National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 27, 2007
In reply refer to: A-07-12 through –17
A-96-54 and A-98-92 (Reiterated)
A-98-91 and A-98-100 (Superseded)

Honorable Marion C. Blakey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 16, 2005, about 0913 mountain standard time,[1] a Cessna Citation 560, N500AT, operated by Martinair, Inc., for Circuit City Stores, Inc.,[2] crashed about 4 nautical miles east of Pueblo Memorial Airport (PUB), Pueblo, Colorado, while on an instrument landing system (ILS) approach to runway 26R. The two pilots and six passengers on board were killed, and the airplane was destroyed by impact forces and postcrash fire. The flight was operating under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91 on an instrument flight rules flight plan. Instrument meteorological conditions (IMC) prevailed at the time of the accident.[3]

The National Transportation Safety Board determined that the probable cause of this accident was the flight crew's failure to effectively monitor and maintain airspeed and comply with procedures for deice boot activation on the approach, which caused an aerodynamic stall from which they did not recover. Contributing to the accident was the Federal Aviation Administration's (FAA) failure to establish adequate certification requirements for flight into icing conditions, which led to the inadequate stall warning margin provided by the airplane's stall warning system.

Flight Crew Performance

Meteorological information indicated that, about the time the accident flight approached the PUB area, icing, including freezing drizzle conditions, existed. Cockpit voice recorder (CVR) evidence indicates that, starting about 0851, the flight crew began taking actions to minimize the icing's hazardous effects, such as activating the airplane's engine and windshield anti-ice systems. An analysis of the CVR and meteorological information indicated that mixed icing conditions existed from about 21,000 to 14,000 feet. Radar data and CVR information indicated

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

[2] Circuit City Stores owned the airplane. Martinair, Inc., an aircraft management and charter company, operated and managed the accident airplane for Circuit City Stores.

[3] For more information, see *Crash During Approach to Landing, Circuit City Stores, Inc., Cessna Citation 560, N500AT, Pueblo, Colorado, February 16, 2005,* Aircraft Accident Report NTSB/AAR-07/02 (Washington, DC: NTSB, 2007).

that the airplane was in this icing layer for about 5 1/2 minutes. At 0858:20, as the airplane was descending through about 18,000 feet, the first officer suggested to the captain that he might want to cycle the deice boots.[4] After cycling the deice boots, the captain indicated that the deice boots might have shed a little of the ice but that some ice remained on the wing, indicating the presence of residual ice.

In accordance with the SimuFlite Cessna Citation V Technical Manual and the Cessna Model 560 Citation V Airplane Flight Manual (AFM), pilots were trained that, when any residual ice is present or can be expected during approach and landing, V_{ref}[5] must be increased by 8 knots. The manuals also contained both a caution and a warning indicating that stall speeds increased during operations in icing conditions, and that, therefore, V_{ref} must be increased.

At 0859:29, the CVR recorded the first officer state that the V_{ref} was 96 knots. In the case of this flight, the V_{ref} should have been increased from 96 to 104 knots because of the icing conditions. The CVR did not record either pilot mention increasing the airspeed at any point during the approach. Therefore, the Safety Board concludes that the flight crew did not increase the V_{ref} while operating in icing conditions, contrary to company procedures and manufacturer guidance.

At 0908:25, while at an altitude of about 9,400 feet, the first officer reported that the flight was in IMC, and, about 1 minute later, while at an altitude of about 7,400 feet, he reported that clear ice had accumulated on the airplane's wing. CVR and meteorological information indicated that the airplane likely encountered supercooled[6] large droplet (SLD) conditions from 9,400 to 6,100 feet (the calculated altitude at the time of the upset) and that the airplane was likely in these conditions for about 4 1/2 minutes. During this time, about 1 to 4 mm (0.039 to 0.156 inch) of additional ice could have accumulated on the wing leading edges. The Safety Board concludes that the airplane encountered SLD conditions, which are most conducive to the formation of thin, rough ice on or aft of the protected surfaces, during about the last 4 1/2 minutes of the flight. The Safety Board further concludes that the airplane had residual ice on the wings after the deice boots were activated earlier in the flight and that this ice would have affected the overall thickness, roughness, and distribution of the SLD ice accumulation.

According to an airplane performance study[7] conducted by the Safety Board, about 0910, the airplane started its final descent from 7,000 feet at an airspeed of about 155 knots. By about 0911:35, the airspeed had started to decrease. CVR evidence indicated that the landing gear was extended at 0911:10, followed by extension of the speedbrakes and selection of full flaps. At

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[4] The pilots had been trained to wait until 1/4- to 1/2-inch-thick ice accumulation was visible on the wing leading edges before activating the deice boots.

[5] V_{ref} is the landing reference airspeed with full flaps and landing gear down.

[6] Supercooled is the liquid state of a substance that is below the normal freezing temperature for that substance.

