing conditions] to be the V_{fs} airspeed; a Comair EMB-120 flight instructor cited a minimum EMB-120 maneuvering airspeed without flaps of 140 knots; and an EMB-120 line check airman stated that "the airplane should fly safely at 150 knots clean, but this is not a practice [we] advocate….V_{fs} (141 knots to 147 knots), those are the minimum clean speeds."

Thus, although Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, the varied responses received from EMB-120 pilots during postaccident interviews indicate that the guidance provided was not consistently understood by Comair's pilots. Based on the inconsistencies in the answers provided by Comair pilots during the postaccident interviews and the complex and varied minimum airspeed requirements established by Comair for both icing and nonicing conditions, the Safety Board concludes that the guidance provided by Comair in its memos, bulletins, manuals, and training program did not adequately communicate or emphasize specific minimum airspeeds for operating the EMB-120 in the flaps-up configuration, in or out of icing conditions, and thus contributed to the accident.

Flightcrew's Airspeed/Configuration Decisions and Actions

The Safety Board's review of the flightcrew's actions revealed that there was no pilot discussion of flap usage, stall speeds, recommended minimum airspeeds for icing conditions, ice accumulation (potential or observed) and its effects on the airplane's performance at any time during the descent from cruise altitude, nor was there any requirement for such discussion. The Safety Board considers it likely that the pilots would have commented and/or taken action (such as activating the deicing boots and/or extending the flaps) if they had perceived an unsafe condition, either as the result of a significant ice accumulation or an unsafe airspeed assignment for the airplane's configuration. The Safety Board acknowledges that increasing the airspeed by some increment (V_{ref} + 5 knots according to Comair's EMB-120 FSM) when ice accretion is observed is a fairly standard adjustment in the aviation industry, and Comair's FSB 96-04 specified a minimum airspeed of 170 knots for holding in icing conditions. However, ATC had not issued holding instructions to the pilots of Comair flight 3272, nor had ATC indicated that the pilots should expect to receive holding instructions during the approach to DTW. Therefore, the pilots might not have considered the 170-knot minimum airspeed for holding in icing conditions. Additionally, as previously discussed, the pilots might not have recognized that they were operating in icing conditions because it is possible that the accident airplane accreted a thin, rough layer of glaze ice that was imperceptible to the pilots. Because there were no comments recorded by the CVR and because the pilots accepted the 150-knot airspeed assignment without hesitation, comment, or reconfiguration, the Safety Board concludes that the pilots likely did not recognize the need to abide by special restrictions on airspeeds that were established for icing conditions because they did not perceive the significance (or presence) of Comair flight 3272's ice accumulation. Further, based on the uncertainty regarding minimum airspeeds exhibited by Comair pilots during postaccident interviews, the Safety Board considers it likely that under conditions similar to those encountered by the pilots of Comair flight 3272, other Comair pilots might have accepted the same 150-knot airspeed assignment.

Although the Safety Board considers Comair's airspeed guidance ambiguous and unclear and acknowledges that the flightcrew might not have perceived that the airplane was accumulating ice that affected its flight handling characteristics, the Safety Board notes that the preponderance of the airspeed guidance available to the pilots indicated that EMB-120 operating airspeeds of 160 or 170 knots were standard for operating without flaps extended under any (icing or nonicing) conditions. Although these airspeeds were not established minimum airspeeds, they were the operator's procedural guidance and the standards to which Comair's pilots were trained. The Safety Board considers that any pilot deviations from standard procedures during flight operations (although not prohibited and not necessarily unsafe) should be accomplished thoughtfully and with full consideration given to the possible risks involved. In this case, operating at 150 knots provided the pilots with a reduced safety margin above the airplane's stall speed. The reduction in stall margin was especially critical to the accident flight because the accident airplane had accreted structural ice during its descent, which was having an adverse effect on the airplane's performance characteristics. The Safety Board notes that the pilots could have increased the stall margin by extending 15^{o} of flaps and still complied with ATC's airspeed assignment. Further, there was no safety or operational reason to avoid extending the flaps.[18]

The Safety Board considers it critical that pilots take into consideration potential adverse conditions, and make correspondingly conservative decisions where they are warranted. Although the pilots might not have perceived that the airplane was accumulating any ice, their activation of the propeller and windshield heat when the airplane entered icing conditions was an indication that they were aware that they were entering conditions in which ice accumulation was possible.

Based on Comair's guidance for an ILS approach (which Comair uses during pilot training) that associates 170 knots with 15^{o} of flaps on the base leg position, and additional airspeed guidance suggesting airspeeds of 160 to 170 knots for the accident flight's conditions, and the pilots' responsibility to make safe, conservative decisions consistent with flight in icing conditions, the Safety Board concludes that whether the pilots perceived ice accumulating on the airplane or not, they should have recognized that operating in icing conditions at the ATC-assigned airspeed of 150 knots with flaps retracted could result in an unsafe flight situation; therefore, their acceptance of the 150-knot airspeed assignment in icing conditions without extending flaps contributed to the accident.

[18] The Safety Board considered the possibility that the flightcrew avoided extending the flaps because of guidance to avoid extended operations in icing conditions with flaps extended. However, as previously discussed, there were numerous indications that the flightcrew was not considering icing as a significant factor in the airplane's operation at the time. The Safety Board also considered that the pilots might have believed that they had already extended the flaps to 15^{o} at the time that they accepted the 150 knot ATC-assigned airspeed. However, at that time, the airplane was about 20 miles from the destination airport and maintaining an assigned airspeed of 190 knots; thus, the pilots had not received any of the usual (distance and airspeed-related) cues to extend the flaps. The Safety Board was unable to determine whether the pilots believed they had extended the flaps at any subsequent time.

FAA-related Information Regarding Minimum Airspeeds

Because the issue of safe minimum airspeeds is complex and critical to safe flight operations, in May 1997 the Safety Board issued Safety Recommendation A-97-31, which asked the FAA to require air carriers to reflect FAA-approved minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions, in their EMB-120 operating manuals. The Safety Board's recommendation letter referenced the FAA's notice of proposed rulemaking (NPRM) 97-NM-46-AD, which established a minimum safe EMB-120 airspeed in icing conditions of 160 knots based on initial icing certification flight test data, stating the following, in part:

> The NPRM addresses many of the safety issues discussed in this letter. The Safety Board is evaluating whether the proposed 160 KIAS [knots indicated airspeed] minimum airspeed in icing conditions is appropriate, and if the single speed adequately addresses the intent of what would have been our first recommendation: that is, for the FAA to approve for inclusion in Embraer's EMB-120 airplane flight manual minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions.

