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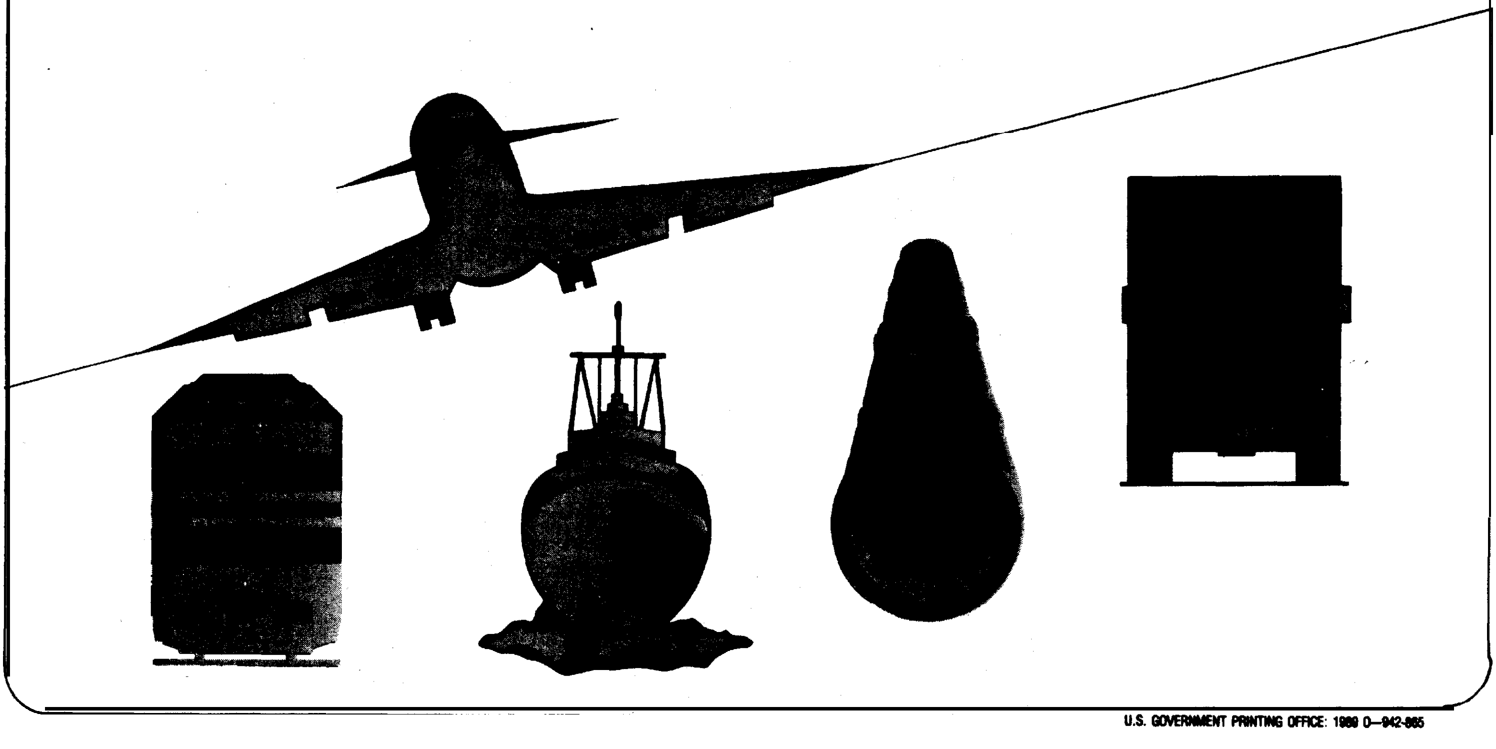
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

IN-FLIGHT ICING ENCOUNTER AND UNCONTROLLED COLLISION WITH TERRAIN
COMAIR FLIGHT 3272
EMBRAER EMB-120RT, N265CA
MONROE, MICHIGAN
JANUARY 9, 1997



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Adopted: November 4, 1998
Notation 6997A/B/C

Abstract: This report explains the accident involving an EMB-120RT, operated by COMAIR Airlines, Inc., as flight 3272, that crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan, on January 9, 1997. Safety issues in the report focused on procedures for the use of ice protection systems, airspeed and flap configuration information, stall warning/protection system capabilities, operation of the autopilot in icing conditions, aircraft icing certification requirements, and icing-related research. Safety recommendations concerning these issues were addressed to the Federal Aviation Administration and the National Aeronautics and Space Administration.

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CONTENTS

EXECUTIVE SUMMARY

About 1554 eastern standard time, on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A EMB-120RT, N265CA, operated by COMAIR Airlines, Inc., as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport, Covington, Kentucky, to the Detroit Metropolitan/Wayne County Airport, Detroit, Michigan. The flight departed Covington, Kentucky, 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 determines 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.

Contributing to the accident were the flightcrew's decision to operate in icing conditions near the lower margin of the operating airspeed envelope (with flaps retracted) and Comair's failure to establish and adequately disseminate unambiguous minimum airspeed values for flap configurations and for flight in icing conditions.

The safety issues in this report focused on procedures for the use of ice protection systems, airspeed and flap configuration information, stall warning/protection system capabilities, operation of the autopilot in icing conditions, aircraft icing certification requirements, and icing-related research.

Safety recommendations concerning these issues were addressed to the FAA and the National Aeronautics and Space Administration. Also, as a result of this accident, on May 21, 1997, the Safety Board issued four safety recommendations to the FAA regarding EMB-120 minimum airspeed information, ice protection system operational procedures, and ice detection/warning systems.

SELECTED ACRONYMS, ABBREVIATIONS, AND DEFINITIONS

AAI-1	Office of the Director, Aviation Accident Investigations, Federal Aviation Administration (FAA)
AC	advisory circular; provides nonregulatory guidance to certificate holders for a means (but not necessarily the only means) to comply with FAA Regulations
AC	alternating current
ACO	FAA aircraft certification office
AD	airworthiness directive; FAA regulatory requirement for immediate mandatory inspection and/or modification
ADC	air data computer
ADS	air data sensor
AEG	FAA aircraft evaluation group
AFM	airplane flight manual
agl	above ground level
AHRS	attitude and heading reference system
AIM	Aeronautical Information Manual; a primary FAA publication that instructs airmen about operating in the U.S. National Airspace System
AIRMET	airmen’s meteorological information; such advisories to flightcrews include, but are not limited to, moderate icing and turbulence
ALPA	Air Line Pilots Association
AOA	angle-of-attack
AOM	airplane operations manual
APM	aircrew program manager
APOI	FAA assistant principal operations inspector
ARAC	aviation rulemaking advisory committee
ARTCC	air route traffic control center
ASA	Atlantic Southeast Airlines
ASR	airport surveillance radar
ASRS	NASA’s aviation safety reporting system
ATC	air traffic control
ATCS	air traffic control specialist
ATCT	air traffic control tower
ATIS	automatic terminal information service
ATP	airline transport pilot
ATR	Avions de Transport Regional
BAA	Bilateral Airworthiness Agreement
CAA	United Kingdom’s Civil Aviation Authority
CAB	Civil Aeronautics Board (predecessor to the FAA)
CAM	cockpit area microphone
CAMI	FAA’s Civil Aeromedical Institute
CCP	control column position
CDL	configuration deviation list

CFIT	controlled flight into terrain
CFM	company flight manual
CFR	Code of Federal Regulations
CG	center of gravity
CRM	crew resource management
CTA	Centro Tecnico Aeroespacial of Brazil
CVG	Cincinnati/Northern Kentucky International Airport
CVR	cockpit voice recorder
CWA	center weather advisory
CWP	control wheel position
CWSU	center weather service unit
DC	direct current
DER	designated engineering representative
DGAC	French Directorate General for Civil Aviation
DO	director of operations
DTW	Detroit Metropolitan/Wayne County Airport
EAD	emergency airworthiness directive
EADI	electronic attitude director indicator indicating pitch and roll
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FDR	flight data recorder
FL	flight level
FMRB	flight manual review board
FOQA	flight operations quality assurance
FPL	full performance level
FSB	flight standards bulletin
FSDO	FAA flight standards district office
FSM	flight standards manual
G	one G is equivalent to the acceleration caused by the Earth's gravity (32.174 feet per second^2)
GAO	General Accounting Office
GOES	geostationary operational environmental satellite
GPWS	ground proximity warning system
HBAW	FAA handbook bulletin for airworthiness
IFR	instrument flight rules
ILS	instrument landing system
IOE	initial operating experience
IRT	icing research tunnel
KIAS	knots indicated airspeed
LOE	line-oriented exercises
LPC	low pressure compressor
LWC	liquid water content; the FAA defines LWC as the total mass of water in all the liquid cloud droplets within a unit volume of cloud; LWC and supercooled liquid water (SLW) refer to the amount of liquid water in a certain volume of air
LWD	left wing down

MAC	mean aerodynamic chord
McIDAS	Man-computer Interactive Data Access System
MED	mean effective diameter of water drop
MEL	minimum equipment list
MFC	multifunction computer
Motif-IRAS	Motif Interactive Radar Analysis Software
msl	mean sea level
MVD	median volumetric diameter of water drop
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration (formerly NACA)
NASIP	national aviation safety inspection program
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NPARC	a computer code used by NASA in its icing tests
NPRM	notice of proposed rulemaking
NRS	National Resource Specialist
NTAP	National Track Analysis Program
NW	Northwest Airlines
NWS	National Weather Service
OAT	outside air temperature
OB	operational bulletin
PA	public address system
PAI	FAA principal avionics inspector
PF	pilot flying
PIREP	pilot report
PNF	pilot not flying
POI	FAA principal operations inspector
PWC	Pratt & Whitney Canada
RWD	right wing down
SAT	static air temperature (synonymous with OAT)
SB	service bulletin supplied by manufacturer
SDR	service difficulty report
SIGMET	significant meteorological information; such advisories to flightcrews include, but are not limited to, severe and extreme turbulence and severe icing
SLD	supercooled large droplet
SLW	supercooled liquid water
SN	serial number
SPS	stall protection system
STC	supplemental type certificate
TAT	total air temperature
TC	type certificate
TCAS	traffic alert and collision avoidance system
TN	technical note
TRACON	terminal radar approach control
Vfs	target airspeed for flap retraction after takeoff or during a go-around

VFR	visual flight rules
Vle/Vlo	maximum landing gear operating speed/maximum gear extended speed
VOR	very high frequency omni-directional radio range navigation aid
Vref	the referenced airspeed for final approach
WSR	weather surveillance radar

Conversion Factors International Standard (SI) Units

To convert from	to	multiply by
mile, U.S. statute	kilometer (km)	1.609344
mile, nautical	meter (m)	1852.0
foot (ft)	meter (m)	0.3048
inch (in)	centimeter (cm)	2.54
cubic centimeter (cc or cm^3)	cubic inch (in^3)	0.06102374
pound (lb)	kilogram (kg)	0.4535924
knot (nautical mile per hour)	meter per second (m/s)	0.5144444
horsepower (550ft lbs/s) (hp)	watt (W)	745.6999

To convert from	to	multiply
Centigrade ©	Fahrenheit (F)	1.8C + 32

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1. FACTUAL INFORMATION

1.1 History of Flight

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 (IFR) flight plan.

The pilots reported for duty at 0940 in Covington, on January 9, 1997, to begin a scheduled 3-day trip sequence. They completed the first two flight segments of the first day's schedule—CVG to Dayton, Ohio, and return to CVG—without incident. After they returned to CVG (about 1241), the pilots were scheduled to change airplanes (to the accident airplane). At 1427, the accident airplane arrived at CVG from Asheville, North Carolina; the airplane was scheduled to depart CVG at 1430, as Comair flight 3272, but actually departed the gate at 1451. According to company personnel, the delay occurred because the airplane arrived late from Asheville and required servicing. An additional delay was encountered because the weather conditions (light snow) necessitated airframe deicing before takeoff. The pilots of flight 3272 taxied the airplane from the gate to the designated deicing area, where, at 1457, the airplane was deiced with Type 1 deicing fluid.[3] Air traffic control (ATC) records indicate that flight 3272 became airborne about 1509.

Review of ATC and cockpit voice recorder (CVR) transcripts from the accident flight indicated that the captain was performing the radio communications and other pilot-not-flying (PNF) duties, while the first officer was performing the pilot flying (PF) duties during the

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

[2] For the remainder of this report, COMAIR Airlines, Inc., will be identified as Comair.

[3] Type 1 deicing fluid is ethylene glycol and was applied in a 50/50 mixture with heated water.

flight from CVG to DTW. The IFR flight plan indicated that flight 3272's final cruise altitude would have been flight level (FL) 190;[4] however, the pilots requested and received clearance to climb to FL 210 to avoid turbulence at the lower altitude. At 1526:59, the CVR recorded the Indianapolis Air Route Traffic Control Center (ARTCC) controller asking the pilots if there were "any improvements…with the climb there?" At 1527:03, the CVR recorded the captain responding, "affirmative…it's…smooth here at two one oh [we were] getting…occasional light chop at one nine oh…we were right at the tops [of the clouds]." At 1531, the pilots were instructed to contact Cleveland ARTCC; the pilots acknowledged and complied with the instructions.

At 1538, the CVR recorded the captain advising the flight attendant that the flight from CVG to DTW would take "only forty minutes today." At 1539, the CVR recorded the air traffic controller stating, "[Comair 3272] continue descent to one one thousand, then fly heading of…zero three zero to rejoin the MIZAR [intersection] arrival [to] Detroit." About 1 minute later, the pilots obtained Detroit's automatic terminal information service (ATIS) information "hotel," which indicated visibility of 1 mile in light snow and included the remarks, "braking action advisories in effect" and "local [ground] de-ice procedure in effect."

At 1542, the CVR recorded the Cleveland ARTCC controller advising flight 3272 to contact Detroit terminal radar approach control (TRACON). The captain acknowledged the instructions and (at 1543) contacted Detroit TRACON, advising the approach controller that flight 3272 was at 11,000 feet mean sea level (msl). According to the ATC transcript, Detroit TRACON responded with instructions to depart MIZAR intersection on a 050° heading, "vector to [the instrument landing system] ILS runway three right final approach course, braking action report poor by a DC niner."

According to the ATC transcript, at 1544, Detroit TRACON requested flight 3272 to reduce airspeed to 190 knots. The ATC transcript indicated that about 14 seconds after Detroit TRACON instructed flight 3272 to reduce its airspeed to 190 knots, the crew of America West flight 50 (call sign Cactus 50) contacted the TRACON feeder controller (who was now working both airplanes), advising that the airplane was level at 12,000 feet msl. During postaccident interviews, the Detroit TRACON feeder controller told Safety Board personnel that although Comair flight 3272 appeared on his radar display and frequency before Cactus 50, he decided that Cactus 50, an Airbus A320, would precede Comair 3272 on the approach to runway 3R because Cactus 50 was faster and had a more direct path to the inbound radar fix. (Additional information regarding the separation between the two airplanes is included in section 1.18.6.)

At 1545, Detroit TRACON cleared flight 3272 to descend and maintain an altitude of 7,000 feet msl; the pilots of flight 3272 subsequently acknowledged the airspeed reduction (190 knots) and the clearance to descend to 7,000 feet msl. Seconds later, the CVR recorded the first officer stating, "Seven [thousand]'s verified, there's MIZAR, and we're turning

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[4] Altitudes below 18,000 feet msl are presented in altitude above msl and are corrected for variations from standard sea level pressure. Altitudes above 18,000 feet msl are expressed as FLs, and are based on an altimeter setting of 29.92 inches of mercury. Therefore, FL 190 = 19,000 feet pressure altitude.

[to] zero five zero." At 1546, Detroit TRACON instructed the pilots to turn left to a heading of 030°, with the remark, "vectors for spacing."

At 1547, Comair flight 3272 was instructed to turn right to a heading of 055°, which the pilots acknowledged. Then, as the airplane descended through about 8,600 feet, the first officer called for the descent checklist.[5] The descent checklist included an ice protection prompt (to be accomplished before the airplane entered icing conditions),[6] to which the first officer responded "windshield, props, standard seven."[7] According to the CVR, the pilots completed the eight items listed on the descent checklist at 1548:12. Two seconds later, the first officer began the approach briefing. Although neither pilot specifically called for the approach checklist, the approach briefing is the first item on the approach checklist. The approach briefing was interrupted at 1548:47 by the approach controller, who issued instructions to turn right to a heading of 070°. About 1549:35, the CVR recorded the first officer completing the approach/missed approach briefing with the query, "Questions? Comments?" The captain responded, "No questions" and continued to the next approach checklist item, advising the first officer, "twenty-one, fourteen, and forty-three are your [airspeed] bugs."[8] At 1549:43, the CVR recorded the first officer's response, "twenty-one, fourteen, forty-three…set." The pilots satisfactorily accomplished the autofeather and navigation radios checklist items at 1549:53 and had the following items remaining to complete the approach checklist:

- flight attendants—notified
- flaps—15/15/checked.[9]

According to ATC and CVR information, at 1549:54, Detroit TRACON instructed the pilots to turn right to a heading of 140° and to reduce airspeed to 170 knots. At 1549:59, the captain acknowledged the instructions. At 1550:15, the CVR recorded the captain's attempt to contact Comair operations personnel at DTW to coordinate arrival information; operations personnel did not respond promptly to the radio call, and, at 1550:28, the CVR recorded the captain stating to the first officer, "Nobody likes to answer me, I'm back." At that

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[5] Company policy dictates that flightcrews accomplish the descent checklist before the airplane descends below 10,000 feet msl and the approach checklist before the airplane is within 30 nautical miles (nm) of the destination airport.

[6] Comair's EMB-120 flight standards manual (FSM) states that "icing conditions exist when the OAT [outside air temperature] is +5° 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)."

[7] According to postaccident interviews with Comair pilots, the term "standard seven" refers to switches for the following anti-ice system items: angle-of-attack (AOA) sensors (left and right sides of the fuselage), sideslip sensor (top center of the fuselage, aft of the windscreen), total air temperature (TAT) sensor, and the pitot/static system (left, right, and auxiliary). These items, with the windshield and propeller systems, comprise the airplane's anti-ice system. The CVR did not record any flightcrew discussion of ice accumulation or leading edge deicing boot activation during the airplane's approach to the Detroit area. For additional ice protection system information, see section 1.6.3.4.

[8] These airspeed settings refer to the airplane's approach reference airspeed, takeoff safety airspeed, and final segment airspeeds (based on airplane performance data), respectively.

[9] According to several Comair EMB-120 pilots interviewed after the accident, the last two approach checklist items would typically be accomplished later during the approach when the airplane was closer to its destination airport. CVR and FDR information and physical evidence indicated that the flaps were in the retracted position when the accident occurred.

time, ATC advised the pilots to contact the Detroit TRACON final approach controller on a different frequency; the pilots acknowledged and complied with the instructions.

According to ATC transcripts, at 1550:48, the final approach controller instructed the pilots to reduce their airspeed to 170 knots and to descend to 6,000 feet msl. At 1551:27, the CVR recorded Comair operations personnel on the radio stating, “thirty-two seventy-two, are you calling Detroit?” The captain responded, advising that they were in range, would be at the gate in less than 10 minutes, and would need to be fueled. During the next 30 seconds, operations personnel gave the captain arrival gate information and outgoing passenger and fuel load information. At 1552:07, the CVR recorded the captain stating to the first officer “[it] took ‘em a while but they came back to me.” The first officer responded that there had been no changes while the captain was talking to company operations.

At 1552:13, the final approach controller cleared the pilots to descend to 4,000 feet msl. The pilots acknowledged and complied with the clearance. Beginning at 1553:03, the CVR recorded ATC’s discussions with Cactus 50 regarding windshear, tailwinds aloft, and pilot reports of “slick runways and low visibilities.” At 1553:25, the CVR recorded the final approach controller instructing the pilots of flight 3272 to turn to a heading of 180° and reduce airspeed to 150 knots. The captain acknowledged the clearance at 1553:29, stating, “heading one eight zero…speed one five zero.…” At 1553:42, the final approach controller restated flight 3272’s instruction to reduce airspeed to 150 knots, and the captain again acknowledged the instructions. During the next 7 seconds, the pilots engaged in a brief dialogue, which included comments about the controller’s short-term memory and the repeated instructions.

At 1553:59, the final approach controller stated, “[Comair 3272] now turn left [to a] heading [of 090°]…plan a vector across the localizer.”[10] The captain acknowledged the heading change, and review of the FDR data (control wheel position [CWP], roll attitude, and magnetic heading) indicated that the airplane began a left turn about 1554:05. FDR data revealed that at 1554:08, the airplane was in a shallow but steepening left bank at 4,000 feet msl; the data further showed that the autopilot mode changed from “Altitude Pre Select (Arm)” to “Altitude Hold” mode. At 1554:10, at an airspeed of 156 knots, the airplane’s roll attitude had steepened to about 23° of left bank, and the CWP began to move back to the right; however, the airplane’s left roll attitude continued to steepen.

Beginning at 1554:15.9, the CVR recorded the “sound of several ‘whirring’ noises, similar to that of the elevator trim servo.” FDR data indicated that the engine power began to increase from flight idle about the same time. At 1554:17, the FDR began to record split engine torque values, with higher torque values recorded for the right engine than the left, which continued until the autopilot disengaged. Beginning at 1554:17.1, the CVR recorded a “significant reduction in background ambient noise.” The FDR data indicated that at this time, the airplane’s left bank continued to steepen, while the CWP was moving farther to the right.

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[10] The final approach controller told investigators that he believed it might be necessary to vector Comair flight 3272 across the localizer to ensure adequate separation between Comair flight 3272 and the airplane preceding flight 3272 on the approach, Cactus 50.

At 1554:20.8, the CVR recorded the captain stating, "Looks like your low speed indicator,"[11] and, at 1554:20.9, the first officer made an unintelligible comment. The FDR information indicated that at 1554:23.6, the engine torque began to increase again; about 1554:23.6, the CVR recorded the captain stating, "power." FDR data indicated that at 1554:24.1, the airplane was at an airspeed of 146 knots and a left bank angle that was steepening beyond 45° and that the autopilot disconnected. The CVR transcript indicated that about that time a sound similar to the stickshaker started. At 1554:24.1, the CVR recorded the first officer stating, "thanks;" simultaneously, it recorded the sound of three chimes and the "autopilot" aural warning. FDR data indicated that in the less than 2 seconds after the autopilot disconnected (1554:24.125 to 1554:25.9), the following changes occurred:

- the airplane's CWP moved from about 18° right to about 19° left,
- the roll attitude increased from about 45° left bank to about 140° left bank, and
- the pitch attitude decreased from nearly 2° nose up to about 17° nose down.

At 1554:25.9, the sound of the stickshaker stopped. At 1554:26.1, the CVR recorded the first officer and the captain stating, "Oh" and "Oh [expletive]," respectively. According to FDR data, the airplane's left roll attitude was increasing to more than 140°, and the pitch attitude was decreasing to nearly 50° nose down by 1554:29. According to the CVR transcript, about 1554:29.1, the ground proximity warning system (GPWS) "bank angle" aural warning annunciated,[12] followed by three chimes and the autopilot aural warning; these warnings annunciated repeatedly as the airplane descended to the ground.[13] At 1554:31, a sound similar to the stickshaker started and continued to the end of the tape. The CVR recorded nonpertinent exclamations on the captain's channel at 1554:37.1 and 1554:39.1; the CVR recording ended at 1554:40.

The airplane struck the ground in a steep nose-down attitude in a level field in a rural area about 19 nm southwest of DTW. A postimpact fire ensued. The accident occurred during the hours of daylight at 41° 57' 48" north latitude and 83° 33' 08" west longitude.

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[11] The low speed indicator referenced by the captain is the fast/slow indicator system, which consists of diamond-shaped indicators located on the left side of the electronic attitude director indicator (EADI). The fast/slow indicator is an angle-of-attack-based indicator that indicates deviations from the optimum approach speeds; up = fast, down = slow, and center = 1.3 V_s. The fast/slow indicator is certificated for the flaps zero configuration.

[12] According to the GPWS manufacturer (Allied Signal Commercial Avionics Systems), the GPWS "bank angle" aural warning is activated when the airplane exceeds 50° of bank angle at altitudes above 210 feet above ground level (agl); the message "bank angle" is repeated every 3 seconds while the bank angle exceedence exists. (When the airplane is maneuvering between the ground and 210 feet agl, the "bank angle" aural warning is activated by smaller bank angles; for example, a bank angle of 30° close to the ground will generate an aural warning.)

[13] The CVR recorded the three chimes and the autopilot aural warning again at 1554:34.3, followed by the GPWS bank angle aural warning at 1554:35.3. Then, at 1554:38.2, the three chimes and the autopilot aural warning sounded again.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Other	Total
Fatal	2	1	26	0	29
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	2	1	26	0	29

1.3 Damage to Airplane

The airplane was destroyed by ground impact forces and a postaccident fire. The value of the airplane was estimated by Comair to be about $7 million.

1.4 Other Damage

The airplane struck the ground in an open level field in a rural area, adjacent to a church campground and ball park.

1.5 Personnel Information

1.5.1 Comair Flight 3272 Captain

At the time of the accident, the captain, age 42, held an airline transport pilot (ATP) certificate with airplane multiengine land and instrument ratings, a commercial pilot certificate with airplane single-engine land and rotorcraft/helicopter privileges, and type ratings in the Canadair Regional Jet (CL-65), the EMB-120, the Fairchild SA-227, and the Boeing Vertol Company 234 (BV-234) helicopter. The captain's most recent first-class medical certificate was issued on August 8, 1996, with no restrictions or limitations.

The captain was hired by Comair on February 5, 1990, as a first officer in the EMB-120. In December 1990, he transitioned from EMB-120 first officer to an SA-227 first officer; he upgraded to an SA-227 captain in August 1991, and in January 1992, he became an SA-227 flight instructor/check airman. In late 1993, the captain became involved in Comair's preparation for its acquisition of the CL-65. Between March 30 and June 16, 1994, the captain was assigned the following duties at Comair (in order): CL-65 captain, CL-65 flight instructor (simulator), CL-65 check airman (simulator), CL-65 flight instructor (airplane), and CL-65 check airman (airplane).

The captain performed duties as a CL-65 flight instructor and check airman until December 1995, when he returned to flight line pilot status; he received an EMB-120 type rating on December 12, 1995, completed his initial operating experience in the EMB-120 on January

18, 1996, and completed his most recent line check on March 31, 1996.[14] The captain's most recent recurrent training, which included crew resource management (CRM) and unusual attitude training, was completed on September 4, 1996, in the EMB-120. He subsequently completed a proficiency check in the EMB-120 on September 12, 1996. According to company records, at the time of the accident, the captain had accumulated 5,329 total flight hours, including about 1,097 hours as pilot-in-command in the EMB-120.

The captain was off duty the 2 days before the accident. During postaccident interviews, the captain's wife told Safety Board investigators that during the off-duty days the captain worked on a computer program, ran errands during the day, and got 8 to 9 hours of sleep each night. She reported that the captain watched a movie the evening before the accident and went to bed about 2300; he arose about 0500 on the day of the accident and left the house about 2 hours before his scheduled report time of 0940.

During postaccident interviews, Comair's director of operations (DO) described the captain as "an absolute genius in mathematics…very detail oriented, professional, and serious about his job." According to the DO, the captain's goal with the airline was to direct the performance engineering department when the company grew to the point at which it could support such a department. Therefore, the captain accomplished airplane performance work for the company; the DO stated that the captain automated the CL-65 weight and balance programs and wrote the performance section of the CL-65 manuals. The DO stated that when he spoke with the captain on the day of the accident, the captain indicated that he planned to transition from the EMB-120 to the CL-65 in February 1997 (when his seniority position permitted him to make that transition). According to the DO and other witnesses who saw the captain on the day of the accident, he appeared well rested, healthy, and in good spirits before the accident flight.

Other postaccident interviews with Comair personnel indicated that the captain was well liked and respected. A first officer who had flown with the captain on several occasions described him as very positive, optimistic, and fun to work with; the first officer stated that the captain flew by the book and was knowledgeable about EMB-120 systems. A Comair line check airman, who at different times had flown with the captain and the first officer, indicated that both pilots had above-average CRM skills and established good two-way communications in the cockpit. A review of Comair's personnel records for the captain revealed no adverse information.

1.5.2 Comair Flight 3272 First Officer

The first officer, age 29, was hired by Comair on October 17, 1994, as a first officer in the EMB-120. At the time of the accident, he held a commercial pilot certificate with airplane single and multiengine land and an instrument rating, and a flight instructor certificate with airplane single and multiengine land and instrument instructor ratings. The first officer's

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[14] When the captain returned to line pilot status, he was not eligible to transition to a flight line position flying the CL-65 because of his seniority.

most recent first-class medical certificate was issued on June 21, 1996, and contained the limitation, “Holder shall wear corrective lenses.”

The first officer’s most recent recurrent training, which included CRM and unusual attitude training, was completed on September 4, 1996, in the EMB-120. He subsequently completed a second-in-command proficiency check in the EMB-120 on September 11, 1996. According to company records, at the time of the accident, the first officer had accumulated 2,582 total flight hours, including 1,494 hours as second-in-command in the EMB-120.

Like the captain, the first officer was off duty the 2 days before the accident. According to the first officer’s fiancée, the first officer spent most of the day before the accident painting their house and went to bed between 2130 and 2200. On the day of the accident, the first officer arose about 0755, saw his fiancée off on her way to work, and reported for duty at CVG at 0940. The first officer’s fiancée indicated that he was always well rested before his trips and took his job seriously.

During postaccident interviews, a captain who had flown with the first officer described him as skillful, procedurally oriented, and “having fun.” The captain indicated that he considered the first officer a “co-captain” rather than just a first officer. In addition, a line check airman who had flown with the first officer for his initial EMB-120 check ride was impressed by his proficiency and demeanor. The line check airman recalled advising the first officer that when he had more experience in line operations, the line check airman would recommend the first officer for an instructor position. A review of Comair’s personnel records for the first officer revealed no adverse information.

1.5.3 Controller at the Feeder Approach Control Position

The air traffic control specialist (ATCS) who was working at the feeder approach control position had been a military air traffic controller for 20 years before he was hired by the Federal Aviation Administration (FAA) on April 23, 1989. The FAA originally assigned him to the air traffic control tower (ATCT) facility at Flint, Michigan. He was reassigned to Detroit TRACON on June 16, 1991, and became a full performance level (FPL) controller at that facility on July 19, 1992. The controller’s most recent FAA second-class medical certificate was issued in August 1996 and contained the limitation that he “shall possess correcting lenses for near vision while performing ATCS duties.” He indicated that he was wearing glasses when he worked with Comair flight 3272.

1.5.4 Controller at the Final Approach Control Position

The ATCS working at the final approach control position was hired by the FAA on February 26, 1979; received his initial training at the FAA’s ATC facility in Oklahoma City, Oklahoma; and was originally assigned to the ATCT facility at Fort Wayne, Indiana, in July

1979. He was reassigned to the Detroit TRACON in November 1983 and became an FPL controller at that facility in December 1984. The controller's most recent FAA second-class medical certificate was issued on June 14, 1996, and contained the limitation that he "shall wear correcting lenses for distant vision while performing ATCS duties." He told Safety Board investigators that he was wearing glasses when he worked with Comair flight 3272. The final approach controller held a commercial pilot certificate with instrument and multiengine ratings.

1.6 Airplane Information

N265CA, an Embraer EMB-120RT, serial number (SN) 120257, was manufactured by Embraer S/A in Brazil in December 1991 and was purchased by Comair. The airplane was flown from Brazil to the United States with a Brazilian Export Certificate of Airworthiness.[15] According to the terms of the Bilateral Airworthiness Agreement (BAA)[16] between the United States and Brazil, before a U.S. airworthiness certificate could be issued, the FAA had to determine that the aircraft conformed to the applicable U.S. type design and certification requirements (in the case of the EMB-120, this is Federal Aviation Regulation

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[15] According to the FAA Type Certificate Data Sheet for the EMB-120 (No. A31SO), a "Brazilian Certificate of Airworthiness for Export…must be submitted for each individual aircraft for which application for U.S. certification is made." Type Certificate Data Sheet No. A31SO also states that a U.S. Standard Airworthiness Certificate may be issued by the FAA "on the basis of a Brazilian Certificate of Airworthiness for Export signed by a representative of the Centro Tecnico Aeroespacial of Brazil (CTA), containing the following statement: 'The airplane covered by the certificate has been examined, tested, and found to conform to the type design approved under Type Certificate No. A31SO and to be in condition for safe operation.'"

[16] According to FAA certification personnel, a BAA is a document that is developed when a foreign country has manufactured aviation products it intends to export to the United States; the document is less formal than an international treaty and is executed between Chiefs of State without Senatorial approval. The BAA is a technically oriented document, intended to prevent unnecessary repetitive certification activities by facilitating cooperation and acceptance of findings between the exporting country's airworthiness authority and the FAA. Before a BAA can exist, the FAA (on behalf of the U.S. State Department) must evaluate the technical competence, capabilities, regulatory authority, and efficacy of the foreign country's airworthiness authority and assess the foreign country's laws and regulations and state-of-the-art manufacturing capability. According to FAA personnel, the fact that a BAA exists between the FAA and the CTA indicates that the FAA recognizes CTA as a competent airworthiness authority with the expertise and organization to apply FAR Part 25 certification requirements.

FAA personnel further stated that a foreign aircraft manufacturer is responsible for completing the same aircraft certification process to the same standards and requirements that a U.S.-based manufacturer would have to complete. One difference in the process is that the airworthiness authority from the exporting country provides "constant oversight of the...certification program and participate[s] in all certification flight tests" instead of the FAA. In this case, however, because Embraer applied for a U.S. type certificate (TC) for the EMB-120 soon after it applied for the Brazilian TC, the FAA was involved in the certification of the EMB-120 throughout both the Brazilian and U.S. certification programs. FAA personnel stated, "[t]his process formally started at the preliminary type board meeting, continued through two interim board meetings and validation flight testing, and concluded with the final type certification board meeting. In addition to these formal meetings in which all specialty areas are typically addressed, a total of twelve additional specialist meetings were held with the FAA during the three year certification program….the FAA…provided guidance on acceptable means of compliance and FAA positions on any new issues and new means of compliance….retains the final authority on equivalencies and other critical issues…."

Under the terms of the BAA, the FAA reviewed data obtained by Embraer during its testing, then conducted comprehensive validation flight tests to confirm EMB-120 compliance with Part 25 requirements. Additionally, the FAA conducted/participated in postcertification EMB-120 flight tests under the auspices of its continuing airworthiness responsibilities.

[FAR] Part 25). On February 20, 1992, the airplane received a U.S. Standard Certificate of Airworthiness from the FAA and was put into service as part of Comair's fleet. (Additional information regarding the certification process as it applied to the EMB-120 is contained in section 1.6.1.)

The EMB-120 is a low wing, T-tail airplane (see figure 1), equipped with two Pratt & Whitney Canada (PWC) PW118 turboprop engines and Hamilton Standard 14RF-9 4-bladed propellers. Aircraft registration records indicated that at the time of the accident, 282 EMB-120 airplanes were operating worldwide, including 220 registered in the United States. According to Comair records, the accident airplane had been operated 12,751.8 hours (12,734 cycles) at the time of the accident. Company maintenance records indicated that at the time of the accident, the left (No. 1) engine, SN 115483, had operated about 12,621 hours, including 1,496 hours since the most recent overhaul; the right (No. 2) engine, SN 115576, had operated about 11,776 hours, including 30.5 hours since the most recent overhaul.[17]

Comair's FAA-approved continuous maintenance inspection program for its EMB-120s included six specific checks (service checks, 400 flight hour interior checks, "E" inspections, "C" inspections, calendar inspections, and flight cycle inspections), which are to be accomplished at various intervals. In addition, Comair performed special inspections if a repetitive inspection was scheduled at times or cycles that could not conveniently be accomplished during another check/inspection. Review of maintenance records revealed that there were no inspections due or scheduled for the accident airplane during the 7 days following the accident. The following inspections were accomplished during the 60 days preceding the accident:

- An E1 inspection was accomplished on the accident airplane on December 27, 1996, at an aircraft total time of 12,662.5 hours (about 89 flight hours before the accident). The autopilot system was included in the E1 inspection; no autopilot anomalies were noted.
- A C1 inspection was accomplished on the accident airplane on November 20, 1996, about 339 flight hours before the accident; the rudder, AOA [angle of attack], and stall warning systems were included in the C1 inspection.

The maintenance records indicated compliance with all FAA airworthiness directives (ADs) applicable to the accident airplane.[18] All but one of the discrepancies reported during the 90 days before the accident had been cleared by maintenance personnel; the uncleared (and deferred) discrepancy was a small (.033 inch deep) dent in the fuselage at fuselage station 2677. (Additional information regarding write-ups on specific systems is included in the applicable airplane systems sections.)

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[17] Comair's maintenance records indicated that after it was overhauled, the right engine was installed on the accident airplane on January 4, 1997, using procedures outlined in the EMB-120 maintenance manual. The EMB-120 maintenance manual included procedures for, in part, engine control system rigging, engine trim adjustment, and an engine trim functional check.

[18] For additional information regarding AD 96-09-24, see section 1.18.2.5.

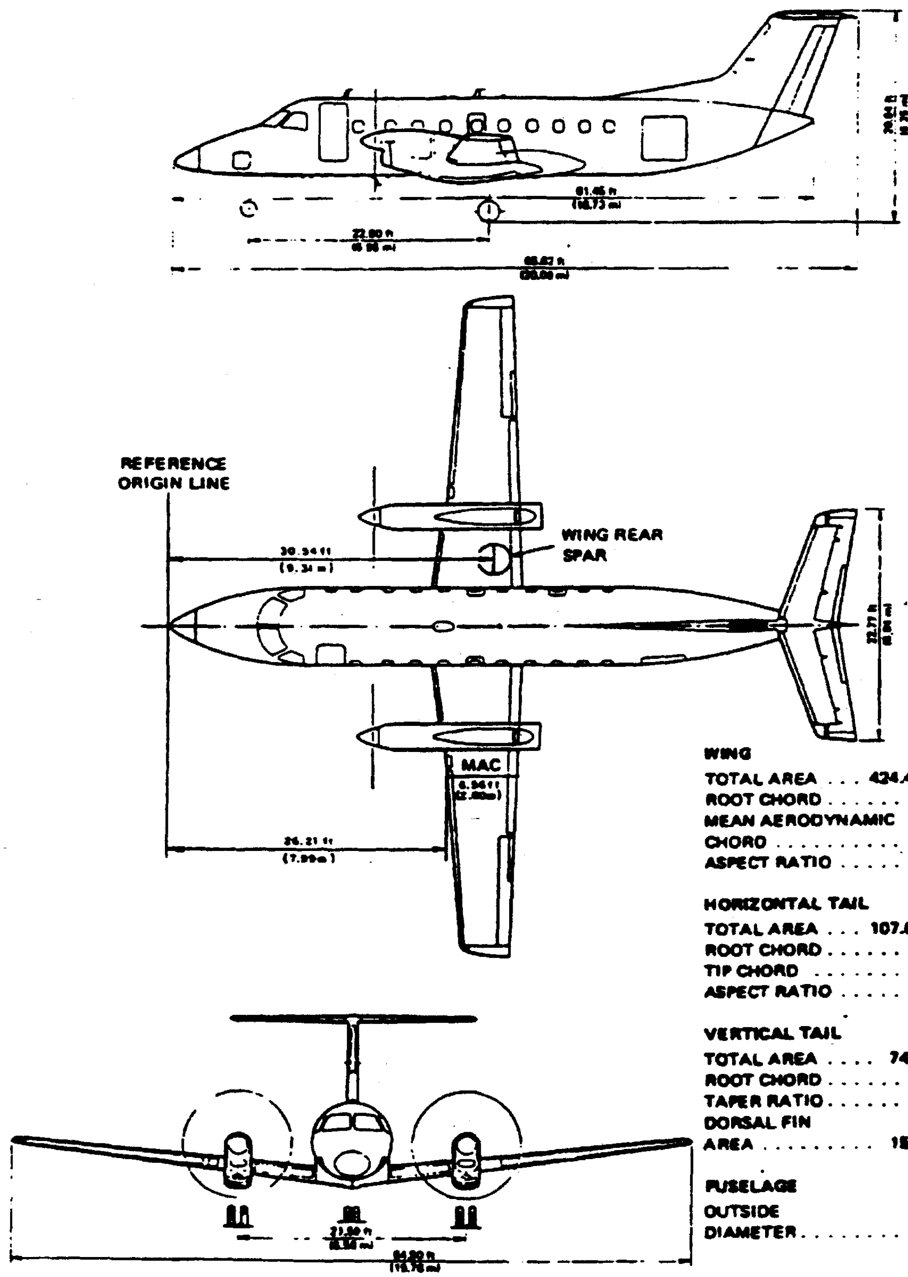
EMBRAER

EMB120 Brasilia

AIRPLANE FLIGHT MANUAL

GENERAL

THREE-VIEW DRAWING



WING	
TOTAL AREA . . .	424.46 ft² (39.43 m²)
ROOT CHORD	9.22 ft (2.81 m)
MEAN AERODYNAMIC CHORD	6.56 ft (2.00 m)
ASPECT RATIO	9.92
HORIZONTAL TAIL	
TOTAL AREA . . .	107.65 ft² (10.00 m²)
ROOT CHORD	6.00 ft (1.83 m)
TIP CHORD	3.64 ft (1.11 m)
ASPECT RATIO	4.63
VERTICAL TAIL	
TOTAL AREA	74.28 ft² (6.90 m²)
ROOT CHORD	10.43 ft (3.18 m)
TAPER RATIO	0.65
DORSAL FIN AREA	15.39 ft² (1.43 m²)
FUSELAGE	
OUTSIDE DIAMETER	7.48 ft (2.28 m)

120 01 350

Figure 1.--EMB-120.