[7] The Safety Board's airplane performance study used enhanced ground proximity warning system data, PUB airport surveillance radar-7 data, manufacturer-provided aerodynamic data, and meteorological information to establish a time history of the airplane's motions and to estimate the airplane's performance parameters (including ground speed, airspeed, descent rate, and aircraft pitch and roll angles) for the final portion of the flight. Nominal error or uncertainty in the radar and wind data led to variables in the airplane performance parameters; therefore, the performance parameters should be considered approximations.

0912:04, the first officer stated, "and you are plus twenty five," to which the captain replied, "slowing." On the basis of a V_{ref} of 96 knots, the airspeed would have been about 121 knots at the time of the first officer's statement. At 0912:37, when the airplane was at an altitude of about 6,100 feet, the first officer told the captain that he might want to run the deice boots and that they had the V_{ref}.

Company procedures for approach and landing in icing conditions stated that, when reconfiguring for approach and landing (extending landing gear and selecting full flaps), pilots should activate the deice boot system when any ice accumulation, regardless of thickness, is visible on the wing leading edges and continue to monitor the leading edges for any reaccumulation. Although the CVR recorded the first officer mention to the captain that they might want to activate the deice boots at 0912:37, there is no evidence that the deice system was activated during the approach. Therefore, the Safety Board concludes that the flight crew did not activate the deice boots when configuring for the approach and landing, which was contrary to company procedures and manufacturer guidance.

The airplane performance calculations showed that, immediately after passing through about 6,100 feet, the airplane entered a large roll to the left concurrent with a sudden decrease in pitch, indicating the start of the loss of control and aerodynamic stall. No evidence exists indicating that the stall warning activated before or concurrent with the upset. In accordance with the Cessna Model 560 Citation V AFM and the design of the stall warning system, the accident airplane's stall warning should have activated about 86 knots.

Although it could not be determined at precisely what airspeed the loss of control occurred, airplane performance calculations indicated that the stall occurred at an airspeed of about 90 knots, which was well above the expected stall speed in icing conditions of 81 knots. According to company and manufacturer guidance on approach airspeeds in icing conditions, the airplane's airspeed at the time of the upset should have been about 114 knots.[8] The performance calculations and enhanced ground proximity warning system ground speed data showed that the airspeed continued to decrease until the loss of control. The Safety Board concludes that the flight crew failed to maintain adequate airspeed during the final approach in icing conditions, which led to an aerodynamic stall from which they did not recover.

As noted, the flight crew did not increase the approach airspeed or activate the deice boots during the approach, which is required for the Cessna 560 when ice is present on the wing. Although it could not be determined precisely why the flight crew did not maintain adequate airspeed or activate the deice boots during the approach, the Safety Board discovered during the investigation that there may be insufficient training on operational procedures in icing conditions. For example, postaccident interviews with simulator flight instructors revealed that these procedures might not be getting emphasized during simulator training because the details of the training are left up to the individual instructors. Further, a review of two flight training centers' syllabuses revealed that they do not state that instructors should emphasize these

[8] According to the guidance, the approach airspeed should be V_{ref}+10 knots, in this case, 106 knots. Because the guidance requires that 8 knots be added to the approach airspeed in icing conditions, the approach airspeed should have been 114 knots.

procedures. The Board is concerned that these operational procedures are not being consistently evaluated during simulator training.

The Safety Board concludes that pilots could benefit from the reinforcement during training of the Cessna 560 AFM requirements to increase the airspeed and operate the deice boots during approaches when ice is present on the wings. Therefore, the Safety Board believes that the FAA should require that operational training in the Cessna 560 airplane emphasize the AFM requirements that pilots increase the airspeed and operate the deice boots during approaches when ice is present on the wings.

Flight Crew Monitoring Skills and Workload Management

The Safety Board examined the flight crew's actions during the approach to determine the role of the timing of the approach briefing in the accident sequence. Although the flight crew had expected to land on runway 8L, based on the current automatic terminal information service information, at 0905:56, approach control issued vectors for the ILS to runway 26R. According to the CVR, the flight crew noted the change in the runway assignment and immediately tuned the radios and set the inbound course. However, subsequent discussion about the details of the runway 26R approach was not initiated until almost 5 minutes later, at 0910:47. During the remaining 2 minutes before the stall, the flight crew needed to intercept the localizer and glideslope and configure and slow the airplane for the approach. However, CVR evidence showed that, although these airplane-handling tasks were being performed, the flight crew was concurrently briefing the ILS 26 approach. Specifically, from 0912:17 to 0912:31, as the airspeed was decreasing, the flight crew briefed the missed approach procedure for runway 26R. It was only at the end of this discussion that the first officer recognized and called for the need to run the deice boots and indicated that the airplane had slowed to V_{ref}.