The Safety Board reiterated its concerns on this subject in its response to the FAA's NPRM 97-NM-46-AD. Despite the Board's concerns, the FAA's final rulemaking for airworthiness directive (AD) 97-26-06 indicated that Embraer's initial icing certification flight tests demonstrated that a minimum airspeed of 160 knots provided an adequate stall margin, "provided the ice protection systems are properly activated." Currently, the FAA-required minimum EMB-120 airspeed guidance consists of 160 knots minimum airspeed for operating in icing conditions.

AD 97-26-06 did not satisfactorily address the concerns that were expressed by the Safety Board in its communications regarding Safety Recommendation A-97-31 and in its response to the NPRM because the 160-knot airspeed was not scientifically determined and does not ensure an acceptable safety margin for all foreseeable flight conditions (evidence of Comair flight 3272's loss of control were apparent at 156 knots—with a slightly different ice accumulation scenario, the loss of control might have occurred earlier in the event) and because the FAA's response did not adequately address the complicated issue of the minimum operating airspeeds (at various flap settings) for the EMB-120 in icing conditions. The Safety Board notes that after this accident, because Comair management did not believe that a 160-knot airspeed ensured adequate stall margin, the company established a minimum airspeed of 170 knots for operating the EMB-120 in icing conditions, thus increasing the stall margin in icing conditions beyond that required by the FAA. The Safety Board is concerned that absent the scientifically determined airspeed guidance it requested from the FAA, some operators are arbitrarily electing to increase their minimum EMB-120 airspeeds, whereas others may continue to follow current FAA guidance that provides an inadequate safety margin. Although an airspeed greater than 160 knots should be required to provide an adequate safety margin, without a scientifically based determination of minimum operating airspeed in icing conditions, some operators may increase the airspeed too much, increasing the risk of tailplane stall.

The Safety Board is aware that manufacturers and operators of many large air transport airplanes have published minimum airspeeds associated with various flap configurations and phases and conditions of flight. These airspeeds are incorporated into operator's manuals and pilot training programs and are helpful for pilots of these airplanes during flight operations. The Safety Board again concludes that minimum airspeed information for various flap configurations and phases and conditions of flight would be helpful to pilots of all passenger-carrying airplanes. Therefore, the Safety Board believes that the FAA should require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in SLD icing conditions, and tailplane icing.

The circumstances of the Westair incident indicate that despite the increased availability of icing-related information since the Comair accident, the increase in icing-related regulations and the heightened awareness of the hazards of structural icing among the operator/pilot population that has resulted from recent icing-related aviation accidents, some EMB-120 pilots remain less vigilant to decreases in airspeed than is prudent. Although EMB-120 pilots have more icing-related information available to them now than they did before the Comair flight 3272 accident, adequate guidance has still not been provided on minimum operating airspeeds and the hazards of various types and amounts (sometimes imperceptible) of ice accumulation. Therefore, the Safety Board believes that the FAA should require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions.

Stall Warning/Protection System

The stall warning systems that are required by 14 CFR Part 25 are intended to provide flightcrews with adequate warning of proximity to the stall AOA; however, they often do not provide adequate warning when the airplane is operating in icing conditions in which the stall AOA is markedly reduced. This was the case in this accident; the airplane had departed from controlled flight before activation of the stick shaker.

The accident airplane's stall warning/protection system used information from the sideslip sensor and the right and left AOA sensors to determine an approaching aerodynamic stall condition. Under normal conditions, with uncontaminated airfoils and the airplane operating with the landing gear and flaps retracted, EMB-120 stick shaker activation would occur at 10^{o} and the AOA at which the airplane actually stalled would be 18^{o}, providing a margin of about 8^{o}. However, with the wings contaminated, the airflow over the upper wing surface is disrupted, the stall airspeed is increased, and the stall AOA is reduced,[19] thus decreasing the margin between

[19] FAA and NASA wind/icing tunnel data indicate that the NACA 23012 airfoil with a thin layer of rough ice on the leading edge with a small ice ridge can stall at angles of attack as low as 5^{o} or 6^{o}.

stall warning and actual stall. The decreased margin can result in a contaminated airplane stalling with little or no prestall warning (i.e., the stick shaker) provided to the pilots and at a higher airspeed and lower AOA than a pilot might expect. Further, if a pilot was confident that the airplane's stall warning/protection system would provide an adequate stall warning margin, that pilot may not be overly concerned about the flight conditions at that time.

The Safety Board notes that the stall warning system installed on the Avions de Transport Regional (ATR) 42/72 decreases the critical AOA for aural alert and stick shaker from 12.5° to 7.5° when the anti-icing system is activated. The 7.5° AOA threshold was selected by ATR to account for a reduced stall AOA with an ice accumulation. In addition, the Safety Board is aware that stall warning/protection systems exist that incorporate airflow sensors into their logic and adjust the stick shaker/pusher activation to compensate for the disruptions in airflow that result from ice accumulation on the airfoil.

Because the accident airplane's FDR and CVR data indicated that the autopilot disengaged and the roll upset occurred before the stick shaker activated, the Safety Board concludes that the stall warning system installed in the accident airplane did not provide an adequate warning to the pilots because ice contamination was present on the airplane's airfoils and the system was not designed to account for aerodynamic degradation or adjust its warning to compensate for the reduced stall warning margin caused by the ice. Thus, the Safety Board believes that the FAA should require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

Operation of the Autopilot

The Safety Board was unable to positively determine whether the autopilot was operating properly based on physical evidence (impact damage precluded functional tests). However, based on FDR data and a review of the autopilot design characteristics, the Safety Board concludes that the accident airplane's autopilot was capable of normal operation and appeared to be operating normally during the last minutes of the accident flight, and the autopilot disconnect and warning systems operated in a manner consistent with their design logic.

The Safety Board evaluated the flightcrew's use of the autopilot as it affected the cues presented to the pilots about the impending loss of control and the behavior of the ailerons as the loss of control developed. The autopilot's actions during the last seconds before it disengaged provided some visual cues that could have warned the pilots of the airplane's performance degradation. For example, during the 15 seconds before the autopilot disengaged, it moved the control wheel to command the ailerons to move in a RWD direction while the flight instruments and the pilots' heading selection indicated that the airplane was in a left bank. Although it would have been possible for the pilots to observe this and deduce that an anomalous flight condition existed, these visual cues began very gradually and were subtle and short lived. The control wheel did not move more than 10°, and the roll angle did not exceed 30° (only slightly greater than the normal autopilot bank limit for the selected left turn), until about 8 seconds before the upset.

The deviations from the desired airplane attitude were becoming noticeable about the time that the pilots were increasing engine power to maintain 150 knots and continued as the captain directed the first officer's attention to the airplane's airspeed (about 5 seconds before the upset). Given this distraction, it is likely that the subtle visual cues that were available were not adequate to prompt the pilots to take the direct and aggressive action that would have been necessary to avoid the upset.