Based on the accident airplane's flight plan data indicating a takeoff gross weight of 24,797 pounds and an estimated 850 pounds of fuel consumed between takeoff and the accident,[19] the Safety Board calculated that the accident airplane had an operating weight of about 23,947 pounds at the time of the accident. The maximum landing weight of the EMB-120 is 24,802 pounds. The estimated center of gravity (CG) at the time of the accident was calculated to be 31 percent of the mean aerodynamic chord (percent MAC); the allowable in-flight CG range at 24,000 pounds was about 16.8 percent to about 43.8 percent.

1.6.1 EMB-120 Icing Certification/Controllability History

1.6.1.1 EMB-120 Icing Certification

According to its Type Certificate Data Sheet (No. A31SO), the EMB-120's certification basis was FAR Parts 21, 25, and 36, Special FAR (SFAR) 27, with specified amendments to (and named exemptions from) those regulations. FAR Part 25, entitled "Airworthiness Standards: Transport-Category Airplanes," contains specifications for general controllability and maneuverability, as well as icing certification requirements for such airplanes, including performance requirements for flight in icing conditions and criteria for evaluating airplane flying qualities in natural icing conditions. Part 25.1419 states the following, in part:

> If certification with ice protection provisions is desired, the airplane must be able to operate in the continuous maximum and intermittent maximum icing conditions of [Part 25] appendix C….[a]n analysis must be performed to establish that the ice protection for the various components of the airplane is adequate, taking into account the various airplane operational configurations [and]…the airplane or its components must be flight tested in the various operational configurations, in measured natural atmospheric icing conditions.

The Part 25 appendix C icing envelope specifies the water drop mean effective diameter (MED),[20] the liquid water content (LWC),[21] and the temperatures at which the airplane

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[19] The estimate of fuel consumed during the flight (850 pounds) was obtained using fuel consumption rates for maximum cruise power settings at FL190 for a flight time of about 44 minutes.

[20] According to the FAA, the MED is the apparent mean volumetric diameter (MVD) that results from having to use an assumed drop size distribution when analyzing data from rotating multicylinder cloud sampling devices (old-style technology). Modern cloud sampling devices measure the drop size distributions directly and can determine the actual MVD. The maximum intermittent droplet size in appendix C is 50 microns, and maximum continuous droplet size is 40 microns. A micron is 1/1000 of a millimeter (mm). (The lead in a 0.5 mm mechanical pencil is 500 microns in diameter, or 10 times larger than the largest droplet defined in Part 25 appendix C.) According to FAA icing experts, normal icing cloud droplets are typically between 2 microns and 50 microns in diameter. However, National Center for Atmospheric Research (NCAR) scientists report that freezing drizzle can occur at droplet sizes between 40 and 400 microns, and freezing rain occurs at droplet sizes greater than 400 microns. Supercooled large droplets (SLD) include freezing drizzle and freezing rain.

[21] According to the FAA, LWC is the total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air. The terms LWC and supercooled liquid water (SLW) refer to the amount of liquid water in a certain volume of air.

must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing. During EMB-120 initial certification work, Embraer demonstrated to the satisfaction of CTA and FAA certification personnel the EMB-120's ability to safely operate within the conditions described in Part 25 appendix C. (Copies of Part 25.1419 and appendix C of Part 25 are included in appendix I of this report.)

According to FAA personnel and certification records, CTA personnel participated in all EMB-120 icing certification flight tests (including tests in natural icing conditions and with simulated ice shapes) to ensure compliance with Part 25 appendix C. FAA personnel reviewed and validated the results of those tests before it approved the EMB-120 for flight into known icing conditions; they stated that the EMB-120 demonstrated satisfactory handling characteristics and no tendency for loss of control during flight tests under Part 25 appendix C (normal icing) conditions. During the CTA's EMB-120 initial icing certification flight tests, the airplane's handling characteristics were evaluated (and determined to be satisfactory) in the following conditions:

- Natural icing conditions, maneuvers within the normal flight envelope to evaluate flight handling qualities, at airspeeds between 130 and 200 knots, at various weights and airplane configurations (configurations ranged between gear up/flaps up and gear down/flaps 45°). Embraer evaluated the EMB-120's handling characteristics during natural icing flight tests with ¼ inch, ½ inch, and ¾ inch of ice accumulation on protected surfaces, and with deicing boots operating until about 4 inches of ice accumulated on unprotected surfaces.

Flight tests conducted by Embraer and CTA during initial certification tests yielded satisfactory results with 3-inch ram's horn ice shapes (calculated by Embraer to be representative of ice accumulated during a 60-minute hold in icing conditions)[22] on unprotected surfaces. Further, the Safety Board's review of the EMB-120 certification flight test data revealed that during several of the natural icing encounters, the EMB-120 encountered conditions that exceeded Part 25 appendix C boundaries for continuous maximum and intermittent maximum icing conditions (in terms of LWC);[23] again, no anomalous handling characteristics were observed.

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[22] "Ram's horn" ice shapes are common rime ice formations in which the ice accumulates away from the leading edge of the airfoil, both above and below it, forming a shape similar to that of the horns on a ram. According to the FAA Aeronautical Information Manual (AIM), rime ice is "rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets." Embraer used "60-minute" ice shapes during the EMB-120 certification work, thus exceeding FAA and CTA icing certification standards, which require airplane manufacturers to conduct ice protection system operative handling and performance tests with ice shapes representative of ice accumulated during a 45-minute hold in icing conditions.

[23] According to the test flight data, the largest droplet size encountered was 37 microns MVD (which falls within the appendix C envelope), with a LWC of .8 grams per cubic meter (which is higher than the maximum LWC corresponding to 37 micron droplet size in the appendix C envelope). Variations in LWC primarily affect the ice accretion rate, not the location of the accretion.

In addition to data from the CTA/FAA EMB-120 icing certification testing, the Safety Board reviewed the results of icing certification conducted by Transport Canada, the Canadian airworthiness authority. During its certification process, Transport Canada required evaluation of the EMB-120's flight handling characteristics and stall tests (power—on, power—flight idle, right and left 30° bank turns with power at 50 percent, at various airplane weights, configurations, and stall entry rates) with 1-inch artificial ice shapes[24] on all protected surfaces and ice shapes representative of ice accreted during a 45-minute hold in icing conditions on unprotected surfaces, and sideslip tests with the same ice shapes. Transport Canada's flight test data from stall/handling tests conducted with the gear up/flaps up, autopilot not activated, 30° of bank, 50 percent power, and with 1-inch ice shapes on unprotected surfaces indicated that the airframe's aerodynamic buffet (indicating approaching stall) began at 136 knots, the stick shaker activated at 123 knots, and the stick pusher activated at 118 knots.[25] Test pilots reported that the stall recovery was easy, and the airplane exhibited no adverse flight handling qualities during its recovery. According to Embraer and Canadian officials, although the tests indicated a significant reduction in the margin between stick shaker activation and the stall, there was sufficient aerodynamic buffet to alert a pilot to the approaching stall in all flight conditions except the landing configuration (gear down, flaps 45°). Transport Canada determined that the airplane had demonstrated satisfactory handling characteristics under the tested conditions, and the EMB-120 was certificated for flight into known icing conditions by the Canadian airworthiness authority.

1.6.1.1.1 Current Icing Certification Guidance for Transport-Category Aircraft

Icing certification guidance for airplanes certificated under Part 25 is contained in sections 231 and 232 (pages 8-6 to 8-9) of Advisory Circular (AC) 25-7, "Flight Test Guide for Certification of Transport-Category Airplanes," dated March 31, 1998. Section 231, "Performance Requirements for Flight in Icing Conditions," states the following:

> When approval of an airplane for operation in known icing conditions is requested, compliance with the approach…and landing climb requirements…should be demonstrated with residual ice accretions on unprotected areas of the airframe. For airplanes with de-ice systems, this would also include any ice not shed from protected surfaces with the system in its normal operating mode. The airplane is assumed to descend into, and be required to hold in, atmospheric conditions meeting the continuous maximum atmospheric icing conditions criteria described in Appendix C to Part 25 of the FAR.

The procedures outlined in section 231 included flight tests conducted with simulated ice shapes (representative of the ice accretion obtained in the ice protection system

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[24] The 1-inch ice shapes used during Canadian certification tests were small ram's horn shapes covering a very small percentage (less than 1 percent) of the wing chord at the leading edge.

[25] Transport Canada's initiated the EMB-120 stall tests at 1.3 stall speed (Vs)—at the airplane's gross weight for this flight test (22,960 pounds) 1.3 Vs was 144 knots—and decelerated at a rate of 1 to 1½ knots per second.

flight testing required by FAR 25.1419) installed on the airplane. The flight tests were to include climb performance testing, stall testing, and approach and landing climb performance.

Section 232, "Flying Qualities in Natural Icing Conditions," states that the airplane's handling characteristics should be evaluated with ice accumulation on unprotected surfaces (including ice that may accumulate on flaps and associated structures, or in slat or flap gaps) and with consideration for residual or intercycle ice on the protected surfaces of the airplane. Further, section 232 states the following:

> To assure that there are no unusual or hazardous differences in handling characteristics between tests with artificial ice shapes and those associated with the critical natural ice buildup, an evaluation of the airplane flying qualities should be performed following a natural icing encounter. The amount of ice on the airplane should be representative of what would be accumulated in a 45 minute hold in icing conditions prior to approach and landing.

Section 232 specified that the flight handling tests should include the following maneuvers (which were representative of maneuvers an airplane would perform while holding in icing conditions and in the subsequent approach to landing):

CONFIGURATION	Center of Gravity	TRIM SPEED	MANEUVER
Flaps UP, Gear UP	Forward	Holding	Level, 40^o banked turn Bank-to-bank rapid roll, 30^o - 30^o Speedbrake extension/retraction
Flaps Down, Gear UP	Forward	Holding	Level, 40^o banked turn Bank-to-bank rapid roll, 30^o - 30^o Speedbrake extension/retraction
Landing	Forward	1.3 V_{so} (V_{ref})	Level, 40^o banked turn Bank-to-bank rapid roll, 30^o -30^o Speedbrake extension/retraction
Landing	Forward	Same as used for uncontaminated airplane stalls	Idle power 1 knot/second deceleration to full stall

Section 232 states that there should be no unusual control responses or uncommanded airplane motions during these maneuvers, and there should be no buffeting or stall warning during the level turns and bank-to-bank rolls.

According to FAA personnel, a new AC (AC 25.1419), which will address the certification of Part 25 airplanes for flight in icing conditions, is currently in draft form; FAA personnel stated that "the anticipated issue date is not available at this time."

The Safety Board's review of the recently revised icing certification compliance guidance for normal, utility, and acrobatic-category (nontransport-category) airplanes revealed that AC 23.1419-2A, "Certification of Part 23 Airplanes for Flight in Icing Conditions," (dated August 19, 1998) is 25 pages long with 9 pages of appendixes and contains very specific, detailed guidance. According to AC 23.1419-2A, the revised document is intended "to continue the current minimum ice protection requirements that have been found necessary for safe operation in icing conditions, to provide specific test requirements, to clarify the requirements for information that must be provided to the pilot, and to allow approval of equivalent components that have been previously tested and approved, and that have demonstrated satisfactory service if the installations are similar." AC 23.1419-2A provides detailed guidance in the following areas:

- Certification design and development plan—should include airplane and systems description, ice protection systems description, certification checklist, analyses or tests performed to date, analyses or tests planned, projected schedules of design, analyses, testing, and reporting.

- Design objectives—to "demonstrate by analyses, tests, or a combination of analyses and tests, that the airplane is capable of safely operating throughout the icing envelope of Part 25, Appendix C, or throughout that portion of the envelope within which the airplane is certificated for operation where systems or performance limitations not related to ice protection exist. Appendix 1 lists various influence items that should be examined for their affect on safety when operating in icing conditions."

- Analyses—should be validated either by tests or by reference to previous substantiation and are normally used for the following: areas and components to be protected; the 45-minute hold condition, flutter analyses, power sources, failure analyses, similarity analyses, impingement limit analyses, and induction air system protection.

- Flight test planning—to evaluate performance and flying quality degradation experienced during flight in natural icing conditions, and to determine that flying qualities and performance are acceptable for flight in an icing environment.

- Flight tests—should include dry air tests with ice protection equipment installed, dry air tests with artificial ice shapes, flight tests in natural and simulated icing conditions, performance and handling qualities (all engines operating, one engine inoperative, balked landing, landing, stall characteristics and airspeeds, trim, lateral stability/control, longitudinal stability/control, Vmc, landing approach airspeeds, maneuvering characteristics, high airspeed characteristics, etc), ice shedding, pneumatic deicing boots, and emergency and abnormal operating conditions.

- Placarding and AFM [airplane flight manual] guidance—placards and/or AFM guidance should include equipment limitations, speed restrictions, environmental limitations, etc.

According to the FAA's Environmental Icing National Resource Specialist (NRS), existing icing certification guidance only requires manufacturers to test to "normal icing operating conditions," which means operating in icing conditions with fully functioning anti-icing and deicing systems. Current icing certification requirements do not consider the effects of delayed activation (or malfunction) of ice protection systems, intercycle ice accumulations, or other variables that might result in less than the "best" case operating condition.

1.6.1.1.2 Draft Aviation Rulemaking Advisory Committee Icing Certification Guidance for Transport-Category Aircraft

The FAA's EMB-120 Aircraft Certification Program Manager and Environmental Icing NRS stated that because of the need to provide in-flight icing certification guidance material and to ensure harmonization of this material with similar European Joint Airworthiness Authority (JAA) guidance material, aviation rulemaking advisory committee (ARAC) working groups were developed to address the necessary changes to Parts 23 and 25 and corresponding ACs for future icing certification projects.[26] The Flight Test Harmonization Working Group has been working on new icing certification standards and criteria since 1995, after the Avions de Transport Regional, model 72 (ATR-72) accident at Roselawn, Indiana.[27] The FAA's Environmental Icing NRS reported that the new regulations and ACs would require manufacturers to examine the effects of delayed deicing boot activation and intercycle/residual ice accumulations before the airplane would be certificated for flight in icing conditions. However, FAA personnel indicated that the new icing standards and criteria are typically only applied to new airplanes for which icing certification is sought; they would not automatically retroactively apply to airplanes that are currently certificated for flight in icing conditions.

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[26] Changes to Part 25 are being addressed by the Flight Test Harmonization Working Group, a group of industry and airworthiness authority representatives from Canada, Europe, and the United States. This group has been working since 1995 to harmonize and provide guidance material regarding acceptable means of demonstrating compliance with in-flight icing flight characteristics regulatory requirements. Changes to Part 23 will be addressed by the Ice Protection Harmonization Group (an ARAC working group structured like the Flight Test Harmonization Working Group) when the Part 25 guidance material is established.

[27] See National Transportation Safety Board. 1996. *Simmons Airlines, d.b.a. American Eagle Flight 4184, Avions de Transport Regional (ATR) Model 72-212, N410AM, Roselawn, Indiana, October 31, 1994.* Aircraft Accident Report NTSB/AAR-96/01. Washington, DC. This accident will be discussed further throughout this report.

1.6.1.2 EMB-120 Severe Icing (Supercooled Large Droplet) Controllability Tests

In addition to addressing certification-related responsibilities, the BAA requires the authorities of both countries to work cooperatively to analyze accidents and incidents involving exported products to ensure the continuing airworthiness of those products.[28] One example of this cooperative effort is the EMB-120 supercooled liquid droplet (SLD) icing controllability testing, which occurred as a result of the Safety Board's investigation of the October 31, 1994, accident in which an Avions de Transport Regional, ATR-72 experienced an uncommanded roll event and crashed near Roselawn, Indiana. During its investigation of the ATR-72 accident, the Safety Board discovered that the airplane encountered SLD between 100 microns MVD and 2,000 microns MVD while operating in a holding pattern. Although these SLD icing conditions exceeded the maximum MVD criteria (50 microns MVD for intermittent icing conditions, 40 microns MVD for continuous icing conditions) specified in the Part 25 appendix C envelope, FAA's Environmental Icing NRS stated that "within the distribution of droplets that result in the [MVD] drop diameters of 40 to 50 microns specified as the limits of Appendix C, drizzle (or SLD) droplets with diameters exceeding 50 microns will occur." Thus, it is possible for an airplane to encounter SLD droplet sizes while operating in icing conditions within the Part 25 appendix C envelope.

The Roselawn accident indicated that it was possible for pilots to unknowingly operate an airplane in icing conditions for which the airplane had not demonstrated satisfactory handling characteristics. Therefore, in June 1995, the FAA requested the manufacturers of all "regional transport-category airplanes with unpowered controls and pneumatic deicing boots" to demonstrate/evaluate the control characteristics of their airplanes while operating in SLD icing conditions. In response to the FAA's request (and in accordance with the BAA), the CTA and Embraer developed a test plan, which originally included wind tunnel tests, flight simulator analysis, and flight tests with artificial ice shapes attached to the airplane's surfaces. The series of tests were accomplished by Embraer and the CTA in October/November 1995. The test plan was later expanded to include flight tests behind a tanker airplane,[29] which were accomplished in December 1995.

Embraer reported that the first step in the SLD icing tests was to measure in a wind tunnel the effect of artificial ice shapes[30] on the aileron hinge moment.[31] Based on the wind tunnel tests, Embraer determined that a strip of 1-inch wood quarter-round molding positioned spanwise along the aft edge of the leading edge deicing boot segments on the upper wing

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[28] The BAA requires airworthiness authorities to keep each other informed of significant airworthiness modifications and special inspections that they determine are necessary and to work cooperatively to determine whether major design changes and major repairs comply with the laws, regulations, and requirements under which the product was originally certificated and approved.

[29] The tanker airplane was a U.S. Air Force KC-135 equipped with a boom-mounted water nozzle array designed to produce an icing cloud with the desired droplet size and water content.

[30] Embraer used 1-inch, ¾-inch, and ½-inch quarter round artificial ice shapes, located in various positions on the upper surface of the wing to evaluate the effect of SLD ice shapes on aileron hinge moment.

[31] Aileron hinge moments are a function of the air pressure distribution on the surface of the aileron and associated balance devices, as well as the chordwise location of the hinge line.

surface[32] produced a severe aerodynamic effect on the aileron (and general flight handling characteristics). The results obtained from the wind tunnel tests (hinge moment coefficient, estimated loss of lift, drag increase and associated rolling and yawing moments) were incorporated into the simulator aerodynamic model, and a series of simulator flights were performed to assess the handling characteristics and controllability of the airplane.

After simulator flights demonstrated that actual flight tests could safely be performed, an EMB-120 prototype airplane was rigged with devices that would allow each ice shape segment to be released in flight. When these devices were installed, the aircraft was configured with the quarter-round artificial ice shapes, which were divided into three equal-length segments on each wing. High-speed taxi tests were performed to verify aileron forces and to confirm operation of the ice shape releasing devices. During the subsequent flight tests, conditions that were presumed to be less critical were simulated first, then the number and size of quarter-round artificial ice shape segments were increased. At each stage, the quarter-round artificial ice shapes were tested at various airspeeds under symmetrical and asymmetrical ice shape conditions.

According to Embraer and the FAA, the flight tests showed that the airplane was “fully controllable without any lateral control degradation” in the most critical ice conditions; however, the pilot force required to return to a wings-level condition (with 1-inch quarter-round artificial ice shapes, asymmetrically positioned, at the recommended holding airspeed of 160 knots) exceeded the maximum (60 pounds of force) permitted by the FARs for certification. Embraer speculated that the control wheel force exceedence occurred because the 1-inch quarter-round artificial ice shapes used during the tests were “much more critical” than the natural ice accretion that would occur on an EMB-120 operating in SLD icing conditions. Therefore, the test program was expanded to include in-flight icing tanker tests. According to Embraer, the purpose of the icing tanker flight tests was the following:

- To determine the real shape of the ice accumulated during freezing rain/freezing drizzle exposure, and
- To determine the visual cues to allow pilots to recognize when they are flying in freezing rain/freezing drizzle.

The icing tanker flight test was accomplished by operating an EMB-120 in a spray of supercooled water droplets generated by the icing tanker; 40 micron MVD and 170 micron MVD droplets were sprayed to simulate Part 25 appendix C and SLD icing environments, respectively. The tanker flight tests were conducted at airspeeds between 160 knots and 175 knots, with the EMB-120’s landing gear and flaps retracted.[33] Using data collected during the

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[32] The wooden strips were placed at 6 percent MAC along the leading edge deicing boot segments; this placement is coincident with the aft edge of the farthest aft inflatable deicing tube and is located well forward of the ailerons.

[33] The airspeeds and configuration used during the SLD icing controllability tests were selected because they were representative of the airspeeds and configuration an EMB-120 would operate at as it descended through clouds approaching its destination. Because the icing tanker airplane flight tests were not intended to identify the EMB-120’s flight handling characteristics throughout its entire range of operation, and to maintain safe

tanker testing, ice shapes that were more realistic than the quarter-round shapes were developed and additional flight testing was accomplished with the new ice shapes. According to FAA and Embraer personnel, during these additional flight tests, the control wheel forces required to maintain or return to a wings-level attitude during all flight conditions (dynamic and static) remained less than the maximum specified by the FAA for aircraft certification.

FAA and Embraer personnel also observed that ice accumulations on both the wing and propeller spinner revealed different accumulation patterns in SLD conditions than those observed in Part 25 appendix C icing conditions. Specifically, on the wing, the unique visual cue consisted of ice accumulation on the deicing boot aft of the last inflatable tube; on the propeller spinner, the ice accumulation extended beyond mid length to the aft end of the spinner. These visual cues could be used by pilots to recognize when the airplane was operating in SLD and not Part 25 appendix C icing conditions.

On April 12, 1996, Embraer published Operational Bulletin (OB) No. 120-002/96 to provide EMB-120 operators and other interested personnel with information regarding the results of the SLD controllability tests. The OB and other information that were available to EMB-120 operators and the FAA are discussed further in section 1.18.2 and its subsections. A copy of OB No. 120-002/96 is attached in appendix G.

1.6.2 Pilot Reports Regarding EMB-120 Flight Characteristics and Operations

During postaccident interviews, Comair pilots, instructors, and check airmen were questioned about the flight handling characteristics of the EMB-120 (in general and in icing conditions) and about Comair's EMB-120 operations and practices. Their responses included the following assessments:

- Easy to fly
- Stable, reliable
- No noted flight handling anomalies during operations in icing conditions
- Needs lots of attention to trim; specifically, the rudder is highly effective, and rudder trim needs to be adjusted frequently
- Powerful, responsive engines; changes in power settings frequently resulted in left yaw, which was corrected by adjustments to rudder trim
- Equipment worked properly; if something broke, the company fixed it

Interviewed personnel reported that they were unaware of any systemic problems with the EMB-120, other than the difficulties the EMB-120 had with propeller overspeeds in the past;[34] these problems were addressed and corrected by actions required in an FAA AD. Many of

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operating airspeeds for the tanker airplane, the EMB-120 was not evaluated at slower airspeeds and/or other configurations.

[34] Although there were no anecdotal accounts of EMB-120 aircraft having more difficulty than other turbopropeller-driven aircraft in icing conditions, six EMB-120 icing-related accidents/incidents occurred

the pilots interviewed reported that they had operated the EMB-120 in icing conditions (one even reported having flown in SLD icing conditions, stating that he exited the conditions as soon as possible) and observed ice accumulation on the airfoils. None of the pilots noted any adverse flight handling characteristics or reported any difficulty controlling the airplane under any circumstances.

1.6.2.1 EMB-120 Airspeed Information (Pilot Interviews/Comair's Manuals)

The Safety Board conducted postaccident interviews with 16 Comair EMB-120 pilots/instructors/line check airmen and asked them (among other things) about EMB-120 configuration and minimum airspeeds. The pilots' responses to these questions varied, although in general, Comair's pilots appeared uncomfortable with the idea of operating the EMB-120 at 150 knots in icing conditions without flaps extended and commented that the manuals did not contain information about minimum airspeeds for various airplane configurations in icing conditions. Most of the pilots stated that they added 5 to 10 knots to the Vref (reference airspeed for final approach) speed while operating in icing conditions. Several pilots reported that they could not envision circumstances under which they would operate the EMB-120 at 150 knots in the clean configuration[35] in icing conditions; they indicated that if they were assigned an airspeed of 150 knots by ATC, they would select 15° of flaps or request a higher airspeed.[36] Many of the pilots stated that they would normally expect to select 15° of flaps when they were relatively close to their destination airport; for example, within 3 to 5 miles of the airport on a base leg during a visual approach, or one dot below the glideslope, or an equivalent position during an instrument approach to land. They indicated that it would be unusual to operate the airplane configured with 15° of flaps while 19 miles from the destination airport (the accident location), but they added that it would also be unusual to be assigned an airspeed of 150 knots while being vectored that distance from the destination airport.

During postaccident interviews, one EMB-120 first officer stated that there was no "operational requirement to have the flaps set at 15°" when the airplane was slowed to 150 knots, but he "usually put the flaps down to 15° around 160 knots" because the minimum airspeed for a no-flap landing was 160 knots. Another EMB-120 first officer stated that at 150 knots and 24,000 pounds gross weight (the approximate weight of the accident airplane), he would normally expect to have 15° of flaps extended; however, he stated that this would normally occur when the airplane was within 3 miles of the airport. Another first officer interviewed after the accident was uncertain whether he would have accepted an assigned airspeed of 150 knots. He cited a flight standards bulletin (FSB)[37] that recommended a minimum holding and climbing airspeed of 170 knots.

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before the Comair flight 3272 accident; these events are discussed in section 1.18.2. Additionally, a postaccident EMB-120 icing-related incident involving Westair flight 7233 is discussed in section 1.18.2.9.

[35] "Clean" refers to an aircraft with its landing gear and flaps retracted.

[36] Wing flaps are designed to change the shape of the airfoil to allow the airplane to operate at slower airspeeds without stalling and are used principally for approach to landing and landing. Use of flaps increases both lift and drag on the airfoil.

[37] For further information regarding this FSB (FSB 96-04), see section 1.18.2.6.

When asked if he would be comfortable on a 20 mile final at 150 knots in a clean configuration, one Comair EMB-120 captain stated that it would "depend upon how ATC was handling the flight." He further stated that it would be unusual to be assigned 150 knots while being vectored 20 miles from the destination airport and that he would not expect to be that slow until he was closer to the airport. He told investigators that "in most situations" at 150 knots, the airplane would be on the approach and he would use 15° of flaps. Another Comair EMB-120 captain stated that he "did not advocate flying at 150 knots" without flaps extended. However, he stated that the published final segment airspeed (V_{fs})[38] for an EMB-120 operating at 24,000 pounds gross weight was 147 knots, which he considered the absolute minimum airspeed for operating the airplane without flaps. (According to Comair's V-speed reference cards, an EMB-120 landing at a gross weight of 24,000 pounds, at a temperature of 0° C, would have a V_{fs} of 143 knots, a $V_{ref\ flaps\ 0}$ [approach reference speed with no flaps extended] of 147 knots, with a stall speed in the clean configuration [landing gear and flaps retracted] of 114 knots. See figure 2.)

One of Comair's EMB-120 flight instructors stated that he did not know the airspeed limitations off hand, and that "your position on the approach, intercept vector or on base," determined when flaps should be lowered. He further stated that the EMB-120 minimum maneuvering airspeed without flaps was 140 knots; he was not aware of a different published minimum airspeed for operations in icing conditions, except for the 170 knot minimum airspeed for holding without gear or flaps extended. However, the flight instructor told investigators that he would "not fly at 150 [knots] clean, would go to flaps 15, unless in icing conditions…may not want to put flaps out. [In that case, he] would tell ATC and stay at 170 knots." He also stated that he would not extend flaps beyond 5 miles from the destination airport in icing conditions.

Comair's EMB-120 chief instructor told investigators "[t]he only speed for icing is minimum of 160, recommended to be 170…train to use 170 in holding in icing." He further stated that there was no flap usage modification for operating in icing conditions. In addition, Comair's EMB-120 Program Manager told investigators that there were no published minimum maneuvering airspeeds for the EMB-120. He stated that the only minimum airspeed he was aware of in the AFM was "a minimum holding speed of 160 knots in icing conditions. Comair added 10 knots to that and made it 170 knots in holding,[39] without consideration of whether icing conditions are present….There are no minimum speeds associated with the terminal area, and no speeds published in the airplane flight manual."

During postaccident interviews, a Comair EMB-120 line check airman stated that he "would personally not reduce to speed slower than [160 knots] without configuring." Another Comair EMB-120 line check airman stated that the suggested minimum airspeed for an EMB-120 on approach is 170 knots; he added, "the airplane should fly safely at 150 knots clean, but it is not a practice [we] advocate. When somebody gets close to V_{fs} [final segment airspeed] (141 knots to 147 knots), those are the minimum clean speeds….It is [an airspeed] bug that is always

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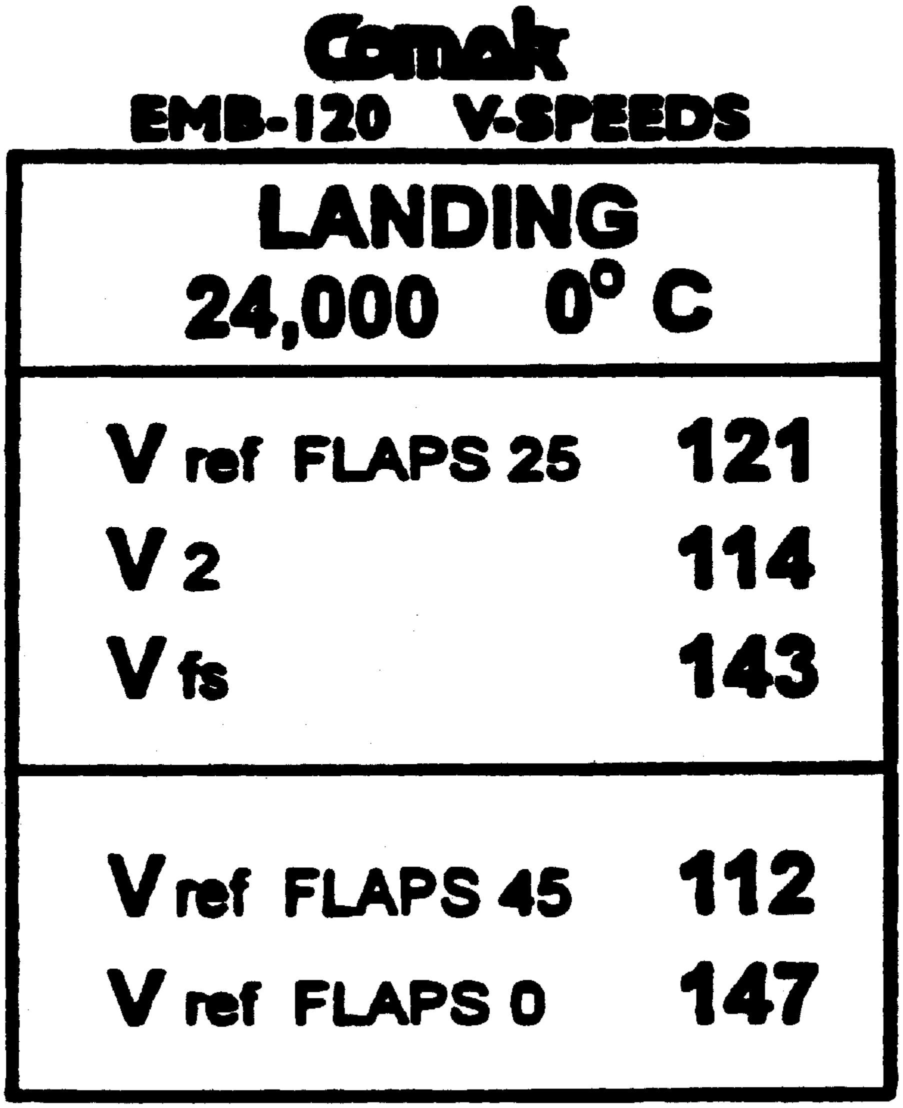
[38] V_{fs} is the target airspeed for flap retraction after takeoff or during a go-around.

[39] In its October 1996 FSB, Comair specified a minimum holding airspeed in icing conditions of 170 knots. 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.



Comair

EMB-120 V-SPEEDS

LANDING

24,000 0° C

V_{ref} FLAPS 25	121
V_2	114
V_{fs}	143
V_{ref} FLAPS 45	112
V_{ref} FLAPS 0	147

Figure 2.--V speeds.

set in front of the pilot and can be used as a reminder of the speed to always remain above. Most pilots would tell you that is the minimum airspeed, clean." Yet another Comair EMB-120 line check airman stated that the recommended minimum airspeed with no flaps was 170 knots, and that 15° of flaps should be added when the airplane was on the base leg of the approach. However, later in the interview, this line check airman told investigators that for an EMB-120 at 24,000 pounds with no flaps extended, "V_{ref} would be 147 knots, but the approach speed is 160 knots. If there's icing on the airframe, manufacturer says to add 5 to 10 knots to V_{ref}. In that situation, with a clean airplane the minimum speed would be 152 knots." He stated that the manufacturer advised pilots to increase their reference airspeed if they suspected that ice was accumulating on the airframe because of possible aerodynamic degradation.

The Safety Board reviewed the airspeed guidance available to pilots at the time of the accident and noted that the limitations sections of Embraer's EMB-120 airplane flight manual (AFM) and Comair's EMB-120 flight standards manual (FSM) contained some guidance regarding maximum airspeeds,[40] and both manuals specified a maneuvering airspeed of 200 knots; however, neither manual contained specific minimum airspeeds for various aircraft configurations/flap settings and phases of flight. Comair's EMB-120 FSM also contained airspeed information in the maneuvers, normal, and nonnormal procedures descriptions. For example, the guidance included in Comair's FSM for an ILS approach associated the base leg vector/procedure turn inbound position with 170 knots and the flaps 15 configuration. Additional guidance in the FSM for the ILS approach associated 150 knots airspeed with the selection of 25° of flaps. Although this airspeed information did not constitute minimum airspeed guidance or a required procedure, it was the procedure that Comair used in its training program and represented in its manuals for operating and configuring the airplane on an ILS approach.

Comair's EMB-120 FSM also contained guidance for a no-flaps approach and landing (a nonnormal 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 nonnormal procedure) checklist procedure advised pilots to add 35 knots to the reference airspeed for 45° of flaps for the zero flaps configuration, resulting in airspeeds between 140 and 150 knots (again depending on the airplane's gross weight). Comair's manuals also addressed final segment airspeeds (V_{fs}) of between 140 knots and 147 knots, depending on the airplane's gross weight.

At the time of the accident, the only icing-related airspeed specified in Embraer's EMB-120 AFM and Comair's EMB-120 FSM was the minimum airspeed for holding in icing conditions (160 knots). The EMB-120 AFM also contained a general icing-related note that advised "[f]or approach procedures in known or forecast icing conditions, increase the airspeed by 5…to 10 KIAS [knots indicated airspeed] until [on] short final." However, during the 13 months before the accident occurred, Comair issued additional icing-related guidance (an

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[40] Maximum airspeed guidance included the following: maximum operating airspeeds (variable with altitude); the maximum flap extension speeds for 15°, 25°, and 45° of flaps (200 knots, 150 knots, and 135 knots, respectively); and maximum landing gear extension/operation speed = 200 knots.

interoffice memo and an FSB) that advised EMB-120 pilots to maintain higher airspeeds than normal when operating in icing conditions. Comair's December 8, 1995, inter-office memo advised pilots not to operate the EMB-120 at less than 160 knots in icing conditions and to operate at 170 knots for holding in icing conditions. According to Comair, this memo was distributed in 1995 to all EMB-120 pilots in their mailboxes and a 30-day pilot-read binder. FSB 96-04, issued on October 18, 1996, 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 nonclimbing/nonholding icing operations. Comair's EMB-120 FSM and FSB 96-04 also stated "when there is any suspected residual airframe icing, use 25° flaps ONLY, and use V_{ref} +5 KIAS for reference speed." Comair pilots were instructed to insert FSB 96-04 in the bulletin's section in the back of their copies of the FSM.

Additional preaccident airspeed guidance was contained on the same page as revision 43 to Embraer's EMB-120 AFM (issued in April 1996 and largely based on information contained in Embraer's OB 120-002/96), which indicated that the manufacturer's recommended minimum airspeed for the EMB-120 in icing conditions with landing gear and flaps retracted was 160 knots. (Although the AFM page containing revision 43 had been inserted in Comair's EMB-120 AFMs [maintained in each EMB-120 in Comair's fleet], at the time of the accident, Comair had not incorporated the AFM revision 43 information into its EMB-120 FSM.) The same AFM page also contained a note advising pilots to increase the airspeed by 5 to 10 knots during approach procedures (until on short final approach). This note had been contained in the EMB-120 AFM at least since revision 27, dated August 1, 1991; however, Comair's FAA-approved FSM did not contain a note advising pilots to increase the airspeed by 5 to 10 knots during approach procedures (until on short final approach). According to Comair representatives, Comair's pilots used the company's Operations Manual and FSM as their primary sources of procedural guidance, not the EMB-120 AFM. Comair's EMB-120 pilots did not receive copies of revision 43 to the EMB-120 AFM. Additional information regarding the December 8, 1995, interoffice memo, FSB 96-04, Embraer's EMB-120 AFM revision 43, and Embraer's OB 120-002/96 is included in section 1.18 and its subsections and appendixes G and H.

1.6.3 EMB-120 Systems

The EMB-120 systems (including flight control, stall warning/protection, autopilot, and ice protection systems) were certificated in accordance with FAR Part 25.1309, "Equipment, Systems, and Installations." According to Part 25.1309, an airplane's systems must be designed to ensure that they perform their intended functions under any foreseeable operating condition. Part 25.1309 further states, "[w]arning information must be provided to alert the crew to unsafe operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards."

1.6.3.1 Stall Warning/Protection System

The stall warning system installed on the EMB-120 was designed and manufactured in compliance with FAR Part 25.207 (dated January 16, 1978), “Stall Warning,” which requires that “stall warning with sufficient margin to prevent inadvertent stalling with the flaps and landing gear in any normal position must be clear and distinctive to the pilot in straight and turning flight….through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications….in each of the airplane configurations….The stall warning must begin at [an airspeed] exceeding the stalling speed…by seven percent or at any lesser margin if the stall warning has enough clarity, duration, distinctiveness, or similar properties.”

The EMB-120 stall warning system provides sequential warning to alert the pilots to an impending stall condition. The system consists of two identical stall warning subsystems (captain’s and first officer’s) that function independently and redundantly to drive two control column (stick) shakers, two pusher servos, and the aural warning system. By design, when the airplane’s angle-of-attack (AOA)[41] reaches 10.2°, the stick shaker activates (the control column vibrates and the aural indication [the “clacker”] activates). When the airplane’s AOA reaches 12.5°, the stick pusher activates (the stall warning tone sounds and the control column is pushed forward). The stick pusher maintains a forward pressure until the airplane reaches a normal acceleration of ½ G, AOA is reduced, or the pilot disconnects the stall warning/protection system.

The FAST/SLOW indicator system is another part of the stall protection system and uses AOA to indicate the optimum approach speed (about 1.3 Vs) for any flap setting. The FAST/SLOW indicators are diamond-shaped indicators located on the left side of the electronic attitude director indicator (EADI), which indicate deviations (up = FAST, down = SLOW) from the optimum approach speeds, as represented by a center reference mark on the EADI.

The stall warning/protection system is designed to activate for each flap setting at specific angular airflow values measured by the AOA and sideslip sensors. The activation schedule was established for a clean EMB-120 wing (without ice contamination). The stall warning/protection on the EMB-120 does not account for the presence and effect of small amounts of contamination, such as ice on the surface of an airfoil.

According to Embraer, there is no logic connection between the ice protection system (see section 1.6.3.4 for a discussion of the ice protection system) and the stall warning system. In its investigation of the ATR-72 accident near Roselawn, Indiana, the Safety Board found that the stall warning system (stick shaker) installed in the ATR-72/42 airplanes at the time of that accident activated at a lower AOA (7.5° instead of 12.5°) when the anti-icing system was activated to account for the aerodynamic changes expected when the airplane was operating in icing conditions defined by Part 25 appendix C. Additionally, the Safety Board learned that ATR has been evaluating a new technology stall warning/protection system that could detect upper

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[41] The stall warning/protection system logic uses information from the two AOA vanes (left and right) and sideslip sensors and applies a conversion factor to determine the airplane’s AOA for system applications.

wing surface airflow turbulence associated with airflow separation.[42] Another new technology stall warning/protection system measures the change in sound (amplitude and frequency) of the airflow over the upper surface of an airfoil; during wind tunnel tests at the National Aeronautics and Space Administration's (NASA) Lewis Research Center, this system demonstrated reliability in the detection of airflow separation.

The Safety Board's review of the accident airplane's maintenance records regarding the stall protection system revealed that during the 60 days before the accident, the following two discrepancies were reported and resolved:

- On December 11, 1996, a flightcrew noted that the right stall warning test did not clear after the test was complete. Maintenance personnel reset the right stall warning system, and the subsequent operational check was satisfactory.
- On December 17, 1996, a flightcrew reported that the right stall warning did not test properly. Maintenance personnel corrected the discrepancy by centering the left and right AOA vanes.

1.6.3.2 Autopilot System Information

The airplane was equipped with an APS-65 three-axis dual flight control autopilot system, manufactured by the Collins General Aviation Division of Rockwell International, in accordance with FAR Part 25.1329, which states that the autopilot must be designed so that pilots are able to "quickly and positively" disengage it to prevent it from interfering with their control of the airplane. FAR Part 25.1329 further states that "within the range of adjustment available to the human pilot, it cannot produce hazardous loads on the airplane, or create hazardous deviations in the flightpath, under any condition of flight appropriate to its use, either during normal operation or in the event of a malfunction, assuming that corrective action begins within a reasonable period of time[43]….Protection against adverse interaction of integrated components, resulting from a malfunction, is also required."