The Safety Board recognizes that a runway change can disrupt a flight crew's planning and may affect their ability to conduct an approach briefing during a relatively low workload phase of flight, such as the top of the descent. When the runway change occurs late in the approach, it is important for flight crews to determine how and when to conduct the briefing to ensure that the objectives of the briefing are achieved without compromising safety of flight.[9] For the accident flight crew, the runway change occurred early enough for the briefing to have been completed before they began to configure and slow the airplane for final approach. Literature on monitoring emphasizes that cockpit workload should be distributed to minimize conflicting task demands during critical phases of flight. In this case, the flight crew's delayed approach briefing served to divert their attention from handling the airplane, managing the deice boot system, and monitoring the tasks that had to be performed during that period. The Safety Board concludes that the briefing conducted late in the approach was a distraction that impeded the flight crew's ability to monitor and maintain airspeed and manage the deice system.

The Safety Board has long recognized the importance of flight crew monitoring skills in accident prevention. For example, the Board's 1994 safety study of 37 major flight

[9] Industry guidance states that flight crews should ask air traffic control for assistance, such as requesting to receive delayed vectors or enter a holding pattern, when they become rushed or otherwise behind on their duties as a result of unanticipated routings.

crew-involved accidents found that, for 31 of these accidents, inadequate monitoring and/or crosschecking had occurred.[10] The study found that flight crewmembers frequently failed to recognize and effectively draw attention to critical cues that led to the accident sequence. As a result of this safety study, the Board issued Safety Recommendations A-94-3 and -4 to the FAA concerning the need for enhanced training of pilot monitoring skills. The recommendations stated, in part, that the FAA should require airlines operating under 14 CFR Part 121 to provide line operational simulation training that "allows flightcrews to practice, under realistic conditions, non-flying pilot functions, including monitoring and challenging errors made by other crewmembers" and that airlines' initial operating experience programs should include training and experience for check airmen and pilots "in enhancing the monitoring and challenging functions."[11]

In response to these recommendations, the FAA upgraded its written guidance to industry to enhance pilot training on monitoring. Specifically, on September 8, 1995, the FAA revised Advisory Circular (AC) 120-51, "Crew Resource Management Training," to emphasize monitoring issues. The guidance in AC 120-51 stated that "effective monitoring and cross-checking can be the last line of defense that prevents an accident" and that "the monitoring function is always essential, particularly during approach and landing." Since that action, other FAA guidance on workload management and monitoring skills has been developed. For example, on February 27, 2003, the FAA expanded its guidance in this area in a revision of AC 120-71, "Standard Operating Procedures for Flight Deck Crewmembers," to emphasize the importance of procedures, such as distributing cockpit workload to avoid interfering with pilot monitoring and assigning cockpit responsibilities so one pilot can monitor continuously during high-workload periods. With respect to conducting approach briefings and their impact on monitoring, the AC states that pilots should "when able, brief the anticipated approach prior to top-of-descent" to allow "greater attention to be devoted to properly monitoring … because the crew is not having to divide attention between reviewing the approach and monitoring the descent." The guidance contained in both ACs is available to operators to support pilot training programs but is not mandatory.

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[10] For additional information, see National Transportation Safety Board, *A Review of Flightcrew-Involved, Major Accidents of U.S. Carriers, 1978 through 1990*, Safety Study NTSB/SS-94/01 (Washington, DC: NTSB, 1994).

[11] The complete text of Safety Recommendation A-94-3 to the FAA was as follows: "Require U.S. air carriers operating under 14 CFR Part 121 to provide, for flight crews not covered by the Advanced Qualification Program, line operational simulation training during each initial or upgrade qualification into the flight engineer, first officer, and captain position that (1) allows flight crews to practice, under realistic conditions, non-flying pilot functions, including monitoring and challenging errors made by other crewmembers; (2) attunes flight crews to the hazards of tactical decision errors that are errors of omission, especially when those errors are not challenged; and (3) includes practice in monitoring and challenging errors during taxi operations, specifically with respect to minimizing procedural errors involving inadequately performed checklists." The complete text of Safety Recommendation A-94-4 to the FAA was as follows: "Require that U.S. air carriers operating under 14 CFR Part 121 structure their initial operating experience programs to include: (a) training for check airmen in enhancing the monitoring and challenging functions of captains and first officers; (b) sufficient experience for new first officers in performing the non-flying pilot role to establish a positive attitude toward monitoring and challenging errors made by the flying pilot; and (c) experience (during initial operating experience and annual line checks) for captains in giving and receiving challenges or errors." On January 19, 1996, the Safety Board classified these safety recommendations "Closed—Acceptable Alternate Action" in response to FAA upgrades of its training guidance.