If at least one of the pilots had been manually monitoring the airplane's (autopilot's) performance by maintaining a light grip on the control wheel, it is more likely that the autopilot-commanded right control wheel application (control wheel movement in the opposite direction to the turn) would have been noticed at some point before the autopilot disengaged. However, the pilots could not have identified the buildup in control wheel forces that would have preceded and accompanied the RWD control wheel movements unless the autopilot had been disengaged and they were flying the airplane manually.

Postaccident simulator tests indicated that throughout most of the airplane's left roll, even up to the time the autopilot disengaged, the pilots could have prevented the loss of control of the airplane by decreasing the AOA. However, when the autopilot suddenly disengaged, the release of the autopilot's RWD control input allowed the ailerons to move rapidly in the left wing down direction, which caused the airplane to immediately roll to a nearly inverted attitude.

The sudden disengagement of the autopilot with no warning to the flightcrew is an essential difference between the Comair flight 3272 accident and the Westair flight 7233 incident (other differences include the following: according to their statements, the Westair pilots had activated the leading edge deicing boots, and the Westair airplane's airspeed was below its target airspeed for about 3½ minutes, whereas Comair's airspeed was below the target airspeed for 10 seconds). The Westair pilots intentionally disengaged the autopilot and resumed flying the airplane manually when they felt the airplane shudder or rumble, before an unusual attitude developed. Although the Westair pilots subsequently experienced several roll oscillations and deviated 600 feet below their assigned altitude before they extended 15^{o} of flaps, they were able to regain control of the airplane. Comair flight 3272's autopilot automatically disengaged, and, because of the left roll tendency, the airplane rolled left to a nearly inverted attitude almost immediately after the autopilot disengaged—before the pilots had their hands on the controls. The Westair airplane remained moderately more controllable because the pilots had their hands on the control wheel and were manually flying the airplane as soon as the autopilot was disengaged; further, the excessive roll oscillations did not begin until about 4 seconds after the autopilot disengaged. It is likely that the Comair flight 3272 upset event would have been more controllable if the Comair pilots had recognized the airplane's degraded aerodynamic condition and disengaged the autopilot to fly the airplane manually before the autopilot disengaged automatically and unexpectedly. The Safety Board concludes that, had the pilots been flying the airplane manually (without the autopilot engaged), they likely would have noted the increased RWD control wheel force needed to maintain the desired left bank, become aware of the airplane's altered performance characteristics, and increased their airspeed or otherwise altered their flight situation to avoid the loss of control.

After the ATR-72 accident near Roselawn, Indiana, the Safety Board issued Urgent Safety Recommendation A-94-184 to the FAA recommending, in part, that it prohibit ATR-42/72 pilots from using the autopilot in icing conditions because of the autopilot's ability to mask the airplane's changing flight condition. The FAA's response prohibited ATR 42/72 pilots from using the autopilot in icing conditions unless specific modifications were accomplished or alternative procedures and training were adopted, and the Safety Board reclassified Safety Recommendation A-94-184 "Closed—Acceptable Action." Further, based on the FAA's AD 96-09-24, in the summer of 1996, Comair revised its manuals (based on Embraer changes) to indicate that because "the autopilot may mask cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited" in SLD icing conditions.

However, the circumstances of the Comair accident demonstrate that restricting use of the autopilot only when the airplane is operating in SLD icing conditions may not be adequate. Moreover, an airplane may encounter a hazardous flight condition from use of the autopilot in icing conditions that may not be perceptible to the flightcrew. Case histories indicate that relying on pilots to activate deicing boot systems or maintain minimum airspeeds in icing conditions does not ensure safe operation of an airplane in icing conditions; pilots may not always be attentive enough to airspeeds, they may not recognize the onset of ice accumulation to trigger deicing boot activation, or deicing boot activation may not be sufficient to prevent icing-related flight control anomalies in some conditions because of intercycle icing. However, if the pilots of Comair flight 3272 had intentionally disengaged the autopilot upon the onset of ice accretion, the autopilot would not have masked the tactile cues to the airplane's aerodynamic degradation, nor would the autopilot have automatically disengaged at a subsequent, more critical time. Thus, the pilots would not have initiated their recovery from an extremely unusual attitude.

The Safety Board considered whether operation of the autopilot in the "[½ bank] angle" mode, as recommended in the "Descent/Holding/Landing" section of Embraer's OB No. 120-002/96, "Operation in Icing Conditions," might provide an adequate level of safety for use of the autopilot during maneuvering flight in icing conditions. The Safety Board notes that the sideslip and severe asymmetric degradation of the accident airplane appeared not to have begun (based on FDR data) until the airplane reached 20^{o} of left bank (at 1554:10). However, the Safety Board also notes that the autopilot's ½ bank angle mode only applies to the lateral control mode in which it is selected—when the autopilot lateral control mode changes during flight (either pilot-commanded, or pilot preselected, such as during the transition from heading mode to approach mode), the autopilot reverts to commanding standard bank angles. Thus, the pilot would need to reengage the ½ bank angle mode in the new lateral control mode, if ½ bank angle mode is desired. This would result in an increased pilot workload during the approach phase of flight (already a high workload phase of flight) or the task (reengaging ½ bank angle mode) might not be accomplished. Thus, the Safety Board considers it unlikely that the use of the autopilot's ½ bank angle mode while operating in icing conditions (as recommended in Embraer's OB 120-002/96) would ensure an adequate level of safety to EMB-120 pilots operating in conditions conducive to the formation of structural ice.

Therefore, the Safety Board concludes that disengagement of the autopilot during all operations in icing conditions is necessary to enable pilots to sense the aerodynamic effects of icing and enhance their ability to retain control of the airplane. Because there is no reason to believe that these circumstances may be confined to the ATR-72 and the EMB-120, the Safety Board believes that the FAA should require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems.

Further, based on this accident and other air carrier incidents (such as the Evergreen International B-747), the Safety Board has considered the feasibility and value of a cockpit warning when an airplane first exceeds the autopilot's maximum bank and/or pitch command limits to alert pilots to an anomalous situation. According to AlliedSignal personnel, it is possible to adjust their recent model ground proximity warning systems (GPWS) to provide a cockpit bank angle warning when the airplane's bank angle exceeds the autopilot's normal command limit with the autopilot activated. The Safety Board concludes that if the pilots of Comair flight 3272 had received a GPWS, autopilot, or other system-generated cockpit warning when the airplane first exceeded the autopilot's maximum bank command limits with the autopilot activated, they might have been able to avoid the unusual attitude condition that resulted from the autopilot's sudden disengagement. Therefore, the Safety Board believes that the FAA should require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits.

FAA Continuing Airworthiness Oversight Issues

The Safety Board notes that, like the ATR-42 and -72, the EMB-120 exhibited a history of icing-related upsets/losses of control before being involved in a related fatal accident. At the time of the Comair accident, six icing-related EMB-120 events had been documented, the first of which occurred in June 1989.[20] The Safety Board's review of these incidents shows that before the Comair accident, the EMB-120 fleet had experienced repeated instances of roll upsets associated with ice accumulations that the pilots either did not observe or did not consider sufficient to prompt activation of the deicing boots.