According to Comair's EMB-120 study guide, the autopilot computer is a flight guidance computer with servo control circuit cards for roll, pitch, yaw, and elevator trim. The autopilot computers are designed to incorporate information from many sources (its internal

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[42] This system measured the pressure of the airflow above the upper wing surface with a probe located at about 70 percent wing chord, inboard of the ailerons. The system has been tested in wind tunnels and on numerous airplanes, including ATR-72/42s, a Cessna 421, a NASA Sabreliner, and a Fokker 100.

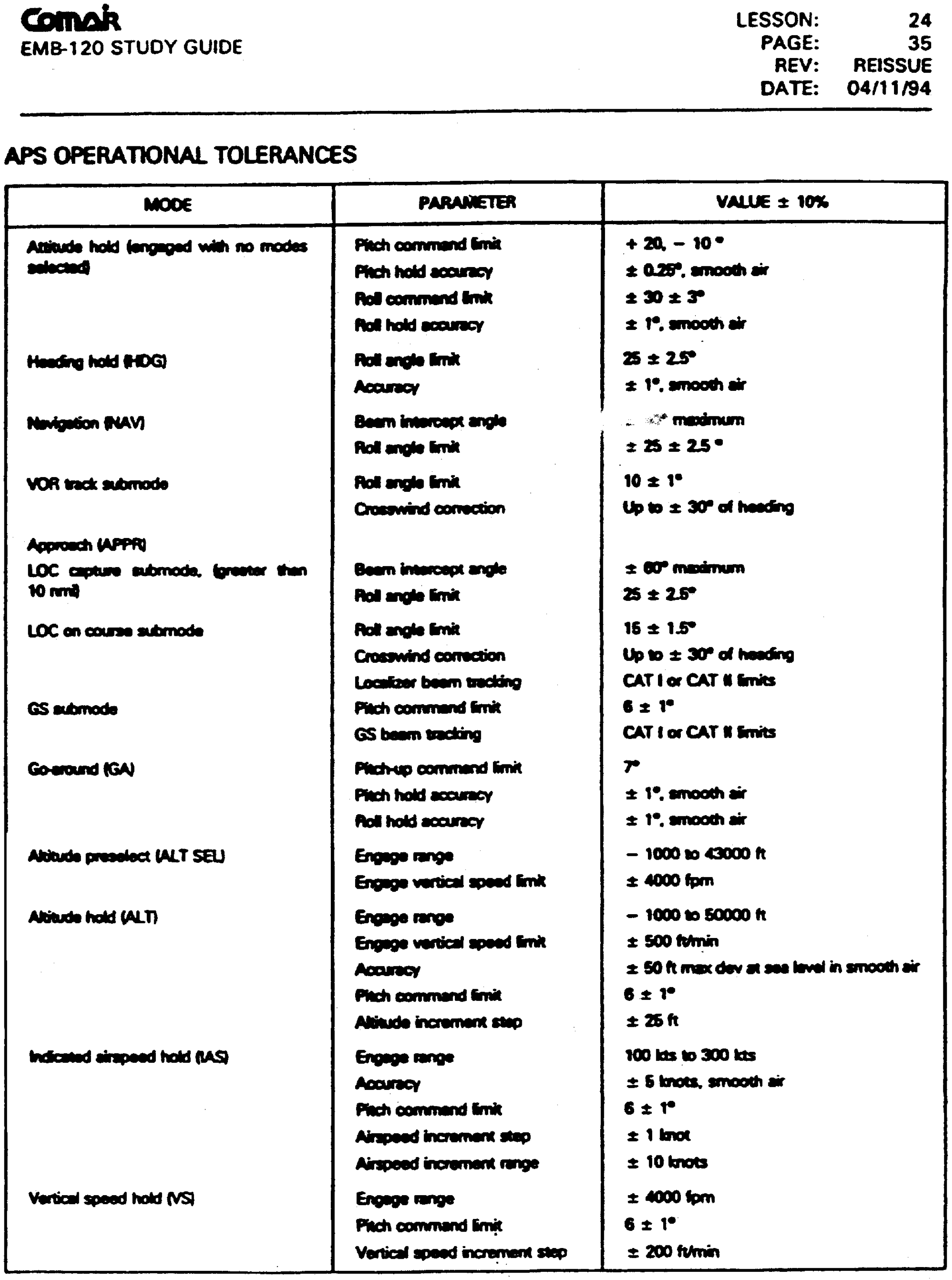
[43] AC 25.1329-1A, "Automatic Pilot Systems Approval," (published by the FAA on July 8, 1968,) sets forth an acceptable means by which compliance with Part 25.1329 may be demonstrated by autopilot manufacturers. According to AC 25.1329-1A, "[a] three-second delay between airplane response to an automatic pilot malfunction and pilot corrective action has been considered an acceptable value on past type certification programs for transport category aircraft….The first indication a pilot has of a malfunction of the autopilot is from a deviation of the airplane from the intended flight path, abnormal control movements, or a reliable failure warning system. Present operating procedures require that at least one pilot monitor the behavior of the airplane and associated autopilot performance at all times. The three-second delay applied in normal climb, cruise, and descent, and the one-second delay applied during low approaches [and maneuvering flight] are, therefore, reasonable delay times, provided that pilot recognition of the malfunction is the basis of these time delays."

cards, the flight control panel, autopilot panel, attitude and heading reference system [AHRS], air data sensors, compass system, and radio navigation system) to provide lateral and vertical steering commands to drive the autopilot servos. The AHRS calculates the airplane's pitch and roll attitude for the computer and provides the computer with turn rate, roll rate, lateral acceleration, and vertical acceleration for proper autopilot computation. Comair training personnel stated that the autopilot computer then compares the autopilot's commanded inputs with the sensed flight conditions and responds by providing additional commands to the autopilot servos to correct/adjust for any differences. For example, if the autopilot commanded a roll angle and calculated that the roll rate was greater than that which would attain the commanded roll angle, the autopilot aileron servos would apply pressure to counter the bank, to prevent the autopilot command limits from being exceeded. (Figure 3 is a list of the autopilot's operational tolerances/command limits.)

The autopilot's vertical operating modes include pitch, altitude, indicated airspeed, and vertical speed hold modes, altitude preselect, and descent and climb rate modes. According to the EMB-120 study guide, in the altitude hold mode, the autopilot maintains the airplane at the selected altitude by changing the pitch attitude of the airplane. The pilot must maintain sufficient power settings to ensure a safe airspeed when the autopilot is engaged because the autopilot installed on the EMB-120 does not control engine power setting.

The autopilot's lateral operating modes include navigation, approach, backcourse, go-around, roll angle (bank and ½ bank options), and heading hold modes. To command a turn, the autopilot commands aileron deflections by applying torque to the aileron control cable system through the autopilot servo mount. (For additional information regarding the autopilot servo mount, see section 1.16.1.4.) According to the EMB-120 Operations Manual, the maximum autopilot-commanded bank angle in the heading mode is 25° +/- 2.5°. FDR information indicated that the autopilot was in the heading mode at the time of the accident. (According to a Comair EMB-120 ground school instructor, Comair's pilots are taught to use the heading knob/mode for primary directional control during flight.)

The autopilot control panel consists of an annunciator panel, a turn control, a vertical trim switch, yaw channel engage, autopilot engage, soft ride mode select, and ½ bank buttons (see figure 4). Operation of the turn control cancels any previously selected lateral modes (except the approach mode). The ½ bank button is a "momentary-action push-on/push-off button. Pushing it selects the [½ bank] angle mode, which limits the maximum command roll angle to [½] of the normal maximum autopilot bank angle command value in the heading mode (12.5°)." The ½ bank angle mode applies only 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 the standard bank angles. The pilot must subsequently reengage the ½ bank button if ½ bank angle mode is desired.



Comair
EMB-120 STUDY GUIDE

LESSON: 24
PAGE: 35
REV: REISSUE
DATE: 04/11/94

APS OPERATIONAL TOLERANCES

MODE	PARAMETER	VALUE ± 10%
Attitude hold (engaged with no modes selected)	Pitch command limit	+ 20, − 10 °
	Pitch hold accuracy	± 0.25°, smooth air
	Roll command limit	± 30 ± 3°
	Roll hold accuracy	± 1°, smooth air
Heading hold (HDG)	Roll angle limit	25 ± 2.5°
	Accuracy	± 1°, smooth air
Navigation (NAV)	Beam intercept angle	[illegible]° maximum
	Roll angle limit	± 25 ± 2.5 °
VOR track submode	Roll angle limit	10 ± 1°
	Crosswind correction	Up to ± 30° of heading
Approach (APPR)		
LOC capture submode, (greater than 10 nmi)	Beam intercept angle	± 60° maximum
	Roll angle limit	25 ± 2.5°
LOC on course submode	Roll angle limit	15 ± 1.5°
	Crosswind correction	Up to ± 30° of heading
	Localizer beam tracking	CAT I or CAT II limits
GS submode	Pitch command limit	6 ± 1°
	GS beam tracking	CAT I or CAT II limits
Go-around (GA)	Pitch-up command limit	7°
	Pitch hold accuracy	± 1°, smooth air
	Roll hold accuracy	± 1°, smooth air
Altitude preselect (ALT SEL)	Engage range	− 1000 to 43000 ft
	Engage vertical speed limit	± 4000 fpm
Altitude hold (ALT)	Engage range	− 1000 to 50000 ft
	Engage vertical speed limit	± 500 ft/min
	Accuracy	± 50 ft max dev at sea level in smooth air
	Pitch command limit	6 ± 1°
	Altitude increment step	± 25 ft
Indicated airspeed hold (IAS)	Engage range	100 kts to 300 kts
	Accuracy	± 5 knots, smooth air
	Pitch command limit	6 ± 1°
	Airspeed increment step	± 1 knot
	Airspeed increment range	± 10 knots
Vertical speed hold (VS)	Engage range	± 4000 fpm
	Pitch command limit	6 ± 1°
	Vertical speed increment step	± 200 ft/min

Figure 3.--Autopilot's operational tolerances/command limits.

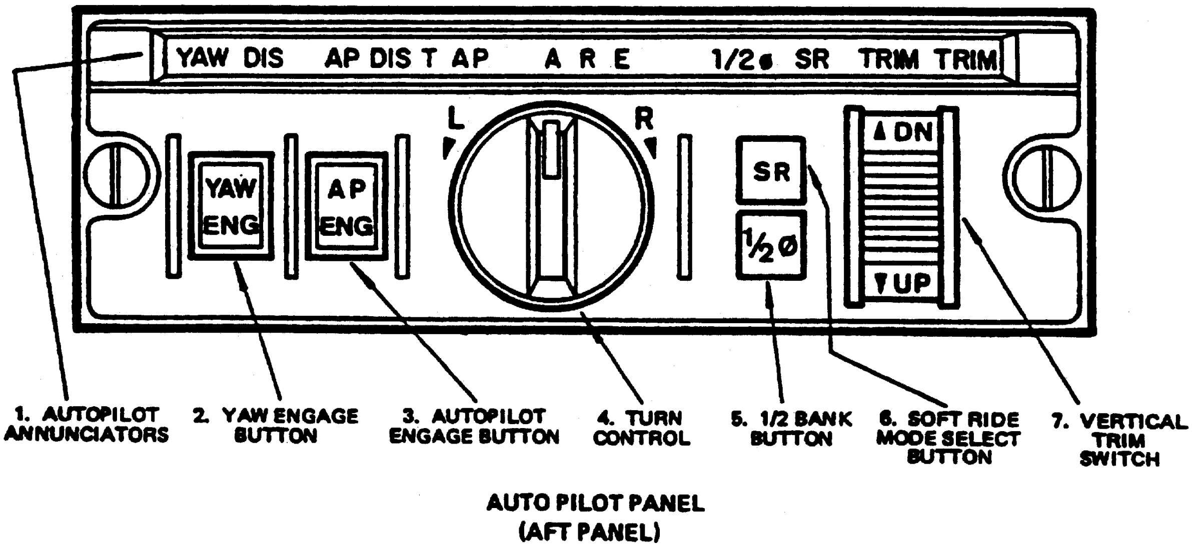


Figure 4.--Autopilot control panel.

According to the manufacturer, several conditions will cause the autopilot to disengage automatically, including the following:[44]

- Roll attitudes in excess of 45^o and
- Activation of the stick shaker system

According to Embraer, a stick shaker activation will cause the autopilot to unclutch the autopilot servos, annunciate an amber DIS (for disengage) light on the autopilot control panel in the cockpit, and activate a single "ding, ding, ding, autopilot" aural alert. If the airplane exceeds the 45^o roll angle limit, the system will unclutch the autopilot servos, activate a repeated "ding, ding, ding, autopilot" aural alert, and illuminate red autopilot fail/disengage lights on the autopilot and flight control panels and the master warning panel. The autopilot is designed to disengage automatically under these conditions to prevent the sensors from providing potentially erroneous information to the autopilot computers. (Although the system's sensors are very accurate and provide valid information to the autopilot while the airplane is operating within a normal operating range, sensor accuracy is reduced at more extreme operating conditions.)

When the autopilot automatically disengages because of bank angle exceedence or stick shaker activation, it remains disengaged unless a flightcrew member reengages the autopilot system. According to Comair's EMB-120 study guide, the autopilot "may be engaged in any reasonable attitude," including bank angles that exceed the normal command limits of the autopilot. The study guide states that if the autopilot is engaged when the airplane is "beyond 30-degree bank, or 15-degree pitch up or 10-degree pitch down" the autopilot will engage and input commands to reduce the bank or pitch to the appropriate autopilot limit. There is no cockpit warning generated when the airplane's roll angle exceeds the maximum angle that the autopilot can command, until the roll angle exceeds 45^o and the autopilot disengages.

Comair's maintenance records indicated that the autopilot servo slip clutch test (recommended at 12,000 hour intervals by the manufacturer) was accomplished on N265CA on September 14, 1996, at an airplane total time of 11,916 flight hours, and the aileron servo breakaway torque values observed were within the specified limits (175 +0/-6 inch-pounds [in-lbs]). Comair's maintenance records revealed one autopilot system discrepancy within the 60 days preceding the accident; on December 7, 1996, a flightcrew reported "flight director on both sides is intermittent and auto-pilot is inop[erative]." Maintenance personnel cleared the discrepancy by performing a full functional check of the system (in accordance with Embraer's maintenance manual procedure No. 22-10-00). Further, no anomalies were noted when the accident airplane's autopilot system was examined during the most recent E1 inspection (on December 27, 1996).

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[44] According to Comair's EMB-120 study guide, other conditions that will cause the autopilot to disengage automatically include any major degradation, interruption or failure of the alternating current or direct current electrical power input, detection of a failure in the autopilot computer, loss of valid information from the AHRS, and pitch attitudes in excess of 30^o. The autopilot can be manually disengaged by pushing the AP/TRIM/PUSHER DISC switch on either pilots' control yoke, pushing the AP ENG switch on the autopilot control panel, operating the TRIM switch on either pilots' control yoke, and/or pulling either autopilot AC or DC circuit breaker.

1.6.3.3 Ground Proximity Warning System

According to Comair's pilot training manual, the ground proximity warning system (GPWS) Mark VI installed in the EMB-120 comprises a ground proximity warning computer that receives input from a number of aircraft systems, including the air data computers, radar altimeter, glideslope receiver, and flap/landing gear position sensors. Comair's pilot training manual states that the GPWS "provides call-outs which serve to enhance pilot situational awareness….During normal flight operations, the GPWS remains essentially silent. Alerts and warnings are given ONLY when the aircraft is within a computed dangerous position with respect to the terrain." The GPWS (which is manufactured by AlliedSignal Commercial Avionics Systems) provides six different modes of cockpit alerts and warnings, five of which correspond to specifically identified controlled flight-into-terrain (CFIT) scenarios (excessive sink rate, excessive closure rate with terrain, descent after takeoff, terrain clearance, and descent below glideslope). The pilot training manual states that the sixth mode of cockpit alert and warning "provides warnings against excessive bank angles. At the surface, a bank angle of 15 degrees will produce the aural message **BANK ANGLE** once every 3 seconds. As [the airplane's altitude above ground level] increases, the alert is shifted to progressively steeper angles of bank up to 50 degrees at approximately [190] feet AGL. The alert…occurs at 50 degrees of bank at any higher altitude. Reducing the bank angle cancels the alert." (Figure 5 shows the bank angle alert envelope.)

AlliedSignal personnel stated that they originally designed the GPWS Mark VI bank angle alert and warning with a similar bank angle alert envelope (increasing with altitude above the ground), except that when the airplane was operating above 190 feet radar altitude, a bank angle alert was generated if the airplane exceeded a 40^o bank angle. According to AlliedSignal personnel, they revised the bank angle envelope up to its current 50^o bank angle threshold to obtain FAA approval for the design. AlliedSignal personnel indicated that FAA personnel required the modification to the current 50^o bank angle warning threshold because they believed the 40^o bank angle alert activation would result in too many "nuisance" warnings during pilot training maneuvers. The FAA's Director of Aircraft Certification Service indicated that the FAA was concerned that too many nuisance warnings could cause more accidents. The accident airplane's CVR recorded the sound of the GPWS "bank angle" aural warning after the airplane exceeded 50^o of left bank—after the autopilot had automatically disengaged at 45^o of left bank.

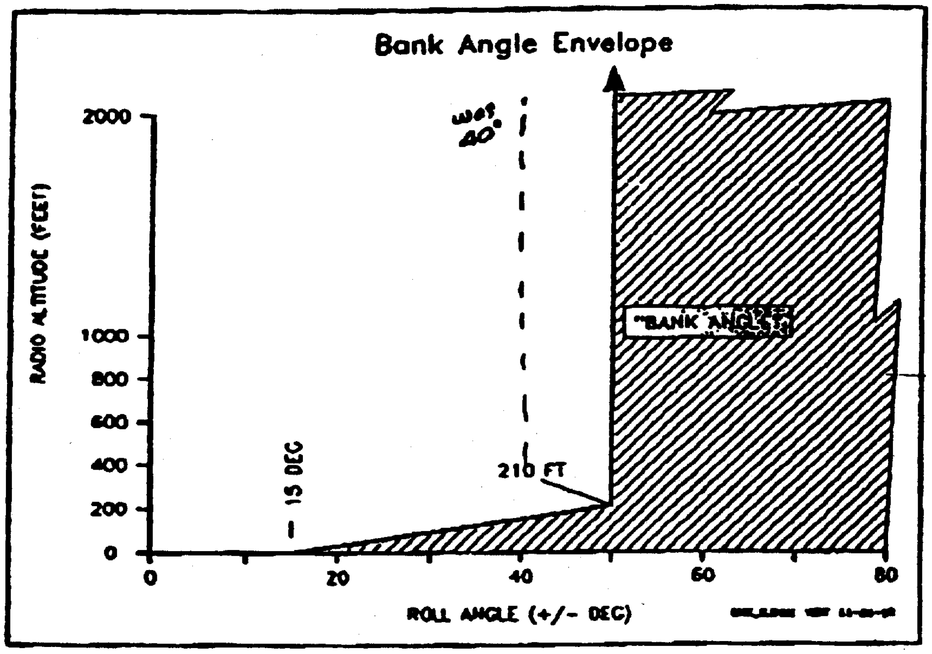
According to AlliedSignal personnel, it would be relatively simple to modify the existing GPWS Mark VI installation so that the bank angle threshold warning would activate at a reduced threshold (for example, 30^o or 35^o of bank) when the autopilot is activated and at 50^o when the autopilot is not in use. This would provide pilots with a bank angle-related warning when the autopilot exceeded its command limits (before it automatically disengaged) and still avoid "nuisance" warnings during training maneuvers when the autopilot is not engaged.

6.6.2 Excessive Bank Angle Callout

The "BANK ANGLE" callout warns against excessively high bank angles. This alert might be triggered by spatial disorientation, instrument failure, or by excessive maneuvering close to the ground to compensate for an approach offset condition, at night or in marginal visibility weather.

When the alert envelope of Figure 6.6.2-1 is penetrated, the message "BANK ANGLE" is repeated every three seconds.

Figure 6.6.2-1: Excessive Bank Angle Alert Envelope



This callout is optional, and requires the availability of a 400Hz synchro Roll Attitude signal in the aircraft per section 7.2.5.

Figure 5.--Bank angle alert envelope.

1.6.3.4 Ice Protection System Information

The EMB-120 ice protection system consists of the following:

- Electrical anti-icing protection for the windshields, pitot/static tubes, static ports, and AOA, side slip, and total air temperature (TAT) sensors.
- Electrical deicing protection for the propeller blades. According to the Airplane Operations Manual (AOM), this feature is intended "to permit unrestricted operation into known icing conditions."
- Pneumatic deicing boot protection for the leading edges of the wings, horizontal stabilizers, vertical stabilizer, engine inlet, and bypass duct.

(The locations of ice-protected components are shown in figure 6.)

According to B.F. Goodrich personnel, the deicing systems installed on the EMB-120 were designed to remove ice that formed on the protected aircraft surface. The wing, horizontal stabilizer, and vertical stabilizer leading edges, and the engine inlet and bypass ducts are deiced by pneumatically inflating the rubber deicing boots. Engine bleed air provides pneumatic pressure for deicing boot operation, and ejector flow control valves cause the deicing boots to inflate[45] and deflate.[46] Deicing boots are designed to crack accumulated ice when they inflate, with the intent that the ice is then removed by the airstream. The deicing boots are bonded to recessed areas of the leading edge surfaces to maintain airfoil shape when they are deflated.[47]

The EMB-120 deicing boot chordwise coverage on the wings varies, depending on the location along the span of the wing; for example, near the root of the wing, the deicing boot extends aft about 4 percent of the wing chord on the upper surface and about 8½ percent of the wing chord on the lower surface. Farther outboard on the wing, at a cross-section location near the aileron's midspan, the deicing boots extend aft about 7½ percent of the wing chord on the upper surface and about 10½ percent of the wing chord on the lower surface. According to Embraer engineers, because of the ice-shedding effects of deicing boot expansion and airflow, the actual area protected by the deicing boots extends slightly beyond the physical deicing boot area.

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[45] When the valves are energized by the timer, pressurized air is allowed to enter the deicing boot tubes to inflate them.

[46] When the valves are deenergized by the timer, the air is routed through a venturi, which causes a vacuum in the deicing boot tubes to deflate the deicing boots.

[47] According to section 30-10-01 of the EMB-120 maintenance manual (pages 401 through 416), after a deicing boot has been installed on the recessed area of the leading edge and trimmed to fit, maintenance personnel should apply a "heavy brush coat of the A-56B conductive edge sealer to the [area where the leading edge deicing boot surface meets the wing skin, at the aft edge of the wing leading edge recessed area]." The conductive edge sealer provides a path for static electricity to move from the leading edge deicing boot to the wing skin during flight. (Conductive edge sealer is discussed further in sections 1.12.2 and 2.4.1.)

LESSON: 21
PAGE: 2
REV: REISSUE
DATE: 04/11/94

Comair
EMB-120 STUDY GUIDE

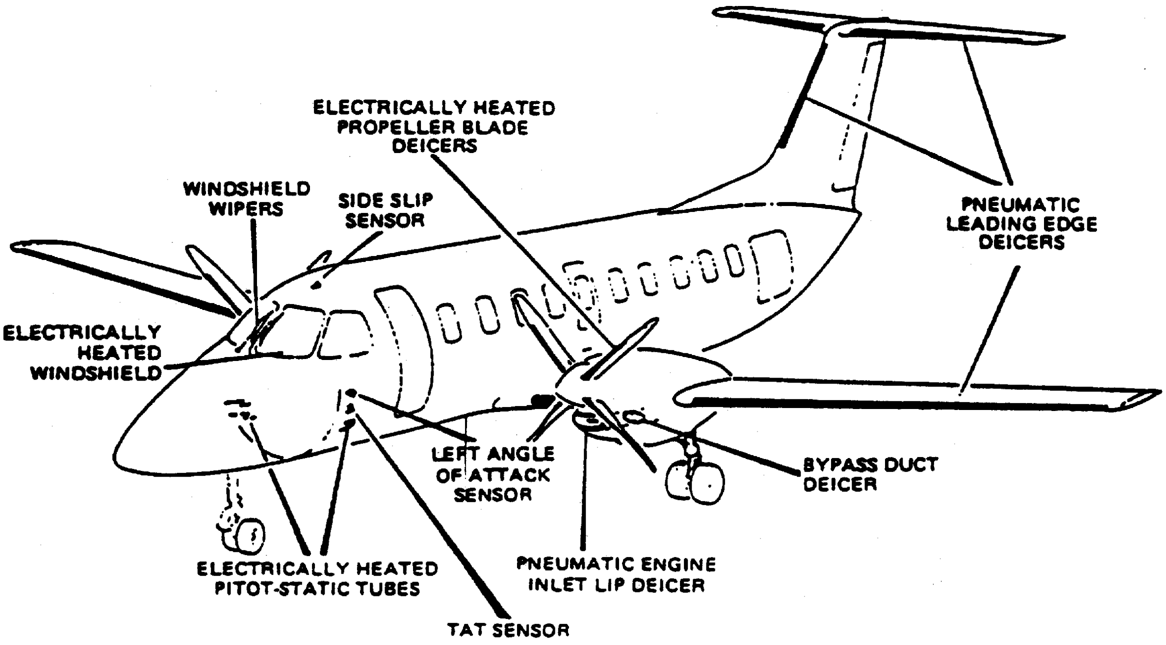

Figure 6.--Ice-protected components of the airplane.

The wing deice boots are divided into three segments (outboard, middle, and inboard), the horizontal stabilizer boots are divided into two segments (inboard and outboard), and the vertical stabilizer boots are a single segment. The tubes in each deicing boot segment are oriented spanwise along the leading edges. The leading edge deicing system is controlled by two toggle switches located on the ice/rain protection panel: the timer select switch and the cycle switch. The cycle switch has two positions: heavy and light. During a heavy cycle, each deicer is inflated for 6 seconds and deflated for 54 seconds; during a light cycle, each deicer is inflated for 6 seconds and deflated for 174 seconds. When activated, the inflation sequence of the deice boots is performed symmetrically, beginning with the outboard wing segments, then middle wing segments, inboard wing segments and inboard horizontal stabilizer segments, and finally outboard stabilizer segments and the vertical stabilizer deicer.

The engine inlet and bypass duct deicers are controlled by two (left engine and right engine) toggle switches located on the ice/rain protection panel. When the toggle switches are in the "on" position, the engine inlet and bypass duct deicers are simultaneously activated, and cycle once every 3 minutes.

Anti-icing systems are designed to prevent ice from forming on an aircraft surface. The EMB-120 anti-icing equipment consists of electrically heated elements attached to or imbedded in the windshield, AOA sensors (left and right), sideslip sensor, pitot/static probes/ports (captain's, first officer's, and auxiliary), and TAT probes.

Also, the propellers are heated by electrical elements that are molded into each propeller blade leading edge, then connected to slip rings in the forward face of the propeller bulkhead. The propeller deice system is controlled by a three-position toggle switch (TIMER 1/OFF/TIMER 2) and a two-position toggle switch (COLD/NORM). The manufacturer recommends selecting COLD when propeller deice is needed while operating in temperatures less than -10° C. According to the cold weather operations guidance in Comair's FSM, "If the temperature is below +5° C, turn ON windshield and propeller heat prior to entering visible moisture."

1.6.3.4.1 Ice Protection System Maintenance History

The Safety Board's review of the accident airplane's maintenance records revealed 19 ice and rain protection system discrepancies/maintenance items reported by flightcrews and/or maintenance personnel between July 5, 1996, and January 2, 1997, (the most recent maintenance write-up/action before the accident). Following is a summary of the 19 reported ice and rain protection system discrepancies/maintenance items:

- Seven ice and rain protection system maintenance write-ups involved the propeller/engine inlet deice systems, two of which were reported by flightcrews after receiving a cockpit indication of a failure. One of these maintenance entries was for a routine propeller deicing system operational check, which was conducted during the December 27, 1996, E1 inspection.

- Seven ice and rain protection system maintenance write-ups involved the leading edge deicing boots. One of these write-ups was a flightcrew report of a leading edge deicing boot failure indication in the cockpit, which resulted in the replacement of the left wing outboard leading edge deicing boot on July 15, 1996. Five maintenance write-ups involved deicing boot patch anomalies that were noted by maintenance personnel, one of which resulted in the July 19, 1996, replacement of the left wing middle and outboard leading edge deicing boot segments for "preventative maintenance"—ICEX was applied to all boots during this maintenance visit. Finally, one maintenance write-up described a routine inspection conducted during the November 20, 1996, C1 inspection, which involved removal, inspection, and reinstallation of the right and left inboard leading edges.
- Four ice and rain protection system maintenance discrepancies involved deicing boot ejector valve and/or pressure regulator discrepancies, all reported by flightcrews after receiving cockpit indication of a failure. ICEX was applied to all leading edge deicing boots during the November 1, 1996, maintenance visit resulting from one of these reports. In addition, during maintenance action resulting from one of these discrepancies, the right outboard deicing boot segment was removed and replaced.
- One ice and rain protection system maintenance write-up noted that a maintenance item (task 30-12, routine cleaning of the deice pneumatic lines, due once per year) due on November 3, 1996, was delayed.[48]

According to the maintenance records, all of the reported discrepancies were satisfactorily addressed through maintenance personnel action, although the delayed task (30-12) had not yet been accomplished at the time of the accident.

1.6.3.4.2 Ice Protection Failure Warning System—Functional Test

During postaccident interviews, the first officer who flew the airplane from Asheville to CVG (the leg before the accident flight) stated that he inadvertently bumped the leading edge deicing boot timer switch on the ice/rain protection panel[49] with his head or shoulder when he stood up in the cockpit after the airplane was parked at the gate in CVG. A chime sounded and a light came on indicating abnormal deice system operation. According to the manufacturer, several system anomalies will result in the deice system failure warning, including the absence of sufficient air pressure. The deice system uses engine bleed air for pneumatic pressure, and the engines were not operating when the warning occurred. The first officer stated that the deice system failure warning appeared to be operating properly, and he returned the deicing boot timer switch to its middle, or OFF, position before he exited the cockpit.

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[48] An FAA-approved change to Comair's maintenance inspection procedure allowed the task to be delayed.

[49] The ice/rain protection panel is located on the right side (first officer's side) of the overhead panel, just below the circuit breakers panel.

1.7 Meteorological Information

The Safety Board collected and examined weather-related information from numerous sources, including the FAA, National Weather Service (NWS), Comair, Embraer, witnesses, and pilots who were operating near the accident site about the time of the accident. The Safety Board also reviewed WSR-88D Doppler weather radar data from three sites (White Lake, Michigan; Wilmington, Ohio; and Cleveland, Ohio) and multispectral digital data from the geostationary operational environmental satellite (GOES) 9. The Safety Board also sought additional expert assistance from scientists of several organizations, including the National Center for Atmospheric Research (NCAR), NASA, and the University of Illinois at Urbana/Champaign (UIUC).

1.7.1 Weather Synopsis

Examination of the NWS 1300 surface analysis chart revealed a low-pressure center in east-central Indiana, with a surface trough extending to the northeast of the low-pressure center. The NWS 1600 surface analysis chart showed the low-pressure area centered over northern Ohio, just southwest of the Detroit area, with a surface trough extending to the northeast. The low-pressure area was moving toward the northeast.

Surface weather observations indicated overcast skies throughout Ohio and southern Michigan, with snow reported to the north and west of the low-pressure area. Weather observations taken at airports in Detroit, Michigan (19 nm northeast of the accident site), Ann Arbor, Michigan (17 nm northwest of the accident site), and Toledo, Ohio (25 nm southwest of the accident site) reported light snow and mist around the time of the accident. (See section 1.7.2 for these and other surface weather observations.)

1.7.2 Weather Advisories and Observations

Several airmen meteorological information advisories (AIRMETs)[50] and significant meteorological information advisories (SIGMETs)[51] for icing and/or turbulence were issued on the afternoon of the accident. Of those AIRMETs and SIGMETs, four AIRMETs and one SIGMET were applicable to Comair flight 3272 and are described in section 1.7.3. There were numerous pilot reports (PIREPs) of icing conditions encountered in Ohio and southeastern Michigan on the afternoon of the accident, and many witnesses on the ground reported precipitation in the form of snow in the Detroit area. These PIREPs and witness statements are addressed in section 1.7.4.

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[50] According to the Weather Service Operations Manual, an AIRMET advises of weather, other than convective activity, that might be hazardous to single-engine and other light aircraft and pilots operating under visual flight rules (VFR). However, operators of large aircraft might also be concerned with these phenomena.

[51] According to the Weather Service Operations Manual, a SIGMET advises of weather, other than convective activity, potentially hazardous to all aircraft.

Additionally, the meteorologist at the Cleveland ARTCC Weather Service Unit issued an Urgent Center Weather Advisory (CWA),[52] valid for an area that included northern Ohio and eastern Michigan (including the location of the accident) between 1235 and 1435, which predicted occasional "moderate-severe rime/mixed/clear icing in cloud and in precipitation at or below 16,000 feet. Severe rime/mixed icing in cloud and in precipitation reported [in the] vicinity [of DTW] and 40 nm southwest of [Cleveland] at 12,000 to 14,000 feet." This CWA did not apply to Comair flight 3272 because it was only valid until 1435, which was about 16 minutes before the accident airplane pushed back from the gate at CVG. A meteorologist at the Indianapolis ARTCC Weather Service Unit also issued a CWA, valid for an area that included west-central through southwestern Ohio between 1545 and 1745, which predicted "Frequent occasional severe ice in clouds/precipitation 3,000 feet to 10,000 feet." This CWA did not apply to Comair flight 3272 because by the time it became valid (1545), the accident airplane was established in its descent to the Detroit area and was no longer operating in the area of CWA coverage (west-central through southwestern Ohio).

The DTW ATIS information broadcast during the 30 minutes before the accident stated, in part, the following:

> Detroit Metropolitan Airport Information Hotel. [1526 local] special [observation]. Wind [out of] 070° at 6 [knots], visibility one [mile], light snow. Six hundred [feet] scattered, 1,400 [feet] broken, 2,100 [feet] overcast [cloud layers]. Temperature, minus 3° C. Dew point, minus 4° C. Altimeter [setting] 29.21 [inches of mercury (Hg)]. ILS approach in use, runway 3 right.…Notices to airmen…braking action advisories in effect, local deice procedures in effect.
>
> Detroit Metropolitan Airport Information Alpha.[53] [1540 local] special. Wind [out of] 070° at 5 [knots], visibility one and one half [miles], light snow, mist. [Cloud] ceiling 600 [feet] broken, 1,100 [feet] broken, 2,100 [feet] overcast. Temperature, minus 3° C. Dew point, minus 4° C. Altimeter [setting] 29.19 [inches Hg]. ILS approach in use, runway 3 right….Notices to airmen…braking action advisories in effect, local deice procedure in effect.

According to the CVR, the pilots obtained ATIS information "hotel" at 1540; then, at 1546:57, ATC advised traffic on their frequency that "information alpha is current" and issued a summary of the information included in ATIS information alpha.

Surface weather observations from facilities around the accident site were as follows:

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[52] According to the Weather Service Operations Manual, a CWA is a regional "aviation weather warning for conditions meeting or approaching national in-flight advisory (AIRMET, SIGMET, or convective SIGMET) criteria."

[53] According to DTW ATC personnel, because the Detroit-area has many airports and a high density of air traffic, they assigned each of the major airports a portion of the standard ATIS designations to reduce pilot confusion. DTW uses ATIS designations alpha through hotel, instead of the standard alpha through zulu.

Monroe, Michigan (D92) [located 6 nm east-southeast of the accident site]: 1541…sky partially obscured; 700 feet scattered, 1,300 feet overcast; visibility 1¼ miles; temperature [-2° C]; dew point [-3° C]; winds 170° at 5 knots; altimeter setting 29.20 inches of Hg.

1601…700 feet scattered, 1,700 feet broken; 5,000 feet broken; visibility 3 ½ miles; temperature [-2° C]; dew point [-3° C]; winds 180° at 6 knots; altimeter setting 29.18 inches of Hg.

Detroit, Michigan (DTW) [located 19 nm north-northeast of the accident site]: 1541…[Special]…winds 060° at 6 knots; visibility 1 ½ miles; light snow, mist; ceiling 600 feet broken, 1,100 feet broken, 1,900 feet overcast; temperature -3° C; dew point -3° C; altimeter setting 29.19 inches of Hg; [trace] of precipitation from 1454.

1554…[Routine]…Winds 070° at 5 knots; visibility ¾ mile; light snow, mist; ceiling 600 feet broken, 1,200 feet broken, 1,700 feet overcast; temperature -2° C; dew point -3° C; altimeter setting 29.19 inches of Hg., ceiling 400 feet variable 900 feet; [trace] of precipitation from 1454.

1603…[Special]…Winds 080° at 3 knots; visibility 1 mile; light snow, mist; 600 feet scattered, 900 feet scattered, ceiling 1,400 feet overcast; temperature -2° C; dew point -3° C; altimeter setting 29.18 inches of Hg.; [trace] of precipitation from 1554.

Ann Arbor, Michigan (ARB) [located about 17 nm north-northwest of the accident site]: 1553…[Routine]…Winds 090° at 8 knots; visibility 4 miles; light snow; mist; few clouds at 600 feet, ceiling 2,000 feet overcast; altimeter setting 29.20 inches of Hg.

1621…[Special]…Winds 100° at 8 knots; visibility 2 ½ miles; light snow, mist; ceiling 1,600 feet broken, 2,100 feet overcast; altimeter setting 29.18 inches of Hg.

1.7.3 Weather Information Provided to the Flightcrew by Comair

The pilots of Comair flight 3272 received a complete preflight weather briefing with their flight release before they departed from Cincinnati. The flight release information was gathered through an automated system, which was developed to provide flight planning and weather information to flightcrews operating the EMB-120. According to Comair personnel, the company's EMB-120 flight schedule is downloaded into the WXAIR Dispatching System database[54] on a monthly basis. About 90 minutes before each scheduled departure, the release for that flight is queued into the system; about 60 minutes before departure, the release is

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[54] The WXAIR Dispatching System database is produced by Jeppesen, Inc.

generated[55] and becomes available for retrieval by the flightcrew. If the flight is scheduled to depart between 10 minutes before the hour and 5 minutes after the hour, the system will not generate the flight release until 5 minutes after the preceding hour, to ensure that the most current weather is incorporated into the flight release.

The Safety Board's review of the weather information in the flight release paperwork documentation for flight 3272 revealed that it included terminal forecasts, surface weather observations for the departure, en route, and destination airports, as well as pertinent weather advisories and PIREPs[56] for the region. The flight release paperwork also included several AIRMETs for icing and turbulence and a SIGMET, which were in effect at the time of the accident. The AIRMETs and SIGMET stated, in part, the following:

> AIRMET Zulu Update 2
> Occasional moderate rime/mixed icing in cloud and in precipitation below [FL 250]. Isolated severe ice possible below 15,000 feet over Ohio.
> AIRMET Zulu Update 3
> (issued 0945 and valid until 1600)…Occasional light to moderate rime icing in clouds below 18,000 feet. Freezing level at or near the surface.
> AIRMET Tango Update 3 (2 AIRMETs; BOS and CHI)
> (BOS, issued 0945 and valid until 1600)…Moderate turbulence below 12,000 feet due to moderate/strong southerly low level winds. Isolated severe turbulence possible [in] Eastern Ohio. Occasional moderate turbulence between 12,000 feet and [FL 330 in the] western half of [the] area….
> (CHI, issued 0945 and valid until 1600)…Occasional moderate turbulence between 15,000 feet and [FL 350] associated with strong jetstream and upper level trough….Occasional light to moderate turbulence below 15,000 feet.
> SIGMET Quebec 4
> (issued 1100 and valid until 1500)…Moderate, occasional severe turbulence between 13,000 feet and [FL 300] associated with strong jetstream and upper level trough.

1.7.4 Pilot Reports and Witness Descriptions of Weather Conditions

The Safety Board's review of PIREPs for the accident date revealed numerous PIREPs regarding icing conditions encountered over southern Michigan and Ohio the afternoon of the accident. One of three icing PIREPs that was issued between 1300 and 1400 was included in the flight release paperwork for flight 3272; the other two icing PIREPs issued between 1300 and 1400 were not pertinent to flight 3272's route of flight. The report indicated that at 1318 the

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[55] According to Jeppesen, Inc., the release is generated based on the following conditions/assumptions: the flight planned route is based on preferred routing, aircraft performance is based on tables derived from the AFM, and average weights for basic operating weight, payload, and cargo are used (winter and summer weights are used accordingly).

[56] Three PIREPs were included in the accident pilots' flight release paperwork—two regarded moderate turbulence and one was icing-related. (A PIREP for severe turbulence near Dayton, Ohio, at 1300 was not included.) The icing-related PIREPs will be discussed further in section 1.7.4.

pilot of a Falcon 20 over Windsor, Ontario (about 17 miles east of DTW), encountered light-to-moderate rime icing during the descent from 14,000 feet to 4,000 feet msl. The following icing-related PIREPs were reported in the Detroit area and were received by the FAA within about 30 minutes of the accident:

- At 1540, a Boeing 757 reported a trace of ice encountered between 3,500 feet and 4,500 feet msl about 15 nm northeast of Detroit.[57]
- At 1610, a Douglas DC-3 reported moderate mixed ice encountered at 5,000 feet msl, about 25 nm southwest of DTW.