The Safety Board is aware of recent accidents in which inadequate pilot monitoring was a causal or contributing factor to the accident and in which pilots on approach to landing failed to observe critical and salient cues.[12] These accidents demonstrate the importance of monitoring skills and effective workload management in ensuring safety of flight. Existing FAA guidance to operators addresses these skills but providing specific pilot training on effective monitoring and cockpit workload management would be a way for the aviation industry to effectively deliver and reinforce the importance of these skills to pilots. The Safety Board concludes that all operators would benefit from an increased focus on providing monitoring skills in their training programs, including those operating under 14 CFR Parts 121 and 135, as would pilots completing FAA-approved training programs for Part 91 operations.[13] Therefore, the Safety Board believes that the FAA should require pilot training programs be modified to contain modules that teach and emphasize monitoring skills and workload management and include opportunities to practice and demonstrate proficiency in these areas.

Deice Boot System Operations

Company and manufacturer guidance states that the surface deice boots should be used when ice buildup is estimated to be between 1/4- to 1/2-inch thick and that “early activation of the boots may result in ice bridging on the wing.” During the investigation of the January 9, 1997, accident involving Comair Airlines, Inc., flight 3272, which experienced a loss of control while maneuvering with ice accumulation on the wings,[14] the Safety Board learned that many manufacturers and operators had similar deice boot operational guidance and concerns about ice bridging.

However, AC 25.1419-1A, “Certification of Transport Category Airplanes for Flight in Icing Conditions,” dated May 7, 2004, states that, although ice may not be completely shed by one cycle of the boots, the residual ice will usually be removed by subsequent cycles and does not act as a foundation for a bridge of ice to form. Further, information gathered at a 1997 Airplane Deice Boot Bridging Workshop, subsequent icing tunnel tests, and flight tests conducted as part of the Comair investigation revealed that ice bridging did not occur on modern airplanes, which are equipped with deice boots that quickly inflate and deflate. The icing tunnel tests also revealed that thin (1/4 inch or less), rough ice accumulations on the wing leading edge deice boot surfaces could be, depending on distribution, as aerodynamically detrimental to an airplane’s performance as larger ice accumulations.

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[12] For additional information, see National Transportation Safety Board, *Collision With Trees on Final Approach, Federal Express Flight 1478, Boeing 727-232, N497FE, Tallahassee, Florida, July 26, 2002,* Aviation Accident Report NTSB/AAR-04/02 (Washington, DC: NTSB, 2004); National Transportation Safety Board, *Crash During Approach to Landing, Air Tahoma, Inc,. Flight 185, Convair 580, N586P, Covington, Kentucky, August 13, 2004,* Aviation Accident Report NTSB/AAR-06/03 (Washington, DC: NTSB, 2006); and National Transportation Safety Board, *Crash During Approach to Landing, Business Jet Services Ltd., Gulfstream G-1159A (G-III), N85VT, Houston, Texas, November 22, 2004,* Aviation Accident Brief NTSB/AAB-06/06 (Washington, DC: NTSB, 2006).

[13] The Safety Board recognizes that many pilots engaged primarily in noncommercial flying under 14 CFR Part 91 do not complete formal training programs but believes that these pilots could benefit from increased industry emphasis and specific training principles on monitoring.

[14] For additional information, see National Transportation Safety Board, *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Airlines, Inc., Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997,* Aircraft Accident Report NTSB/AAR-98/04 (Washington, DC: NTSB, 1998).

A search of the Safety Board accident database revealed no accidents related to ice bridging. Conversely, the Board has investigated many icing accidents in which the airplane stalled prematurely and the stall warning system did not activate before the stall because of ice accumulation on the wing leading edges. This accident, previous accident investigations, Safety Board accident data, and existing icing information clearly show that delaying the activation of the deice boots can create unsafe operations. The Safety Board concludes that ice bridging does not occur on modern airplanes; therefore, it is not a reason for pilots to delay activation of the deice boots.

As a result of its findings during the Comair flight 3272 investigation, the Safety Board issued Safety Recommendation A-98-91, which recommended that the FAA do the following:

> 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 emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions.

In May 2002, the FAA issued an icing test report that recommended an “early and often” approach to deice boot usage to limit the size of residual and intercycle ice accretions. Further, in January 2003, an Aviation Rulemaking Action Committee (ARAC) Ice Protection Harmonization Working Group (IPHWG) recommended revisions to Parts 25 and 121 to require that deice systems be activated as soon as an airplane enters icing conditions. However, since that time, the FAA has taken no action to issue a final rule adopting the regulatory changes proposed by the ARAC IPHWG.

Although the accident airplane most likely accumulated less than 1/4-inch-thick ice while operating in the lower cloud layer, the pilots’ failure to activate the deice boots during the approach led to the continued accumulation of thin, rough ice on the protected surfaces, which can severely degrade an airplane’s performance. The circumstances of this accident, information gathered during the Comair flight 3272 accident, and reports issued by the FAA and the ARAC IPHWG clearly demonstrate that existing guidance instructing pilots to delay activation of the deice boots until they observe 1/4- to 1/2-inch-thick ice accumulation is not adequate because it does not protect against the detrimental effects caused by thin, rough ice accumulation on or aft of the protected surfaces. If pilots continue to adhere to guidance about delaying deice boot activation, similar accidents could still occur.