FAA and Embraer personnel had noted the recurring events, and the FAA presented a summary of the six events at an FAA/industry meeting (attended by Safety Board staff) on November 7, 1995. Further, the FAA and Embraer discussed the events with representatives from Comair and other operators at a meeting on November 15, 1995, and additional discussion took place during the EMB-120 SLD icing tanker tests in December 1995. An FAA engineer reviewed these six incidents in a draft report dated January 26, 1996.

The Safety Board has been unable to obtain information about the specific disposition of the draft report within the FAA, although the FAA asserted after the accident that this report did not reflect the official views of the FAA. Nevertheless, the Safety Board notes that more than

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[20] Similarly, before the ATR-72 accident at Roselawn, Indiana, the FAA had been aware of a number of prior ATR upset events. The FAA had concluded that these incidents were essentially pilot-induced stall events; however, further investigation revealed that there were more complex airplane controllability issues involved in the ATR upset events.

1 year before the accident, at least some members of the FAA certification staff responsible for handling EMB-120 icing issues were concerned about, and were considering recommendations on, the following issues: 1) the airplane's roll behavior with ice accretion, 2) high drag from ice accretions that are not considered by the flightcrew to warrant activating the deicing boots, 3) inadequate stall warning in icing conditions, 4) inadequate stall margin with the airspeed established for use in icing conditions, and 5) problems stemming from the use of the autopilot in these conditions.

The FAA's official response to the six preaccident EMB-120 icing-related events, as expressed to the Safety Board by aircraft certification office (ACO) personnel, was that these incidents shared a common factor—flightcrew failure to activate the leading edge deicing boots. The FAA apparently believed that the EMB-120 was safe to operate in icing conditions as long as the boots were operated.

Hence, the FAA's primary action regarding EMB-120 icing before the accident was to approve the Embraer-proposed, CTA-approved revision to the AFM that pilots activate the boots at the first indication of ice accumulation (revision 43). In doing so, the FAA ACO apparently did not accept the draft report's conclusions, which recognized that pilots would not activate the boots if they did not recognize ice accumulation, that an engaged autopilot masked the tactile cues of icing, and that under these conditions, the flightcrew also could be deprived of an adequate stall warning.

The Safety Board notes with disappointment that this was the latest in a series of limited actions taken by the FAA to address the problems of structural icing in transport airplane certification and operation. Basic knowledge about the aerodynamics of icing (including the knowledge regarding the hazards of small amounts of surface roughness/ice) has been well established for the past 50 years, and there is nothing that has been learned in the most recent, postaccident wind tunnel tests and analyses that could not have been learned before this Comair accident.

Many of the concerns raised about icing in this investigation were previously identified by the Safety Board as early as its September 1981 study on icing avoidance and protection. The study raised concerns about the adequacy of the Part 25 appendix C envelope and icing certification and the difficulties in defining and forecasting icing conditions; as a result of the study, the Safety Board recommended, in part, that the FAA evaluate individual aircraft performance in icing conditions and establish operational limits, review icing criteria in Part 25 and expand (adjust) the Part 25 appendix C envelope as necessary, and establish standardized procedures for icing certification. For many years, the FAA did not respond positively to the Safety Board's recommendations, indicating that icing was not a significant problem for airplanes certificated under Part 25 appendix C. However, subsequent icing-related accidents at Pasco, Washington (in December 1989), and Beckley, West Virginia (in January 1991), revealed that flight control anomalies could result from tailplane icing and an icing-related accident at Cleveland, Ohio (in February 1991), revealed that slightly rough ice accumulations on the wing upper surface can result in hazardous flight handling characteristics.[21] Further, the October 1994 ATR-72 accident at Roselawn, Indiana, demonstrated that icing outside the Part 25 appendix C envelope could be a significant problem for airplanes certificated to operate in icing conditions.

After this series of fatal accidents (all of which involved icing in transport airplanes operated in air carrier service) drew attention to icing-related hazards, the FAA reacted incrementally to tailplane icing, then rough ice accumulations on the upper wing, and then, later, to runback icing (SLD). The Safety Board recognizes that following the Comair flight 3272 accident, the FAA began an important icing-related research program with Embraer and the UIUC. This work has resulted in findings about the effects of thin/rough ice accretions and ice ridges on boots, with other possible factors (such as intercycle icing and residual ice on boots) as yet unknown or unresolved. However, had the FAA adequately responded to the Safety Board's 1981 icing recommendation, the earlier accidents, or the concerns expressed in its own staff's draft report on the EMB-120 and conducted a thorough program of icing-related research that defined a course of action to prevent similar incidents by addressing the certification and operational issues (autopilot use in icing conditions, no autopilot bank angle exceedence warning, no stall warning/protection system adjustment for icing conditions, the effects of thin, rough ice and SLD accretions, etc.), this accident would likely have been avoided.

The Safety Board notes that the failure of the FAA to promptly and systematically address these certification and operational issues resulted in the pilots of Comair flight 3272 being in a situation in which they lacked sufficient tools (autopilot bank angle warning, adjusted stall warning/protection system, ice detection system, adequate deice procedures) and information (airspeed guidance, hazards of thin rough ice accretions, and absence of ice bridging) to operate safely. The Safety Board concludes that despite the accumulated lessons of several major accidents and (in the case of the EMB-120) the specific findings of a staff engineer, the FAA failed to adopt a systematic and proactive (rather than incremental and reactive) approach to the certification and operational issues of turbopropeller-driven transport airplane icing, which was causal to this accident.

Icing Certification Requirements

The Safety Board reviewed EMB-120 test data from the original certification of the airplane for flight in icing conditions (U.S. and Canadian tests) and the subsequent SLD icing certification tests, which were conducted in 1995 as a result of the ATR-72 accident near Roselawn, Indiana. The Safety Board found no evidence that the EMB-120 did not satisfy the tests to which it was subjected; in fact, during these tests, Embraer demonstrated the airplane's flight handling qualities under conditions that exceeded the boundaries of the Part 25 appendix C envelope in terms of LWC.

[21] There have been five DC-9 series 10 airplane takeoff accidents attributed to upper wing ice contamination in the United States since 1968. Although these accidents involved turbojet-driven airplanes (not turbopropeller-driven airplanes, like the other icing-related incidents/accidents discussed in this report), the issue of the FAA's failure to address icing-related operational and certification issues is pertinent to all airplanes certificated for flight in icing conditions.

Despite the apparent fulfillment of all icing certification requirements by the EMB-120, Comair flight 3272 crashed after apparently accreting a thin layer of rough, "sandpaper-type" ice, in icing conditions that likely fell mostly within the boundaries of Part 25 appendix C, although droplets as large as 400 microns might have been present.