To gather more information about the weather conditions that existed when the accident occurred, the Safety Board developed a weather/icing questionnaire, which was provided to a number of pilots who were operating in the Detroit area around the time of the accident. Of the 11 pilot responses received, 8 pilots reported encountering rime icing conditions, and 1 pilot reported rime/mixed icing conditions.[58] Six of the responding pilots reported that they encountered snow during the approach to Detroit; one pilot reported encountering sleet, and four pilots reported no precipitation. In response to a question about the intensity of icing,[59] one pilot reported trace-to-light, one pilot reported light, three pilots reported light to moderate, two pilots reported moderate, and one pilot (Northwest Airlines [NW] flight 272, a DC-9) reported moderate-to-severe icing. When asked to describe the rate of ice accumulation, one pilot reported ¼ inch of rime ice accumulated in 5 to 8 minutes (Cactus 50), one pilot reported ½ inch of ice accumulated in 15 to 20 minutes, one pilot reported ½ inch of ice accumulated during the descent from 11,000 feet msl (NW 243, a B-727), and two pilots reported ½ inch of ice accumulation per minute (NW flight 272, approaching DTW from the southwest, 2 minutes behind the accident airplane, and NW flight 9451, a DC-10 approaching DTW from the southeast).

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[57] According to FAA Order 7110.65, "Air Traffic Control," general PIREPs are to be included in the ATIS broadcast "as appropriate," and as "…pertinent to operations in the terminal area."

[58] Eight of the responding pilots who indicated that they encountered icing conditions had not submitted a PIREP for the conditions they observed on the day of the accident. In response to a survey question regarding PIREPs, two pilots stated that they did not submit PIREPs because the conditions they encountered were consistent with the forecast icing conditions; one of these pilots added that he did not perceive them to be a hazard. Another pilot, who stated that he encountered moderate-to-severe icing shortly after the accident, reported that he did not submit a PIREP because of accident-related congestion on the ATC frequency. 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.

[59] According to FAA Order 7110.10L, "Flight Services," icing intensity is defined as follows:

- A "trace" of ice is when "ice becomes perceptible. Rate of accumulation slightly greater than sublimation. It is not hazardous even though deicing/anti-icing equipment is not utilized unless encountered for an extended period of time (over 1 hour)."
- "Light" icing occurs when "the rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deicing/anti-icing equipment removes/prevents accumulation. It does not present a problem if deicing/anti-icing is used."
- "Moderate" icing occurs when the "rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or diversion is necessary."
- "Severe" icing occurs when the "rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate diversion is necessary."

Because a wide variety of conditions were reported by pilots operating in the Detroit area (see figure 7), the Safety Board tried to narrow the focus to those airplanes that were closest to the accident time and location. Radar data[60] and pilot statements indicated that the ground tracks of NW flight 208, NW flight 483, Cactus 50, and NW flight 272 passed near the accident site within minutes of the accident and reported the following icing conditions:

- NW flight 208—about 10 minutes ahead of Comair flight 3272 on the approach to runway 3R (landed at DTW at 1550), pilot reported light rime icing.
- NW flight 483—about 5 minutes ahead of Comair flight 3272 on the approach, pilots observed no icing.
- Cactus 50—about 1 minute ahead of Comair flight 3272 on the approach, pilots reported moderate rime icing.[61]
- NW flight 272—about 2 minutes behind Comair flight 3272 on the approach, pilots reported moderate-to-severe rime icing.

The pilot of NW flight 208 reported that he observed about ½ inch of rime ice accumulation on the icing probe as the airplane descended on the approach to DTW. The captain of NW flight 272 (who was flying along the same flightpath about 2 minutes behind the accident airplane and 10 minutes behind NW flight 208) stated that the icing conditions they encountered during the approach to Detroit were the "heaviest I've seen this season…[there was] some splash back [to side windows, which] does not happen too often on [a] DC-9, only heavy ice will do this." During subsequent interviews, the captain of NW flight 272 stated that the cloud tops were near 7,000 or 8,000 feet msl and that the airplane started to accumulate ice rapidly when the airplane leveled off at 4,000 feet msl. The captain further noted that a trace of icing was encountered at 5,000 feet.[62] The first officer of NW flight 272 also stated that the most rapid accumulation occurred "in the vicinity of 4,000 feet," and indicated that "this encounter was as bad as I have ever seen it." According to radar data, NW flight 272 reached its assigned altitude of 4,000 feet msl at 1558:00.

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[60] National Track Analysis Program (NTAP) radar data from Detroit ARTCC and Airport Surveillance Radar (ASR) data from Detroit ATCT were reviewed.

[61] In response to a survey question about the droplet size encountered, the captain of Cactus 50 stated, "small, I believe, clouds, possibly freezing drizzle or snow."

[62] A review of the ATC tape transcripts and radar data indicated that about 1½ minutes after the accident, NW flight 272 was descending through 5,000 feet on its way to its assigned altitude of 4,000 feet msl, when ATC advised the pilots of NW flight 272 "its gonna be quite a bit of a delay for you…turn right heading two five zero." When the pilots of NW flight 272 queried the controller about the length of the delay, the controller stated "I just lost an airplane, I believe." Between 1556:40 and 1557:47, ATC instructed the pilots of NW flight 272 to turn right to headings of 270° and 360°. At 1558:03, the controller issued the pilots of NW flight 272 a frequency change. When the pilot of NW flight 272 contacted ATC on the different frequency, the airplane was level at 4,000 feet msl; the pilots requested and received a higher assigned altitude because of the ice accumulation.

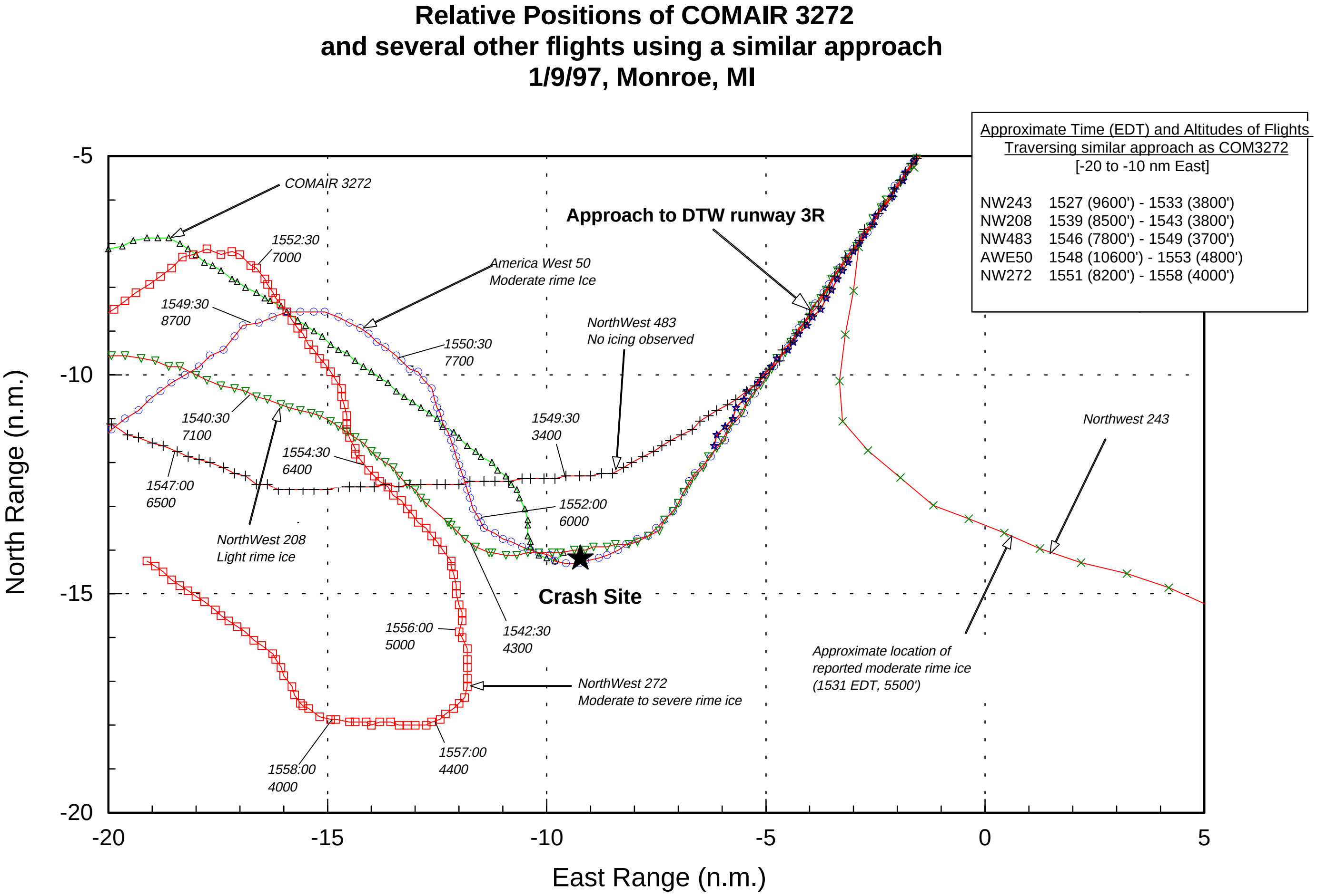
Relative Positions of COMAIR 3272
and several other flights using a similar approach
1/9/97, Monroe, MI

Figure 7.--Ground tracks of aircraft.

Also, NW 243, a B-727, and NW flight 9451, a DC-10, were operating south of DTW about the time of the accident (albeit arriving from the southeast). According to the pilot of NW 243, the flight encountered light-to- moderate rime icing, at a rate of accumulation of ½ inch in 15 to 20 minutes.[63] The pilot of NW 9451 reported encountering "very heavy ice above 10,000 feet [msl] on approach, both windshields iced over with max heat."

The Safety Board also interviewed witnesses and emergency response personnel about weather conditions in the Detroit area at the time of the accident. Most witnesses and local residents told investigators that low overcast skies and limited visibility, with snow, prevailed near the accident site at the time of the accident. However, one witness reported a "real heavy…wet snow…freezing rain." Another witness reported that the sun was "just trying to break through the clouds."

1.7.5 Information from Weather Radar and Satellite Data

WSR-88D Doppler weather radar data from NWS facilities at White Lake, Michigan; Wilmington, Ohio; and Cleveland, Ohio, indicated a widespread area of precipitation weather echoes located to the north of the Ohio/Michigan border. The data indicated that within the large area of weather echoes, the intensity of the echoes varied from about 0 dBZ to peak values of 30 dBZ,[64] with most of the higher intensity echoes positioned to the north of the accident site.

The Doppler weather radar data indicated weather echoes with a maximum intensity of 5 to 10 dBZ and tops of about 7,000 to 8,000 feet msl in the Cincinnati area when Comair flight 3272 departed. (An EMB-120 reported trace-to-light mixed icing at 8,000 feet msl over CVG at 1503.) Weather radar data indicated that about 65 nm north of CVG, weather echo tops reached 17,000 feet msl; when Comair flight 3272 passed this point, the airplane was at FL 210, and the pilots of Comair flight 3272 reported that the cloud tops were near 19,000 feet msl. Weather radar data indicated that during flight 3272's descent to the Detroit area, the airplane first encountered weather echoes at 11,000 feet msl. The weather radar data showed that the airplane was in and out of weather echoes (with a maximum intensity of 7.5 dBZ) as it descended between 11,000 feet msl and 8,200 feet msl. Based on that data, the accident airplane was continuously in weather radar echoes with intensities of 5 dBZ or greater between 8,200 feet msl and 4,100 feet msl; the maximum weather echo intensities (10.5 dBZ) encountered by the accident airplane were observed between 4,100 feet msl and 3,900 feet msl.

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[63] At 1531, the pilots of NW flight 243 reported encountering moderate rime ice to the DTW final approach controller; at the time, the airplane was about 14 nm south of DTW at 5,500 feet msl. This information was not incorporated into a formal PIREP and, although this pilot report was received by ATC almost 15 minutes before the accident, it was not communicated to other pilots operating in the DTW area.

[64] The unit dBZ is a measure of weather echo intensity in decibels corrected for range. The higher the LWC, the higher the value of dBZ.

The Safety Board combined the NTAP radar data for airplanes that were flying DTW arrival routes similar to that of Comair flight 3272[65] with the plotted weather echo intensity radar data. Examination of the combined radar information revealed that the airplanes were operating in an area of weak weather echoes along the southeastern edge of the larger region of weather echoes. In addition, weather radar echo intensities as a function of altitude were plotted for the ground tracks of Comair flight 3272, Cactus 50, NW flight 272, and NW flight 483. Review of the plotted data between 7,000 and 4,000 feet msl showed that the weather radar echo intensity values that Comair flight 3272 encountered fell within an area of possible moderate-or-greater icing from about 6,000 feet to 4,000 feet msl. Figure 8 shows the combined flightpath and weather radar echo information.

Because icing research[66] has shown that GOES 9 multispectral imager data can be used to sense possible aircraft icing regions, the Safety Board reviewed GOES 9 data (visible and shortwave and longwave infrared images) from 1500, 1530, and 1600 on January 9, 1997. Examination of the GOES 9 visible images indicated an extensive lower cloud cover over Ohio and southeastern Michigan that was moving to the northeast. A small area of higher clouds was visible moving from west central Ohio to the northeast. The GOES 9 infrared images indicated that cloud tops near the accident site were between 9,000 and 11,000 feet msl. According to the icing research, the brightness and radiative temperature values observed in the images indicated possible icing conditions along Comair flight 3272's flightpath.

The LWC in the area of the accident was not directly observed; however, estimates of the LWC ranged from less than 0.01 gram per cubic meter to about 1.0 gram per cubic meter, depending on the method used and/or the assumptions made for the estimate. Based on the observed weather echo intensities and the estimated LWCs, calculations indicated that droplet sizes of up to 400 microns were possible, indicating that SLD icing conditions might have existed in the accident area.

1.7.6 Information from the National Center for Atmospheric Research Mesoscale Meteorological Study

The Safety Board requested assistance from the research meteorologists at NCAR to help determine whether Comair flight 3272 encountered icing conditions during its descent in the Detroit area and to explain the varying icing reports received from pilots operating in the area about the time of the accident. NCAR research meteorologists reviewed the accident data and conducted an in-depth ("mesoscale") study of the weather at the time of the accident. They concluded that the evidence for the existence of icing conditions along the Comair flight 3272 flight track was strong and that there were some indications suggesting that freezing drizzle-size droplets (40 to 400 microns) might have also existed, especially near the cloud base; the research

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[65] Radar data for Comair flight 3272, NW flight 272, Cactus 50, NW flight 483, and NW flight 208 was overlaid on the weather intensity radar information.

[66] "Remote Sensing of Aircraft Icing Regions Using Multispectral Imager Data," Gary P. Ellrod and James P. Nelson; 15th Conference on Weather Analysis and Forecasting. 1996.

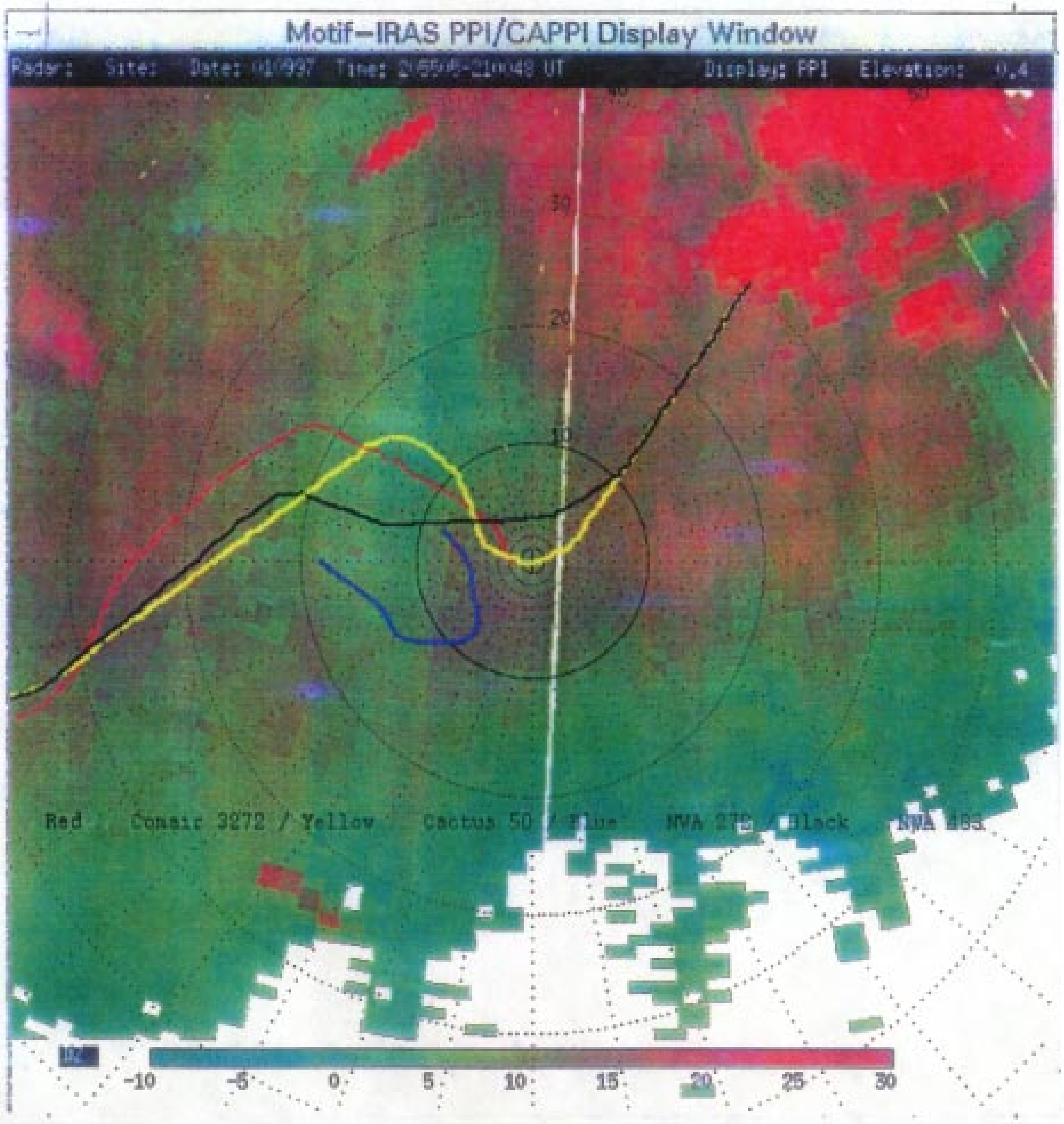

Figure 8.--Flightpath and weather radar echo information.

meteorologists further concluded that it was unlikely that freezing rain-size droplets (greater than 400 microns) were present.

The NCAR research meteorologists reported that their review of the data indicated that the average LWCs in the clouds near the accident site varied from 0.025 to 0.4 grams per cubic meter when averaged over a 2,000 meter cloud depth. However, they stated "[i]t is important to note that higher and lower values of LWC and corresponding lower/higher droplet sizes are likely to have existed within a portion of the cloud depth, since the liquid water is unlikely to have been evenly distributed throughout the depth of the cloud." According to one NCAR research meteorologist, within the range of conditions present at the time of the accident, a typical cloud structure would have higher LWCs and smaller droplets present near the cloud tops and lower LWCs and larger droplets present near the cloud base. Specifically, he stated that the accident airplane might have encountered "LWC values on the higher end of the range (0.5-0.8) around the 7,000 foot level, with mostly smaller droplets (non-SLD, more like 10-30 microns). This matches well with lower [weather radar] reflectivity values up high. **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."

According to the NCAR report, the variations in flightcrew icing reports may be explained by close examination of the airspeeds, flightpaths, altitudes, timing, and exposure times of the five airplanes. A copy of the NCAR report is included in appendix D. Additional information regarding general icing conditions (and the effects thereof) is included in section 1.18.

1.8 Aids to Navigation

There were no known malfunctions with the aids to navigation involved in this accident.

1.9 Communications

There were no known difficulties with internal or external communications.

1.10 Airport Information

The accident occurred while the airplane was being vectored for an instrument approach to runway 3R at DTW, in Detroit, Michigan. There were no known difficulties with the airport.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The CVR was a Fairchild model A100A, SN 61146. Although the CVR case exhibited impact and postaccident fire/smoke damage, the recording medium (magnetic tape) remained intact. The CVR recording consisted of four channels of audio information: the cockpit area microphone (CAM), the captain's position, the first officer's position, and the intercom/public address (PA) system. The recording was of excellent quality,[67] enhanced by the use of the intracockpit intercom system. A transcript was prepared of the entire 31 minute, 4 second recording.

1.11.2 Flight Data Recorder

The solid state FDR was a 98-parameter Loral Fairchild model F1000, SN 997, recorder, which used solid-state flash memory technology (nonvolatile memory) as the recording medium. Like the CVR case, the FDR case exhibited impact and postaccident fire/smoke damage; however, the recording medium remained intact. A list of the parameters recorded by the FDR is included in appendix C. The FDR did not record—nor was it required to record—leading edge deicing boot operation. Figure 9 is a copy of excerpts from the FDR data plot, with excerpts from the CVR transcript overlaid. The following is a summary description of the FDR information recovered from the final 45 seconds of the accident flight:

- At 1553:56, as the airplane neared its assigned altitude of 4,000 feet msl at an airspeed of 169 knots, its pitch attitude began to increase (from about 1.6° nose down to about 3° nose up). The airplane was established on a heading of 180°, with engine power set near flight idle (engine torque values of about 15 percent and 12 percent for the left and right engines, respectively). From this time until the end of the recording, the FDR recorded vertical acceleration loads that were higher and choppier than the vertical acceleration values recorded earlier in the flight during periods of relatively level flight (between 1553:49 and 1554:10, the airplane averaged about 1.05 G,[68] instead of 1 G).

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[67] The Safety Board uses the following categories to classify the levels of CVR recording quality: excellent, good, fair, poor, and unusable. Under the recently revised definitions of these categories, an "excellent" recording is one in which virtually all of the crew conversations can be accurately and easily understood. The transcript that was developed may indicate only one or two words that were unintelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.

[68] A G is a unit of acceleration equivalent to the acceleration caused by the Earth's gravity, used to measure the force on a body undergoing acceleration and expressed as multiples of the body's weight.

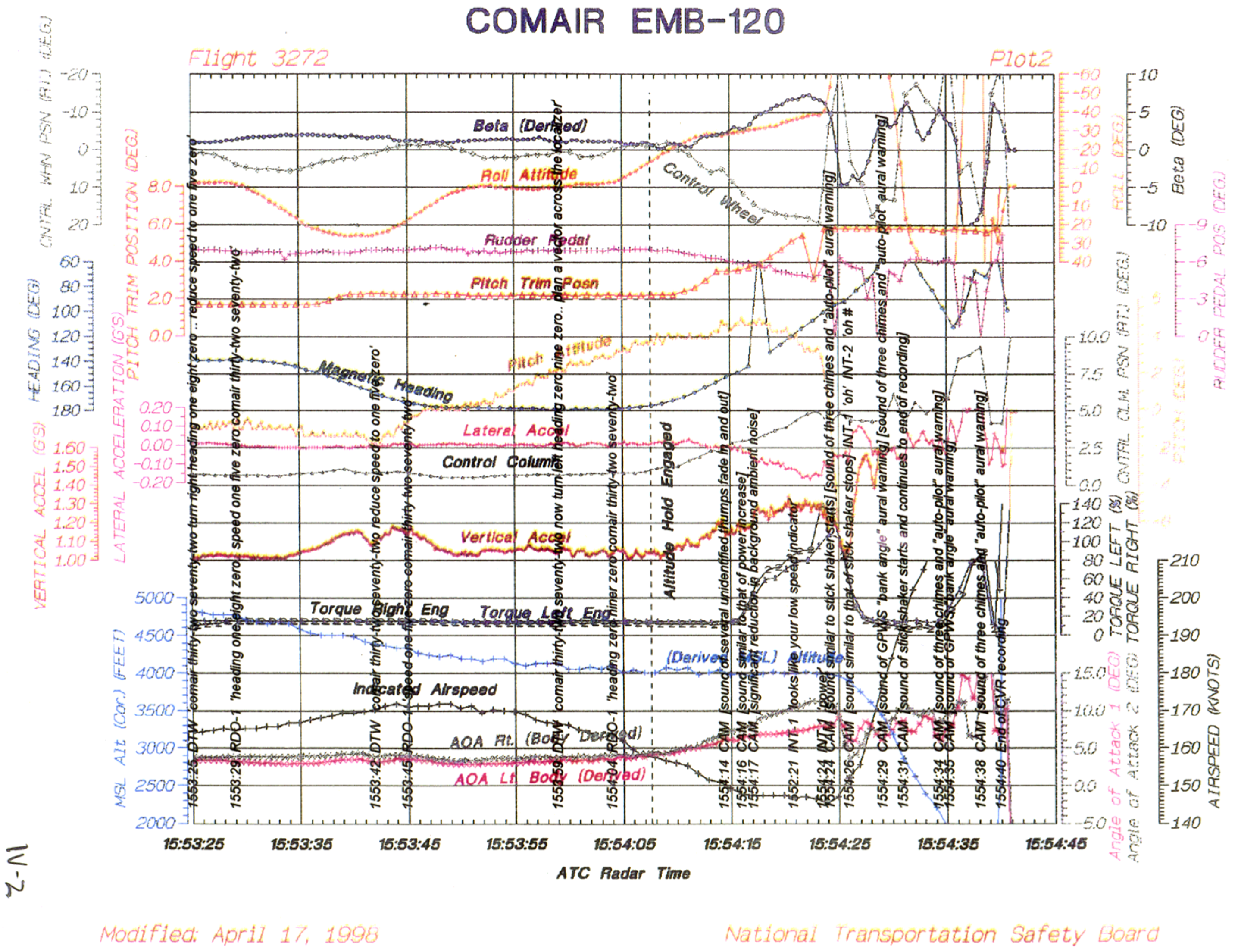

Figure 9.--Excerpts from FDR data plot and CVR transcript.

- At 1554:04, the airplane’s airspeed had decreased to 164 knots, the pitch attitude was about 3^o nose up, with engine power remaining near flight idle, and the airplane entered a left bank. At 1554:05, the airplane was level at 4,000 feet msl, at an airspeed of 162 knots, when the heading data indicated the start of a left turn. At 1554:08, (at an airspeed of 157.6 knots), the autopilot mode changed from “Altitude Pre Select—Arm” to “Altitude—Hold” mode.[69]

- During the next 2 seconds (1554:09 and 1554:10), as the airplane’s airspeed decreased through 155 knots, the values for CWP and roll attitude began to move in opposite directions (the CWP moved toward the right, changing from 2.04 left wing down [LWD] to 0.14 LWD, while the roll attitude increased to the left from 18.22^o LWD to 22.01^o LWD). Simultaneously, the pitch trim and control column position (CCP) values moved in the nose-up direction. At 1554:10, the vertical acceleration values began to increase further as the airplane’s left bank increased beyond about 20^o of bank; the vertical acceleration values averaged about 1.3 G from 1554:20 until the autopilot disengaged. At 1554:12, the left and right AOA vanes began to diverge, and the lateral acceleration values began to increase to the left from about zero.

- At 1554:13, the airplane’s airspeed was 151.5 knots, and the roll angle values stopped at 27^o LWD (the autopilot roll command limit in the heading mode) for about 2 seconds. During that 2 seconds, the CW position values fluctuated between 5.1^o and 6.3^o right wing down (RWD). At 1554:15, the roll angle increased beyond 28^o LWD, as the airspeed decreased to 149 knots, and the heading values decreased past 153^o.

- At 1554:16, engine torque began to increase (from flight idle) as the airspeed decreased to 148 knots; evidence of an engine torque split (with the right engine torque values exceeding the left engine torque values) began at this time and continued until 1554:25, when engine torque values on both engines began to decrease toward flight idle.

- At 1554:18, the pitch attitude reached its peak nose-up value (about 5^o) and began to decrease; however, the CCP and pitch trim position data continued to move in a nose-up direction (a trend started 9 seconds earlier).

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[69] According to the Embraer/Comair airplane operating manual (AOM) the “altitude preselect—arm” phase of the altitude select mode will automatically transition to the “altitude preselect—capture” phase when the numerical difference between the airplane altitude and the preselected altitude is approximately 1/3 of the numerical vertical speed value. (The FDR does not record an “altitude preselect—capture” parameter.) The transition from the “altitude preselect—capture” phase to the “altitude preselect—track” phase (or the “altitude—hold” mode in FDR nomenclature) normally takes about 30 seconds; when the selected altitude is attained, the system automatically engages the “altitude—hold” mode.

- At 1554:23, the roll angle had increased to 38° LWD, while the CWP and rudder inputs continued to move in a RWD direction. At this time, the engine torque values increased suddenly and reached their peak—108 percent (left engine) and 138 percent (right engine).[70] The airplane's airspeed was 147 knots. Also at this time, the pitch trim position reached its maximum recorded value (resulting in a CCP of about 5° nose up) and remained there for the remainder of the flight.

- At 1554:23.27, the CWP values reached 19.5° RWD, and the "autopilot fail mode" discrete (normally in the "not fail" mode) transitioned to the "fail" mode.[71] The airspeed decreased to 146 knots, pitch attitude decreased to 3.3° nose up, and the roll angle increased to 38.04° LWD.

- At 1554:24.2, the status of the "autopilot disconnect"[72] indicated "normal," and 0.03 seconds later, the status of the "master warning" parameter indicated that a "warning" was issued.[73] At 1554:24.27, the CWP parameter changed from 19.5° RWD to 6.3° LWD, ending a 14 second trend of RWD values.

- At 1554:23.8, the roll attitude began to change rapidly—within ½ second, the roll changed from 40° LWD to 51° LWD. The left roll continued, reaching 146° LWD within 2 seconds. Also at 1554:23.8, the pitch attitude began to decrease from 3° nose up—within 5 seconds the pitch had decreased to 50° nose down.

- The next time "autopilot disconnect" parameter's status was sampled (at 1554:25.12) the status had changed to "disconnected."

- By 1554:25.6, the CWP was moving to the right, opposing the sudden left roll of the airplane. During the next 15 seconds or so (until the FDR recording ended at 1554:41), the CWP varied between about 20° right input and 30° left input, and the airplane continued to descend with oscillations in roll attitude that generally followed (but lagged behind) the CWP movements. Also during the last 15 seconds of the flight, the FDR recorded oscillations in pitch attitude between 20° and 80° nose-down pitch values. During this time, the FDR recorded CCP values that remained fairly steady at 4½° to 5° until about 5 to 6 seconds before the FDR recording ended, when the CCP increased to about

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[70] The peak engine torque values were present for less than 1 second. Over the next 4 seconds (until 1554:26.5), the engine parameters indicated a power reduction on both engines to values near flight idle.

[71] The FDR records information in numerous autopilot-related parameters, including the following: autopilot engage (engaged/not engaged), autopilot disconnect (disconnected/engaged), autopilot fail mode (fail/not fail), and master warning (warning/normal). All referenced autopilot-related parameters are sampled at approximate 1-second intervals.

[72] The FDR parameter uses the term "disconnect" to describe the autopilot's "disengage" action.

[73] According to Embraer's autopilot information, an autopilot failure will generate an AUTOPILOT FAIL light on the master warning panel.

> 9.2 degrees nose up. (FDR data indicated that the airplane was descending through about 1,700 feet msl 5 to 6 seconds before the recording ended.)

The FDR data indicated that the landing gear and wing flaps remained in the retracted position throughout the upset event/accident sequence.

1.11.2.1 FDR Anomalies and History

The Safety Board has been concerned about the absence of FDR data critical to accident investigations for many years and has made a number of recommendations intended to (in part) increase the number of parameters recorded and improve FDR recording accuracy quality. Despite these recommendations, FDR anomalies continue to appear in FDR data from accident/incident airplanes. Examination of the accident airplane's FDR data revealed that the following parameters displayed anomalous, spurious, or out of calibration values at various times during the recording:

Parameters[74]	**Remarks**
Elevator CCP (left)	Noisy, not consistent with roll and heading values
CWP (left)	Noisy, not consistent with roll and heading values
Pitch trim position	Random spurious data points
Propeller imbalance (left)	Not active
Static air temperature	Noisy
Heading	Random spurious data points
Rudder pedal position[75]	Random periods of noisy data; values exhibit a bias of 7° to 8° (left), as established during simulation.

The Safety Board has observed similar anomalous values for flight control parameters on seven of eight previous Embraer EMB-120 accident/incident investigations and on one more recent EMB-120 incident.[76] As a result of the anomalous values noted during the

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[74] Because the elevator CCP (right) and CWP (right) parameters recorded valid values, it is unlikely that the FDR anomalies adversely affected the information contained in the summary description of the FDR data in section 1.11.2. Further, the accident airplane's CWP and CCP FDR data from the seconds immediately before and after the upset were validated during the simulation process. (See section 1.16.1 and its subsections and appendix E for descriptions of the simulations.)

[75] In the seconds before and during the upset, the rudder pedal position parameter was steady and clear, although the 7° to 8° bias existed.

[76] See: National Transportation Safety Board. 1996. *Atlantic Southeast Airlines, Inc., Flight 529, Embraer EMB-120RT, N256AS, Carrollton, Georgia, August 21, 1995.* Aircraft Accident Report NTSB/AAR-96/06. Washington, DC; National Transportation Safety Board. 1992. *Atlantic Southeast Airlines, Inc., Flight 2311, Embraer EMB-120, N270AS, Brunswick, Georgia, April 5, 1991.* Aircraft Accident Report NTSB/AAR-92/03. Washington, DC; National Transportation Safety Board. 1992. *Britt Airways, Inc., dba Continental Express Flight 2574, EMB-120RT, N33701, Eagle Lake, Texas, September 11, 1991.* Aircraft Accident Report NTSB/AAR-

investigation of these previous accidents/incidents, on June 27, 1996, the Safety Board issued Safety Recommendations A-96-33 and -34, which recommended the following to the FAA:

> [C]onduct a design review of the Embraer EMB-120 FDR system, with emphasis on potentiometer failures, and mandate design, installation, and/or maintenance changes, as necessary, to ensure that reliable flight control data are available for accident/incident investigation. (A-96-33)
>
> [R]equire Embraer EMB-120 operators to perform a FDR readout or a potentiometer calibration test per section 31-31-00 of the EMB-120 Maintenance Manual every 6 months until FDR sensor design, installation, and/or maintenance improvements are incorporated. (A-96-34)

In its September 5, 1996, response letter, the FAA stated that Embraer had initiated a design review focusing on the FDR potentiometers and associated attaching hardware and that the FAA would determine a course of action when the design review was completed. In addition, in its response letter, the FAA stated that it would contact the manufacturer and coordinate the necessary maintenance instructions with an appropriate inspection interval. Pending final action, on October 15, 1996, the Safety Board classified Safety Recommendations A-96-33 and -34 “Open–Acceptable Response.”

On December 5, 1997, the Safety Board received another letter from the FAA, which stated that Embraer had issued Service Bulletin (SB) 120-31-0038, which provided corrective action to minimize the potential for a potentiometer calibration error and included information regarding the proper installation and inspection of the system. Embraer also revised its maintenance manual to implement a revised potentiometer test procedure to more readily identify noisy potentiometers. The FAA’s letter indicated that after it finished reviewing the EMB-120 service information that resulted from the SB with the CTA, the FAA planned to issue an AD to require corrective action. On May 5, 1998, the Safety Board classified Safety Recommendation A-96-33, “Open—Acceptable Response,” pending receipt and review of the AD.

The FAA’s December 5, 1997, letter further stated that the FAA issued Flight Standards Handbook Bulletin for Airworthiness (HBAW) 97-14 on September 16, 1997, which established new FDR inspection/potentiometer calibration requirements for operators of EMB-120 airplanes. The HBAW stated that principal avionics inspectors (PAIs) should:

> [R]equire their affected operators to perform an initial and subsequent recurring potentiometer calibration test every six (6) months….An initial inspection of the affected operator’s total fleet should be accomplished within sixty (60) days after notification of this inspection requirement. Subsequent

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92/04. Washington, DC; and National Transportation Safety Board. 1994. *Continental Express, Inc., Embraer EMB-120RT, N24706, Pine Bluff, Arkansas, April 29, 1993.* Aircraft Accident Report NTSB/AAR-94/02. Washington, DC. Also, see the following NTSB aircraft incident reports: FTW90IA169, DEN92IA074, and ATL96IA053. Section 1.18 and its subsections contain information regarding EMB-120 upset events.

> repetitive inspections must be accomplished every six months until the FDR sensor design, and installation has been enhanced to improve data reliability. The inspection interval, thereafter, may be adjusted as the reliability data allows.

As a result of the inspection requirements addressed in HBAW 97-14, on May 5, 1998, Safety Recommendation A-96-34 was classified "Closed—Acceptable Action." However, the Board's examination of the FDR data from an EMB-120 uncommanded roll incident that occurred on March 5, 1998,[77] revealed that the rudder pedal and control wheel position sensors recorded anomalous information. The incident airplane's maintenance records indicated that its FDR system had been inspected in December 1997, with no discrepancies noted. The inspection was conducted in compliance with HBAW 97-14 and involved a potentiometer calibration, as defined by the EMB-120 maintenance manual. The potentiometer calibration test was conducted with the airplane parked on the ground and required observation of the values generated by the control column, control wheel, and rudder pedals positioned in three distinct positions: neutral, full left, and full right for the rudder pedal and control wheel. No FDR readout (which would have revealed the recording history of the various parameters) was accomplished in conjunction with the potentiometer calibration/inspection, nor was such a readout required.

In its report regarding the August 7, 1997, accident involving a Fine Airlines, Inc., Douglas DC-8-61 at Miami, Florida,[78] the Safety Board again referenced FDR recording and inspection problems. The Board's analysis stated the following, in part:

> Although an FDR's primary function is to provide detailed flight information following an accident or incident, this detailed flight information is useful even in the absence of an accident or incident. The Safety Board notes that the…quick access capabilities of modern solid-state FDRs offer operators the opportunity to develop and implement a flight operations quality assurance (FOQA) program. Analysis of downloaded FOQA data enables operators to enhance crew and aircraft performance; develop tailored training and safety programs and increase operating efficiency. FOQA programs can also be used to refine air traffic control procedures and airport configurations and to improve aircraft designs….the potential safety and operational benefits…are significant.
>
> Because frequent FDR data downloads and data analysis are components of a viable FOQA program, the requirement for periodic readouts to validate the quality of the mandatory FDR parameters would likely be met if the operator corrected recording problems discovered in the readout. The need to download and analyze FDR [data] would also require operators to maintain sufficient FDR system documentation to meet the Safety Board's needs in the event of an accident or incident.

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[77] See section 1.18.3 for additional information regarding this uncommanded roll incident.

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

1.12 Wreckage and Impact Information

The airplane struck the ground in a nose-down attitude at a high rate of speed and came to rest, oriented on a southwesterly heading, in a field adjacent to a church campground. The accident site was approximately 19 miles southwest of the destination airport.

Fragmented airplane wreckage was found in and around three impact craters, with airplane debris located up to 340 feet from the largest (center) impact crater. The largest impact crater was about 15 feet 7 inches wide, 25 feet long, and 4 feet deep at its deepest point and contained most of the fuselage wreckage and human remains. The two smaller impact craters were located on both sides of the larger (main) impact crater and contained the right and left engines and their respective components. The right and left propeller assemblies were located in the southwest ends of their respective craters imbedded in dirt.

The cockpit was located at the south-southwest edge of the main crater aligned on a heading of about 245^{o}. The fuselage was fragmented by impact forces and further damaged by postimpact fire; various-sized portions of fuselage were scattered throughout the debris area. The vertical stabilizer, with a large portion of the horizontal stabilizer attached, was located between the center and the southern edge of the main crater on top of other remains and debris. The vertical and horizontal stabilizers exhibited fore-to-aft and down-and-aft crush damage, respectively. The top rudder and the top portion of the lower rudder remained attached to the vertical stabilizer, and the left elevator and the inboard portion of the right elevator remained attached to the horizontal stabilizer.

Both wings were separated from the main wreckage and fragmented; however, most of the wing debris was located near the three craters. The landing gear were found in the retracted position. Both main landing gear separated from their respective wing structures (although the right main landing gear was located beneath portions of the right wing) and exhibited fire damage. The nose landing gear was located beneath the airplane wreckage in the main crater. The inboard and outboard flap actuators on both wings and the left nacelle wing flap actuators were in the retracted position; the right nacelle wing flap actuator was not in the retracted position; however, Safety Board investigators noted soot markings indicating that when the documentation took place, the actuator was not in its preimpact position. The wing flap selector in the cockpit was found in the flaps 0^{o} position.

1.12.1 Engines and Propellers

On-scene examination of the engines revealed that although both engines were sooted on their exterior surfaces, there was no indication of in-flight fire, case rupture, uncontained failure, or other preimpact distress or damage to either engine.

Subsequent examination and disassembly revealed that both engines sustained damage that shattered and/or separated the front and rear inlet case housings, the reduction gear boxes, accessory gear boxes, and their respective components. The low pressure compressor (LPC) vane tips were rubbed, gouged, and bent in a direction opposite to normal engine rotation, and the LPC impeller shroud exhibited circumferential rub marks consistent with impeller vane tip contact. Examination of the remaining internal components of both engines revealed additional evidence of smearing, rubbing, and blade bending in a direction opposite to their normal operation; the damage was consistent with engine rotation at impact. There was no physical evidence of preimpact anomaly or mechanical malfunction of either engine.