The Safety Board concludes that activating the deice boots as soon as an airplane enters icing conditions provides the greatest safety measure. On the basis of this accident and the Board’s continued concerns in this area, the Board believes that the FAA should require manufacturers and operators of pneumatic deice boot-equipped airplanes to revise the guidance contained in their manuals and training programs to emphasize that leading edge deice boots should be activated as soon as the airplane enters icing conditions. The new recommendation will supersede Safety Recommendation A-98-91 and will be classified “Open—Unacceptable Response.”

The Safety Board is concerned that workload increases significantly when pilots of airplanes equipped with deice boots that do not cycle automatically operate in icing conditions because they must continuously monitor the ice accumulation on the airplane's surfaces and determine when to reactivate the deice boots. This consideration is consistent with FAA concerns in AC 23.1419-2C, "Certification of Part 23 Airplanes for Flight in Icing Conditions."[15] Having to operate the deice boot system manually is even more critical during the approach and landing phases of flight when pilot workload and monitoring demands are greatest.

The Safety Board concludes that manual operation of the deice boot system increases pilot workload, which can result in distraction during critical phases of flight such as approach and landing. Therefore, the Safety Board believes that the FAA should require that all pneumatic deice boot-equipped airplanes certified to fly in known icing conditions have a mode incorporated in the deice boot system that will automatically continue to cycle the deice boots once the system has been activated.

Certification Requirements for Flight Into Icing Conditions

The Safety Board has previously identified concerns about inadequate flight test certification requirements. For example, it was revealed during the investigation for the October 31, 1994, accident involving American Eagle flight 4184 in which the airplane crashed during a rapid descent after an uncommanded roll excursion during icing conditions[16] that SLD conditions can cause ice accretions that are more aerodynamically detrimental than those accretions that fall within the Part 25, Appendix C envelope.[17] As a result, the Board issued Safety Recommendation A-96-54, which asked the FAA to do the following:

> 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 developments in both the design 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.

Further, icing tunnel tests conducted as part of the Comair flight 3272 accident investigation indicated that the effects of ice accretion on airplane performance could vary widely depending on the size, distribution, and type of ice accumulated on the airplane's surfaces. However, the Board learned that manufacturers are not required to demonstrate an airplane's flight handling characteristics or stall margins using thin, rough ice that can accrete on protected surfaces before the activation of the deice boot system or between activation cycles. As a result of its findings, the Board issued Safety Recommendation A-98-92, which asked the FAA

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[15] AC 23.1419-2C stated that the effect on pilot workload of continuously cycling the deice boots should be evaluated.

[16] For additional information, see National Transportation Safety Board, *In-flight Icing Encounter and Loss of Control, Simmons Airlines, d.b.a. American Eagle Flight 4184, Avions de Transport Regional (ATR) Model 72-212, N401AM, Roselawn, Indiana, October 31, 1994; Volume I Safety Board Report,* Aircraft Accident Report NTSB/AAR-96/02 (Washington, DC: NTSB, 1996).

[17] Part 25, Appendix C specifies the kind of icing conditions in which an airplane's ice protection system must be able to operate.

(in cooperation with the National Aeronautics and Space Administration and other interested aviation organizations) to do the following:

> [C]onduct 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 also issued Safety Recommendation A-98-100, which asked the FAA to review the icing certification of all turbopropeller-driven airplanes currently certificated for operation in icing conditions, perform additional testing, and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards asked for in Safety Recommendation A-98-92.

The FAA indicated in a March 6, 2006, response to Safety Recommendation A-96-54 that the ARAC IPHWG is continuing to develop a revision to Part 25 to require a demonstration that an airplane can safely operate in SLD conditions for an unrestricted time or can detect SLD and safely exit icing conditions. However, the FAA has still not received the recommendations from the IPHWG, prepared regulatory analyses, issued the NPRM, analyzed comments, or completed the many other tasks involved in issuing new regulations.

The FAA indicated in an October 26, 2005, response to Safety Recommendation A-98-92 that it had completed and would shortly issue a draft revision to AC 20-73, which included the certification guidance on determining critical ice shapes, descriptions of intercycle and residual ice accretions, and the aerodynamic penalties associated with these ice shapes. Although the FAA issued AC 20-73A on August 16, 2006, it has still not provided the Safety Board with information regarding any new research conducted in response to this recommendation.

Regarding Safety Recommendation A-98-100, the FAA issued a notice of proposed rulemaking (NPRM) in November 2005, which proposed to expand 14 CFR Part 25 to include specific certification requirements for airplane performance or handling qualities for flight in icing conditions and to specify the ice accumulations that must be considered for each phase of flight. Further, the FAA proposed changes to AC 25-1X, which intended to provide guidance for implementing the regulations proposed in the NPRM.