Consequently, the Safety Board reviewed the adequacy of the current FAA requirements for the certification of airplanes for flight in icing conditions. For an airplane to be certificated for flight in icing conditions, the FAA requires the manufacturer to demonstrate a limited number of test data points within the Part 25 appendix C envelope. The FAA's icing certification requirements are based on fully functioning and operating anti-icing and deicing systems. Although there is no requirement for manufacturers to consider the effects of delayed activation of ice protection systems, intercycle or residual ice accumulations, or other variables that might result in significant aerodynamic effects, Embraer exceeded the minimum FAA requirements when Embraer tested the EMB-120 with ¾-inch (U.S.) and 1-inch (Canada) ice accretions/shapes during initial icing certification.[22] Certification records indicate that the EMB-120 successfully exhibited satisfactory flight handling characteristics with 3-inch ram's horn ice shapes installed on unprotected surfaces. Further, during the SLD icing controllability tests, the FAA tested the EMB-120 with quarter-round artificial ice shapes as large as 1 inch located at the aft edge of the farthest aft inflatable deicing boot segment (to represent ice accumulated in icing conditions that fall outside the Part 25 appendix C envelope). The airplane exhibited full lateral controllability and satisfactory stall warning characteristics in this condition.[23]

However, Embraer had not demonstrated (nor was the company required by the certification authorities to demonstrate) the EMB-120's performance in other ice configurations that would result from weather conditions within the Part 25 appendix C LWC and droplet size envelope, including realistic ice shapes (or natural ice) representing a thin layer of sandpaper-type ice with a small ice ridge (as may have been experienced by Comair flight 3272). Postaccident icing and wind tunnel information indicated that with a small ice ridge along that thin rough surface, the aerodynamic effect on handling and stall margin/stall warning (reduced stall AOA and rapid decrease in lift) can be worse than any of the ice shapes that the FAA required for icing certification.

The Safety Board's review of data from natural icing flight tests revealed that the airplane's handling characteristics were evaluated with ½-inch accretions on protected surfaces and that the deicing boots' ability to remove ice accretions of up to ½-inch was assessed.

[22] For U.S. (FAA) icing certification, the EMB-120 was tested with ¼ inch, ½ inch, and ¾ inch of natural ice on protected surfaces, up to 4 inches of natural ice accumulation on unprotected airfoil surfaces, and 3-inch ram's horn artificial ice shapes on unprotected surfaces; except for the ¾-inch natural ice on protected surfaces, these conditions could be encountered while operating in icing conditions in accordance with procedures outlined in the EMB-120 AFM. However, for Canadian icing certification, the EMB-120 was tested with artificial ice shapes representing conditions considered to be outside normal operation with deicing boots activated (1-inch ram's horn ice shapes on protected surfaces).

[23] Although some control wheel force exceedences were observed, tanker tests identified more realistic ice shapes; during subsequent tests with the realistic ice shapes, no excessive control wheel forces or other anomalies were noted.

Embraer was not required to demonstrate the EMB-120's stall characteristics in adverse operational scenarios, including delayed boot activation, intercycle ice accretion, or residual ice on boots. As a result of the existing icing certification procedures, the FAA did not account for a thin ice accumulation (as was identified during this investigation, and which may not be observed or perceived by pilots to be a threat) that could result in a more hazardous situation than the 3-inch ram's horn shape (which is readily recognizable by pilots as a hazard and would certainly prompt activation of the boots). The Safety Board is concerned that there may be other unaccounted for ice shapes and/or accretion patterns that could result in potentially hazardous performance degradation.

The Safety Board is also concerned that the current icing certification process is overly dependent upon pilot performance; the FAA has long based its icing certification policies and practices on the assumption that pilots will perform their duties without error or misperception. FAA icing-related publications indicate that if ice formations other than those considered in the certification process are present, the airplane's airworthiness may be compromised. After an airplane is certificated by the FAA for flight in appendix C icing conditions, it becomes primarily the pilots' responsibility to ensure that the airplane is operated in icing conditions for which it was certificated. However, as noted during the investigation of the ATR-72 accident at Roselawn, during normal flight operations, pilots often cannot tell the difference between icing conditions that fall within the appendix C envelope and icing conditions outside the appendix C envelope.[24] (For example, a pilot cannot differentiate between 40 micron droplets and 100 micron droplets.) Because pilots often cannot determine whether icing conditions are consistent with "those considered in the certification process" (i.e., limited points within the appendix C certification envelope), or not (i.e., SLD icing conditions, or other potentially hazardous conditions that were not subjected to testing, analysis, or demonstration during icing certification work), it is virtually inevitable that the airplane will unknowingly be operated in icing conditions that fall outside the certification envelope, or in which the airplane had not demonstrated that it could operate safely.

Further, as has been recognized for 50 years or more, and demonstrated in accidents in the 1970s, 1980s, and early 1990s, and then again in the Comair flight 3272 accident, surface roughness/ice accretions that may be imperceptible or appear insignificant to pilots can adversely affect the operation of the airplane. However, because of the imperceptible or seemingly insignificant nature of those accretions, pilots who operate the airplane's deicing boots in accordance with manufacturer's guidance (that advises them to wait until a recommended thickness of ice accretes) may not activate the deicing boots under these circumstances. An article written by a Douglas Aircraft Company design engineer (published in January 1979) indicated that although most pilots are aware of the adverse aerodynamic effects of large amounts of ice, pilots appear less aware that seemingly insignificant amounts of thin, rough ice on an airfoil's leading edge can significantly degrade the airplane's flight characteristics. The deicing boot operating procedures now contained in most airplane manuals contribute to this lack of awareness by advising pilots to wait until a recommended thickness of ice accretes.

[24] The FAA has since required manufacturers of turbopropeller-driven airplanes to develop visual cues for SLD icing; however, the cues were based on very limited testing. Thus, the Safety Board is not convinced that such cues will exist for all icing conditions outside the appendix C icing envelope.

During the investigation of this accident, arguments were made that the pilots caused the accident because they accepted an airspeed 10 knots slower than Comair's FSM recommended for holding in icing conditions. However, the Safety Board notes that an EMB-120 loaded and configured similar to Comair flight 3272, and operated at 150 knots without any ice accretions, would have a 36-knot margin between its operating airspeed and the stall speed. This margin would likely appear to be an adequate safety margin to a pilot who did not recognize that the airplane was accumulating ice or did not believe that enough ice had accumulated to warrant activation of the deicing boots. The flight handling testing that occurred during the icing certification process did not identify that control problems that were observed in the accident airplane's performance at an airspeed of about 156 knots (only 4 knots below the 160-knot minimum speed for flight in icing conditions set by the FAA following the Comair accident) with only a small amount of ice accreted on the deicing boots. It is possible that if the FAA had required manufacturers to conduct tests with small amounts of rough-textured ice accreted on the protected surfaces (as might occur before boot activation and between boot cycles) during icing certification testing, the absence of an adequate safety margin above the stall speed would have been identified. Further, the FAA could have ensured pilot awareness of icing and adequate stall warning by requiring manufacturers to install ice detectors[25] and stall warning systems with reduced AOA thresholds for operations in icing conditions.