Examination of both propeller assemblies and their respective propeller blades revealed extensive impact damage; however, there was no evidence of preexisting anomaly. The left propeller assembly, with all four propeller blades, was located in the small crater to the south side of the main crater. Three of the four propeller blades were intact (full-length); however, the fourth blade had a 28-inch-long, 6-inch-wide section of the blade tip missing (the missing section was discovered about 75 feet east of the main wreckage), and three of the four blades had separated from the propeller hub. The right propeller assembly and its propeller blades were located in the small crater to the north side of the main crater. All four propeller blades were intact lengthwise; however, the leading edges had separated. One of the right propeller blades had separated from the propeller hub.

Disassembly of the propeller assemblies and blades did not reveal evidence of preimpact damage or malfunction. All eight propeller blade spars were bent (at varying degrees) in a direction opposite to normal propeller rotation. Measurements taken during the disassembly indicated that the right and left propeller blade pitch angles at impact were consistent and averaged about 40°.[79]

1.12.2 Deicing/Anti-icing Equipment

Leading Edge Deice System

Investigators recovered the following leading edge deicing boot segments from the wreckage and examined them in an attempt to determine whether they were operating (or capable of normal operation) at the time of the accident: the middle and outboard segments from both wings, the right horizontal stabilizer segments, and the vertical stabilizer segment. (Investigators were not able to identify the leading edge deicing boot segments from the inboard wing sections and the left horizontal stabilizer.) The identified leading edge deicing boot segments exhibited varying amounts of impact and heat damage; however, in general, the right wing middle and outboard leading edge deicing boot segments were more fragmented and exhibited more indications of heat damage than the left wing leading edge deicing boots. Examination of the deicing boot segments revealed no evidence of preimpact damage or anomaly that would have precluded normal operation of these deicing boots.

Postaccident examination revealed that the leading edge deicing boot segments installed on the middle and outboard sections of the left wing and the vertical and horizontal stabilizers did not have the conductive edge sealer on the seam/gap where the aft edge of the

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[79] According to Hamilton Standard specifications, the 14RF-9 propeller blade angle operational range extends from -17.28° (reverse position) to 79.2° (full feather position).

deicing boot fits into the recessed area of the leading edge surface. The outboard segment of the right wing leading edge deicing boots appeared to have conductive edge sealer covering that seam/gap, while the middle segment of the right wing leading edge deicing boot did not have the conductive edge sealer.[80] Further examination of the left wing leading edge deicing boots revealed that filler compound and fiberglass material were visible at this seam/gap on the upper surface of the middle and outboard deicing boot segments. Safety Board investigators reported that there was no ridge or gap between the two materials and no roughness; they stated that the unpainted, unsealed area was as smooth to the touch as the painted wing skin surfaces or the deicing boot surfaces. Additionally, there was no evidence of delamination or erosion of the wing composite materials.[81]

Safety Board staff consulted NASA Lewis Research Center (NASA-Lewis) experts regarding the significance of the missing conductive edge sealer to this accident. The experts stated that (based partially on NASA's icing research tunnel [IRT] tests) there was little potential for the lack of conductive edge sealer to be a preferred ice accumulation location because of its location (on the upper wing surface at the aft edge of the leading edge deicing boot) and because the area was as smooth as surrounding deicing boot and painted wing surfaces. (For additional information regarding the significance of the missing conductive edge sealer, see section 2.4.1. The IRT tests are discussed in detail in section 1.16.2.1.)

The leading edge deicing timers were recovered from the wreckage, but crush damage precluded any functional tests of those components. According to the manufacturer, the deicing timers do not contain nonvolatile memory that would indicate if a timer was operating at the time of impact. The following additional leading edge deicing system components were identified in the wreckage: two horizontal stabilizer pressure switches, two wing pressure switches, the vertical tail switch, one pressure regulator, and one pressure relief valve. Examination of these components did not reveal whether the leading edge deicing system was operating at the time of the accident.

Propeller Deice System

The propeller deicing equipment was also recovered and examined in an attempt to determine its operational status at the time of the accident. The deicing elements on the four left-side propeller blades were torn and detached in places, leaving various-sized pieces of deicing boots, broken wires, and various connectors attached for examination. Damage precluded confirmation of continuity on the wiring and connectors of all but one propeller blade deicing element. A segment of the left propeller assembly bulkhead was missing, and the inner and outer slip rings were broken; however, the center slip ring was intact. Examination of the

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[80] On December 24, 1996, maintenance personnel noted several holes in the outboard leading edge deicing boot on the right wing; that deicing boot segment was removed and replaced, and the airplane was returned to service that day.

[81] During postaccident interviews, Comair maintenance personnel described the leading edge deicing boot installation procedure to investigators; their description matched the procedures outlined in the EMB-120 maintenance manual. Additionally, the Safety Board examined the deicing boot installations on several Comair EMB-120s; all the airplanes that were examined had the conductive edge sealer applied in accordance with the guidance contained in the maintenance manual.

slip ring surfaces revealed no evidence of arcing, pitting, or unusual wear. Damage precluded confirmation of continuity from the bulkhead leads to the propeller blades on two of the four propeller blades.

The deicing elements on the four right-side propeller blades were not attached to the blades—they remained attached to the leading edges, which had separated. However, the connectors were still attached to the four propeller blades; a continuity check of the leads confirmed continuity on both leads for three of the four blades. On the fourth propeller blade, one lead was found to have continuity, but continuity could not be checked on the other lead because the broken end of the wire could not be located in the deicing boot. The right propeller assembly bulkhead and the three slip rings were intact, although the bulkhead exhibited sooting and heat damage on the forward face. The three slip rings exhibited no evidence of arcing, pitting, or unusual wear. A continuity check of the bulkhead leads to the four propellers confirmed continuity on each lead.

1.13 Medical and Pathological Information

Toxicological samples were obtained from the captain and first officer and were sent to the FAA's Civil Aeromedical Institute (CAMI) for examination. Toxicological test results from the captain's muscle tissue were negative for drugs of abuse, prescription and over-the-counter medications. However, the toxicological report for the captain stated the following, in part, under the heading "volatiles:"

- 17.000 (mg/dL, mg/hg) [0.017 percent weight/volume] Ethanol detected in Blood
- NO Ethanol detected in Heart

NOTE: The ethanol found in this case is most likely from postmortem ethanol production.

The toxicological test results from the first officer's muscle tissue were negative for drugs of abuse, and prescription and over-the-counter medications. The toxicological report for the first officer stated the following, in part, under the heading "volatiles:"

- NO Ethanol detected in Kidney
- NO Ethanol detected in Muscle

No suitable (testable) blood samples were obtained from the first officer.

1.14 Fire

The postaccident fire consumed the portions of the airplane wreckage in which fuel was present and melted portions of the wreckage, particularly in and around the main crater. There was no indication that any fire existed before the airplane impacted the ground.

1.15 Survival Aspects

The accident was not survivable because the impact forces exceeded human tolerances and aircraft design strength; no occupiable space remained intact.

1.16 Tests and Research

1.16.1 EMB-120 Performance and Simulator Studies

Under the Safety Board's direction, in February 1997, Embraer performed several EMB-120 performance and simulator studies at its facilities in Sao Jose dos Campos, Brazil, to identify the following: the aerodynamic differences between the accident airplane's performance during the minutes before the autopilot disengaged (as recorded by the FDR) and the performance of Embraer's EMB-120 engineering simulator flying the accident airplane's control inputs and tailoring the aerodynamic database to match the recorded headings, altitudes, airspeeds, times, and rates of climb/descent/bank; the effects of the timing and asymmetrical nature of the power increase at the beginning of the upset event; and the aileron behavior/elevator efficiency before the autopilot disengaged and during the initial stages of the upset event. The EMB-120 simulator is a six degree of freedom simulation computer program[82] that uses Embraer's EMB-120 Aerodynamic Data Bank Version 3C as the source of aerodynamically clean (uncontaminated) aircraft flight dynamic data. The simulator studies were conducted in Embraer's EMB-120 engineering and flight training simulators.

Simulations were performed in an attempt to identify and quantify the adjustments required for the EMB-120 engineering simulator's performance (which was representative of the EMB-120 without ice contamination) to match the accident airplane's performance (according to FDR data) for the seconds before the autopilot disengaged (from 1553:53 to 1554:24.7).[83] In the first simulation, no aerodynamic modifications (representing aerodynamic degradation from assumed icing conditions) were introduced to the engineering data bank; thus, the simulator was free to respond to the accident airplane's FDR control inputs (aileron position = 18° right, elevator position = 11° nose up, rudder position = 4° right) as an uncontaminated airframe would. The resultant simulator data differed from the accident airplane's FDR data in that the simulation pitched up, climbed, and rolled to the right during the final seconds before the autopilot disengaged, whereas the accident airplane data indicated a pitch down, descent, and left bank. To assess the validity of the engineering data bank simulation results, investigators retrieved data from the accident airplane's FDR from a steady condition earlier in the accident flight (1549:55

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[82] Embraer's EMB-120 engineering simulator differs from flight training simulators in that it is a number processor—its input is data (in the form of files of numbers) and its output is data (in the form of numbers and/or graphs). The EMB-120 engineering simulator has no flight control, motion, or visual capacity.

[83] Although the FDR data continues until the FDR recording ended at 1554:40, the last 12 seconds of simulation data were not considered during these simulations. According to Embraer's engineers, the flight simulation is valid only up to the AOA at which the stick pusher is activated (12.5°); therefore, the simulation was only valid for about 4 seconds after the autopilot disengaged because "the angular rates become very high and some asymmetric flow separation could occur;" these highly dynamic maneuvers are not adequately represented in the aerodynamic data banks.

to 1550:45). Again, the simulation was performed with no aerodynamic modifications introduced; with the data from the earlier time period, the resultant simulator data closely matched the values recorded by the accident FDR at that time.

To more closely reproduce the FDR data, investigators modified some of the simulator data bank aerodynamic coefficients, based on "steady state" FDR values (roll angle, CWP, CCP, altitude, pitch angle, rudder pedal position, and vertical acceleration) and other calculated conditions (weight and CG) that were present about 1554:23, just before the autopilot disengaged and the upset event occurred. The following modifications were introduced to obtain a simulation that closely matched the FDR data: lift degradation, increase in drag, left rolling moment, change in pitch moment, and left yawing moment.

For comparison purposes, the lift degradation observed in the accident airplane's FDR data was compared to the lift decrement obtained during developmental wind tunnel tests with 60-minute-holding ice shapes on all protected surfaces of a model EMB-120 airplane.[84] Data obtained in the wind tunnel were extrapolated to obtain valid values for a full-scale EMB-120 airplane; the total lift degradation observed on the accident airplane was about 33 percent of the 45-minute-holding ice shape degradation. However, to obtain the left rolling moment observed in the accident airplane's performance, investigators had to assume a difference in lift degradation between the left and right wings. When the lift degradation was applied asymmetrically based on one set of calculations, the degradation on the left wing lift was about 45 percent, and the degradation on the right wing lift was about 22 percent (resulting in a total airplane degradation of 33 percent). (Details of the calculations are included in appendix E.) This asymmetrical lift degradation would result in a left roll rate of about 12^{o} per second without any aileron input.

During early postaccident simulations, Embraer engineers were not able to reproduce the FDR pitch angle and AOA data using the elevator values recorded by the FDR. (The simulations resulted in data indicating higher pitch angle and AOA values than indicated by the FDR.) Therefore, an assumed elevator deflection was gradually introduced into the simulation data to produce a simulation that matched the pitch angle and AOA recorded by the FDR in the seconds immediately before and after the autopilot disengaged. To match the FDR elevator position, it was necessary to introduce a loss of elevator and elevator trim tab efficiency (simulating aerodynamic degradation caused by ice contamination) in the EMB-120 aerodynamic data bank. The reductions in elevator and elevator trim tab efficiency were assumed to vary linearly with the body AOA. For example, the elevator and elevator trim tab were 100 percent efficient when the airplane's AOA was 3.3^{o} or less, but the elevator and elevator trim tab were only 63 percent efficient when the airplane's AOA was 10^{o} or greater. (See appendix E for data/figures.)

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[84] The EMB-120 degradation calculated by Embraer based on its wind tunnel tests was similar to the 3-inch ram's horn ice shapes commonly used to represent a "critical case" ice accretion scenario by the FAA during icing certification testing.

1.16.1.1 Determination of the Approximate Onset of the Drag Increase

During the simulations conducted in the engineering simulator, investigators observed that drag increments had to be added to the engineering simulator's aerodynamic data bank to match the FDR data as the airplane departed 7,000 feet msl; the drag increments needed to match the FDR data continued to increase as the airplane descended to 4,000 feet msl. Investigators further reviewed the data and performed additional simulations in an attempt to determine more precisely the point in the airplane's descent at which the drag first began to increase. Throughout much of its descent, the airplane was changing airspeed, engine torque, heading, rate of descent, etc.; under those dynamic conditions, it was difficult to compare the accident airplane's FDR data (airspeed, descent rate, engine power setting) to the aerodynamic data bank's predicted performance (based on a clean—uncontaminated—airframe). However, investigators identified six intervals of relatively stable flight conditions that occurred during the airplane's descent between 8,000 feet msl and 4,500 feet msl. Simulations were then conducted, using the performance information that was recorded by the accident FDR during these five intervals, and varying the number of drag counts[85] until the simulator's performance closely matched the FDR data.

The intervals of relatively stable flight conditions—and the drag counts needed to match FDR data—are described in the table below:

Time	Altitude (msl)	Airspeed (KIAS)	Descent rate (ft/min)	Drag Counts added
1548:02	8,000	190 KIAS	1,500	0
1549:55	7,000	variable	variable	80
1552:02	6,300	177 KIAS	750	90
1552:52	5,500	176 KIAS	1,000	120
1553:27	4,800	165 KIAS	1,350	210
1553:42	4,500	170 KIAS	1,500	230[86]

Figure 10 depicts Comair flight 3272's ground track during its descent, with drag count and CVR information overlaid.

According to Embraer personnel, during the initial EMB-120 icing certification, flight tests were conducted with 3-inch double (ram's) horn ice shapes on unprotected surfaces (representing ice accumulated during 45 minutes of holding in maximum continuous icing conditions with ice protection equipment activated). The resultant airplane drag was measured in flight, and a value of 80 drag counts was obtained for the flap and landing gear up configuration.

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[85] A drag count is a unit of drag that was introduced into the simulation to match existing FDR or other real-world data. For example, if the landing gear was extended during the simulation, the aerodynamic data bank drag value would need to be increased by 300 drag counts to approximate the effects that extending the landing gear would have on the performance of the airplane.

[86] FDR data indicated that during the last few minutes of the flight the airplane's AOA was increasing; a portion (but not all) of the increase in drag counts reflected in the later flight conditions described in the table can be attributed to that increasing AOA.

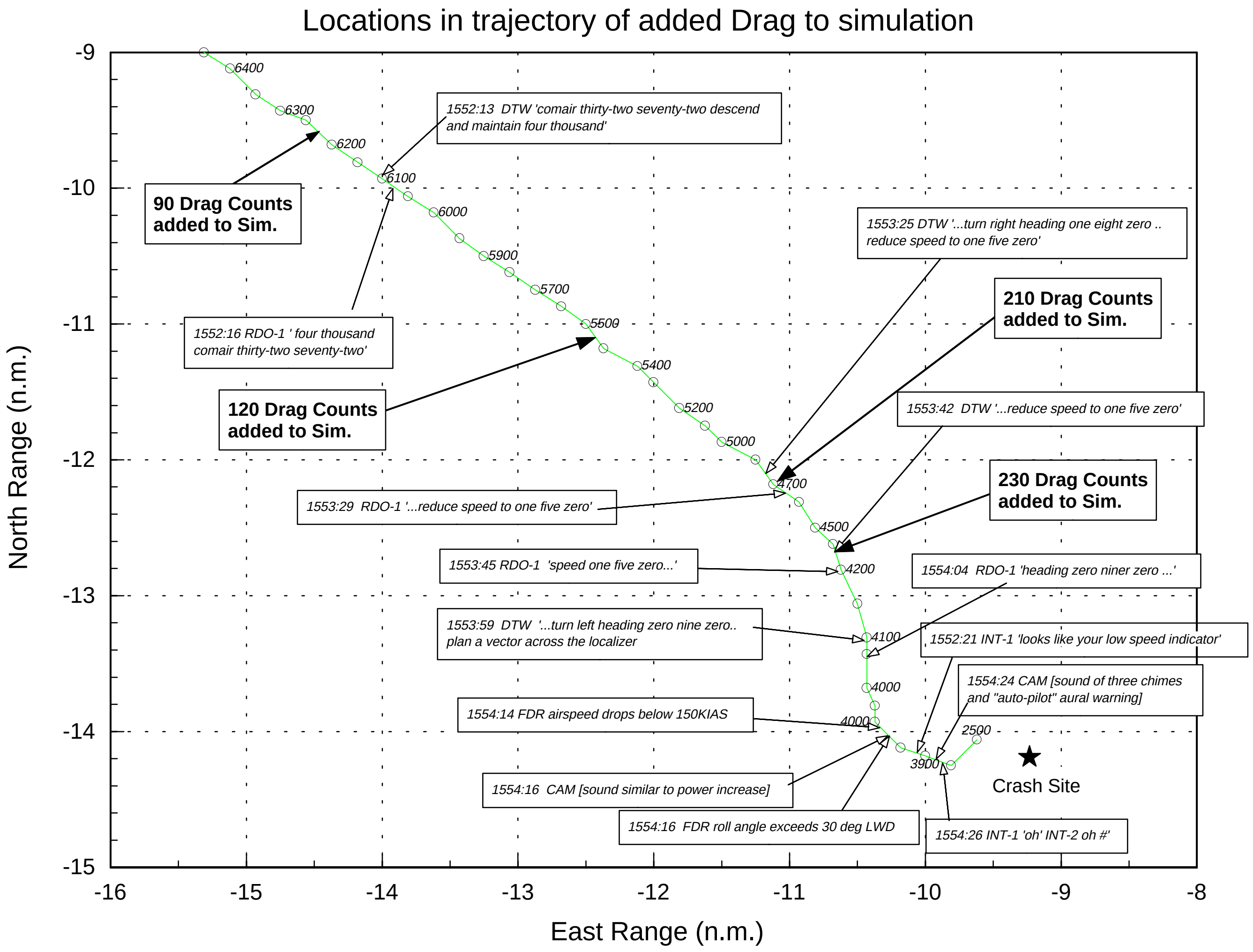

Figure 10.--Ground track of Comair flight 3272.

1.16.1.2 Effect of Power Increase on Upset (No Increase in Power, Symmetrical, and Asymmetrical Power Applications)

Because the accident airplane did not exhibit an increase in airspeed and/or pitch in response to the engine power increase that occurred at 1554:16 (about 9 seconds before the autopilot disengaged),[87] additional simulations were performed in Embraer's EMB-120 engineering simulator to better understand the airplane's response to the power application. The FDR data (see figure 9) from the accident airplane indicated that after the engine power increased at 1554:16, the airplane's AOA continued to increase, its left roll continued to steepen, and its airspeed continued to gradually decrease through 148 knots. The airplane's airspeed reached its lowest recorded value of 146 knots at 1554:23, as the engine torque continued to increase (left engine—85.2 percent, right engine—94.7 percent).[88] The FDR data, aerodynamic modifications, and degradations described in section 1.16.1.1 were introduced again for this simulation, with the exception of the engine torque parameters; in this case, the torque for both engines was maintained in the flight idle range throughout the simulation. The simulation resulted in a data plot that resembled the FDR data plot until 1554:16. At that point, the data (see appendix E) from the simulation (in which engine power remained at flight idle, instead of increasing as indicated by the FDR data) showed a steady decrease in airspeed (at a faster rate than the FDR data), a decrease in the AOA, and less tendency to roll to the left.

In January 1998, additional simulations were conducted in the EMB-120 training simulator at Embraer's facilities in an attempt to identify the effect of the asymmetrical power application on the left roll during the upset sequence. Unlike the engineering simulator, the EMB-120 training simulator was designed with flight and power controls similar to those in a real airplane—the power controls allowed for separate engine torque inputs, as they would in an airplane. These simulations were performed using all the modifications to the aerodynamic data that had been identified in previous simulations, including lift degradation, drag increase, nose-down pitching moment, yawing moment, rolling moment (induced by lift asymmetry), and loss of elevator/elevator tab efficiency. The simulator was flown by an Embraer test pilot with the autopilot engaged as it was during the accident flight; engine power was applied manually by the simulator pilot.

The simulations revealed that the timing and rate of power application affected the mode of autopilot disconnect in the following ways:

- When asymmetrical power application was initiated at an airspeed of 150 knots (power application and torque splits occurring at similar times and

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[87] Although the accident airplane's airspeed and pitch did not increase (or stabilize) as a result of this engine power application, the FDR data indicated that the airplane's deceleration was arrested at that time, and longitudinal acceleration increased from about .04 G to .23 G before the autopilot disengaged, indicating a positive effect from the power application.

[88] Although the FDR data showed that the engine torques for the right and left engines were split during the power application, Embraer's engineering simulator was not capable of accurately replicating the split torque condition. The split engine torque was subsequently simulated in Embraer's flight training simulator, which had throttles that could be manipulated to duplicate the split torque condition.

extents as those observed in the accident FDR data—see figure 9, FDR plot with CVR overlay, or appendix C), the autopilot disengaged when the roll angle exceeded 45°, and an upset occurred similar to the accident scenario.

- When a similar asymmetrical power application was initiated at an airspeed of 145 knots, the autopilot disengaged when the stick shaker activated as the airplane approached 45° of bank, and an upset occurred.
- When a similar asymmetrical power application was initiated at an airspeed of 155 knots (3 seconds earlier/5 knots faster than the accident scenario), the airplane's roll angle did not exceed 45°; the autopilot maintained the maximum autopilot command limit for the heading mode (27.5°), it did not disengage, and an upset did not occur. The lowest airspeed observed was 150 knots.
- When power was applied symmetrically, beginning at an airspeed of 150 knots, the airplane's roll angle never exceeded 45°; the autopilot maintained the maximum autopilot command limit for the heading mode (27.5°), it did not disengage, and an upset did not occur. The lowest airspeed observed was 146 knots.
- When power was applied symmetrically, beginning when the simulator's airspeed decreased to 145 knots, the autopilot disengaged when the stick shaker activated at a roll angle of 33°; the airplane's roll angle subsequently exceeded 45°, and an upset occurred.

To determine the effect of the aerodynamic degradation on the criticality of the torque split, additional simulations were performed without the modifications to the aerodynamic database that were used in the earlier simulations (i.e., lift degradation, increase in drag, etc.). In this case, when the asymmetrical power application and the resultant torque split were initiated at 150 knots, and occurred at times and rates similar to those observed in the accident FDR data, no upset occurred.

The simulator pilots also varied the recovery technique used[89] and reported the following results:

- When the aerodynamic modifications (lift degradation, drag increase, etc.) were removed immediately after the upset (as if by deicing equipment activation or cycling), the simulator pilots were able to regain/maintain control of the airplane without difficulty and with minimal altitude loss.

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[89] The Safety Board notes that Embraer's engineering and training simulators were not able to accurately reproduce the dynamic situation recorded by the accident airplane's FDR after the autopilot disconnected, and the aerodynamic coefficients used in the simulator may not be valid in these dynamic maneuvers; therefore, the recovery results described here have not been validated.

- When the aerodynamic modifications were not removed and recovery was attempted solely by reducing the bank angle, the simulator pilots were able to regain/maintain control of the airplane with minimal difficulty but with large (1,000 feet to 3,500 feet) altitude losses.

The investigation revealed several possible reasons for the engine torque split observed in the accident airplane's FDR data, including the following: uneven flightcrew throttle movement, improperly rigged engine controls, improper engine trim adjustment, or the ingestion of ice by the engine.

1.16.1.3 Additional Information Obtained During Simulator Studies—Visual Cues

Investigators who participated in the simulator flights reported that there were visual cues associated with the EMB-120 control wheel displacement that corresponded to the autopilot-commanded right aileron input, especially during the 3 to 4 seconds before the autopilot disconnected and an upset occurred. According to the investigators, as the autopilot applied force to move the control wheel and ailerons to the right to counter the left roll tendency, the left grip portion of the EMB-120 control wheel (which is shaped like a ram's horn) moved up; in some cases, the control wheel partially obstructed the pilots' view of the lower portion of the instrument panel.

1.16.1.4 Additional Autopilot Aileron Servo Mount/Servo Torque Information

During the flight training simulator sessions, the CWPs recorded by the accident FDR differed from those produced by the simulator's autopilot. To obtain EMB-120 simulator CWP values that matched the FDR data, investigators incorporated a slight amount of aileron servo torque slippage into the simulator's data bank, beginning at 1554:14 and incrementally increased the amount of slippage until the autopilot disengaged at 1554:24.725.

Although these adjustments resulted in a simulator data plot that matched the accident airplane's FDR data plot, they did not explain the accident airplane's performance. The autopilot installed on the accident airplane commands aileron deflections by applying torque to the control wheel/aileron system through the autopilot servo clutch. Embraer and Collins personnel reported that it is not possible for the autopilot servo clutch installed on the airplane to provide torque incrementally—it provides torque until it begins to slip and then it provides no torque. Comair's maintenance records indicated that during a maintenance inspection 4 months before the accident, the aileron servo mount breakaway torque was measured and found to be within the manufacturer's specified limits of 175 +0/-6 in-lbs; according to Embraer's records, the aileron servo mount was adjusted to this value by the manufacturer on June 24, 1991, during production.[90] To determine why the CWPs recorded by the accident airplane's FDR differed

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[90] According to Embraer and Collins representatives, although servo mount breakaway torque was set at 175 +0/-6 in-lbs, the autopilot system has an electronic torque limiting system that will limit electrical current delivered to the servo at a level equivalent to 150 in-lbs. Thus, the maximum torque value of 175 in-lbs is not reached operationally.

from those produced by the simulator, investigators conducted a series of ground tests on an Embraer EMB-120.

According to Embraer personnel, because the EMB-120 aileron was directly connected to the autopilot aileron servo, their engineering simulator's flight dynamic data bank reflected a direct relationship between torque at the servo and aileron hinge moment (i.e., 150 in-lbs of torque at the servo = 150 in-lbs commanded at the aileron) and did not account for aileron system loads. To determine whether the direct relationship in the engineering simulator's data was accurate on a real airplane, investigators applied weights to the trailing edge of the aileron to simulate the aerodynamic aileron hinge moment that Embraer calculated would result from 150 in-lbs of torque. After the weights were installed, the autopilot was engaged and a heading change was selected, and the resultant aileron rate commanded by the autopilot servo was documented. Weights were incrementally added until the autopilot's electronic aileron servo torque limit was reached. Investigators observed that the 150 in-lbs electronic torque limit was reached when the 110 pounds of simulated aerodynamic load (weight) was applied at the aileron.

The tests demonstrated that the aileron servo was capable of maintaining the maximum aileron rate of about 5.5° per second until it reached a calculated servo torque of about 110 in-lbs; at 110 in-lbs, the aileron servo stopped moving the aileron. Embraer personnel stated that when they set up the EMB-120 engineering simulator's flight dynamic data bank they had not accounted for resistance resulting from aerodynamic forces acting on the aileron in flight and friction in the aileron control cable system. They stated that because of resistance in the aileron control system downstream of the aileron servo clutch "the servo will reach its torque limit of 150 in-lbs when the aileron hinge moment is [30 to 40 in-lbs] less than the equivalent 150 in-lb value for a…friction free system as in the flight simulator." When the EMB-120 engineering simulator data was modified based on this information, and the accident scenario simulations were flown again; the resultant simulator data plots closely matched the accident airplane's FDR data plots.

1.16.1.5 Examination of the Airplane's Roll Behavior/Aileron Effectiveness/Roll Rate Information

These simulations and calculations were performed to understand the airplane's roll behavior immediately before and after the autopilot disconnect occurred and to determine whether the roll behavior was the result of a total or partial separation of the airflow over the left wing. Investigators compared aileron behavior and FDR data in an attempt to determine the following characteristics/parameters:

1. The maximum roll rate for full control wheel deflection (45° either side of neutral = maximum control wheel deflection) at the moment of the upset.
2. An accounting of the roll rate during the 1 second before/2 seconds after the autopilot disengaged (addressing aileron, lift asymmetry, power increase).

3. The aileron free-floating[91] angle just after the autopilot disengagement.
4. The aileron torque just before the upset.

The FDR data indicated that during the 2 seconds after the autopilot disengaged, the accident airplane’s CWP moved from 19.5° right to 21.4° left (41° of travel). According to Embraer’s engineering data, 41° of control wheel travel with an uncontaminated air foil should result in a maximum roll rate of 49° per second;[92] however, the airplane’s maximum roll rate after the autopilot disconnect occurred (as recorded by the FDR) was 67° per second.

Because the accident airplane’s roll rate exceeded the maximum design roll rate for the observed control wheel travel, the Safety Board considered the effect of forces other than aileron deflection, such as asymmetric lift distribution and engine power increase. Embraer’s flight test data indicated that symmetric power application resulted in an additional left roll rate of about 5° per second. Additionally, the asymmetrical engine power application that occurred during this accident resulted in more right engine thrust and would result in an increased left yaw/roll tendency (unquantified). Thus, the total roll rate, including the roll rate that resulted from the 41° of total control wheel travel (from 19.5° RWD to 21.4° LWD; up to 49° per second roll), the roll rate that resulted from the asymmetric lift degradation (12° per second), and the roll rate induced by the symmetrical application of engine power (5° per second—this does not take into account the asymmetrical power application, which would have exacerbated the left roll rate) was determined to be up to 66° per second.

The FDR data indicated that as the airplane rolled to the left before the autopilot disengaged, the autopilot was commanding an increasing aileron deflection to the right; however, about 1 second before the autopilot disconnected, the FDR data revealed an increase in the left roll rate. The Safety Board examined the aileron autopilot servo torque just before the upset in an attempt to determine the reason for the increase in left roll rate before the autopilot disengaged. According to Embraer, the designed aileron autopilot servo torque value equals control wheel force in pounds divided by 0.288. Embraer’s calculations indicated that the control wheel force applied by the autopilot just before it disengaged was 43.4 pounds, and the resultant calculated autopilot aileron servo torque was 150.6944 in-lbs (43.3 divided by 0.288 = 150.6944), which would correspond to the autopilot fail condition sensed immediately before the autopilot disengaged.

The Safety Board reviewed FDR and engineering data in an attempt to determine what the expected aileron “floating” angle (aileron angle without autopilot or pilot input) would have been just after the autopilot disengaged. The FDR that was installed on the accident airplane did not record aileron position; therefore, investigators applied Embraer’s standard EMB-120 conversion formula to obtain the accident airplane’s aileron position from the CWP recorded by the FDR throughout the upset event. As the airplane rolled to the left after autopilot disconnect, the local AOA of each wing changed as a result of that rolling motion; the AOA on

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[91] The aileron free-floating angle (also known as “zero hinge moment” position) is the aileron angle without control forces applied by the autopilot or the flightcrew.

[92] This maximum roll rate is based on control wheel travel from a neutral position to 45°; the roll rate for control wheel travel from 19.5° right to 21.4° left would be less than 49° per second.

the downward moving (left) wing increased, while the AOA on the upward moving (right) wing decreased. Based on the aerodynamic conditions that existed, including the change in local AOA, calculations indicated that the EMB-120's total aileron floating angle would correspond to a control wheel deflection of 21° to the left.

The Safety Board's review of Embraer's EMB-120 initial developmental flight test data revealed that the airplane exhibited a slight tendency to roll to the left with symmetrical power applied in some test flight conditions. Specifically, during flight tests intended to demonstrate the airplane's flight characteristics during power on, no flap stalls, the airplane exhibited a slight tendency to yaw, then roll to the left during the incipient stall stage. The results indicated that although the tendency was slight and easily controlled, the airplane exceeded the FAA's 20° roll certification limit during the recovery procedure. According to Embraer personnel, Embraer incorporated a stick pusher into the system to prevent the airplane from reaching the AOA at which the yaw and subsequent roll would occur. Because the left roll tendency was observed at airplane AOA of about 18°, the stick pusher was designed to prevent the AOA exceeding 12.5°. The flight test data revealed no other instances that exhibited a left roll tendency.

FAA Aircraft Certification Office (ACO) personnel and the FAA's environmental icing NRS stated that even under normal flight conditions (uncontaminated airfoils, symmetrical power settings, etc.) turbopropeller-driven airplanes tend to yaw/roll to the left when operating at power settings above flight idle; they attribute this tendency to the aerodynamic effects of the large, non-counterrotating propeller blades.[93] As previously discussed, EMB-120 pilots reported that the EMB-120 exhibited a strong left yaw/roll tendency with power applications at all airspeeds.

1.16.2 Postaccident Icing/Wind Tunnel Tests

During the Safety Board's investigation of this accident, two series of icing/wind tunnel tests were conducted: 1) Safety Board staff and scientists at NASA-Lewis conducted a series of icing tunnel tests to determine the possible ice accumulations experienced by Comair flight 3272 and to identify the aerodynamic effects of ice accumulations of various roughness and symmetry, at various airfoil AOA, airspeeds, and temperatures; and 2) as part of its continuing airworthiness program (and to explore the aerodynamic effects of delayed activation of deicing boots), the FAA contracted with UIUC to conduct a series of wind tunnel icing tests to assess the aerodynamic effects of delaying activation of deicing boots and of residual ice or roughness remaining on the leading edge after the deicing boots' inflation cycle.

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[93] According to the FAA's AC 61-21A, "Flight Training Handbook," "[w]ith the airplane being flown at positive angles of attack, the right (viewed from the rear) or downswinging [propeller] blade, is passing through an area of resultant velocity which is greater than that affecting the left or upswinging blade. Since the propeller blade is an airfoil, increased velocity means increased lift. Therefore, the downswinging blade…tends to pull (yaw) the airplane's nose to the left." This "unbalanced thrust" becomes greater as the airplane's AOA increases.

Both icing/wind tunnel tests used airfoil segments representative of the mid-to-outboard section of the EMB-120 wing—a National Advisory Committee for Aeronautics (NACA) 23015 to 23012 airfoil,[94] with leading edge deicing boots similar to the deicing boots on the EMB-120 wing. The UIUC airfoil was about a 1/3 scale model of the NACA 23012 airfoil installed near the wing tip of the EMB-120, with an aileron. The icing tunnel tests conducted at NASA-Lewis used a full-scale airfoil (representative of a section of the EMB-120 wing slightly inboard of the wing tip—a NACA 23014.5 to 23015 airfoil), with functional deicing boots.[95] NASA's airfoil differed from the EMB-120 wing section slightly; most notably, the airfoil had a fixed-position aileron, and the deicing boot extended farther aft on the airfoil's lower surface. (Figure 11 is a cross-section of a NACA 23012/23015 airfoil, with deicing boot limits indicated.)

1.16.2.1 NASA Lewis Research Center Wind/Icing Tunnel Test Results

The tests conducted at NASA-Lewis used FDR information from the accident airplane and meteorological conditions that were identified by the NCAR mesoscale meteorological study to determine what ice accretions might result and to determine the aerodynamic effects of those ice accumulations at various representative airfoil AOAs (3°, 5°, and 7°). The test process was outlined as follows:

1. The LEWICE computer program[96] was used to provide information about the ice accumulation and the extent of ice coverage (impingement limits) that might have accreted on the accident airplane during its descent.

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[94] NACA was the predecessor to NASA, renamed in 1958. NACA performed thousands of tests on airfoil shapes to develop information regarding which were most efficient for various flight conditions. NACA identified different airfoil shapes with a logical numbering system, described in "Fundamentals of Aerodynamics."

[95] The scientists at NASA-Lewis had previously used this airfoil during post-Roselawn IRT tests (initiated in late 1994) intended to determine the effects of SLD ice accretion on the NACA 23012 airfoil. NASA-Lewis scientists presented the results of the earlier IRT tests at the FAA's "International Conference on Aircraft Inflight Icing," May 6 through 8, 1996; the IRT test results indicated that the most detrimental aerodynamic effects occurred at an air total temperature of 28° F, and stated the following, in part:

> aircraft ice formed from [SLD] icing clouds accretes further aft on aircraft surfaces than that formed from the more common 10 to 40 [micron] droplet icing clouds….This is primarily due to the fact that large droplets impinge further aft on the airfoil surfaces than do small droplets. A significant amount of runback and secondary impingement has also been observed in these tests. Secondary impingement is a term used to describe the action of unfrozen water droplets blowing off the accreted ice, the impinging on the model further downstream.
>
> The NASA-Lewis report concluded the following:
>
> - An increase in droplet size moved the impingement limits further aft on the airfoil. In addition, runback and secondary impingement accreted ice aft of the impingement limits on the airfoil.
> - Increasing the angle of attack caused more ice to accumulate on the pressure [lower wing] surface and less ice on the suction [upper wing] surface.

[96] LEWICE is a computer program developed by NASA-Lewis to predict the extent of ice accretion on the leading edges of airplane wings. The LEWICE program cannot predict surface roughness features but will predict impingement limits and ice thickness for specified conditions.

2. To determine representative ice shapes for a computational performance study, experimental icing tunnel tests were performed on a 6 foot section of NACA 23014.5 to 23015 airfoil mounted vertically in the IRT test section, equipped with deicing boots to represent the mid-to-outboard section of the EMB-120 wing. The chord of the model varied from 73 inches at the floor to 65 inches at the ceiling and was 68 inches at the model centerline.[97]

3. Two-dimensional computational studies were conducted to determine the aerodynamic effects of the identified ice shape accumulations. The studies examined the airflow over the airfoil with and without a deflected rear surface (simulating aileron movement) to determine the relative aerodynamic effects of the identified ice shapes.

4. The final phase of the test process involved three-dimensional computational studies, which were performed to determine the flowfield of the entire wing with the identified ice shapes. The results from this phase of the study were not available at the time of this report; however, NASA scientists intended to compare them to the results from the two-dimensional studies to determine the spanwise flow and to identify how that flow affected the wing aerodynamics, particularly near the wing ailerons.

The NASA-Lewis IRT is a closed-cycle, refrigerated wind tunnel, with spray equipment installed upstream of the test section (see figure 12). The test section is 6 feet high by 9 feet wide and can accommodate full-scale wing sections. The IRT atmospheric conditions can be varied to provide a range of total air temperatures (TAT), droplet sizes, and LWCs. Also, the airfoil mounting system can be adjusted to vary the airfoil's AOA. The IRT test section is observable through windows from adjoining rooms, and the test facility has video and photographic documentation capability.

During NASA's IRT tests, the EMB-120 wing section was exposed to icing conditions at airfoil AOA (3°, 5°, and 7°), LWCs (0.58 grams/cubic meter to 0.8 grams/cubic meter), droplet sizes (20, 40, 70, 100, 120, 175, and 270 microns MVD), TATs (26° F to 31° F), and an airspeed (172 knots)[98] that approximated the conditions encountered by Comair flight 3272 as it descended from 7,000 feet msl (the altitude at which evidence of increased drag appeared—see section 1.16.1.1). The exposure time used in the tests was 5 minutes (similar to the length of time that drag counts were observed on the accident airplane), and the deicing boots

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[97] These chord lengths are representative of a section of the EMB-120 wing from a point near the outboard edge of the outboard trailing edge flap to approximately ½ span of the aileron.

[98] As Comair flight 3272 descended through the clouds, the airspeed was decreasing in response to a series of ATC airspeed instructions. The 172 knot airspeed was selected for the IRT tests because it was the mean airspeed observed in the accident airplane's FDR data during the last 4½ to 5 minutes of the accident flight, when drag was observed in the FDR data/simulations. The mean airspeed was selected for the IRT tests (rather than a range of airspeeds) because the NASA-Lewis experts reported that for the range of airspeeds observed in the airplane's FDR data, airspeed was not a significant factor in determining the type and location of ice accretion on an airframe.

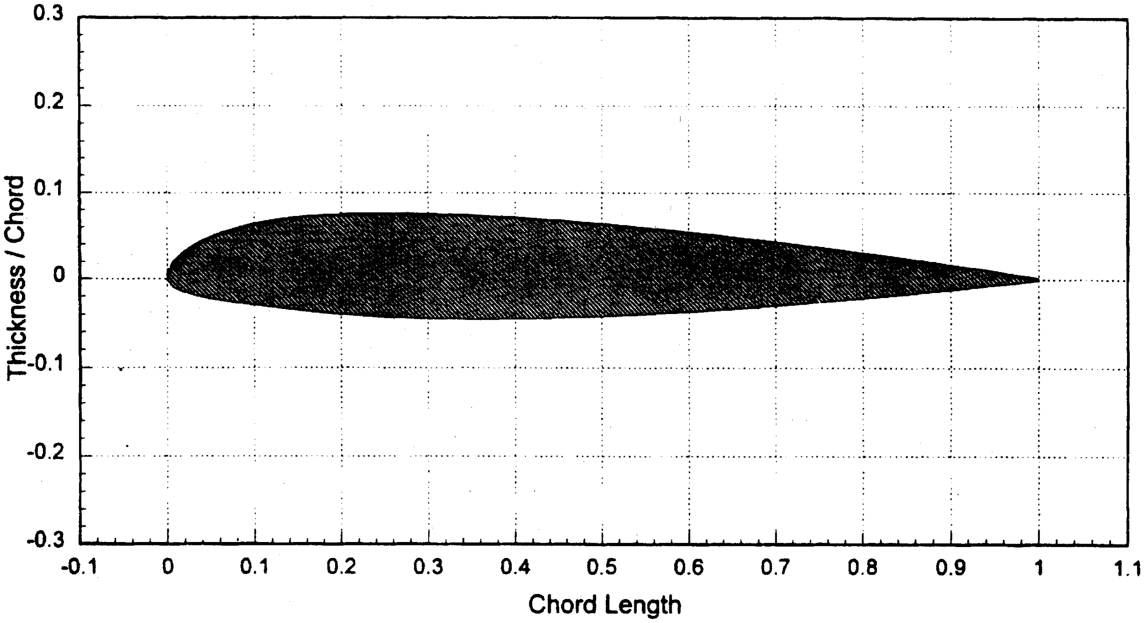

Figure 11.--Cross-section of a NACA 23012/23015 airfoil.