In May 2006, the Safety Board expressed concern that, although it agreed with the proposed regulatory changes, the FAA had not applied the new standards to all in-service turbopropeller-driven aircraft. The FAA further indicated that no airplanes have an unsafe condition in icing environments despite a number of accidents in the 1990s that involved airplanes that had passed the certification standards. The Board stated that, to meet the intent of Safety Recommendation A-98-100, the FAA would need to formally evaluate (perhaps by conducting flight tests) all in-service turbopropeller-driven aircraft to ensure that these aircraft comply with all current icing certification criteria for new aircraft. The Board asked the FAA to provide a list of the aircraft that it had formally evaluated and a summary of the findings and resultant actions. To date, this information has not been received.

The circumstances of the Comair flight 3272, American Eagle 4184, and Pueblo accidents and the icing tunnel test data show that the ice shapes used during initial certification flight tests were not adequate because the tests did not account for thin, rough ice on the wing. The 1996 ice shapes tests on the Cessna 560 were also inadequate because, although tests were conducted with ice shapes on the protected surfaces, tests were not conducted using thin, rough ice. Therefore, additional ice sizes, distribution patterns, and types need to be considered during flight testing to more adequately gauge an airplane's performance in icing conditions.

The Safety Board concludes that existing flight test certification requirements for flight into icing conditions do not test the effects of thin, rough ice on or aft of an airplane's protected surfaces, which can cause severe aerodynamic penalties. The circumstances of this accident clearly show that the actions requested in Safety Recommendations A-96-54 and A-98-92 are needed to improve the safety of all airplanes operating in icing conditions. Therefore, the Safety Board reiterates Safety Recommendations A-96-54 and A-98-92.

As noted, Safety Recommendation A-98-100 only addressed turbopropeller-driven airplanes. The circumstances of this accident clearly demonstrate that deice boot-equipped turbojet airplanes also require additional testing in an expanded Appendix C icing certification envelope, which would include thin, rough ice accumulations and intercycle and residual ice. 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 pneumatic deice boot-equipped 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. The new recommendation (A-07-16) will supersede Safety Recommendation A-98-100 and will be classified "Open—Unacceptable Response."[18]

Inadequate Stall Warning Margins in Icing Conditions

Stall warning systems are intended to provide flight crews with adequate warning of an impending stall to give them enough time to take necessary action to prevent a stall. The CVR sound spectrum study indicated that the accident airplane's stall warning did not activate until after the stall. The Pueblo accident is not the first accident in which a stall has occurred before the stall warning activated. For example, the Safety Board determined during the Comair flight 3272 accident investigation that the airplane departed controlled flight before the stall warning activated and that stall warning systems "often do not provide adequate warning when the airplane is operating in icing conditions."

As a result of the Comair investigation, the Safety Board issued Safety Recommendation A-98-96, which recommended that the FAA require manufacturers and operators of all airplanes certificated to operate in icing conditions to install stall warning systems that provide a cockpit warning before the onset of a stall when the airplane is operating

[18] Safety Recommendation A-98-100 is on the Safety Board's list of Most Wanted Transportation Safety Improvements. Accordingly, Safety Recommendation A-07-16 will automatically be placed on the Most Wanted List.

in icing conditions. The FAA stated in an October 26, 2005, response letter that it was pursuing rule changes to require only that newly certificated airplanes have stall warning systems installed that provide a cockpit warning before the onset of a stall when operating in icing conditions and that it would take appropriate action on in-service airplanes only if an unsafe condition were identified.

The November 2005 NPRM proposed changes to 14 CFR 25.207 to require that only newly type-certificated airplanes be equipped with stall warning systems that provide a stall warning before the onset of a stall when the airplane is operating in icing conditions. In its comments on the proposed NPRM and in its May 2006 response letter to the FAA, the Safety Board stated that it was not acceptable for the FAA to wait until an accident or serious incident occurred to reveal that an unsafe condition existed on an in-service airplane and that, because the proposed changes did not address in-service airplanes, Safety Recommendation A-98-96 was classified "Open—Unacceptable Response." The Board continues to believe that not requiring in-service airplanes to be equipped with improved stall warning systems until an unsafe condition is identified is unacceptable and encourages the FAA to expedite issuance of a final rule that contains such a requirement.

Regarding the Cessna 560's stall warning system, in 1996, the FAA conducted ice testing using 1/2-inch ice shapes installed on the protected surfaces. As a result of these tests, in early 1999, Cessna began incorporating a modified stall warning system on Cessna 560 airplanes (including the accident airplane) to provide a 5-knot increase in the stall warning margin for operations in icing conditions. However, as this accident has shown, these modifications were not adequate because they did not take into account the effects of thin, rough ice on the protected surfaces; therefore, additional modifications to the airplane's stall warning system are necessary.