Based on its concerns that the current icing certification standards did not require testing for all realistic hazardous ice accretion scenarios, in its 1981 icing-related safety study, the Safety Board recommended that the FAA review the adequacy of the 1950s-era Part 25 appendix C icing envelope, update the procedures for aircraft icing certification, and oversee the manufacturers' evaluations of aircraft performance in various icing conditions. The circumstances of the Comair flight 3272 accident demonstrated again the continuing need for these FAA actions. The Safety Board considers the information that has been available regarding thin, rough ice accretions sufficient to have prompted the FAA to require additional testing within the appendix C envelope to demonstrate the effects of thin, rough ice as part of the icing certification process. Had the FAA required such additional testing, the resultant information regarding the stall margin and operational envelope of the EMB-120 might have been used to define minimum airspeeds for operating the airplane in icing conditions. Therefore, based on its review of the history of icing information, the icing-related incident and accident history, the EMB-120 initial icing certification data, the EMB-120 SLD icing controllability test results, and the circumstances of this accident, the Safety Board concludes that the icing certification process has been inadequate because it has not required manufacturers to demonstrate the airplane's flight handling and stall characteristics under a sufficiently realistic range of adverse ice accretion/flight handling conditions.

As a result of its investigation of the 1994 Roselawn accident, the Safety Board issued Safety Recommendations A-96-54 and A-96-56 (currently classified "Open—Acceptable Response"), which, respectively, stated that the FAA should do the following:

> Revise the icing criteria published in 14 CFR Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent developments in both the design

[25] Rosemount ice detectors were first used in military and transport-category airplanes in the early 1970s.

and use of aircraft. Also, expand the Appendix C icing certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary.

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification.

Further, based on a perceived depletion of the FAA's technical expertise, the 1993 U.S. General Accounting Office report entitled "Aircraft Certification: New FAA Approach Needed to Meet Challenges of Advanced Technology" recommended that the FAA should hire more technical subject matter specialists in various areas, including that of environmental icing. After the Roselawn accident, the FAA developed a three-phase, multi-pronged plan to address icing-related concerns, including operational issues, forecasting/defining icing conditions, certification issues, validating simulation methods, identifying the aerodynamic effects of accretion, and identifying visual cues to various hazardous icing conditions and (about 2 years after the Roselawn accident) hired its current Environmental Icing National Resource Specialist (NRS). In January 1998, the FAA's Environmental Icing NRS updated the Safety Board on the FAA's progress with its plan, indicating that the first two phases have been completed and progress is being made in several aspects of Phase III (specifically in the areas of understanding the effects of various ice accretions, operational issues such as bridging, and development of ice detection/protection equipment).

The Safety Board notes that the FAA's three-phase plan could potentially satisfy the need for a comprehensive review of all aspects of structural icing in turbopropeller-driven transport airplanes. However, the regulatory/certification changes addressed during Phase III have encountered delays. FAA personnel reported to the Safety Board that their attempts to produce an advisory circular (AC) that would appropriately revise methods of compliance with Parts 23/25 and Part 25 appendix C were not successful;[26] therefore, they changed their approach to the problem and issued two of three proposed ACs addressing changes to methods of compliance and are going through the rulemaking process for the needed regulatory changes. According to FAA personnel, ACs addressing methods of compliance with Parts 23 and 25 were issued on August 19, 1998, and March 31, 1998, respectively, and the newly created AC 25.1419 is currently in draft form, with no estimated issue date available. FAA personnel estimated that the rulemaking process will probably not be completed until January 2000.

In response to the Safety Board's Safety Recommendations A-96-54 and A-96-56, the FAA assigned aviation rulemaking advisory committee (ARAC) working groups to accomplish, in part, the following: to establish criticality of ice accretions on airplane performance and handling

[26] According to the FAA's Environmental Icing NRS, FAA legal personnel determined that portions of the AC appeared to require regulatory changes and therefore could not be addressed solely by means of an AC.

qualities, to develop icing certification criteria for the safe operation of airplanes in icing conditions that are not covered by the current certification envelope, and to consider the development of a regulation requiring the installation of ice detectors or equivalent means to warn flightcrews of ice accumulations. The Safety Board appreciates the efforts of the FAA Environmental Icing NRS and the ARAC working groups, and the Safety Board concludes that the work conducted by the FAA Environmental Icing NRS and the ARAC icing-related working groups is of crucial importance to the future safety of icing operations. Consequently, the Safety Board believes that the FAA should expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. Further, the Board reiterates Safety Recommendation A-96-54 and A-96-56 to the FAA.

The Safety Board further notes that according to the FAA's EMB-120 Aircraft Certification Program Manager and Environmental Icing NRS, the new standards, criteria, and methods of compliance contained in Parts 23 and 25 and corresponding ACs that are currently being developed would be applied only to future icing certification projects and would not be retroactively applied to airplanes currently certificated for flight in icing conditions. The Safety Board is concerned that if the FAA does not retroactively apply the revised icing certification standards and methods of compliance to airplanes currently certificated for flight in icing conditions, flight handling/controllability anomalies that have not been accounted for may remain unaccounted for until after a fatal accident, as occurred in the ATR-72 accident at Roselawn and the EMB-120 accident at Monroe, Michigan. The Safety Board concludes that the potential consequences of operating an airplane in icing conditions without first having thoroughly demonstrated adequate handling/controllability characteristics in those conditions are sufficiently severe that they warrant as thorough a certification test program as possible, including application of revised standards to airplanes currently certificated for flight in icing conditions.

Therefore, the Safety Board believes that the FAA should, when the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. Further, pending the accomplishment of these actions, the Safety Board believes that the FAA should review turbopropeller-driven airplane manufacturers' AFMs and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated).

FAA Policies for Airplane Flight Manuals and Air Carrier Operating Manual Revisions

Because FAA Order 8400.10, "Air Transportation Operations Inspector's Handbook," only requires operators to maintain a flight manual that complies with existing regulations and "safe operating procedures," Comair was not required to incorporate manufacturer-recommended procedures or revisions. In addition to the air carrier's decision not to incorporate the procedures contained in Embraer's EMB-120 AFM revision 43 into its own FSM, Comair also had not incorporated Embraer's long-standing procedures for the use of engine ignition and inlet deice boots in icing conditions. Because this investigation revealed several instances in which Comair elected not to incorporate potentially critical safety-of-flight AFM procedures into its operating manual and because the POI for Comair (although he had received a copy of AFM revision 43 from Embraer) was apparently not concerned by the operators' failure to incorporate such procedures, the Safety Board became concerned that the FAA's procedures for the management and oversight of air carriers' manuals may not be adequate.