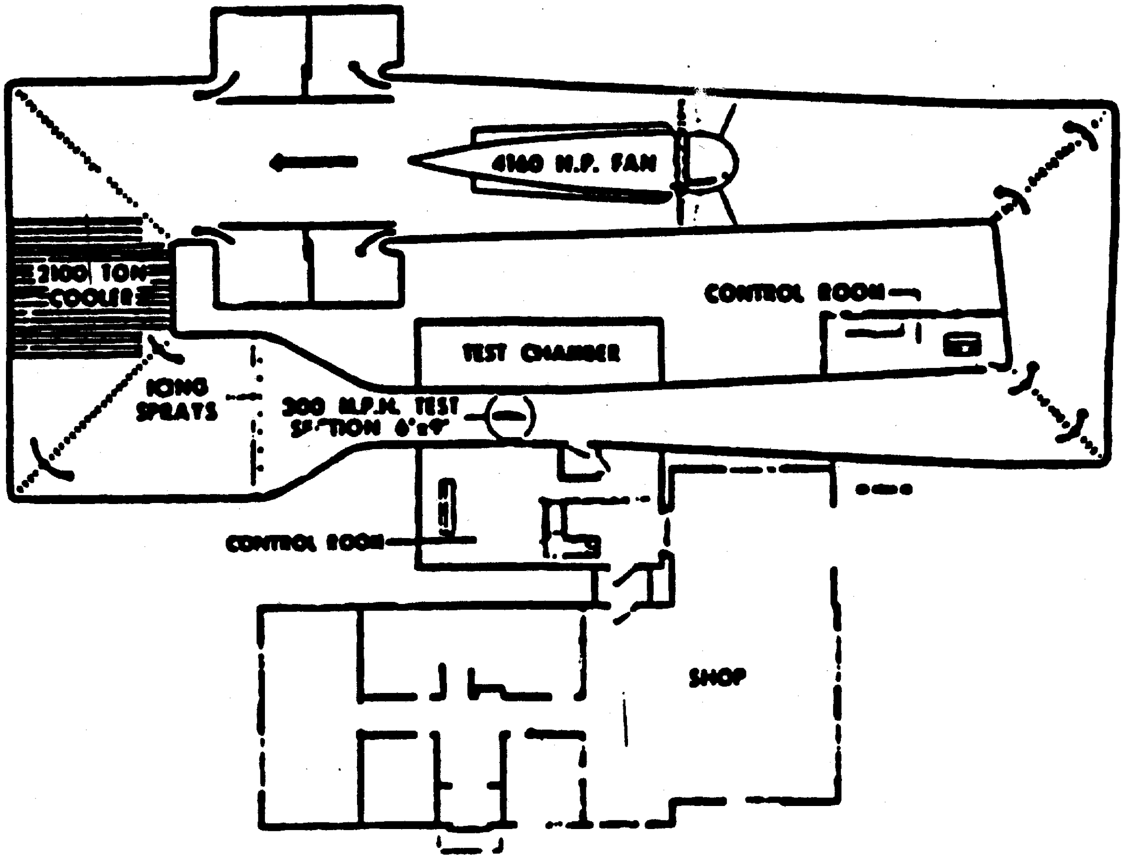

Figure 12.--NASA Lewis Icing Research Tunnel.

were cycled at different exposure times during some test conditions. (See appendix F for a complete description of the test conditions and copies of ice traces for various test conditions.)

Review of the IRT test data indicated that in all the tested conditions, ice began to accumulate within the first minute of exposure; early accumulations were rough and thin, and observers[99] reported that they were generally difficult to identify (let alone gauge in thickness). NASA-Lewis specialists reported that early in the exposure period, the rough ice accretion appeared to develop over the entire impingement area (leading edge deicing boot coverage), then grew in thickness and density (without much change in the area of coverage) as exposure time increased. Also, in many of the test conditions, as the ice accretion increased, a small ridge (or small ridges) of rough ice began to accumulate at or about the deicing boot surfaces located between the individual tubes. These "stitchlines" on the leading edge deicing boots ran spanwise along the leading edge deicing boot segments and were about 1 inch to 1½ inch apart (depending on the location of the tube within the deicing boot segment).[100] Although in some test conditions ice ridges were observed at locations other than stitchlines on the leading edge boot surface, NASA-Lewis's experts estimated that when ice ridges formed during the IRT tests, the stitchlines tended to serve as "preferred ice collection locations" about 70 percent of the time.

The maximum overall ice thickness accumulated during the tests was about 0.25 inch,[101] with most icing conditions producing thinner accretions; in all the tested conditions, the surface of the accreted ice was described by NASA-Lewis and Safety Board observers as "extremely rough," "like sandpaper," and appeared to be a "glaze" type of ice, "slightly clearer" than rime ice. The IRT observers further noted that environmental lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation; the thin, rough ice coverage that accreted on the EMB-120 wing was somewhat translucent and was often difficult to perceive from the observation window.[102] 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 (i.e., in clouds and precipitation, at dusk). (See appendix F for photographs and profile traces of the ice accumulations encountered during the tests.)

NASA's IRT tests revealed that the extent of the rough ice accumulation on the airfoil surfaces varied, depending on the LWC, droplet size, and airfoil AOA (all tests were conducted at 172 knots airspeed); however, all conditions tested resulted in extremely rough ice accumulation on the leading edge of the airfoil. IRT tests conducted at 5^{o} airfoil AOA with a droplet size of 175 microns MVD resulted in rough ice that extended well aft of the deicing boot

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[99] Safety Board staff observed several icing tunnel tests with NASA personnel through windows in adjoining rooms.

[100] NASA's LEWICE program predicted a thin layer of ice over the leading edge surface, with a sparse accumulation of thin ice aft of the leading edge deicing boot on the lower airfoil surface for the range of conditions tested; however, since LEWICE does not model the surface dynamics associated with ice ridge accumulation, it did not predict the ice ridge accumulation that was observed during some IRT tests.

[101] In one test condition, one of the ridges that accumulated at a deicing boot "seam" (the surface located between two individual tubes) exceeded ½ inch.

[102] Although observers found it difficult to perceive the ice accumulation during the icing exposure periods, they reported that the ice was more evident after the icing exposure period when the icing tunnel was brightly lighted for photographic documentation of the ice accretion. When brightly lighted, the thin, rough "glaze" ice coverage looked slightly like rime ice because of its roughness.

coverage on the bottom airfoil surface and feather-type accumulations along deicing boot surfaces located between the individual tubes aft of the leading edge on the airfoil's upper surface (feather-type accumulations on the upper airfoil surface did not extend aft of the normal EMB-120 deicing boot coverage during the NASA IRT tests). Tests conducted at 5° airfoil AOA with smaller droplet sizes (20, 40, and 70 microns) resulted in smaller amounts of rough ice that extended aft of the deicing boot coverage on the lower airfoil surface,[103] a small ridge-type accretion along the leading edge, and multiple lines of feather-type accretions along deicing boot surfaces located between the individual tubes on the upper airfoil surface.

In general, tests conducted at lower airfoil AOA resulted in ice accumulating farther aft on the upper deicing boot surface, while at higher airfoil AOA, the ice accretions tended to accumulate along the leading edge, with many accumulating as a small ridge near the stagnation point.[104] According to NASA experts and the FAA's Environmental Icing NRS, ice accumulation on the lower wing surface is primarily a drag producer and would not result in significant lift degradation, whereas ice accumulation on the leading edge and upper wing surface (especially rough ice or ice ridges) would result in significant lift degradation.

The IRT tests also revealed that at TATs[105] between 26° F to 30° F (-3° C to -1° C), some of the ice accumulations self-shed[106] in small patches, with no apparent pattern to the shedding. Further, ice that accumulated after the self-shedding occurred tended to build on the remaining/adjacent ice accretions and was more irregular and rough than other ice accumulations observed. According to icing experts from the FAA, NASA, and UIUC, and evidence from the wind and icing tunnel tests and other research, the ice that accumulated on airfoils that were operating at TATs between 0° C and -3° C was more "slushy" than ice accumulated at colder temperatures (especially the ice in direct contact with the airfoil) and tended not to adhere to the airfoil very firmly. This ice was more subject to the aerodynamic forces acting on it and tended to slide or move around on the airfoil. The FDR from the accident airplane recorded static air temperature (SAT) data; the SAT temperatures recorded during the minute before the accident ranged between -2° C and -6° C. When the SAT was converted to TAT (with consideration for the airspeeds the airplane was operating), the resultant TATs ranged between 0° C and -4° C.

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[103] NASA's scientists stated that the ice accretions located aft of the deicing boot on the lower wing surface might have been (at least partially) an artifact of the icing tunnel; however, as previously noted, NASA's LEWICE program predicted some sparse frost-like ice accretion aft of the deicing boot on the lower wing surface. Additionally, an ice impingement study conducted by B.F. Goodrich when it designed the deicing boots for the EMB-120 leading edges indicated that in an icing cloud with a 40 micron MVD, some ice would accrete on the lower wing surface aft of the deicing boot. According to Embraer personnel, the B.F. Goodrich ice impingement study showed "very small traces of ice beyond the boot [which] because its influence is on drag only and not on lift…does not effect the safe operation of the aircraft." Embraer further stated that during the EMB-120 natural icing flight tests, no ice was observed aft of the deicing boot coverage.

[104] The stagnation point is the point on the leading edge of the airfoil where the relative airflow diverges to pass above and below the wing so that the local airflow velocity is zero.

[105] TAT is obtained by a probe on the airplane that measures the temperature of the free stream air at the airspeed of the airplane. Because of the fluid dynamic effects of airspeed on air temperature, TAT is warmer than the outside air temperature (OAT—also referred to as static air temperature [SAT]).

[106] According to icing experts, self-shedding is the process of ice being removed from the leading edge by aerodynamic forces, without deicing boot activation.

1.16.2.1.1 Results of NASA's Two-Dimensional Computational Studies

Because NASA's experts advised that the drag measurements they were able to obtain in the IRT were not very accurate (because of turbulence generated in the IRT), they conducted computational studies to obtain more accurate lift and drag information. In April 1998, NASA-Lewis' scientists and icing experts briefed Safety Board staff on the results of the two-dimensional computational study completed by NASA. (Excerpts from NASA's review paper are included in appendix F.) To conduct the study, NASA's experts reviewed the ice shapes documented in the IRT tests and noted that the ice shapes obtained fell into three basic shape categories. They selected the following three representative ice shapes for use in their computational study (all sample shapes were accumulated at an airspeed of 172 knots, an AOA of 5°, LWCs of 0.8 g/m cubed, and 5-minute exposure time):

- Run No. 2, TAT 30° F, droplet size 20 microns; resulted in no ice ridge formation, but a lot of relatively small, rough bumps.
- Run No. 3, TAT 30° F, droplet size 40 microns; resulted in beginning of ridge formation, slightly larger rough bumps than run No. 2.
- Run No. 6, TAT 26° F, droplet size 20 microns; resulted in predominant ice ridge formation between tube segment stitchlines on the leading edge, rough bumps extending aft on the upper airfoil surface (about halfway to the aft edge of the upper surface deicing boot), and a layer of rough ice coverage extending from the ridge to the deicing boot's aft edge on the lower surface.

Because the digitized ice shape had many sharp corners that made the simulation difficult, NASA's experts performed systematic smoothing at different levels and studied their effects on lift and drag. Three levels of smoothing (100 percent, 50 percent, and 25 percent control point curves) were reviewed for this study. NASA's scientists stated that the 50 percent control point curve was chosen for the computational study because its lift and drag predictions were very close to those of the digitized ice shape 100 percent control point curve.

Because the study indicated that the ice accretion obtained during run No. 6 resulted in the most severe decrease in lift and increase in drag of the runs examined, the run No. 6 results were applied to the accident airplane's flight conditions. Consistent with FDR information from the accident airplane at 1554:12 (as the autopilot began to command right aileron in response to the airplane's steepening left bank), the following conditions were assumed for the remainder of the computational studies:

- Temperature—25.5° F TAT
- Airspeed—152 knots
- Pressure altitude—4,000 feet
- Aileron deflection: left aileron—2.56° down, right aileron—2.74° up
- AOA: 5.8° (body) + 2.0° (wing incidence) = 7.8°[107]

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[107] The local AOA of the EMB-120 wing varies from the wing root to the wing tip because of the three-dimensional flow effects. According to Embraer data, at an airplane body AOA of 9°, the local AOA at the

NASA’s two-dimensional computational studies based on run No. 6 indicated that a thin layer of rough ice with a small but prominent ice ridge located about 0.5 to 1 percent MAC produced the most adverse effect on lift and drag of all the studied test conditions. According to NASA personnel, when compared with EMB-120 flight test data, the thin layer of rough ice with a small ice ridge observed in run No. 6 could have had a more adverse effect on lift, drag, and stall AOA than the 3-inch ram’s horn ice shapes (on unprotected surfaces) commonly used as a “critical case” ice accretion scenario for FAA icing certification. NASA’s two-dimensional computational studies also indicated that at lower angles of attack the left wing produced more lift than the right wing; however, the difference in lift produced by the two wings decreased as the AOA increased, until, at 9° local AOA a lift reversal occurred, and the left wing produced less lift than the right wing.[108] The computational studies did not produce a drag reversal—the left wing always exhibited more drag than the right wing, and the drag increased sharply as the AOA increased. NASA’s review report stated “[c]omputational results indicate that there might have been a possibility of roll to the left against the wish of the pilot [or autopilot] at around or slightly higher AOA of the accident airplane [at 1554:12].” NASA’s experts also indicated that if ice shedding occurred on the right wing, it could lower the lift reversal AOA. The accuracy of the lift and drag degradations calculated is unknown since NPARC has not been validated for the specific ice shapes examined during this study. Also the NASA experts feel that the ice shapes measured in the IRT are only “representative” because of the uncertainty of the flight and meteorological conditions used for this study.

1.16.2.2 FAA/UIUC Wind Tunnel Test Results

As previously mentioned, the UIUC performed the wind tunnel tests using a 1/3 scale model section of NACA 23012 airfoil (18 inch chord), equipped with a moveable aileron. Force and surface pressure measurements were performed with no contamination on the test airfoil to obtain aerodynamic coefficients and aileron hinge moments for the clean airfoil throughout a range of aileron deflections and AOAs. Then a 0.025-inch carborundum grit,[109] representing the surface roughness of intercycle and initial ice accretions, was distributed over the impingement area (ice/roughness coverage area, extending aft from the leading edge to a point 8 percent of wing chord on upper surface, 33 percent of wing chord on lower surface)[110] at

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wing tip would be 4.5°, near the center of the aileron the local AOA would be about 8°, and near the wing root the local AOA would be more than 10°.

[108] These results were obtained using the Baldwin-Barth turbulence model; the Spalart-Allmaras turbulence model produced similar results, but the lift reversal/crossover point occurred at a slightly higher AOA (about 10°).

[109] Full-scale roughness at 0.075 inch was observed during NASA’s wind tunnel tests and was considered by NASA’s scientists to be representative of intercycle ice residue or ice accretion before delayed activation of the ice protection system, in weather conditions similar to the accident conditions. UIUC used 0.025 inch for the 1/3 scale airfoil.

[110] The FAA/UIUC wind tunnel tests were initiated by the FAA as part of its continuing airworthiness program to study the effects of intercycle and residual ice on airplane leading edges; although this research was conducted in parallel with the Safety Board’s investigation of the Comair flight 3272 accident, it was not conducted as a result of the accident. The impingement limits used in the FAA/UIUC tests were calculated using NASA’s LEWICE program with the following conditions: an airfoil AOA of 3°, an airspeed of 166 knots, an altitude of 5,500 feet, an OAT of -11° C, and a droplet size of 90 microns. (According to the FAA’s Environmental

surface roughness densities of 5 to 10 percent, 15 to 20 percent, and greater than 50 percent. Other wind tunnel conditions included the following: 166 knots airspeed, a variety of airfoil AOAs (-12° to beyond stall AOA), and aileron deflections from -15° to +15°, in 5° increments.

The resultant basic wind tunnel data revealed that the 5 to 10 percent density contamination resulted in an increase in the airfoil's minimum drag of almost 100 percent, more than 30 percent loss of maximum lift, and a loss of aileron effectiveness. When the contamination densities were increased to 15 percent to 20 percent and to greater than 50 percent, the minimum drag increased 130 percent and 140 percent, respectively, and maximum lift loss increased to about 40 percent. Contamination coverages greater than 20 percent did not appreciably change the lift or drag values over those of the 15 to 20 percent coverage tests. The wind tunnel data also showed a shift from the airfoil's nearly neutral pitch stability (when uncontaminated), toward an unstable pitch stability.[111]

According to wind tunnel and engineering data, the clean airfoil had a maximum lift coefficient (stall) AOA of about 14° to 15°,[112] while an airfoil with 5 percent to 10 percent roughness coverage had a stall AOA of about 9° to 10.° This reduction in stall AOA is similar to that observed using 3-inch ram's horn ice shapes on protected surfaces during Embraer developmental tests; however, the ice roughness resulted in a deeper poststall break than that observed with the 3-inch ram's horn ice shapes.

These data demonstrated that the wing's spanwise stall progression with contaminated leading edge surfaces and deflected ailerons can be affected by small spanwise AOA variations. (See appendix F.) The wind tunnel data observed by the FAA/UIUC researchers demonstrated that small amounts of rough (initial or intercycle) contamination result in a significant decrease in maximum lift and increase in drag; further, downward control surface deflections increase the aerodynamic effects of small amounts of contamination in the localized area. FAA/UIUC researchers also stated that their data demonstrated that with contamination on an airfoil, a localized stall or separation of airflow will occur at a lower AOA with a downward deflected aileron than it would with no aileron deflection or with an upward deflected aileron.

Icing NRS, within the Langmuir distribution of a cloud droplet spectrum having a median effective diameter of 50 microns, a portion of the droplets will be 90 microns; therefore, these values could be considered to fall within the Part 25 appendix C envelope.)

[111] On an airplane, such a shift in pitch stability would require an airplane nose-up pitch trim input to maintain a stable attitude with increasing AOA. FDR data indicated that the accident airplane's pitch trim was moving in an airplane nose-up direction as the AOA increased during the 15 seconds before the autopilot disengaged.

[112] For the remainder of this report, the AOA at maximum lift coefficient will be referred to as the stall AOA. The 14° to 15° stall AOAs described here are local stall AOAs and apply to the clean NACA 23012 airfoil used in the wind tunnel tests. (As previously discussed, Embraer used a combination of NACA airfoils in its EMB-120 wing design, including the NACA 23012 airfoil for the outboard section of the wings; each of the airfoils has its own specific stall AOA.)

1.16.2.2.1 FAA Environmental Icing NRS/UIUC Conclusions Based on Wind Tunnel Tests

During a December 1997 meeting at the Safety Board's headquarters in Washington, D.C., the FAA's Environmental Icing NRS reported that the original EMB-120 certification flight tests to evaluate the airplane's handling characteristics were conducted with large, critical artificial ice shapes (representing accumulations obtained during a 45-minute hold in appendix C icing conditions) on unprotected surfaces. He believed that the adequacy of the EMB-120's flight handling characteristics under those circumstances were well-documented during the certification process. However, he also indicated that the UIUC wind tunnel tests demonstrated that much smaller amounts of accumulation—in fact, sandpaper-type roughness covering as little as 5 to 10 percent of the leading edge surface area (which had previously been considered a relatively insignificant accumulation)—resulted in significant reductions in airplane performance and stall speed margins. The FAA's Environmental Icing NRS stated that the EMB-120's flight handling characteristics and controllability with small amounts of sandpaper-type roughness on the leading edge area had not been documented during the icing certification process; however, there was documentation that indicated that the leading edge deicing boots operated successfully throughout the flight tests.

In May 1998, the FAA's Environmental Icing NRS told Safety Board staff that he believed that NASA's IRT tests were well-performed, and stated that "the scientists at NASA-Lewis Research Center Icing Technology Branch had performed an exceptionally excellent Navier-Stokes computerized fluid dynamics analytical study of the aerodynamic effects of the ice accretion shapes found in the Icing Research Tunnel." He stated "Exceptional efforts were made…to carefully [smooth] the ice accretions…and several turbulence models were evaluated to assess proper simulation of the turbulent boundary layer and wake. Also, considerable computer resources were expended…to define the airfoil's aerodynamic characteristics with increasing [AOAs] and with various aileron deflections." He stated that the general trends identified by NASA's IRT tests and two-dimensional computational study were consistent with studies conducted by NACA/NASA in the late 1930s through the 1950s and with the FAA/UIUC wind tunnel results, which he believed lent credibility to NASA's two-dimensional computational study results.[113] He also stated that he was interested to see the results of NASA's three-dimensional analytical studies for the entire wing, "especially since such a study would provide reasonably accurate spanwise upwash, or local [AOAs], to assess the contaminated wing's spanwise stall progression with deflected ailerons."

The FAA's Environmental Icing NRS indicated that he was concerned that most pilots were not aware that such slight amounts of roughness on the airfoils (wings, tail) could result in the significant performance degradation that was demonstrated during the NASA-Lewis IRT and FAA/UIUC wind tunnel tests. He stated that pilots may observe what they perceive to be an insignificant amount of ice on the airplane's surface and be unaware that they may still be

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[113] The FAA's Environmental Icing NRS commented that NASA's two-dimensional computational study results should be used with caution, especially near and beyond the maximum lift AOA and for configurations for which the fluid dynamics computer code had not been validated.

at risk because of reduced stall margins resulting from icing-related degraded airplane performance.

Further, the FAA's Environmental Icing NRS stated that his review of several airplane flight manuals revealed that manufacturers were recommending that pilots wait until they observed measurable thicknesses (thicknesses that ranged between ¼ inch and 1½ inches, depending on the manufacturer) of ice on the airframe structure before activating the leading edge deicing boots. He reported that the recommended delays before activating the deicing equipment were probably the result of concerns regarding ice bridging;[114] however, he added that the UIUC wind tunnel test results indicated that considerable (potentially very hazardous) aerodynamic degradation could occur before a pilot perceived ice accumulation on the airplane. In November 1997, the FAA and NASA conducted a workshop to address the phenomenon of ice bridging; additional information regarding the phenomenon of ice bridging and the FAA/NASA Airplane Deicing Boot Ice Bridging Workshop is included in section 1.18.4.2.

The FAA's Environmental Icing NRS reported that the UIUC wind tunnel data supported a practice of activating deicing boots at the first sign of ice, to minimize the contamination and resultant aerodynamic degradation. He further stated that pilots and operators should strive to "keep it clean," with regard to in-flight airframe ice accumulation. Based on the wind tunnel test results and other research data, the FAA's Environmental Icing NRS stated that he believed that the safest practice would be for pilots to activate the leading edge deicing boots immediately upon entering icing conditions—"the earlier the better, cycle them and keep the wing contamination less than 5 percent, if possible."

1.16.2.3 Limitations of NASA-Lewis Icing Study and FAA/UIUC Wind Tunnel Tests

The data generated during the NASA-Lewis icing study and FAA/UIUC wind tunnel tests may not replicate the airflow situations that would occur on a full-span EMB-120 wing installed on the airplane for several reasons. For example, a full span EMB-120 wing has aileron fences, vortex generators, flaps, ailerons, variable airfoil design,[115] and taper, and the airflow over an entire wing (or an entire airplane) has both spanwise and chordwise aspects. Additionally, a three-dimensional wing develops vortices that shed from the wing tips. These vortices alter the airflow over the entire wing, although the most pronounced effect is near the wing tip; they produce a spanwise airflow and alter the local AOAs along the wing. Data provided by Embraer indicated that with an airplane body AOA of 9^{o}, the local AOA near the

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[114] B.F. Goodrich Ice Protection Systems (deicing boot manufacturer) personnel defined ice bridging as follows: "If the pneumatic de-icers are activated (inflated) too soon i.e. when the ice layer is too thin, a shell of ice will form. The ice shell continues to build thickness and resists removal during subsequent de-icer inflation cycles." According to the FAA's icing handbook (DOT/FAA/CT-88/8-1), Section III 1.6, "Operational Use," "a nominal ice thickness of 0.5 inches is allowed to accrete before the de-ice system is turned on. Bridging is the formation of an arch of ice over the boot which is not removed by boot inflation. This can occur if the system is activated too early or too frequently."

[115] The EMB-120 wing is a combination of NACA airfoil types, ranging from NACA 23018 at the wing root to NACA 23012 at the wing tip.

wing tip would be 4.5°, the AOA at the wing section near the center of the aileron would be about 8°, and the AOA near the wing root would be about 10°.

Further, NASA experts stated that the ice shapes measured in the NASA IRT should only be considered "representative" ice shapes because of the uncertainty in the flight and meteorological conditions used for the study.

Another limitation of the FAA/UIUC wind tunnel tests occurred because the model airfoil used in those tests was a 1/3 scale model (with a proportionally smaller airfoil chord), which affects the airflow Reynolds number. The Reynolds number is a measure of the relative magnitude of the viscous effects of a fluid flow, or an airflow. The Reynolds number is a nondimensional parameter, a measure of the ratio of inertia forces to the viscous forces in the airflow over a characteristic length. In this case, the length would be the airfoil chord (18 inches), and the resultant wind tunnel test Reynolds number was about 1.8 million. According to Abbott and Von Doenhoff,[116] the Reynolds number for the NACA 23012 airfoil was 6 million.

According to research conducted by Abbott and Von Doenhoff in the 1940s and 1950s, an increase in Reynolds number resulted in a higher stall AOA up to a point; beyond that point, subsequent increases in Reynolds number did not result in a significant increase in stall AOA. (See the plot in appendix F.) Because the 1/3 scale model airfoil used in the FAA/UIUC studies had a smaller chord than a full-scale NACA 23012 airfoil, the effect the scale difference would have on the Reynolds number must be considered before generalizing the FAA/UIUC test results to a full-scale airfoil. Comparison of the Abbott and Von Doenhoff NACA 23012 data with the FAA/UIUC airfoil data indicated consistent incremental aerodynamic effects of the simulated surface roughness. (According to the FAA's Environmental Icing NRS, this suggests that the FAA/UIUC test results would reasonably apply to the EMB-120 outboard wing section.) Abbott and Von Doenhoff's research further indicated that a small amount of roughness on the leading edge of the airfoil reduced the stall AOA; these results were similar to the FAA/UIUC test results. The results of Abbott and Von Doenhoff's research will be further discussed in section 1.18.1.1, and excerpts from their book are included in appendix F.

1.17 Organizational and Management Information

1.17.1 Comair—General Information

Comair Airlines was founded in April 1977 as a small commuter airline, providing scheduled service between Cincinnati, Cleveland, Akron, and Detroit. The company became a publicly owned corporation in July 1981 and began using Delta Air Lines' computerized reservations system to manage Comair's flight reservations in December 1981.

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[116] *Theory of Wing Sections: Including a Summary of Airfoil Data*, by Ira H. Abbott and Albert E. Von Doenhoff, Dover Publication, New York, New York. 1959. This reference is considered to be the definitive text on the subject of wing section and airfoil theory and is currently used in engineering education programs.

On September 1, 1984, Comair became an official Delta Connection air carrier,[117] and in July 1986, Delta purchased about 20 percent of Comair's common stock, which remained in Delta's ownership at the time of the accident. Comair Airlines was one of seven subsidiaries of COMAIR Holdings, Inc.[118] At the time of the accident, Comair employed about 850 pilots and operated 7 Saab 340, 40 EMB-120, and 45 Canadair CL-65 airplanes throughout a route system that primarily encompassed Florida and the north central United States.

In 1995, Comair established a Safety Office. Safety Office personnel were responsible for ensuring that safety-related information was disseminated appropriately throughout the airline, for attending Delta's Safety Partner meetings, and for holding safety meetings for Comair personnel. In Comair's chain of command, the Director of the Safety Office reported to Comair's DO. According to the DO, 2 months before the accident, the Director of the Safety Office was promoted to Vice President of Flight Operations; however, at the time of the accident, he still served as Director of the Safety Office because the company had not yet replaced him in that position.

Comair's DO stated that when the accident occurred, Comair was transitioning to a two-airplane fleet (EMB-120 and CL-65), and the company was attempting to standardize procedures across airplanes.

1.17.1.1 Comair's Pilot Training

Comair's DO stated that since he was hired by Comair in February 1985, the company had used COMAIR Aviation Academy to screen pilot applicants and conduct initial interviews.[119] Pilots who passed the academy's initial screen became part of a "pool" of applicants available to the airline. New-hire initial training (classroom, simulator, and airplane) was provided by Comair, Inc. instructors at COMAIR Aviation Academy. Initial operating experience (IOE) was accomplished by Comair Airlines before the new hire becomes a flight line pilot. The airline's primary training facilities were located in Cincinnati and Orlando (the Aviation Academy). Comair's DO reported that Comair Airlines' instructors and check airmen provided recurrent, upgrade, and transition pilot training, using simulators and classrooms at the Aviation Academy and other facilities; Comair's airplanes were used for all in-airplane flight training.

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[117] Under the Delta Connection marketing agreement, Comair operates flights under the DL code, and schedules are coordinated for more efficient connections.

[118] At the time of the accident, other subsidiaries of COMAIR Holdings, Inc., included COMAIR Aviation Academy, Comair Aviation, Comair Aircraft, Comair Services, Comair Jet Express, and Comair Investment Company.

[119] COMAIR Aviation Academy's initial screening included background checks, simulator evaluation, written tests, and the academy generated a pilot candidate profile of experience and aeronautical knowledge. Although the academy was not part of the airline, Comair Airlines' pilots were employed as instructors by the academy, and most successful pilot applicants were placed with Comair Airlines. Occasionally pilot candidates were placed with other airlines, including Great Lakes Aviation and an American Eagle carrier (unnamed).

According to Comair's manager of training, Comair's captains were scheduled to receive another line check 6 months after they were assigned to flight line duty (after initial training). One year after their initial training, Comair captains were scheduled for annual recurrent training and evaluation under a single visit training exemption.[120] Thus, Comair captains were scheduled to receive either recurrent training[121] and a line check or single visit training and evaluation at 6-month intervals every year, unless an upgrade or transition to different equipment altered the schedule. The company implemented a CRM training program for pilots, flight attendants, and dispatchers in 1992; at the time of the accident, CRM was a required portion of every scheduled training exercise (initial, recurrent, upgrade, etc.). Comair's pilots, flight attendants, and dispatchers received CRM training separately but were taught by the same instructors—the eight facilitators consisted of six pilots and two flight attendants. According to Comair's training manager, the company uses line-oriented exercises (LOE), videotapes, and teamwork to emphasize dealing with problems as a flightcrew.

1.17.1.1.1 Stall/Unusual Attitude Recovery Training

As a result of the ATR-72 accident in Roselawn, Indiana, Comair management requested that its EMB-120 training department develop an unusual attitude, or "upset," training program. According to Comair's training manager, the unusual attitude training had since been informally incorporated as an item normally accomplished during every phase of Comair's pilot training program (initial, upgrade, transition, and recurrent); it included classroom and simulator training sessions, but it was not a testing item. At the time of the accident, unusual attitude training was not required by the FAA, and Comair did not have a formal syllabus for this training; however, Comair's simulator instructors included unusual attitude training at the end of most recurrent training sessions. The captain of flight 3272 taught unusual attitude recognition and recovery in the CL-65 when he was a CL-65 instructor. As previously mentioned, the pilots of Comair flight 3272 received CRM and EMB-120 unusual attitude training during their recurrent training in September 1995.

According to Comair's DO and EMB-120 Program Manager, the upset training was considered a demonstration and familiarization item. Their goal was to help flightcrews recognize upset situations and to know what to expect and how to respond to an upset. The Safety Board reviewed Comair's upset/unusual attitude training, which included cockpit familiarization, system demonstration, and airplane characteristics. The training addressed the following scenarios:

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[120] Single visit training is an exemption that allows captains to be trained and evaluated at 12-month intervals (consistent with the requirement for first officer training and evaluation), instead of the traditional 6-month interval captain's training. Single visit training exemptions are approved by the FAA and facilitate a transition to annualized training as part of the Advanced Qualification Program for flightcrew training.

[121] According to Comair's EMB-120 recurrent training instructor guide, current topics and interoffice memos were discussed during recurrent training ground school. The Safety Board's review of the 1996 instructor guide revealed that several Comair interoffice memos were issued in 1995/1996; however, Comair's December 8, 1995, interoffice memo, entitled "Winter Operating Tips," was not included in the 1996 instructor guide. See section 1.18.2.1 for additional information regarding Comair's December 8, 1995, interoffice memo.

- Autopilot limitation/modes
- Control wheel displacement
- Stall series to stick pusher and stick shaker
- Unusual attitudes
- Slow/fast indicator demonstration
- Yaw demonstration with rapid power lever advancement

During the simulator session, pilots were instructed to attempt to roll the simulator to get the attitude indicator in an unusual presentation. According to Comair instructors, most pilots lost about 1,000 feet of altitude during the first demonstration. The demonstration was then repeated, with the instructor stopping (“freezing”) the simulator at various points to discuss the visual cues and attitude indications that occur during the roll. According to the instructors and pilots interviewed, Comair emphasized that the EADI will always contain information regarding both the sky and the ground, even in the most extreme attitudes. During the “stop and go” roll demonstration, instructors pointed out the blue/brown (sky/ground) indications and the chevron and arrow indications on the EADI, which indicate the “up” direction during unusual attitudes, including inverted flight. Further, Comair emphasized that when the airplane is upside down, the pilots must push forward, not pull back on the control yoke.

After the “stop and go” roll demonstration and discussion, the training session continued with random simulated wake turbulence-related upset events. According to Comair’s Chief Flight Instructor (EMB-120), “students have an aversion to an airplane up-side-down” and indicated that pilots usually tried to right the airplane by rolling against the turn, although in some cases it would be easier to continue through the roll. He also stated that “the people who do the best are the ones who add power.” Another EMB-120 instructor reported that pilots with previous acrobatic experience usually did better with the upset training. If a pilot does not satisfactorily complete the upset maneuver, the demonstration is continued until a successful outcome is achieved.

1.17.1.1.2 Winter Weather Operations/Icing Training

According to Comair’s EMB-120 Program Manager, during recurrent training pilots received training in winter weather operations that includes normal icing, SLD, and deicing procedures at CVG and outstations. He indicated that pilots were taught to be attentive to temperatures, icing forecasts/weather reports/PIREPs and cues, such as airspeed degradation, as well as visual cues to recognize potential ice buildup on the aircraft (such as ice on the propeller spinner or cockpit windscreen).

The EMB-120 Chief Flight Instructor indicated that they taught winter weather operations in accordance with the FSM. He stated they “don’t want students to find themselves in icing conditions too slow and using autopilot.” They wanted them to use a vertical mode that gives them airspeed protection (IAS mode). In the event that they were in severe icing,[122] pilots were instructed to turn the autopilot off immediately. According to the EMB-120 Chief Flight Instructor, the only speed specified for icing is a minimum of 160 knots, "recommended to be 170 [knots]." At the time of the accident, Comair's pilots were trained to activate deicing boots when they observed between ¼ and ½ inch of ice accumulation.

1.17.1.2 Comair's Manuals

Comair's manual system consisted of 10 separate manuals that contained the policies and procedures that governed the operation of all Comair airplanes and all Comair personnel—including flightcrews, flight attendants, dispatchers, ground service personnel, maintenance personnel, and station personnel—and all Comair equipment. Although the Safety Board examined all Comair manuals during its investigation, this report focuses on Comair's Operations Manual and EMB-120 FSM. The Safety Board also reviewed Embraer's EMB-120 Airplane Flight Manual (AFM).

1.17.1.2.1 Comair's Operations Manual

Comair's Operations Manual contained guidance regarding the company's organization, general policies, weather, emergency procedures, hazardous materials, maintenance, and weight and balance. The Operations Manual also contained Comair's FAA-approved operations specifications and Comair's OBs.[123] In accordance with Federal regulations, the operations manual stated, "all flight crewmembers must carry this manual [the Operations Manual] *and* the appropriate Flight Standards Manual when performing their duties as a flight crewmember."

In accordance with FAA Order 8400.10, "Air Transportation Operations Inspector's Handbook," an air carrier's operations manual may be revised by the company as needed without prior FAA approval (although the FAA is required to review the revisions to ensure compliance with regulations), except that changes to the company's operations specifications require prior FAA approval. Comair also issued temporary revisions to the operations manual, which were to be retained "until notice of revision or cancellation." The Safety Board's examination of the manual revealed no temporary revisions pertinent to the accident.

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[122] Comair's EMB-120 recurrent training syllabus defined severe icing as follows: "The rate of accumulation is such that the deicing/anti-icing equipment fails to control the hazard. Immediate flight diversion is necessary." The training syllabus lists the following items under the heading "Related to Severe Icing:" 1) results in aerodynamic degradation; 2) high drag, dynamic buffet, premature stall; 3) freezing drizzle or freezing rain can be described as severe if it exceeds the limit of the ice protection; and 4) SLD.

[123] The Operations Manual stated that bulletins were issued by the company "to aid in communicating important information to all flight crews when dissemination of new/revised policy or information is necessary."

1.17.1.2.2 Comair's EMB-120 Flight Standards Manual

Comair's EMB-120 FSM[124] described the "various normal, abnormal and emergency procedures to be followed by flight-crews when operating the EMB-120." The EMB-120 FSM contained the airplane's operational limitations (including airspeeds), performance information, weight and balance/flight planning procedures, the minimum equipment list/configuration deviation list (MEL/CDL), and descriptions of all checklists, flight training maneuvers, instrument approaches and procedures. According to the FSM, "procedures outlined in this manual are intended to standardize flight operations and maximize the available cockpit resources."

According to the EMB-120 FSM, revisions to its content were developed and issued when Comair deemed it necessary for improved flight operations and standardization. FAA flight standards personnel (usually the principal operations inspector [POI]) were required to review and approve revisions, and sign and date affected pages, before they were issued and implemented. The Safety Board's review of the FSM revealed that at the time of the accident, the most recent revision was revision 8, dated January 1, 1996; additionally, the FSM contained EMB-120 FSBs 96-02 and 96-04, which addressed severe icing conditions and winter flying tips, respectively. The FSBs will be discussed further in section 1.18.2.6.

1.17.1.2.3 Embraer's EMB-120 Airplane Flight Manual

The EMB-120 AFM was prepared by Embraer and provided to EMB-120 operators (including Comair). The contents of (and revisions to) the AFM were reviewed by FAA Aircraft Certification Office (ACO) personnel, then (in accordance with international certification procedures and at the FAA's request) approved by the Centro Tecnico Aeroespacial (CTA) on behalf of the FAA. (Additional information regarding FAA oversight of the EMB-120 AFM is included in section 1.17.2.1.2.) The EMB-120 AFM contained the manufacturer's guidance regarding operating limitations, emergency and abnormal procedures, normal procedures, and standard and supplemental performance information. Unlike the operations manual and the EMB-120 FSM, Comair pilots were not issued a copy of the EMB-120 AFM; rather, copies were maintained in each Comair EMB-120 airplane.

According to Embraer's Technical Liaison, when revisions to the EMB-120 AFM were needed, the manufacturer provided the proposed revisions to the FAA and CTA for review and approval and to all operators for their information. Any revisions were then reviewed by appropriate ACO and Aircraft Evaluation Group (AEG) personnel; when the FAA's reviewing personnel were satisfied with the content of the document, they requested the CTA to approve the revisions on the FAA's behalf. Embraer then provided Comair and other EMB-120 operators with copies of the FAA ACO-reviewed/CTA-approved revisions to the EMB-120 AFM, with the manufacturer's recommendation that the EMB-120 operators incorporate the revisions into the FAA-approved FSM. One such revision was issued by Embraer on April 23, 1996: FAA-

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[124] Flight Standards Manual is the terminology used by Comair for the manual that fulfills the FAA's company flight manual (CFM) requirement.

reviewed/CTA-approved AFM change 43[125] contained procedural changes pertaining to ice protection system activation (leading edge deicing "ON" at the first sign of ice formation) and the use of flaps while operating in icing conditions. AFM change 43 and Comair's responses to the change will be further discussed in section 1.18.2.4 and 1.18.2.5, respectively.

1.17.2 FAA Information—Oversight Personnel

FAA oversight responsibility for the EMB-120 was shared by FAA certification personnel from the ACO in Atlanta, Georgia, and flight standards personnel from the AEG in Seattle, Washington. FAA flight standards personnel from the flight standards district office (FSDO) in Louisville, Kentucky, had the oversight responsibility for Comair. Section 1.17.2.1 will describe the oversight responsibilities of personnel from each office, with emphasis on oversight of the manufacturer's AFM and the operator's CFM, and coordination of information in that regard.

1.17.2.1 ACO and AEG Personnel Oversight Responsibilities

According to FAA personnel, ACO personnel were primarily responsible for the review, evaluation, and validation of test data/information pertaining to the EMB-120 and for determining that the airplane, its systems, and its documentation and manuals complied with Federal requirements before approving initial certification. Additionally, ACO personnel were responsible for the continuing airworthiness of the EMB-120 fleet and its manuals. ACO personnel were assisted in their initial and continuing airworthiness responsibilities by AEG and CTA personnel. FAA records indicate that engineers from the ACO and AEG participated in the EMB-120 initial certification reviews, the 1996 SLD icing controllability testing, and have been involved in the continuing oversight of the EMB-120 flight manuals.