The Safety Board concludes that the Cessna 560 airplane's stall warning system did not provide a stall warning before the upset. The Safety Board further concludes that the Cessna 560 airplane's stall warning system does not provide a warning in all icing conditions, including those conditions in which thin, rough ice can accumulate on the protected surfaces. Therefore, the Safety Board believes that the FAA should require modification of the Cessna 560 airplane's stall warning system to provide a stall warning margin that takes into account the size, type, and distribution of ice, including thin, rough ice on or aft of the protected surfaces.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Require that operational training in the Cessna 560 airplane emphasize the airplane flight manual requirements that pilots increase the airspeed and operate the deice boots during approaches when ice is present on the wings. (A-07-12)

> Require that all pilot training programs be modified to contain modules that teach and emphasize monitoring skills and workload management and include opportunities to practice and demonstrate proficiency in these areas. (A-07-13)

> Require manufacturers and operators of pneumatic deice boot-equipped airplanes to revise the guidance contained in their manuals and training programs to emphasize that leading edge deice boots should be activated as soon as the airplane enters icing conditions. (A-07-14) (This safety recommendation supersedes Safety Recommendation A-98-91 and is classified "Open—Unacceptable Response.")

> Require that all pneumatic deice boot-equipped airplanes certified to fly in known icing conditions have a mode incorporated in the deice boot system that will automatically continue to cycle the deice boots once the system has been activated. (A-07-15)

> When the revised icing certification standards (recommended in Safety Recommendations A-96-54 and A-98-92) and criteria are complete, review the icing certification of pneumatic deice boot-equipped 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-07-16) (This safety recommendation supersedes Safety Recommendation A-98-100 and is classified "Open—Unacceptable Response.")

> Require modification of the Cessna 560 airplane's stall warning system to provide a stall warning margin that takes into account the size, type, and distribution of ice, including thin, rough ice on or aft of the protected surfaces. (A-07-17)

In addition, the National Transportation Safety Board reiterates the following recommendations:

> 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)

> 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)

Chairman ROSENKER, Vice Chairman SUMWALT, and Members HERSMAN, HIGGINS, and CHEALANDER concurred with these recommendations. Member Hersman filed a concurring and dissenting statement and was joined by Member Higgins.

[*Original Signed*]

By: Mark V. Rosenker
Chairman

Member Deborah A. P. Hersman, Concurring in part and Dissenting in part:

While I agree with the general outcome of this report, I believe the probable cause ultimately approved by the Board is not entirely consistent with the rest of the report. As I asserted at the Board meeting on January 23, 2007, the inadequate guidance provided to aircraft operators regarding the operation of deice boots should have been cited as a contributing factor. Furthermore, the FAA's inadequate certification requirements for flight into icing conditions should have been cited as one of the two primary causes of the accident, rather than as a contributing cause.

The final probable cause would lead one to believe that this was not an icing accident but simply an accident of pilot failures—failure to effectively monitor and maintain airspeed and failure to properly activate the deice boots. However, the rest of the report lays a foundation for finding that this accident was very much about ice and a lack of understanding among operators about whether an aircraft can safely operate in any type of ice and how to appropriately manage ice accumulation.

FAA's failure to establish proper certification requirements for aircraft flying in icing conditions should be cited as one of the primary causes of this accident. The Board has long been concerned about aircraft icing and inadequate certification standards. Following the Safety Board's 1981 study on aircraft icing, numerous recommendations were issued to the FAA to revise certification standards regarding ice accretion under varying conditions. In over 25 years, the FAA has done little to address this issue and we have reiterated the original recommendations over and over and they remain on our Most Wanted List of Safety Improvements in an unacceptable status.

According to the Cessna Model 560 Citation V AFM, the airplane's anti-ice and de-ice systems were not designed to protect against freezing rain or severe conditions of mixed or clear ice. However, during the investigation of this accident, the National Center for Atmospheric Research determined that, on the basis of surface, radar, upper air, and satellite data, the airplane likely encountered Supercooled Large Droplet conditions, which are more conducive to the accumulation of thin, rough ice, between 9,400 to 6,100 feet (the altitude at which the upset occurred). The pilots were unaware that they were flying in conditions that the plane was not certificated for because there are no reliable methods for flight crews to differentiate, in flight, between water drop sizes that are outside the certification envelope. Furthermore, the Cessna 560 airplane's stall warning system does not provide warning in this type of icing condition.

In a recommendation in 1996, the Board recommended that FAA revise its icing criteria. That recommendation is being reiterated in this report. Another recommendation issued to FAA in 1996 is being revised and re-issued in this report, recommending that FAA revise icing certification requirements for airplanes equipped with pneumatic deice boots. Perhaps, if FAA had taken such measures 10 years ago, much more would have been understood by the pilots about flying in this type of icing condition. For that reason, FAA has a place in the probable cause equal to that of the pilots who executed the errors in the conduct of this flight.