Although it was somewhat controversial, revision 43 had been reviewed by FAA and CTA certification personnel and had been approved by these certification authorities as the proper way to operate the equipment. However, at the time of the accident, Comair and four of the other six U.S.-based EMB-120 operators had not incorporated revision 43 in their flightcrew operating manuals. This was possible, in part, because the FAA had not mandated incorporation of AFM revision 43 into operators' procedures. (Further, the FAA had not required Comair to incorporate AFM guidance advising pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions.) In its October 1997 memo, the FAA stated that it would only issue an AD to mandate an AFM revision when it considered the change "significant enough to warrant retroactive application to all aircraft." No AD was issued when revision 43 to the EMB-120 AFM was approved; therefore, the FAA apparently did not consider the procedural changes contained in AFM revision 43 "significant enough" to require air carriers' compliance. Further, existing FAA policy does not require interaction or dialog between FAA flight standards and air carrier personnel regarding AFM procedures or revisions. Because Comair had not adopted the AFM revision 43 procedures, the pilots of flight 3272 were (unknowingly) operating in icing conditions without the most current, safest icing-related guidance. Had Comair incorporated AFM revision 43 into its EMB-120 operating procedures, the flightcrew might have activated the deicing boots before the loss of control of the airplane, possibly precluding the accident. Therefore, the Safety Board concludes that the current FAA policy allowing air carriers to elect not to adopt AFM operational procedures without clear written justification can result in air carriers using procedures that may not reflect the safest operating practices. The Safety Board believes that the FAA should require air carriers to adopt the operating procedures contained in the manufacturer's AFM and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure.

Based on the history of revision 43 and the need for the FAA to more closely review and approve air carrier compliance with AFM procedures, the Safety Board assessed the capacity of the FAA flight standards organization to perform such an enhanced function. The Safety Board considers the FAA's current system inadequate because it allows for less than thorough review and communication regarding safety-of-flight data/information in a number of areas (i.e., certification, icing certification, continuing airworthiness/oversight). Before the Comair accident, the FAA POI who was responsible for oversight of Comair was not aware of the background information justifying revision 43 to the EMB-120 AFM and thus did not pursue corresponding procedural changes with Comair. According to a memo received by the Safety Board in October 1997 from FAA personnel (the Acting Director of Flight Standards Service and the Director of Aircraft Certification Service), at the time of the accident, there was no procedure to ensure that information (including AFM changes) not mandated by an AD was shared between ACO and/or AEG personnel and other Flight Standards personnel (specifically, the POIs). The memo stated that although informal communications (described by FAA personnel as "discretionary") can occur in some cases between ACO and/or AEG personnel and POIs, there was no formal procedure to ensure that the necessary communication and coordination take place. (The memo further stated that the airplane operators "typically supply that revision to the POI.")

According to the authors of the memo, when the FAA receives an AFM revision from a manufacturer, the ACO personnel would not engage in discussions with Flight Standards personnel unless they believed that the AFM revision was particularly noteworthy, in which case they would discuss it with flight standards AEG personnel. Further, there was no explicit line of communication between the AEG and POIs. Thus, under the current system, the POI (or other pertinent flight standards personnel) might never know about the revision (if ACO personnel deemed it unnoteworthy) unless they receive a copy from the manufacturer (as was the case with Embraer's AFM revision 43) or unless an operator requests approval for an associated change to its flightcrew operating manual.

The Safety Board has observed similar communication/coordination problems between FAA offices during other investigations—specifically, during the investigation of the 1987 CASA C-212-CC accident at Romulus, Michigan, and the 1994 ATR-72 accident at Roselawn. As a result of the ATR-72 accident, the Safety Board recommended (in Safety Recommendation A-96-62) that the FAA develop an organizational structure and communications system to ensure that accident/incident information is disseminated to ensure effective continuing airworthiness oversight, with specific emphasis on the AEG. In April 1997, the FAA agreed that it would review its then-current organizational structure and processes to determine the adequacy of the communications and monitoring of the continuing airworthiness of aircraft, and the Safety Board classified the recommendation "Open—Acceptable Response." On February 25, 1998, the FAA responded that it had initiated positive improvements. Based on this action and the Board's continuing dialogue with the FAA on this issue, Safety Recommendation A-96-62 remains classified "Open—Acceptable Response."

During a June 11, 1998, meeting, FAA management personnel advised Safety Board staff that the FAA had completed the review of its internal communications procedures and had identified areas in which improvements were warranted. The Director of Aircraft Certification Services stated that the FAA is "committed to making changes, [and is] putting a team together" to establish new procedures to ensure that information is shared with all pertinent personnel in all branches of the FAA. He reported that under the new system, the ACO Project Manager and Flight Test Manager will discuss all flight manual revisions with flight standards AEG personnel, who will in turn discuss the revisions with the POIs whose operators are affected; the discussions will not hinge on a subjective determination of significance, and a dispute resolution process will be established. The Safety Board considers these improved communication procedures to be essential under both the existing FAA policy in which air carrier adoption of AFM procedures is optional, and the Safety Board's proposed policy that would in most cases mandate adoption of these procedures. Under the proposed policy, flight standards and ACO personnel would need to coordinate the evaluation of AFM revisions and the equivalence of alternatives proposed by the air carriers.

Thus, the Safety Board concludes that at the time of the Comair flight 3272 accident, pertinent flight standards personnel (specifically, the POI assigned to Comair) lacked information critical to the continued safe operation of the EMB-120 fleet and would have been unable to evaluate the need to incorporate AFM revision 43 or any alternatives proposed by air carriers. Therefore, the Safety Board believes that the FAA should ensure that flight standards personnel at all levels (from AEGs to certificate management offices) are informed about all manufacturer OBs and AFM revisions, including the background and justification for the revision.

Westair EMB-120 FDR Sensor Information

The Safety Board has observed anomalous FDR-recorded values for flight control parameters on seven of eight Embraer EMB-120 FDRs it has reviewed, including the FDRs from the Comair and the Westair airplanes. The Westair incident occurred after the FAA established new FDR inspection/potentiometer calibration requirements for operators of EMB-120 airplanes, and Westair's maintenance records indicated that an FDR system check was conducted on the incident airplane on December 27, 1997, with no system discrepancies noted. The test procedure was conducted with the airplane stationary and the engines not running; there was no requirement for an FDR readout during the test procedure.