According to FAA Order 8000.5 (dated February 1, 1982), the AEG is responsible for providing the initial operational evaluation of airplanes during the initial certification process, monitoring the fleet service history of airplanes to maintain continuing airworthiness, performing operational evaluations of airplanes, maintaining service difficulty reports (SDRs), and evaluating supplemental type certificates (STCs). FAA Order 8400.10 change 11, dated March 3, 1997, advises flight standards inspectors (including POIs) to contact the AEG office for assistance and background information when they are investigating airplane incidents and/or accidents.

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[125] According to the FAA ACO's EMB Program Manager, the contents of the then-proposed revision 43 to the EMB-120 AFM were discussed and agreed upon by ACO and AEG personnel during the EMB-120 SLD tanker tests conducted in December 1995. FAA records indicate that the FAA provided Embraer with changes to the proposed AFM revision via facsimile (fax) on March 4, 1996. Embraer responded on March 15, 1996, stating that they changed the proposed AFM revision in accordance with the FAA's suggestions, and on April 17, 1996, the FAA ACO's EMB Program Manager sent a fax to Embraer that stated, "[w]e have completed our review and acceptance of proposed Revision 43 to the EMB-120 AFM which incorporates changes for operation in icing conditions. We ask that CTA please approve this revision on our behalf."

1.17.2.1.1 FAA Oversight of Comair's EMB-120 Flight Standards Manual

According to FARs 121.141 and 91.9, air carrier operators must maintain a current flight manual for each airplane used in their operations, and the flight manual must be available to the flightcrew during flight operations. FAA Order 8400.10 change 11, states that operators may use the approved manufacturer's AFM (commonly used with small, less complex airplanes), or the operator may develop, obtain approval for, and use a CFM or equivalent manual. The latter option was the method Comair used to satisfy the regulatory requirement. Comair called its CFM a flight standards manual (FSM).

According to FAA Order 8400.10 and FAA personnel, the POI was responsible for reviewing and evaluating the "approved"[126] and "accepted"[127] sections of an operator's CFM/FSM to ensure compliance with existing regulations and safe operating practices. The "approved" sections include the procedures, performance, and limitations sections, and FAA Order 8400.10 contains the following guidance regarding their content:

- The procedures section of a CFM [FSM] must contain all procedures required by the AFM…and for each operation the operator conducts….the operator must include sufficient detail to allow a trained crew to safely and effectively operate the aircraft. The procedures section…may be divided into subsections such as normal, nonnormal, and emergency procedures.
- The…performance data in a CFM [FSM] must contain the data from the AFM and instructions on how to use that data.
- The limitations section of a CFM [FSM] must be clearly identified as FAA approved….must contain each limitation…contained in the AFM.

Additional information pertaining to procedures is located in section 2169 of FAA Order 8400.10, which states the following, in part:

> POI's should not construe procedures published in an AFM…to be the only or best means of accomplishing a specific objective….Procedures incorporated in a CFM [FSM] should be tailored by the operator to accommodate the operator's type of operation, fleet standardization objectives, and cockpit management objectives…..POI's should encourage those operators that do not have extensive experience in developing their own procedures to follow the manufacturer's recommendations.

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[126] FAA-approved sections of an operator's flight manual (limitations, performance, and procedures sections) are specifically reviewed and endorsed (approved) by the POI for that operator's manual; however, only the limitations and performance sections are required (by the FAA) to match the limitations and performance sections of the FAA (CTA) approved manufacturer's AFM. The procedures section of the operators' manuals includes procedures that are approved by the POI for that operator's flight operations; these procedures may differ from those contained in the manufacturer's AFM.

[127] FAA-accepted sections of an operator's flight manual are generally reviewed by the POI to ensure compliance with FARs, but are not specifically endorsed by the FAA. The accepted sections of a manual may contain supplemental information, such as expanded checklists and bulletins.

FAA Order 8400.10 also states that operators may modify the procedures contained in the procedures section with the approval of the POI and advises inspectors and POIs to “be alert to deficiencies in the operator’s manuals and procedures and for conflicts between company manuals and the [manufacturer’s] AFM.”

The “accepted” sections of a CFM/FSM may contain supplemental information, such as airplane/systems descriptions, an expanded explanation of procedures, special policies, and other topics pertinent to operation of the airplane. Although the information contained in the accepted sections of a CFM/FSM does not have to conform with the AFM, FAA Order 8400.10 states that POIs should ensure that the CFM/FSM contains sufficient guidance/explanation to allow flightcrews to operate that airplane type safely. During postaccident interviews, the Comair POI stated that when the accident occurred, Comair’s EMB-120 FSM had recently (in January 1996) undergone a major revision as part of Comair’s attempt to standardize checklists and other items across its fleet.

According to Embraer’s records, the FAA POI assigned to Comair received a copy of AFM revision 43 from Embraer on June 10, 1996;[128] the POI stated that it was his practice to pass AFM revisions to the assistant POI (APOI) to be incorporated into the FAA’s copy of the EMB-120 AFM. At the time of the accident, the POI assigned to Comair had not required the company to incorporate revision 43 to the AFM into its FSM and procedures. During postaccident interviews, the POI stated that he was not aware that OB 120-002/96 existed until after the accident and thus was not aware of the rationale behind revision 43 to the EMB-120 AFM;[129] he indicated that if Comair had approached him to incorporate AFM revision 43 into its FSM before the accident, he probably would have sought background information and documentation before approving the revision. (Comair had received revision 43 to the EMB-120 AFM and Embraer’s OB No. 120-002/96, which contained supporting documentation for revision 43. Comair personnel had been involved in the discussions with Embraer and other EMB-120 operators regarding those documents, but the company did not discuss OB 120-002/96 or the content or validity of revision 43 with the POI before the accident.)

1.17.2.1.2 FAA Oversight of Embraer’s EMB-120 Airplane Flight Manual

According to FAA Order 8400.10, proposed AFMs “are reviewed by a flight manual review board (FMRB) and, based on the FMRB’s recommendation,” are approved by an ACO when the aircraft is certificated. The FMRB was a team composed of ACO engineers from each discipline (i.e., flight test, propulsion, mechanical systems, etc.) and chaired by the FAA project test pilot. FAA Order 8400.10 stated that the FMRB team was formed at the beginning

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[128] Embraer routinely distributes EMB-120 AFM revisions to all EMB-120 operators and to other interested parties as requested. According to Embraer, Comair’s POI had requested that he be sent copies of all revisions to the AFM.

[129] ACO and AEG personnel were involved in a review of previous EMB-120 incidents and the EMB-120 SLD icing controllability tests that occurred in the fall/winter of 1995. Information from these activities was summarized in Embraer’s OB No. 120-002/96, which was disseminated to all EMB-120 operators in early April 1996 and which Embraer considered justification for revision 43 to the EMB-120 AFM (issued in late April 1996).

of a type certification project to provide guidance for the development of the AFM and later to review revisions to the AFM.

During the investigation, the Safety Board received information that described the FAA's current procedures and division of responsibilities pertaining to certification of manufacturers' and operators' manuals and oversight of those manuals (including revisions) from the following sources: 1) a memorandum (memo) from the FAA's Director of Accident Investigation (AAI-1)[130] to the Safety Board regarding FAA responsibilities and procedures for certification of manufacturers' and operators' manuals and oversight of those manuals (including revisions), and 2) FAA personnel's responses to questions asked during a meeting held at the Safety Board's Washington, D.C., headquarters on August 20, 1997. Both sources of information described some initial certification and continuing airworthiness oversight procedures that differed from those described in FAA Order 8400.10. (A copy of the FAA memo is included in appendix I.)

During the August 20 meeting, FAA personnel stated that because the AEG had become more established, since 1991 the FAA had "moved away" from the formal FMRB process. At the time of the accident, the FAA used a less formal process that required information and revisions to be reviewed and initialed by each pertinent ACO and/or AEG specialist. The FAA memo stated that although the term "FMRB" is no longer used, "the same principle is applied today by coordinating AFM's, and revisions thereto, among the ACO engineering specialties branches prior to [final] approval signature. Revision 43 to the EMB-120 AFM would have been subjected to this current practice, which mimics the role of the FMRB. [However, a]ny changes made to an operator's CFM [FSM] would not be subjected to…the system that has replaced the FMRB in the ACOs."

According to FAA personnel, the oversight responsibilities for Embraer's EMB-120 AFM was shared by FAA offices and the Brazilian airworthiness authority (CTA). The ACO had the responsibility for reviewing, evaluating, and approving/authorizing foreign airworthiness authority approval of Embraer's EMB-120 AFM for initial aircraft certification and subsequent revisions to the AFM.

The FAA's memo stated that a manufacturer desiring to issue a revision to the AFM was responsible for providing the revision to certification personnel for review and approval. The memo further stated that ACO personnel "will coordinate the subject revisions with the cognizant ACO technical branches or specialists, the AEG, and the appropriate FAA Flight Standards office. Once approved, the manufacturers distribute the AFM revisions to operators and other interested parties." The FAA's memo continued, stating, "[t]here are no established procedures mandated to communicate to an operator's POI that a revision to an AFM has been approved. A manufacturer will distribute AFM revisions to the affected airplane

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[130] The memo was prepared and signed by the Acting Director of the FAA's Flight Standards Service (AFS-1) and the Director of the FAA's Aircraft Certification Service (AIR-1) and was dated October 1, 1997.

model's owners who in turn typically supply that revision to the POI[131]….Any coordination of approved 'AFM revisions' by the responsible ACO with FAA operations personnel will be done on a discretionary basis." (During a June 1998 meeting, the FAA's Director of Aircraft Certification Service stated that AFM revisions are routed through the ACO Project Manager, who coordinates with the ACO Flight Test Manager; if the ACO personnel involved did not perceive any significant issues, no further communication took place and flight standards personnel were never specifically consulted or informed.)

The FAA's October 1997 memo further stated, "FAA Order 8400.10…prescribes the information to be contained in the [FSM], '[t]he procedures section of a [FSM] must contain all procedures required by the AFM…and for each operation the operator conducts.' Since in some cases a POI may not be aware of an AFM revision…, unless it is supplied by the operator, that POI will obviously not have control over maintaining the equality of the AFM and [FSM] procedures." The memo further stated, "[I]n order to assure that AFM or [FSM] procedures are changed, an…AD mandating that specific text be a part of the AFM/[FSM] or that specific, dated revision be incorporated, must be issued. AD's are only issued in instances where the AFM changes are considered to be significant enough to warrant retroactive application to all aircraft."

1.17.2.1.3 FAA Flight Standards Office Oversight of Comair—Additional Information

Until about 1 month before the accident, the Louisville, Kentucky, FSDO staffing for the operational oversight of Comair consisted of the POI and the APOI. About 30 days before the accident, two aircrew program manager (APM) positions were created—one for the EMB-120 and one for the CL-65. The (former) APOI was selected to fill the EMB-120 APM position; at the time of the accident, the APOI position was vacant.

The POI was hired by the FAA in 1987 and had been POI for Comair for 7 years at the time of the accident. He held type ratings in the EMB-120, the CL-65, and the Saab SF-340. The POI stated that he had about 10,000 total flight hours, including less than 50 hours in the EMB-120. He reported that managing the Comair certificate was a full-time job for him and the APOI; neither inspector was assigned duties unrelated to the Comair certificate. He stated that he was uncertain when or if the APOI position would be refilled.

According to the POI and Comair personnel, the relationship between the FAA and Comair was professional, cordial, and businesslike. He stated that Comair's management was very stable and receptive to the FAA's recommendations and that communications were open and direct between Comair personnel and the FAA. He reported that in October 1995, the FAA conducted a national aviation safety inspection program (NASIP) inspection of Comair, and "only 3 or 4 minor findings were reported;" he indicated that it had been several years since a violation had been written against Comair.

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[131] Although the memo indicated that POIs normally received revisions to the AFM and associated manufacturers' OBs from the airplane operators, Embraer indicated that Comair's POI was on its distribution list, and received AFM revisions directly from the manufacturer.

When he was asked about Comair's unusual attitude training, the POI stated that he had mixed opinions on the subject. He stated that the benefit of the unusual attitude training was that it familiarized pilots with the visual cues they would encounter in a variety of airplane attitudes and emphasized the proper recovery techniques for those situations; the purpose of the familiarization was to better prepare pilots to recover from an in-flight upset or unusual attitude. However, the POI pointed out that the simulator was neither designed nor certificated for unusual attitude encounters; further, he stated that the simulator could not duplicate the forces caused by gravity and inertia that would be experienced by a flightcrew performing unusual attitudes in an airplane. Despite this, the POI considered Comair's training in stall recovery and unusual attitudes to be satisfactory.

1.17.2.2 Previously Identified Deficiencies in FAA Organizational Structure and Staffing

In the Safety Board's report regarding the ATR-72 accident near Roselawn, Indiana, the Board noted that following a 1988 icing-related ATR-42 incident at Mosinee, Wisconsin, the FAA became aware that the ATR-42 was susceptible to aileron hinge moment reversals in SLD icing conditions. At that time, the FAA recommended the installation of vortex generators, believing that this would correct the aileron anomaly. In a briefing paper dated March 25, 1989, the manager of the Seattle AEG expressed concern about 10 icing-related ATR incidents that he believed warranted further study, to include flight tests with irregular icing shapes "…emulating 'runback' [ice]." There was no evidence of a formal FAA response to the concerns raised by the AEG manager; however, in 1991, the FAA led a team in developing information regarding incidents/accidents that have been attributed to tailplane icing; this team was also involved in discussions regarding SLD icing conditions. ATR icing-related incidents continued to occur. In 1992, ATR published an *All Weather Operations* brochure, and, in 1993 and 1994, ATR incidents occurred in Newark, New Jersey, and Burlington, Massachusetts, respectively; yet, the FAA did not take any further action to remedy the icing-related problems. The Safety Board concluded that "the FAA's failure…to require additional actions be taken to alert operators and pilots to the specific icing-related problems affecting the ATRs, and to require action by the manufacturer to remedy the airplane's propensity for aileron hinge moment reversals in certain icing conditions, contributed to this accident." Further, the Safety Board noted that "this is not the first time that the Safety Board has identified problems with the timeliness and effectiveness of the FAA's continuing airworthiness oversight of foreign-built aircraft," citing conclusions from the Board's 1987 Construcciones Aeronauticas, S/A (CASA) C-212-CC accident report.

Additionally, in its report on the ATR-72 accident near Roselawn, Indiana, the Safety Board cited the 1993 General Accounting Office (GAO) report132 entitled "Aircraft Certification, New FAA Approach Needed to Meet Challenges of Advanced Technology." The GAO report stated the following, in part:

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[132] U.S. General Accounting Office. 1993. Report to the Chairman, Subcommittee on Aviation, Committee on Public Works and Transportation, House of Representatives. *Aircraft Certification, New FAA Approach Needed to Meet Challenges of Advanced Technology*. September 1993. Report GAO/RCED-93-155.

> The FAA has not ensured that its staff is effectively involved in a certification process that delegates the vast majority of responsibilities to aircraft manufacturers. Despite the National Academy of Sciences' recommendation in 1980 that the FAA develop a more structured role in the certification process, the agency has increasingly delegated duties to manufacturers without defining such a role….As a result, FAA staff no longer conduct all of such critical activities as the approval of test plans and analyses of hypothetical failures of systems….
>
> Under the direction of the National Academy of Sciences, the ["blue-ribbon" committee to assess the adequacy of the FAA's certification program] reported in 1980 that the FAA's system of delegation to Designated Engineering Representatives (DERs) was sound, in part because the FAA reserved most of the critical activities…for its own staff.[133] The report warned however, that the FAA's technical competence was falling far behind the DERs.

The GAO report issued several recommendations to the Secretary of Transportation, suggesting that the FAA "define a minimum effective role for the agency in the certification process by identifying critical activities requiring the FAA's involvement or oversight; establish guidance and the necessary level and quality of the oversight of the designees; and develop measures through which a staff member's effectiveness can be evaluated." The GAO also recommended that the FAA formally examine the need to hire experts in areas of technological advancement, specifically citing the area of icing, as follows:

> For example, according to the certification staff, the FAA has no one who is maintaining state-of-the-art expertise in the effects of ice on new airplane designs, as the relevant position in the program has been vacant since 1987….Because the position has not been filled and engineers with some expertise in this area are retiring, the new staff are falling farther behind in understanding the principles and effects of ice.

The GAO recommended that the Secretary of Transportation direct the FAA Administrator to formally examine the need to hire NRSs in areas of technological advancement over the preceding 14 years and to require NRS involvement early in the certification process and at other key certification junctures. The FAA responded that it periodically assesses its NRS program. Subsequently (in winter 1996/1997), the FAA hired its current Environmental Icing NRS.

Further, during its investigation of the ATR-72 accident near Roselawn, Indiana, the Safety Board observed deficiencies in the FAA's organizational structure and communications system that resulted in AEG personnel not receiving pertinent information regarding domestic- and foreign-manufactured aircraft. The Board's report concluded that the

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[133] *Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft*, National Academy of Sciences, National Research Council, Committee on FAA Airworthiness Certification Procedures (June 1980).

inadequately defined lines of communication and the inadequate means for retrieval of information prevented effective monitoring of the continuing airworthiness of the ATR-72, and stated the following, in part:

> This deficiency in communication resulted in the AEG's failure to receive pertinent documentation…that could have been used to monitor the continued airworthiness of the airplane. Further, this is not the first time that the Safety Board has identified problems with the timeliness and effectiveness of the FAA's continuing airworthiness oversight of foreign-built aircraft. The Safety Board noted in its 1987 report on the crash of a CASA C-212-CC…that there "was an apparent lack of standardization and coordination" among various offices within the FAA.[134]

As a result of the noted deficiencies in the FAA's monitoring and communication of in-service fleet history, the Safety Board issued Safety Recommendation A-96-062 with the Roselawn accident report, recommending that the FAA do the following:

> Develop an organizational structure and a communications system that will enable the aircraft evaluation group (AEG) to obtain and record all domestic and foreign aircraft and parts/systems manufacturers' reports and analyses concerning incidents and accidents involving aircraft types operated in the United States, and ensure that the information is collected in a timely manner for effective…monitoring of the continued airworthiness of aircraft.

In response to the recommendation, on April 30, 1997, FAA and Safety Board staff had a meeting at which they discussed the respective roles of the various FAA offices regarding effective communications, monitoring continuing airworthiness, and the specific problems observed by the Board during the Roselawn investigation. Based on discussions at the meeting, the FAA agreed that it would review its then current organizational structure and processes regarding communications and monitoring the continuing airworthiness of aircraft. In its August 20, 1997, letter, the Safety Board agreed that if upon completion of the FAA's review, the FAA could assure the Safety Board that it had remedied any deficiencies, the safety recommendation could be closed in an acceptable status. On August 20, 1997, the Safety Board classified Safety Recommendation A-96-062 "Open—Acceptable Response." Then, on February 25, 1998, the FAA responded that it had "initiated positive improvements to its continued airworthiness review process" and had taken other actions, including doubling the Standardization Branch staff and instituting a new database to track foreign airworthiness matters more closely. Safety Board and FAA staff met several times on this issue. In the interim, the Safety Board has received, and is evaluating, a petition for reconsideration from the Director General de l'Aviation Civile (DGAC) of France, which bears on the certification of the ATR-72. Pending the outcome of the evaluation, Safety Recommendation A-96-062 remains classified "Open—Acceptable Response."

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[134] See National Transportation Safety Board. 1988. *Fischer Bros. Aviation, Inc., dba Northwest Airlink, Flight 2268, Construcciones Aeronauticas, S/A (CASA) C-212-CC, Detroit Metropolitan/Wayne County Airport, Romulus, Michigan, March 4, 1987.* Aircraft Accident Report NTSB/AAR-88-08. Washington, DC.

According to the FAA's October 1, 1997, memo, the FAA Aircraft Certification Service and Flight Standards Service "are in the midst of a special project to review AFM and…Operating Manual revision processes, including the level of review and approval of those revisions and the lines of communication between certification and operations specialists. The final report and recommendations resulting from this project are being developed." On June 11, 1998, FAA management personnel advised the Safety Board that they had completed their review, in which they identified inadequacies in the FAA's internal communications procedures. The FAA's 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.

1.18 Additional Information

1.18.1 Aerodynamic Effects of Rough Ice Accumulations on Airplanes' Flight Handling Characteristics

The adverse aerodynamic effects of surface roughness have been known to aerodynamicists and engineers since the late 1930s/early 1940s, when NACA conducted research (and began to publish reports based on its research) related to the lift and drag characteristics of airfoils and the effects of surface roughness and ice accumulation. For example, in 1933, NACA published its technical note (TN) 457, which concluded the following, in part:

> [T]ests on airfoils…indicate that serious adverse effects on the aerodynamic characteristics are caused by surface roughnesses so small that they may ordinarily be overlooked.
>
> The airflow over the leading edge of an airfoil is sensitive to both the location and size of an irregularity….Irregularities and scratches 0.0002 [airfoil chord] in depth and not more than 0.016 [airfoil chord] distant from the leading edge were found to be sufficient to cause measurable adverse effects.

The book "Theory of Wing Sections: Including a Summary of Airfoil Data," by Abbott and Von Doenhoff (first published in 1949 and updated in 1959) contained a compilation of the NACA data. According to the NACA data cited in this book, measurements of the effects of surface irregularities on the characteristics of wings have shown that the stall AOA is particularly sensitive to leading edge roughness and that surface roughness results in substantial increases in drag. The standard leading edge roughness selected by NACA (for the 24 inch chord airfoil used in NACA's research) consisted of 0.011 inch carborundum grains applied to cover 5 to 10 percent of the surface extending from the leading edge aft to 8 percent of the airfoil's chord on both upper and lower surfaces. This standard was considered "more severe than that caused by usual manufacturing irregularities or deterioration in service, but…less severe than that likely to be encountered in service as a result of ice, mud, or damage."

A review of the coefficient-of-lift curves for numerous airfoils (with various chords, thicknesses, cambers, etc.) revealed that surface roughness on the airfoils reduced the stall AOA significantly[135]; for example, the curve for the NACA 23012 airfoil indicated that standard roughness on the airfoil resulted in a decrease in stall AOA of nearly 6°. (The 23012 airfoil and derivatives of it are commonly used in modern airplane designs, including the EMB-120, the ATR-42 and -72, the Beech King Air series airplanes, and the Mitsubishi MU-2.) The coefficient-of-lift curves for several representative airfoils, including the NACA 23012 airfoil, are included in appendix F.

Based on the research information that existed at the time, in the late 1940s and 1950s, the Civil Aeronautics Board (CAB—the predecessor to the FAA) developed icing certification regulations, standards, and criteria; the current appendix C icing envelope was subsequently published on August 25, 1955.

Additional information regarding the hazards of small amounts of surface roughness/ice accumulation has become available through continued research and tests, some of which were conducted as a result of icing-related airplane accidents that occurred from the 1960s to the present. During the late 1960s and 1970s (and later in the 1980s and early 1990s), a series of accidents involving DC-9-10 series airplanes[136] made the aviation industry aware of the hazards of small amounts of rough ice on the upper wing surface. The Safety Board found that the cause of each of these accidents was related to an attempt to take off with small amounts of rough ice on the airfoil that prevented the wings from producing the normal and required amount of lift. As a result of the DC-9-10 series airplane accidents, the Deputy Chief Design Engineer, DC-9 Program, Douglas Aircraft Company, began collecting data regarding the effects of surface roughness (caused by frost, ice, large amounts of insect debris, badly chipped paint, etc.) on stall AOA.[137]

In January 1979, a technical article authored by Douglas' design engineer stated that "Most flight crew members are aware of the highly adverse aerodynamic effects of large amounts of [ice],…the irregular shapes that can form on the leading edge during an icing encounter. However, what is not so popularly know is that seemingly insignificant amounts of wing surface roughness" could significantly degrade an airplane's performance. The article further stated the following:

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[135] The roughness did not affect the stall AOA for the NACA 00-series airfoils of 6 percent thickness as significantly as it affected the stall AOA for the other NACA airfoils.

[136] See: National Transportation Safety Board. 1970. *Ozark Airlines, Inc., McDonnell Douglas DC-9-15, N947Z, Sioux City Airport, Sioux City, Iowa, December 27, 1968.* Aircraft Accident Report NTSB/AAR-70/20. Washington, DC; National Transportation Safety Board. 1979. *Trans World Airlines, Flight 505, McDonnell Douglas DC-9-10, Newark International Airport, Newark, New Jersey, November 27, 1978.* Washington, DC; National Transportation Safety Board. *Airborne Express, Flight 125, McDonnell Douglas DC-9-15, Philadelphia International Airport, Philadelphia, Pennsylvania, February 5, 1985.* Washington, DC; National Transportation Safety Board. 1988. *Continental Airlines, Flight 1713, McDonnell Douglas DC-9-14, Stapleton International Airport, Denver, Colorado, November 15, 1987.* Aircraft Accident Report NTSB/AAR-88/09. Washington, DC; and National Transportation Safety Board. 1991. *Ryan International Airlines, DC-9-15, N565PC, Cleveland-Hopkins International Airport, Cleveland, Ohio, February 17, 1991.* Aircraft Accident Report NTSB/AAR-91/09. Washington, DC.

[137] Technical documents were produced by R. E. Brumby, then Deputy Chief Design Engineer of Douglas Aircraft Company's DC-9 Program, and were published in July 1970, January 1979, December 1982, June 1985, January 1989, and April/May 1991.

> [A] flightcrew may be called upon to decide if a particular amount of roughness and its location are sufficient to significantly degrade the aircraft's flight characteristics. The intent of this article is to assist in that decision-making by providing an insight into the effects of small amounts of wing surface roughness….
>
> Most aircraft are designed for the stall to begin inboard [on the wing] in order to maintain lateral control as long as possible, and to achieve satisfactory pitching characteristics throughout the stall….
>
> The effects of small amounts of wing surface roughness may not be particularly noticeable to a flightcrew operating within the normal flight envelope. Since all transport aircraft operating speeds have some margin above the actual smooth wing stall speeds, the roughness effects may have only decreased that margin. For example, a 1.3Vs approach speed may have had margin reduced to 1.1Vs, leaving little actual stall margin for maneuvering or gust tolerance.
>
> The article concluded the following, in part:
>
> Accumulations equivalent to medium or coarse sandpaper covering the full span of the wing's leading edge can cause a significant increase in stall speeds, leading to the possibility of a stall prior to the activation of stall warning.
>
> Unsymmetrical roughness can cause wing drop, or rolloff, at stall.
> Roughness occurring slightly aft of the leading edge on the wing's lower surface will have little effect on stall.

Also in 1979, as a result of wind tunnel research into tailplane icing events, Trunov and Ingelman-Sundberg published a report[138] in which they concluded, "An icing layer which has a relatively small effect on cruising speed can have a large effect on the stall speed." They further concluded, "a roughness band on the leading edge with a roughness height only 1/1300 of the chord, reduced the maximum lift and altered the elevator hinge moment dramatically, almost as much as the large deposits did."

Based on its concerns about aircraft operations in icing conditions and the varying consequences that ice accretions had on different aircraft types following a series of icing-related accidents, the Safety Board conducted a special study, and in September 1981, published a report entitled "Aircraft Icing Avoidance and Protection."[139] The Safety Board's report stated, in part, that the "icing criteria for aircraft certification as defined in 14 CFR Part 25 are based upon research done by NASA in the…1950's with the transport aircraft of that period. Although the

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[138] *Wind Tunnel Investigations of the Hazardous Tail Stall Due to Icing*, by M. Ingelman-Sundberg and O. K. Trunov; a joint report from the Swedish-Soviet Working Group on Scientific-Technical Cooperation in the Field of Flight Safety, Report No. JR-2, 1979.

[139] See National Transportation Safety Board. 1981. *Aircraft Icing Avoidance and Protection, September 9, 1981*. Safety Report NTSB-SR-81-1. Washington, DC.

results of this research and the ensuing practices and regulations that came out of it are still basically valid, there have been changes in aircraft, deicing/anti-icing equipment, and improvements in the instruments used to measure atmospheric icing parameters." The Board's report included a recommendation that the FAA review the icing criteria published in Part 25 "in light of both recent research into aircraft ice accretion…and recent developments in both the design and use of aircraft" and expand the appendix C envelope as necessary. (The Safety Board's report and the recommendations it contained are discussed in detail in section 1.18.4.)

AC 20-117, "Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing," was issued by the FAA on December 17, 1982,[140] and states that "misconceptions exist regarding the effect of slight surface roughness caused by ice accumulations on aircraft performance and flight characteristics." The AC further states, in part, the following:

> Regulations were established by the [CAB] in 1950 prohibiting takeoff…when frost, snow, or ice is adhering to wings, propellers, or control surfaces of the aircraft. These regulations remain in effect….The basis of these regulations, which are commonly referred to as the clean aircraft concept, is known degradation of aircraft performance and changes of aircraft flight characteristics when ice formations of any type are present….Wind tunnel and flight tests indicate that ice, frost, or snow on the leading edge and upper surface of a wing, having a thickness and surface roughness similar to medium or coarse sandpaper, can reduce wing lift by as much as 30 percent and increase drag by 40 percent. These changes…will significantly increase stall speed, reduce controllability and alter aircraft flight characteristics….
>
> …If ice formations are present, other than those considered in the certification process, the airworthiness of the aircraft may be invalid and no attempt should be made to fly the aircraft until it has been restored to the clean [condition].

Appendix 3 to AC 20-117, entitled "General Information Relating to Ground and Flight Operations in Conditions Conducive to Aircraft Icing," states, "This appendix provides general information necessary for the overall understanding of these hazards and includes causes and effects of ice formations (induced on the ground or in flight)." The appendix further states the following:

> The effects that inflight or ground accreted ice formations will have on aircraft performance and flight characteristics are many, are varied and are highly dependent upon aircraft design, ice surface roughness, ice shape, and areas covered.

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[140] AC 20-117 was reissued by the FAA on March 29, 1988. According to a notice on the AC, "Recent accidents involving large transport and small general aviation aircraft have prompted the Federal Aviation Administration to re-distribute AC 20-117." There were no changes to the text of the AC.

> Aircraft that are certificated for flight in icing conditions are equipped with ice protection systems to reduce the adverse effects of ice formations, either by preventing the formation of ice (anti-icing) or by periodically removing ice (deicing)….Aircraft so certificated have been demonstrated to be capable of safe flight with ice of certain shapes adhering to critical areas.
>
> Slight surface roughness can have significant effects on stall speed and power required to achieve or sustain flight….Stall angle-of-attack will decrease and in some aircraft stall will occur prior to activation of stall warning devices….

Appendix 1 to the AC contained lists of FAA and other related publications and materials, several of which were dated in the late 1960s and 1970s.

In its report regarding the February 17, 1991, accident involving a Ryan International Airlines DC-9 that crashed on takeoff at Cleveland-Hopkins International Airport in Cleveland, Ohio, the Safety Board cited another technical paper prepared by the Deputy Chief Design Engineer, DC-9 Program, Douglas Aircraft Company, entitled, "The Effect of Wing Ice Contamination on Essential Flight Characteristics." This paper was presented in 1988 and again (after the Ryan accident) in 1991. The technical paper stated the following, in part:

> Contamination of critical aerodynamic surfaces by ice, frost, and/or snow has been identified as the probable cause of a significant number of aircraft accidents. In most cases, the ice contamination has not been large ice accretions on the leading edges or thick layers of adhering snow on the top of the wings. Rather, dangerous reduction in stall margins and handling qualities can occur because of ice-related roughness equivalent to that of medium-grit sandpaper.
>
> The most predominant adverse effect of ice contamination is on the lifting characteristics of the wing. It may be recalled that wing lift coefficient varies with angle of attack….Under normal conditions, the airflow over a wing smoothly follows the shape of the wing….At some fairly high angle of attack, the airflow begins separating from the wing, causing the lift curve to become nonlinear, or "break."
>
> The normal variation of lift with angle of attack can be significantly altered by ice contamination….reduce the maximum lift capability of the wing, and cause the wing to stall at a lower than normal angle of attack.…the increasingly unsteady airflow over the wing results in correspondingly degraded lateral stability, requiring larger and larger control wheel inputs to keep the aircraft from rolling off.
>
> The report concluded the following:
>
> From an aerodynamic viewpoint, there is no such thing as "a little ice." Strict attention should be focused on ensuring that critical aircraft surfaces are free

of ice contamination.

Further, as a result of the DC-9 accident at Cleveland, on March 21, 1991, Douglas issued a letter to DC-9 operators describing the hazards of surface roughness ice accumulations. This letter stated, in part, "recent…data for slight roughness extending aftward from the leading edge to about 7-percent chord on both the upper and lower surfaces…can cause lift losses similar to those caused by a fully roughened upper surface….We hope that you will make the contents of this letter widely available to your flight crews, ground crews, and flight training people." Douglas' letter to the operators included a list of 20 related articles and publications, the earliest of which was dated January 30, 1969.

The Safety Board's report regarding the Ryan International Airlines accident at Cleveland stated, "The written material, industry presentations, and operator seminars that were offered for more than 20 years should have eliminated any operational problem with icing….However, similar accidents continue to occur….no real understanding of the significance of the problem has been evident….Accumulations of ice as thin as 0.015 inch…can reduce the stall angle of attack below stall warning activation."

As a result of the series of DC-9 accidents, several other technical articles addressing the hazards of small amounts of rough ice were published in aviation industry magazines and in All Operators Letters over a period of 20 years. Further, the subject of the aerodynamic effects of rough ice was addressed at numerous aviation industry seminars and conferences.

Additionally, from the late 1980s through the 1990s, several series of icing-related incidents and accidents involving turbopropeller-driven airplanes drew attention to the hazards of operating in SLD icing conditions and runback ice accretions (ATR-42/-72 incidents and accidents, including Roselawn), tailplane ice accretions (BA-3100 accidents at Pasco, Washington, and Beckley, West Virginia), and (again) thin, rough ice accretions (EMB-120 incidents and accidents, including Comair flight 3272 at Monroe, Michigan). During this time, numerous aviation industry icing-related conferences and seminars were conducted, and significant icing-related research and testing occurred. These events are discussed in detail in section 1.18.

The adverse aerodynamic effects of surface roughness (ice) was also addressed in a 1996 report prepared by an FAA engineer, entitled "Pilots Can Minimize the Likelihood of Roll Upset in Severe Icing."[141] In this report, the FAA engineer stated that "in recent years, reports of roll excursions associated with icing appear to have increased in frequency, especially among turbopropeller airplanes used in regional airline commuter operations." The report

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[141] Flight Safety Foundation's Flight Safety Digest. 1996. *Pilots Can Minimize the Likelihood of Roll Upset in Severe Icing*, by John P. Dow, Sr., Volume 15, No. 1, January 1996. This FAA Aviation Safety Engineer (Small Airplane Directorate) reviewed and evaluated all potential icing-related incidents and accidents after the Roselawn accident; this article and the January 26, 1996, draft memo (addressed in section 1.18.2.3) was the result of his review and evaluation of incidents and accidents that were documented at the time.

suggested that the increase may be the result of the increased number of regional operations,[142] exacerbated by the conditions in which the turbopropeller-driven airplanes generally operate—the turbopropeller-driven airplanes typically remain at lower altitudes for longer periods of time than larger jet aircraft and thus are exposed to icing conditions for a greater percentage of their flight time.

The report stated that different airfoil designs are more sensitive to lift loss with ice accretion than others and that an infinite variety of shapes, thicknesses, and textures of ice can accrete at various locations on an airfoil. According to the report, "[e]ach ice shape essentially produces a new airfoil with unique lift, drag, stall angles and pitching moment characteristics that are different from the wing's own airfoil, and from other ice shapes….Sometimes the difference in ice accretion between a benign shape and a more hazardous shape appears insignificant….Ice can contribute to partial or total wing stall followed by roll, aileron snatch or reduced aileron effectiveness."

The FAA engineer's report stated that to further complicate the ice accretion/effect formula, wings are typically designed with a different airfoil at the tip than at the root; the wing tip is often thinner, shorter chordwise, with a different camber relative to the wing root section. However, the report also indicated that when the airfoil started to accrete ice, the wing tip becomes "a more efficient ice collector" percentage-wise, and ice accretion there has a more adverse effect. (According to the report, operating at lower AOAs in icing conditions tends to exacerbate the accretion on the upper wing surface.)

1.18.1.1 New Technology in Ice Detection/Protection Systems

The FAA engineer's report, "Pilots Can Minimize the Likelihood of Roll Upset in Severe Icing," also cited recent advancements in ice protection systems, including a high-pressure pneumatic system that uses a 600 pounds per square inch (psi) pulse of air to reliably clear ice of as little as 0.02 inch thickness. Also, electrothermal systems consisting of metal-coated fibers embedded within the airframe's paint system and combined electrothermal/conventional pneumatic boot systems are being tested. Another feature of the new technologies is a closed-loop operation in which a detector signals that ice has accreted, and cycles the deice system; this system would allow independent activation of deicing boot surfaces.

During the November 1997 Airplane Deicing Boot Ice Bridging Workshop (which will be discussed further in section 1.18.4.2), B.F. Goodrich personnel presented information about a "SMARTboot" ice detection/alert system that they developed in response to tailplane icing concerns. (The FAA issued STCs in June 1997, and the system is currently being installed as standard equipment on Piper Malibus/Malibu Mirages.) According to B.F. Goodrich, the system will perform the following tasks:

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[142] The report states, "[I]n 1975, the total number of annual departures for all U.S. major airlines was 4.74 million…in 1994…, the regional segment alone [had] grown to 4.6 million annual departures."

- Detect and measure ice build up
- Indicate when to activate the system
- Confirm deicer inflation
- Verify ice removal
- Detect any residual ice

In addition, according to the FAA's Environmental Icing NRS, ATR installed a new ice detector on two flight test and seven in-service ATR-72s, at 5 percent and 7 percent chord, for a flight test period that continued for about 1 year, and ended in spring 1997. The new ice detector was designed to sense ice accretion behind the extended deicing boots. According to the FAA's Environmental Icing NRS, the results of the initial tests indicated that the detector configuration was inadequate (two confirmed SLD encounters were undetected by the system); he indicated that ATR would continue to test alternatives to that system/configuration.

1.18.2 Chronology of EMB-120 Icing-Related Events and Information

(Figure 13 is a chronology of EMB-120 icing-related events/information.)

1.18.2.1 Preaccident EMB-120 Icing-Related Events/Information

At the time of the accident, the Safety Board had investigated one previous EMB-120 icing-related accident;[143] however, a review of the FAA's accident/incident and NASA's Aviation Safety Reporting System (ASRS) databases revealed that five additional EMB-120 icing-related events were reported between June 1989 and the day of the Comair flight 3272 accident.[144] The six accidents/incidents are summarized in figure 14 and are described in the following text:

- In April 1995, near Tallahassee, Florida, an EMB-120 was in cruise flight at FL 250, when the pilots noticed the airspeed decrease from 180 KIAS to 140 KIAS, pitch increase to 5° nose up, with only trace icing observed on the leading edge of the wing. They activated the deice boots; the airspeed subsequently increased, and the pitch decreased.

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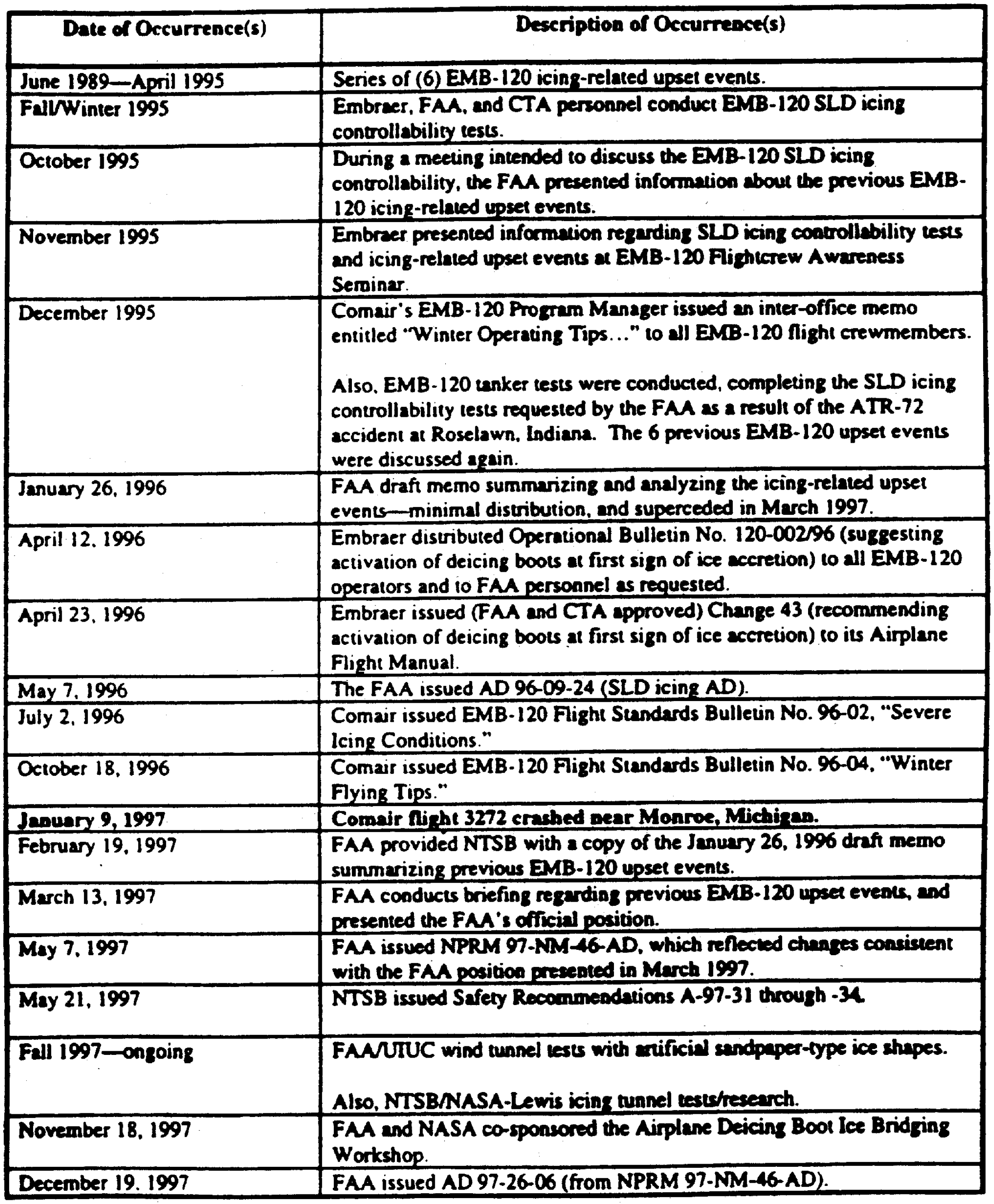
[143] See National Transportation Safety Board. 1994. *Continental Express, Inc., Embraer EMB-120RT, N24706, Pine Bluff, Arkansas, April 29, 1993*. Aircraft Accident Report NTSB/AAR-94/02. Washington, DC.