The narrative of the accident is clear that the pilots of this aircraft did not fail to monitor the icing conditions. The cockpit voice recorder revealed that they were aware of the icing conditions and they activated the de-ice boots at least once. The First Officer talked about the color of the ice, the rate of accumulation, and compared it to the ice accumulated on the previous day, and the Captain discussed the ice remaining on the wings after the initial activation of the deice boots. The probable cause faults the crew, not because they did not *effectively* monitor the icing conditions, but because they failed to activate the deice boots at the correct time.

The report states that the manufacturer's guidance and language in the AFM recommends that the deice boots be used when the ice buildup is between ¼ to ½ inches thick and that early activation of the boots could result in ice bridging. Despite information revealed during previous NTSB accident investigations (Comair Flight 3272, Monroe, Michigan, January 9, 1997), NASA published research on the topic, public information events such as the November 1997 Airplane Deicing Boot Ice Bridging Workshop, and various FAA publications, the ice bridging concept is still real to some pilots and operators. This concern about ice bridging was reinforced to this Board Member during a conversation earlier this month, with a well-respected pilot of a modern Cessna aircraft equipped with pneumatic boots, who repeatedly spoke of ice bridging and the guidance from the manual requiring a ¼ to ½ inch of ice accumulation before activating the boots. Regrettably, it appears that little has changed in the 10 years since the Board investigated the Monroe accident, the following language was contained in our November 30, 1998, recommendation letter to Administrator Garvey on recommendations A-98-88 through –106:

> *"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 that 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… 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."*

Yet in another part of the AFM, the direction to the crew is contradictory, "When configuring for approach and landing… with any ice accretion visible on the wing leading edge, regardless of thickness, activate the surface deice system. Continue to monitor the wing leading edge for any accumulation." Unfortunately, our investigators found that the SimuFlite training syllabus had no specific instruction to evaluate crew performance of the AFM procedures to increase the airspeed and operate the deice boots during approaches when ice is present on the wings. In addition, one of the instructors was unaware of these AFM procedures. Furthermore, this guidance about activating the deice boots on approach with any ice accretion seems to nullify the earlier guidance about waiting for a measurable ice build up prior to boot activation and de-bunking the myth of ice-bridging. Which leads me to question why Cessna requested, and the FAA agreed to withdraw NPRM 99-NM-136-AD, which was applicable to Cessna model 500, 501, 550, 551, and 560 series airplanes and proposed revising the applicable AFMs to include a requirement to activate the deice boots at the first sign of ice accumulation and to cycle the boots to minimize ice accumulation. When the NPRM was withdrawn, Cessna continued to publish the ¼ to ½ inch accumulation language. If it is safer to eliminate any visible ice from the wings during the approach phase of flight, then the same logic ought to apply to all phases of flight.

FAA Advisory Circular AC 25.1419-1A states that residual ice does not act as a foundation for bridging ice. Furthermore, our report states, additional tests have shown that ice bridging does not occur on modern airplanes and deice boots should be activated as soon as an aircraft enters icing conditions. This contradiction between recent studies, the FAA Advisory Circular, and manufacturer guidance led the Board to include in this report a recommendation that FAA require manufacturers and operators of airplanes with deice boots to *revise the guidance* in their manuals to emphasize that deice boots should be activated as soon as the airplane enters icing conditions. Furthermore, the Board reiterated an older recommendation that FAA conduct additional research on the effects of residual ice accumulations behind the deicing boots and incorporate those new findings into the certification requirements and pilot training programs.

I believe that in failing to cite the inadequate guidance as a contributing factor in the probable cause, and in relegating FAA's failures to only a contributing cause, the Board is leaving a part of this investigation report undone. In our quest to make flying ever safer, we may never reach a time when pilots don't sometimes make inexplicable errors. But in a case such as this one where we can piece the evidence together and spot plausible reasons *why* the pilots made the mistakes they made, we should do so emphatically. In almost 40 years of accident investigations, we have improved aviation safety and improved our process of accident investigations, but I believe we can and should reach further in our efforts. Simply citing the flight crew's failure to monitor and maintain airspeed and de-ice the wings as required by the AFM is not going far enough. Until the AFMs fly the airplanes, we need to address the actions of the human beings who do fly the airplanes. In this accident, the reason the pilots failed in their critical tasks is because they did not have the benefit of proper guidance from the FAA and from the manufacturer about flying in the conditions they found themselves. While the Board articulated this issue very clearly in our conclusions and our recommendations, I believe the Board should have included this aspect in the probable cause as the best means of helping to prevent other pilots from making the same error in the future.

Member Higgins joined Member Hersman in this statement.

[Original signed]

Deborah A. P. Hersman
January 30, 2007