Although there were no sensor discrepancies noted during the Westair FDR system check, the Safety Board's postincident review of the incident airplane's FDR data revealed discrepancies in the control wheel and rudder pedal position parameters. The Safety Board's evaluation of the potentiometer calibration test criteria and the symptoms displayed by the problem sensors indicated that the sensor anomalies may not have been detectable during static tests on the ground. The test procedure did not provide an evaluation of sensor performance under normal operating conditions and, therefore, may be of limited use in detecting noisy signals or invalid signals that are confined to only a portion of the sensor's normal operating range. The Safety Board considers it likely that if an FDR readout had been conducted and pertinent parameters reviewed in conjunction with the FDR system check, the control wheel position and rudder sensor anomalies would have been observed, and efforts would have been taken to correct them.

Reliable FDR information is critical to understanding accident/incident scenarios and invaluable in identifying complex safety issues and solutions; when FDR information is not recorded (or is recorded incorrectly) for any given parameter, it becomes more likely that potentially significant safety issues will not be identified. Further (as noted in the Safety Board's report regarding the August 1997 accident involving a Fine Airlines Douglas DC-8-61 at Miami, Florida),[27] reliable FDR data, read out at regular inspection intervals, can be useful for purposes other than accident/incident investigation. Analysis of such FDR data could be used by operators to monitor trends and efficiency in their flight operations through a flight operations quality

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[27] See National Transportation Safety Board. 1998. *Fine Airlines Flight 101, Douglas DC-8-61, N27UA, Miami, Florida, August 7, 1997.* Aircraft Accident Report NTSB/AAR-98/02. Washington, DC.

assurance program and could be used on an industry-wide basis to streamline flight operations, refine ATC procedures and airport configurations, and improve aircraft designs.

The Safety Board concludes that the FAA's current EMB-120 FDR system inspection procedure is inadequate because it allows existing flight control sensor anomalies to go undetected, and thus uncorrected. Therefore, the Safety Board believes that the FAA should revise its current EMB-120 FDR system inspection procedure to include an FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane.

The Lack of Additional Icing-Related Pilot Reports

The Safety Board's investigation of the meteorological aspects of this accident revealed that about 16 icing-related pilot reports (PIREPs) were issued by pilots operating in the northwestern Ohio/southern Michigan area between 1300 and 1700 on the day of the accident. However, when the Safety Board distributed a weather conditions survey to additional flightcrews that were operating near Detroit about the time of the accident, 9 of the 11 pilots who responded to the survey reported that they encountered icing conditions. Of the nine pilots who indicated that they encountered icing conditions, only one pilot had submitted a pilot report for the conditions they observed on the day of the accident. (In response to a survey question that asked if they submitted a PIREP, two pilots stated that they did not submit a PIREP because the conditions encountered were consistent with the forecast icing conditions; one pilot reported that he did not submit a PIREP because of accident-related congestion on the ATC frequency; and the pilots of another airplane reported that they were too busy during the approach, landing, and taxi to submit a PIREP. The survey responses from the other four responding pilots did not state why they did not submit PIREPs.)

Although the Safety Board does not believe that the absence of these additional PIREPs affected the accident flightcrew's actions (because they were provided with adequate preflight, en route, and arrival weather information to conduct the flight safely; they should have been aware that they would be operating in potential icing conditions), it is possible that the PIREP information would have greatly benefited other pilots. Because PIREPs are an important and valuable source of weather information for pilots, the Safety Board is concerned that pilots had observed icing in the Detroit area the day of the accident but did not share that information with other pilots. Thus, the Safety Board concludes that the failure of pilots who encounter in-flight icing to report the information to the appropriate facility denies other pilots operating in the area the access to valuable and timely information that could prevent an accident. Therefore, the Safety Board believes that the FAA should reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable.

Also, because a Detroit air traffic controller did not disseminate icing-related information that he had received from another flight operating in the area about 20 minutes before the accident, the Safety Board examined the dissemination of icing-related information through the ATC system. The Board notes that the Standard Operating Procedures handbook for DTW Air Traffic Control Tower and Terminal Radar Approach Control did not require that icing reports be included on the automatic terminal information service (ATIS) recording that is monitored by all pilots. Although FAA Order 7110.65, "Air Traffic Control," contains guidance that PIREPs of any type should be included in the ATIS broadcast "as appropriate" and "pertinent to operations in the terminal area," this guidance is too broad and subjective to adequately ensure the transmission of icing-related information in an airport terminal environment. Reports of icing conditions should be of interest to all pilots operating within that environment, especially considering the normally reduced airspeeds and decreased stall margins for airplanes operating in the approach and departure phases of flight. Therefore, the Safety Board concludes that the FAA ATC system has not established adequate procedures for the dissemination of icing-related pilot reports received in the airport terminal environment; these reports should be incorporated into ATIS broadcasts so that all arriving and departing pilots can become aware of icing conditions in the area. Consequently, the Safety Board believes that the FAA should amend FAA Order 7110.65, "Air Traffic Control," to require that ATIS broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report.

Therefore, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Amend the definition of trace ice contained in Federal Aviation Administration (FAA) Order 7110.10L, "Flight Services," (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous. (A-98-88)
>
> Require principal operations inspectors (POIs) to discuss the information contained in airplane flight manual revisions and/or manufacturers' operational bulletins with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes. (A-98-89)
>
> With the National Aeronautics and Space 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-98-90)
>
> Require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions. (A-98-91)

With the National Aeronautics and Space 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-98-92)

Actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions. (A-98-93)

Require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in supercooled large droplet icing conditions, and tailplane icing. (A-98-94)

Require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions. (A-98-95)

Require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions. (A-98-96)

Require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems. (A-98-97)

Require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits. (A-98-98)

Expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. (A-98-99)

> When the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. (A-98-100)
>
> Review turbopropeller-driven airplane manufacturers' airplane flight manuals and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated). (A-98-101)
>
> Require air carriers to adopt the operating procedures contained in the manufacturer's airplane flight manual and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure. (A-98-102)
>
> Ensure that flight standards personnel at all levels (from aircraft evaluation groups to certificate management offices) are informed about all manufacturer operational bulletins and airplane flight manual revisions, including the background and justification for the revision. (A-98-103)
>
> Revise its current EMB-120 flight data recorder (FDR) system inspection procedure to include a FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane. (A-98-104)
>
> Reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable. (A-98-105)
>
> Amend Federal Aviation Administration Order 7110.65, "Air Traffic Control," to require that automatic terminal information service broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report. (A-98-106)

In addition, the Safety Board reiterates the following safety recommendations to the Federal Aviation Administration:

> Revise the icing criteria published in 14 Code of Federal Regulations Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent development in both the design and use of aircraft. Also, expand the Part 25 appendix C icing

certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary. (A-96-54)

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification. (A-96-56)

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

[Original Signed]

By: Jim Hall
Chairman

**Vice Chairman Francis did not participate in the vote to reiterate Safety Recommendations A-96-54 and A-96-56.