[144] For additional information regarding four of the five incidents, see ASRS reports 115422, 189745, 286127, and 302910. The 5th incident occurred in France and was reported to Safety Board staff during the Safety Board's investigation of the ATR-72 accident at Roselawn, Indiana.



Date of Occurrence(s)	Description of Occurrence(s)
June 1989—April 1995	Series of (6) EMB-120 icing-related upset events.
Fall/Winter 1995	Embraer, FAA, and CTA personnel conduct EMB-120 SLD icing controllability tests.
October 1995	During a meeting intended to discuss the EMB-120 SLD icing controllability, the FAA presented information about the previous EMB-120 icing-related upset events.
November 1995	Embraer presented information regarding SLD icing controllability tests and icing-related upset events at EMB-120 Flightcrew Awareness Seminar.
December 1995	Comair's EMB-120 Program Manager issued an inter-office memo entitled "Winter Operating Tips..." to all EMB-120 flight crewmembers. Also, EMB-120 tanker tests were conducted, completing the SLD icing controllability tests requested by the FAA as a result of the ATR-72 accident at Roselawn, Indiana. The 6 previous EMB-120 upset events were discussed again.
January 26, 1996	FAA draft memo summarizing and analyzing the icing-related upset events—minimal distribution, and superceded in March 1997.
April 12, 1996	Embraer distributed Operational Bulletin No. 120-002/96 (suggesting activation of deicing boots at first sign of ice accretion) to all EMB-120 operators and to FAA personnel as requested.
April 23, 1996	Embraer issued (FAA and CTA approved) Change 43 (recommending activation of deicing boots at first sign of ice accretion) to its Airplane Flight Manual.
May 7, 1996	The FAA issued AD 96-09-24 (SLD icing AD).
July 2, 1996	Comair issued EMB-120 Flight Standards Bulletin No. 96-02, "Severe Icing Conditions."
October 18, 1996	Comair issued EMB-120 Flight Standards Bulletin No. 96-04, "Winter Flying Tips."
January 9, 1997	**Comair flight 3272 crashed near Monroe, Michigan.**
February 19, 1997	FAA provided NTSB with a copy of the January 26, 1996 draft memo summarizing previous EMB-120 upset events.
March 13, 1997	FAA conducts briefing regarding previous EMB-120 upset events, and presented the FAA's official position.
May 7, 1997	FAA issued NPRM 97-NM-46-AD, which reflected changes consistent with the FAA position presented in March 1997.
May 21, 1997	NTSB issued Safety Recommendations A-97-31 through -34.
Fall 1997—ongoing	FAA/UIUC wind tunnel tests with artificial sandpaper-type ice shapes. Also, NTSB/NASA-Lewis icing tunnel tests/research.
November 18, 1997	FAA and NASA co-sponsored the Airplane Deicing Boot Ice Bridging Workshop.
December 19, 1997	FAA issued AD 97-26-06 (from NPRM 97-NM-46-AD).

Figure 13.--Chronology of EMB-120 icing-related events/information.

- On October 16, 1994, near Elko, Nevada, an EMB-120 was in cruise flight at 13,000 feet msl, at 160 KIAS. The pilots checked for ice on the wings and propeller spinners but did not see a significant amount; moments later, as they entered a right bank with the autopilot engaged, the stick shaker and pusher activated. The pilots resumed manual control of the airplane and recovered. Postflight inspection of the aircraft revealed clear ice on the leading edge and spinner. The deice boots were not activated during the flight because the crew did not believe the ice was of sufficient thickness. Review of the FDR data indicated that the airplane's airspeed had decreased to 138 KIAS before stick shaker activation.
- On April 23, 1993, at Pine Bluff, Arkansas, while climbing on autopilot, an EMB-120 stalled, experienced an upset event and subsequent separation of propeller blades. FDR data indicated that the airplane's airspeed had decreased to 138 knots before stick shaker activation and autopilot disconnect. The Safety Board concluded that an accretion of ice on the wing was the only reasonable explanation for the occurrence of stick shaker activation and subsequent loss of roll control at higher than expected airspeeds. There was no evidence that any ice protection systems were activated before, during, or after the upset, and the flightcrew did not recall seeing evidence of icing before the loss of control.
- On November 22, 1991, in Clermont-Ferrand, France, an EMB-120 was in an autopilot-controlled descent when the captain disconnected the autopilot manually to slow the descent, stabilizing the aircraft at 4,500 feet. FDR data indicated that the airplane's airspeed decreased to 150 KIAS, the stick shaker activated, the airplane rolled to the right and lost about 1,000 feet of altitude. During recovery, the engine power was increased and the deice boots were cycled by the first officer. Postflight inspection revealed clear ice on the horizontal stabilizer, wing tips, and inboard section of the wing.
- In September, 1991, at Fort Smith, Arkansas, an airplane[145] was in level flight with the autopilot engaged at 19,000 feet msl when the pilots felt vibration through the floorboards. The pilots inspected the wings, propeller spinners, and engine inlets for ice, but did not observe excessive amounts of ice. Thirty seconds after the first vibration, the stick shaker activated and the captain called for all ice protection equipment on. The airplane entered a right bank, nose-down descent; the pilots regained control at 16,000 feet msl.

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[145] Although the type of airplane was not specified in the ASRS report, the airplane was identified as an EMB-120 based on the pilots' description of the airplane and its systems; according to the FAA, the EMB-120 is the only low-wing, T-tail airplane equipped with ice protection system failure lights.

Event	Summary	Attitude After Upset	Crew Aware Of Ice Condition/ Thickness	Wing &Tail De-Ice ON Before Upset	A/P ON Prior To Upset	Airspeed (KIAS)	Altitude Phase	Bank Angle At Upset	Meteoro-logical Conditions	Ice Type Severity	Altitude Loss
Tallahassee, Fl. April 95	Speed. Dec.	No Upset	Yes	No Upset	No Upset	180 - 140	25,000 level	No Upset	IMC	Trace	No
Elko, NV October 94	Shaker, pusher, stall, roll upset	90°	Yes	No	Yes	150 (138 on DFDR)	13,000 level	20°	Night IMC	Clear	not available
Pine Bluff, AR April 93	Shaker, pusher, stall, roll upset	90°roll -67° pitch	No	No	Yes	145	17,000 climb	not available	Day IMC	Rime	14,500
Clermont-Ferrand, FR November 91	Shaker, stall roll upset	≈ 80°	No	No	No	150 on DFDR	4,500 level	not available	Night IMC	Clear Severe	1,000
Ft. Smith, AR September 91	Vibration, shaker, stall	not available	Yes	No	No	not available	19,000 level	right bank	Night IMC		3,000
Klamath Falls, OR June 89	Speed dec., shaker, roll upset	40°	Yes	not available	not avail-able	160 decr.	15,000	not available	Day IMC	Mixed rime/clear Heavy?	3,000

Figure 14.--EMB-120 in-flight icing event summary.

- On June 28, 1989, at Klamath Falls, Oregon, an EMB-120 was operating at 16,000 feet msl in icing and turbulence with the autopilot engaged. When the airplane descended to 15,000 feet msl, the pilots observed light mixed rime and clear ice, followed by a rapid decrease in airspeed from 180 to 160 KIAS, stick shaker activation, and an uncommanded roll/upset. The pilots resumed manual control of the airplane and applied maximum power; they restabilized the airplane at 12,000 feet msl. Both pilots reported that the airplane was operating in light icing conditions when the upset occurred. (Although the pilots reported light icing, ALPA's [Air Line Pilots Association] report of this incident stated that a United Airlines Boeing 727 flight engineer occupying seat 3C in the cabin described the icing conditions as "moderate" and indicated that up to 1 inch of ice may have accumulated on the wing leading edges.) There was no indication in the FDR data or the ASRS report that any ice protection equipment was used.

After the ATR-72 accident near Roselawn, Indiana, the FAA conducted a review of in-service accidents and incidents involving roll axis control events in icing conditions and identified about 50 events, including the 6 EMB-120 events listed above. The FAA held a meeting (attended by FAA, CTA, ALPA, Embraer, and Safety Board personnel, and representatives from EMB-120 operators—including Comair) on November 7, 1995, to discuss the results of the EMB-120 SLD icing controllability tests that had been accomplished at the time.[146] During this meeting, the FAA gave a presentation summarizing the six previous EMB-120 icing-related events and discussed possible remedial actions with all involved parties. According to FAA personnel, the six incidents were discussed among FAA, CTA, Embraer, and Comair personnel at numerous subsequent meetings, including Embraer's Flightcrew Awareness Seminar (see section 1.18.2.2) and during the SLD icing tanker tests.

1.18.2.2 EMB-120 Flightcrew Awareness Seminar—November 1995

On November 15, 1995, Embraer held an EMB-120 Flight Crew Awareness Seminar for EMB-120 operators and other interested parties, during which the six events and possible remedial actions were further discussed. The stated purpose of the seminar was as follows:

- To discuss operation of the EMB-120 in icing conditions.
- To generate recommendations for a flightcrew awareness program to be implemented by EMB-120 operators.
- To recommend changes or additions to aircraft publications regarding operations in icing conditions.

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[146] As previously discussed, during EMB-120 tests with 1-inch quarter-round ice shapes, the control wheel force required to return to a wings-level condition exceeded the maximum control wheel force allowed by the FAA for certification.

- To identify any specific test points to be incorporated in the icing tanker tests to be conducted in the near future.

According to the meeting minutes, the seminar attendees included three representatives each from Embraer and Comair (Comair attendees included the DO, the EMB-120 Program Manager, and the Assistant Chief Inspector) and one representative each from Mesa Airgroup, ASA, Skywest Airlines, and the FAA's Miami Flight Standards Service. The meeting minutes indicated that representatives from other EMB-120 operators (Great Lakes Aviation and Continental Express) were unable to attend but were informed of the meeting issues and recommendations.

During the seminar, Embraer briefed the attendees regarding the results of the quarter-round artificial ice shape controllability testing that had been completed at that time, described the planned in-flight tanker tests (which took place in December 1995), and conducted discussions regarding aircraft characteristics, aircraft procedures, and FAA/ATC topics, including the following: aircraft flight characteristics in icing, ice recognition and monitoring, autopilot characteristics in icing conditions, stall warning system characteristics, autopilot modes of operation/procedures, approach and landing in icing conditions with and without deice system failures, escape procedures for SLD icing encounters, and identification of icing conditions in weather reports and forecasts.

Although the meeting attendees reported that in-service experience had not revealed any specific or unique problems associated with the operation of the EMB-120 in icing conditions, the group did discuss the previous EMB-120 icing events (previously discussed in section 1.18.2.1). The meeting attendees noted that the icing events demonstrated crew awareness and procedural issues such as a "lack of proper monitoring of ice formation," "probable failure to properly operate the leading edge deicing systems," "improper use of autopilot modes," and "failure to maintain speed in a turn with the autopilot engaged."

The seminar discussions resulted in eight recommendations to Embraer, including the following:

- Consider the effects of missing vortex generators relative to ice shapes ahead of the ailerons and determine if testing in this area is warranted.

- Make the following changes to the EMB-120 AFM:….add notes regarding airspeed increases in icing conditions to the applicable abnormal procedures section.

- Produce an OB to address operation of the EMB-120 in icing conditions. The group recommended that the OB include information pertaining to the following: identification of various ice types and unique signatures applicable to the EMB-120; decreased stall margins with ice on the aircraft; temperature ranges and conditions conducive to ice formation; autopilot mode usage; recommended airspeeds for all phases of flight in icing conditions; proper monitoring of ice formation; proper operation and testing of the deice systems; and stall warning system operation relative to operations in ice. According to the meeting minutes, "[t]his document would form the basis for operator crew awareness programs and would be distributed through current communication channels." (Embraer issued OB 120-002/96 in April 1996—the bulletin will be discussed further in section 1.18.2.4.)

- Investigate low cost visual aids that would help pilots identify clear ice and gauge the thickness of ice formation during night operations.

As a result of the November 1995 meeting, on December 8, 1995, Comair's EMB-120 Program Manager issued an interoffice memo, entitled "Winter Operating Tips—Freezing Rain/Drizzle," to all EMB-120/SAAB 340 flight crewmembers. The memo advised the pilots that routine vigilance and proper operation of ice protection systems should suffice to safely manage flight in icing conditions that fall within the Part 25 appendix C envelope; however, it stated "[t]here have been incidents of EMB-120 aircraft flown by other carriers encountering [icing] conditions, which resulted in controllability problems….major factors…were lack of airspeed control (and operation of the autopilot in the wrong vertical mode causing airspeed deviations); [and] failure to recognize the ice accumulation and utilize the installed deicing equipment." The memo listed guidelines for operations in icing conditions within the Part 25 appendix C envelope, including the following:

> **Autopilot Use**
>
> If icing conditions are experienced or residual ice is present, operate the autopilot in the IAS mode only (climb). The IAS mode will allow the aircraft to descend if airspeed cannot be maintained at the present power setting. Other autopilot modes will allow the aircraft to slow in order to hold the selected mode, or may not give the necessary stall margin required for residual ice on the aircraft. Monitor power settings and increase as necessary.
>
> **Airspeed**
>
> When flying in icing conditions, do not fly the EMB-120 at less than 160 KIAS….This will add to the stall margin when maneuvering with airframe ice….Use a holding speed of 170 KIAS when residual [inter-cycle] airframe icing is suspected. Monitor airspeed closely when in icing conditions, especially in turns.

The memo concluded that the problems associated with operating in icing conditions could be lessened by increased crew vigilance and adherence to the recommended minimum airspeeds while operating in icing conditions. According to Comair's POI, when the company issued an interoffice memo, it posted the memo in a "pilot-read" binder and distributed copies of the memo to all pertinent flight crewmembers via office mailboxes. He indicated that the company typically removed interoffice memos from the book after 30 days and that there was no procedure for documenting whether all pertinent flight crewmembers had read the memo.

The POI further stated that if Comair deemed the contents of the memo significant enough, the company could issue a FSB, or formally revise its FSM to reflect that information. However, the POI indicated that Comair tended to "manage by memo," which he found inadequate, because the memos were only posted for 30 days, and there was "no guarantee that each pilot sees the memos."

The Safety Board's review of Comair's "Instructor Guide 1996 EMB-120 Recurrent Ground School" revealed that the document included several interoffice memos that were issued in 1995 and 1996. However, the December 8, 1995, memo, "Winter Operating Tips" was not included in the instructor guide.

1.18.2.3 FAA Draft Memo and Subsequent Actions

In a January 26, 1996, FAA draft memo, an FAA engineer summarized the incidents and his observations regarding EMB-120 operations in icing conditions. The memo stated that the EMB-120 had demonstrated the following:

- after the ATR-42/72 and the MU2B, the highest number of reported loss of control (not including tailplane) events;
- unexpected rapid onset of unusually high drag with ice accretion visible but not considered significant enough by the crew to warrant operation of the deicing boots;
- total or partial wing stall resulting in roll excursions in icing conditions;
- that the 160 KIAS recommended holding speed may not provide adequate margin above stall when considering maneuvering loads, turbulence and gust encounters with certain kinds of ice accretion;
- that buffet onset with certain kinds of ice accretion may not be present in advance of stall and that the stall protection system may not provide sufficient margin above contaminated wing stall for certain probable icing conditions;
- that the autopilot design features (in the presence of the above conditions) apparently do not provide sufficient characteristics to provide time for the pilot to react, as claimed by the manufacturer, to prevent roll upset;
- a roll characteristic associated with ice that appears to be caused by a different mechanism than the one associated with the Roselawn ATR-72 accident; but,
- a similar history to other ATR-42/-72 events insofar as the EMB-120 airplane with certain kinds of ice accretion may not provide an adequate stall margin for airline pilots of average alertness, skill, or strength.

The author of this draft FAA memo listed the following recommendations:

1.) Handling characteristics be examined at speeds approaching stick pusher thresholds during flight test with acceptable artificial ice shapes to determine if adequate stall warning margins exist with unclearable ice.
2.) If adequate stall warning margins do not exist with unclearable ice, develop

appropriate corrective means to prevent ice formation or remove ice on those critical surfaces to maintain safety margins at acceptable levels.

3.) If inadequate stall warning margins are found to exist that cannot be corrected by preventing ice from forming or removing it periodically, then reliable means must be provided for the crew to assess conditions on critical surfaces of the airplane so that they can take appropriate action before hazardous degradation of performance or control occurs.
4.) Mandate the appropriate actions by Airworthiness Directive.

The Safety Board became aware of the January 26, 1996, FAA draft memo after the Comair flight 3272 accident occurred, and Safety Board staff subsequently requested a copy of the draft memo from the FAA. On February 19, 1997, the FAA provided Safety Board personnel with the draft memo; however, FAA certification staff emphasized that the draft memo (which contained the signature of the FAA engineer's supervisor) was one engineer's draft summary of the six incidents and had not been widely distributed because it did not represent the FAA's official position regarding the incidents. According to the FAA's EMB-120 Aircraft Certification Program Manager, the draft summary was based on one FAA engineer's assessment of the events; however, the draft summary did not necessarily take into consideration the underlying premise in FAA airplane certification—that flightcrews will operate the airplane and its systems appropriately in all circumstances. For example, the FAA's EMB-120 Aircraft Certification Program Manager pointed out that none of the six EMB-120 icing-related events occurred when the flightcrews had the leading edge deicing boots activated. (The March 1998 Westair flight 7233 EMB-120 roll upset event may be an exception; it may have occurred with deicing boots activated—see section 1.18.2.9 and its subsections for additional information regarding this incident.)

The FAA subsequently organized a meeting (held on March 13, 1997, and attended by Safety Board staff) to review and discuss the EMB-120 icing-related events at the FAA's ACO in Atlanta, Georgia; other attendees included FAA and CTA personnel and representatives from Embraer, ALPA, Comair, and ASA. During this meeting, the FAA indicated that its examination of the available information regarding these six events revealed the following information: (1) five of the six flightcrews reported that an uncommanded roll upset occurred,[147] (2) three of the five flightcrews involved in the uncommanded roll upsets observed the presence of ice (although not significant ice accumulation) before the upset, (3) none of the flightcrews had activated the leading edge deicing systems before the upset occurred, (4) in all five uncommanded roll events, stick shaker activation occurred—and in two events the stick pusher activated, (5) four of the five roll upset events occurred at altitudes of 13,000 feet msl or higher (the remaining event occurred at 4,500 feet msl), and (6) all six icing-related events were recovered without loss of life.

Based on the review of these events, the FAA drew the following preliminary conclusions at the March 13, 1997, meeting:

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[147] The sixth flightcrew observed a 40 knot decrease in airspeed and an increase in pitch attitude (with no change in altitude) that did not correspond to an increase in visible (wing leading edge) ice accumulation. Activation of the leading edge deice system corrected the anomaly; the flightcrew suspected severe tailplane icing.

1. The visual cues were not sufficient for the crew to decide to activate the deice system. Therefore, it is necessary to provide the flightcrew with a more precise method for identifying the need for activation of the deice system.
2. Mandatory activation of the boots with the first indication of ice appears warranted.
3. A minimum maneuver speed, flaps up, during cruise and descent, or revised stall prevention system activation schedules in icing conditions, should be considered.

The FAA partially addressed these issues in Notice of Proposed Rulemaking (NPRM) Docket 97-NM-46-AD and in the resultant AD 97-26-06 (see section 1.18.3).

1.18.2.4 Operational Bulletin 120-002/96/AFM Revision 43—April 1996

On April 12, 1996, Embraer published OB No. 120-002/96 to provide EMB-120 operators and other interested personnel with information regarding the results of the SLD icing controllability tests, including the December 1995 in-flight tanker icing tests, which were conducted following the ATR-72 accident near Roselawn, Indiana. Embraer representatives reported that OB 120-002/96 was distributed to the U.S.-based EMB-120 operators, as follows: Atlantic Southeast Airlines, Inc., Comair, Inc., Continental Express, Inc., Great Lakes Aviation, Ltd., Mesa Airlines, Inc., Skywest Airlines, Inc., and Westair Commuter Airlines, Inc. Additionally, according to Embraer's records, on May 17, 1996, OB No. 120-002/96 was distributed to the following FAA offices: Seattle ACO and AEG, Atlanta ACO, Southern Region Flight Standards Office, Salt Lake City FSDO, and the Program Management Branch of the Flight Standards Service. There was no evidence that Embraer provided Comair's POI (at the FAA's Louisville, Kentucky, FSDO) with a copy of OB 120-002/96; further, Comair's POI reported that he did not receive a copy of the OB until March 1997. (As previously discussed, FAA personnel were not required to approve, forward, act, or comment on the manufacturer's bulletin.)

OB 120-002/96 contained the following guidance with regard to the effects of ice accreted in non-SLD icing conditions:

> When drag is increased due to ice, an increase in angle of attack is required to maintain altitude….such an increase in the angle of attack may lead to a stall, followed by an uncommanded roll excursion if ice accretes asymmetrically in the wing, at a speed somewhat above that normal stall speed for the associated configuration.

In addition, the OB listed procedures for operating in icing conditions within Part 25 appendix C, which included the following instructions: "Monitor ice continuously during…cruise. At the first sign of ice formation, turn all ice protection systems on." OB No. 120-002/96 cautioned readers that its content may not have been approved by airworthiness authorities at the time of issuance and advised that "[i]n the event of conflict with the approved publication (AFM, WB, MMEL, or CDL) the approved information shall prevail."

OB No. 120-002/96 also described the results of the SLD icing controllability tests, stating the following, in part:

> Tests with simulated ice shapes following the icing tanker flights [have] demonstrated the satisfactory handling characteristics of the EMB-120 aircraft under freezing rain and freezing drizzle conditions. Airplane handling was demonstrated to be adequate for safe operation. Aileron control forces are somewhat increased, but still are well within the normal certification limited values.[148]

OB 120-002/96 also stated, “During the [SLD] icing test series, the aircraft demonstrated nominal control response even when flying in SLD conditions. As such, the procedures to be used under those conditions do not differ significantly from that of the normal icing.” A copy of OB No. 120-002/96 is included in appendix G.

As previously mentioned, on April 23, 1996, Embraer issued FAA- and CTA-approved AFM revision 43, which officially revised the ice protection system procedures to include activation of the leading edge deicing boots at the first sign of ice formation. According to Comair’s EMB-120 Program Manager, the company received AFM change 43 on June 13, 1996, after AD 96-09-24 was issued (see section 1.18.2.5 for additional information regarding the AD). According to Comair’s EMB-120 Program Manager, the proposed procedural changes contained in AFM revision 43 were contrary to Comair’s trained procedures and practices; he stated that for years the company had trained pilots to be aware of ice bridging, thought to be the result of early activation of deicing boots. He further stated that Comair personnel believed that enacting the changes would result in potentially unsafe operations because of ice bridging. Therefore, according to Comair’s EMB-120 Program Manager, company personnel decided not to incorporate the procedures described in revision 43 to the EMB-120 AFM into the company’s FSM and training program. Discussions with management personnel at each of the seven U.S.-based EMB-120 operators indicated that at the time of the accident only two of these operators had changed their EMB-120 procedures to reflect the information in revision 43 to the AFM.

During postaccident discussions, B.F. Goodrich Ice Protection Systems personnel stated that icing/wind tunnel tests and flight tests revealed no indication of ice bridging (as previously defined in this report) on airfoils/airplanes equipped with modern, fully functional pneumatic deicing boots. They stated “[g]enerally a cleaner shed [by area] results if the ice layer is allowed to build to the ‘recommended thickness…’ prior to activation. If the de-icers are activated when the ice thickness is less than the ‘recommended thickness,’ the shed will not be as clean (by area). However, even if this occurs, the ice layer will eventually shed when it builds to the recommended thickness.” B.F. Goodrich personnel further stated that because airplanes that are certificated for flight into known icing conditions have been tested and approved for flight in icing conditions as an entire airplane system, “[a]ny airframe manufacturer who wishes to

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[148] As previously discussed, these in-flight icing tanker tests were conducted at airspeeds between 160 and 175 knots.

modify FAA approved operating procedures for activating the pneumatic de-icers should retest the…system and secure FAA approval." In a July 8, 1996, engineering coordination memo from B.F. Goodrich to Embraer on the subject of pneumatic deicer operation, B.F. Goodrich stated the following, in part:

> The basic design of the pneumatic de-icer requires that a layer of ice…be accreted onto the de-icer in the deflated condition, and then inflated to crack the layer of ice which is then removed by the scavenging effect of the air stream over the airfoil….
>
> If the de-icer is used as an anti-icer, the ice thickness may be too thin when the de-icer tubes are inflated to produce the cracking and shearing stresses necessary to break the ice into pieces for removal from the de-icer.
>
> Icing tunnel testing has shown that the anti-ice function of a pneumatic de-icer will…remove small amounts of thin ice during [the initial] inflation cycle allowing the ice still bonded to the de-icer to increase…larger areas will be removed [during subsequent boot inflation cycles].
>
> The anti-ice use of the de-icer increases de-icer flex cycles, reduces de-icer life.
>
> AFM change 43 and ice bridging will be discussed further in section 1.18.4.2.

1.18.2.5 Supercooled Liquid Droplet Icing Airworthiness Directive 96-09-24—May 1996

To more clearly define procedures and limitations associated with operating in SLD icing conditions, on May 7, 1996, the FAA issued AD 96-09-24, applicable to all EMB-120 series airplanes. AD 96-09-24 required EMB-120 operators to take the following actions:

1) Revise the FAA-approved AFM by incorporating the following warning in the Limitations Section of the AFM. The warning stated, in part:

> Severe icing may result from environmental conditions outside of those for which the airplane is certificated. Flight in freezing rain, freezing drizzle, or mixed icing conditions (supercooled liquid water and ice crystals) may result in ice build-up on protected surfaces exceeding the capability of the ice protection system, or may result in ice forming aft of the protected surfaces. This ice may not be shed using the ice protection systems, and may seriously degrade the performance and controllability of the airplane.
>
> - During flight, severe icing conditions that exceed those for which the airplane is certificated shall be determined by the following visual cues…

    - ♦ 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.
    - ♦ Accumulation of ice on the propeller spinner farther aft than normally observed.
- Since the autopilot may mask tactile cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited when any of the visual cues specified above exist, or when unusual lateral trim requirements or autopilot trim warnings are encountered while the airplane is in icing conditions.
- In icing conditions, use of flaps is restricted to takeoff, approach, and landing only. When the flaps have been extended for approach or landing, they may not be retracted unless the upper surface of the wing aft of the protected area is clear of ice, or unless flap retraction is essential for go-around.

and, 2) Revise the FAA-approved AFM by incorporating the following procedural information in the Procedures Section of the AFM. The procedural information stated, in part:

> These procedures are applicable to all flight phases from takeoff to landing. Monitor the ambient air temperature. While severe icing may form at temperatures as cold as -18^{o} [C], increased vigilance is warranted at temperatures around freezing with visible moisture present. If the visual cues specified in the Limitations Section of the AFM…are observed…:
>
> - Immediately request priority handling from [ATC]…to exit the severe icing conditions….
> - Avoid abrupt and excessive maneuvering that may exacerbate control difficulties.
> - Do not engage the autopilot.
> - If the autopilot is engaged, hold the control wheel firmly and disengage the autopilot.
> - If an unusual roll response or uncommanded roll control movement is observed, reduce the angle-of-attack.
> - Do not extend flaps during extended operation in icing conditions. Operation with flaps extended can result in a reduced wing angle-of-attack, with the possibility of ice forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.
> - If flaps are extended, do not retract them until the airframe is clear of ice.

1.18.2.6 Comair Bulletins/Revisions Resulting from the Operational Bulletin and Airworthiness Directive

On July 2, 1996, Comair issued EMB-120 FSB No. 96-02, “Severe Icing Conditions [per AD 96-09-24],” which contained the information detailed in the AD. On October 14, 1996, (in accordance with the airline’s FSM revision process) Comair accomplished the AD by issuing FAA-approved revisions to the procedures and limitations sections of the FSM. Additionally, on October 18, 1996, Comair issued FSB No 96-04, “Winter Flying Tips,” which provided flightcrews with additional guidance regarding operations in icing conditions as follows, in part:

- The autopilot may only be used in IAS mode when climbing in icing conditions. In any other mode the aircraft may be slowed to a stall if the autopilot is trying to maintain a climb or pitch attitude. When in the IAS mode the autopilot will descend if necessary to maintain the desired airspeed (below FL200 minimum desired airspeed is 170 KIAS), thereby not allowing the airspeed to drop to stalling speeds….
- If an unusual roll response or uncommanded roll control movement is observed, reduce the angle- of-attack.
- Do not extend flaps during extended operation in icing conditions. Operation with flaps extended can result in a reduced wing angle-of-attack, with the possibility of ice forming on the upper surface further aft on the wing than normal, possibly aft of the protected area.
- If the flaps are extended, do not retract them until the airframe is clear of ice.
- Minimum airspeed for holding is now 170 KIAS[149] (will be in FSM Rev. 9).
- When there is any suspected residual airframe icing, use 25 degrees flaps ONLY, and use Vref25 + 5 KIAS for reference speed.

Comair’s changes and additional guidance did not identify a minimum airspeed for flaps-up operations other than climbing and holding in icing conditions, nor did it address operation of the leading edge deicing boots. (Since the accident, Comair has revised its FSM to specify a minimum airspeed of 170 knots for all EMB-120 operations in icing conditions and to indicate that deicing boots should be activated at the first sign of ice accumulation.)

In addition, on December 23, 1996, Comair issued a memo to all turbopropeller flight crewmembers, which addressed “Freezing Precipitation AD.” The memo summarized the information contained in AD 96-09-24 and advised flightcrews that “use of the autopilot may mask tactile cues, and is prohibited when [freezing rain or freezing drizzle] conditions exist.”

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[149] The 170 knot minimum EMB-120 airspeed for holding in icing conditions superseded the previous FSM guidance, which specified a 160 knot minimum airspeed for holding in icing conditions.

1.18.2.7 Guidance in Embraer's EMB-120 Airplane Flight Manual at the Time of the Accident

Embraer's EMB-120 AFM, which had been revised in accordance with FAA/CTA-approved change 43 in April 1996, advised operators/pilots that the following procedures should be followed during operation in icing conditions (within the Part 25 appendix C envelope):

When flying into known or forecast icing conditions, proceed:

IGNITION Switches ……………………………ON
Ice Protection System……………………………TURN ON AS REQUIRED
The ice protection system should be turned on as follows:

- AOA, TAT and SLIP: before flying into known icing conditions.
- Propeller: before flying into known icing conditions or at first sign of ice formation.
- Wing and tail leading edges, engine air inlet and windshield: at the first sign of ice formation.

Holding configuration:
Landing Gear Lever………………………UP
Flap Selector Lever……………………….UP
Airspeed…………………………………..160 KIAS Minimum
Np[150]………………………………………85 percent Minimum

NOTE: For approach procedures in known or forecast icing conditions, increase the airspeed by 5 up to 10 KIAS until the short final.

Previous AFM guidance regarding ice protection system activation (included in Revision 27 to the EMB-120 AFM) indicated that the ice protection system should be activated as follows:

- AOA, TAT and SLIP: before flying into known icing conditions.
- Propeller: before flying into known icing conditions or at the first sign of ice formation.
- Engine air inlet and windshield: at the first sign of ice formation.
- Wing and tail leading edges: when ice accumulation is ¼" to ½".

Embraer's Technical Liaison told Safety Board investigators that the revised procedure was intended to reduce the likelihood of upset events resulting from the pilots' failure to activate leading edge deicing boots and to reduce the pilots' workload by relieving them of the

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[150] Np means propeller revolutions per minute (rpm).

responsibility for monitoring and gauging ice accretion in an effort to determine when to activate the wing and tail leading edge devices. Copies of the AFM revisions are included in appendix G.

1.18.2.8 Guidance in Comair's FSM Before the Accident

In addition to the AD 96-09-24-related revisions and the subsequent FSBs (one of which superseded the FSM's 160 knot minimum EMB-120 airspeed for holding in icing conditions with a 170 knot minimum airspeed for holding in icing conditions), the Cold Weather Operation section of the EMB-120 FSM stated the following, in part:

> **General Policy Regarding Use of Anti-ice Equipment**
>
> **Note**:
> Icing conditions exist when the OAT is +5° C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)….
>
> **Ignition…**
>
> Continuous ignition must be used for flight through moderate or severe icing.
>
> **Wing/Engine Inlet De-Ice**
>
> Allow ice accumulation to build approximately ½ inch prior to inflating the wing and engine inlet de-ice boots. When it is difficult to see the wing leading edge, or operating at night, an airspeed loss of 10 to 15 knots is a good indicator of ice accumulation.
>
> Comair's EMB-120 FSM also contained the following note:
>
> **CAUTION**
>
> Premature activation of the surface de-ice boots could result in ice forming the shape of an inflated de-ice boot, making further attempts to de-ice in flight impossible.

1.18.2.9 Postaccident EMB-120 Upset Events/Information

The Safety Board is aware of two postaccident EMB-120 upset events. The first occurred on May 21, 1997, and involved a Base Airlines[151] EMB-120 (OO-DTO), which experienced "uncommanded violent roll tendencies" immediately after takeoff from the airport at Gatwick, England. Although the airplane rolled left and right at bank angles that sometimes

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[151] Base Airlines is a regional air carrier based in Eindhoven, Netherlands.

exceeded 60°, it returned to Gatwick and landed without further incident. Postincident examination of the airplane revealed a spanwise crack (about 1½ feet long and 2 inches wide) in the fiberglass surface of the right wing, aft of the leading edge deicing boots. According to Delta Air Transport (the company responsible for maintaining the incident airplane), further examination revealed that the delamination damage occurred because "[t]hrough carelessness at installation of the boot a narrow band of bare composite between the sealant at the edge of the boot and the coated/painted area to the aft of the leading edge [was] exposed. Probably through erosion and aerodynamic loading the first layer of the composite has delaminated and is torn right along the edge of the painted area, creating a loose flap."

As a result of this incident, on September 13, 1997, Embraer issued SB 120-51-A004, which recommended that EMB-120 operators perform "a visual inspection of the wing and empennage leading edge area behind the de-ice boots for erosion, delamination and condition of sealing and anti static paint….at [the] operator's earliest convenience but not later than the next line check."[152] In addition, on September 22, 1997, the CTA issued Brazilian (Emergency) Airworthiness Directive (EAD) 97-09-07, which required all EMB-120 operators to perform the actions described in SB 120-51-A004 and all approved revisions. Although all U.S.-based EMB-120 operators received the manufacturer's SB 120-51-A004 (and its revision), compliance with Embraer's SB is not mandatory. Further, U.S.-based EMB-120 operators are not required to comply with the Brazilian AD (or EAD); only FAA-issued ADs carry the force of law for U.S. operators. According to the FAA's EMB-120 Aircraft Certification Program Manager, initially the FAA did not believe that mandatory action was warranted in this case. Subsequently, however (on March 27, 1998), the FAA issued NPRM 98-NM-33-AD, which would (if it becomes an AD as written) require all U.S.-based EMB-120 operators to comply with Embraer's SB 120-51-A004, Revision 01.

The second postaccident EMB-120 upset event occurred on March 5, 1998, about 2038, and involved a Westair Commuter Airlines, Inc. (Westair),[153] EMB-120, N284YV, operated as flight 7233, that experienced uncommanded roll oscillations while operating in icing conditions after it departed Sacramento, California.[154] The pilots were able to regain control of the airplane and continued to their destination airport without further incident.

During postincident interviews, the pilots of Westair flight 7233 told Safety Board investigators that the airplane accumulated ice during the descent into Sacramento, and they expected to encounter similar icing conditions again during their climb out, so they activated the leading edge deicing boots as soon as they entered the clouds (about 3,000 feet msl). Based on their observations of the windshield, propeller spinners, and unprotected areas of the wing leading edges, the pilots estimated that the airplane's unprotected surfaces had accumulated about ¼ inch to ½ inch of rime ice when the upset occurred, in what they described as moderate icing conditions. The pilots stated that the leading edge deicing boots were operating in the heavy mode, and when they visually inspected the wings, it appeared that the deicing boots were

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[152] Embraer SB 120-51-A004, Revision 1 was issued on November 10, 1997, and incorporated the application of a coat of conductive edge sealer over the sealer/anti-static paint where applicable.

[153] Westair is a regional air carrier based at Fresno, California, doing business as United Express.

[154] See NTSB brief of accident report DCA98SA029.

doing a good job of keeping the wing leading edges clean. They did not report observing any intercycle ice accumulation, any ridge-type accumulations, or any ice accretion aft of the leading edge deicing boot coverage.[155]

Shortly after the flight departed Sacramento, the pilots received ATC instructions to enter a holding pattern. The pilots reported that the captain was performing flying pilot duties, and was operating the airplane with the autopilot engaged. The first officer stated that when the airplane arrived at the assigned holding fix, it was level at 10,000 feet msl and the engine torque was reduced to between 50 and 55 percent to maintain their target holding airspeed of 170 knots. The captain used the autopilot heading mode to begin a left turn to the outbound leg of the hold. Both pilots reported that as the airplane began its left bank, they felt an unusual airplane movement or vibration,[156] but their scan of the instruments revealed no anomalies, except that the airspeed was slightly below their target airspeed of 170 knots (the captain estimated the airspeed was about 165 knots). When the airplane began to roll out of the left bank on its outbound heading, the captain felt the airplane shudder again and noticed that the airplane's pitch had decreased and the roll angle had increased beyond the autopilot's command limits (25°, +/-2.5°). He reported that he added engine power (FDR information indicated that the engine power increased to about 100 percent by 2037:37), but the airplane "was not doing what I wanted," so the captain applied "max power" and disengaged the autopilot about 2037:40.

At 2037:44, the airplane began a series of uncommanded roll and pitch oscillations. During postincident interviews, both pilots estimated that the airplane reached right and left 30° bank angles and lost about 500 feet during the excursion; the captain recalled observing airspeeds as low as 125 to 130 knots during the event. The captain stated that during the oscillations, neither the ailerons nor the elevator were responding normally to his flight control inputs. However, he recalled an ALPA memo that advised pilots to extend the flaps if they experienced an upset event, so he asked the first officer to extend 15° of flaps. The captain stated that as the flaps extended, the flight controls became normally effective again; the pilots flew the remainder of the flight with the flaps extended and landed without further incident.

FDR information from the Westair airplane indicated that the airplane's airspeed decreased below the pilots' target airspeed of 170 knots about 3 minutes before the upset occurred and continued to decrease, reaching 146 knots just before the autopilot disconnected and the upset occurred. After the autopilot disconnected (during the subsequent roll and pitch oscillations), the airspeed further decreased to about 123 knots before the pilots were able to regain control. FDR data showed that when the pilots disengaged the autopilot, the airplane was rolling right out of the left holding pattern turn. Within the next 4 seconds, the airplane began to roll rapidly to the right to about 63° of right bank; the airplane rolled back to the left to about 45° of left bank, then rolled right again to about 36° of right bank, and continued to oscillate back and

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[155] Although they did not report observing any ice accumulation aft of the leading edge deicing boot coverage, the pilots stated that they saw some frost-type accretion on the aft (noninflatable) portion of the leading edge deicing boots. They stated that they could see the boot surface through the frost; they reported that because of the color of the paint on the wing surface, they could not determine if the frost extended aft of the deicing boot material.

[156] The captain reported that he felt a little "twitch" or a shudder; the first officer stated that he felt a "rumble" or shudder.

forth between shallower right and left banks for the next 50 seconds or so before it leveled off. During these roll oscillations, the airplane also experienced pitch excursions from a maximum nose-down pitch of about 7° to a maximum nose-up pitch of about 17°. The airplane lost about 500 feet (to 9,500 feet msl) during these excursions before it pitched up and began climbing; the pilots declared an emergency, advising ATC that they were encountering icing conditions. The pilots requested and received clearance to climb to a higher altitude (13,000 feet msl).

1.18.2.9.1 Meteorological Conditions Encountered by Westair Flight 7233

A surface weather observation taken at Sacramento (KSAC) at 2047 (about 17 minutes after the upset occurred) indicated moderate rain and fog near Sacramento when the incident occurred. The 2056 surface weather observation taken at Stockton, California (KSCK), located about 39 nm south-southeast of KSAC, indicated an overcast cloud layer at 3,900 feet with 9 miles visibility. The most recent upper air data from Oakland, California, indicated moisture from the surface to about 9,500 feet msl, with drier air above. The data indicated that the freezing level in the Sacramento area was about 4,600 feet msl. There were two AIRMETs in effect for the Sacramento area at the time of the incident; one AIRMET indicated that occasional moderate rime/mixed icing was likely in clouds and in precipitation between the freezing level and FL 180; the other AIRMET indicated the possibility of occasional moderate turbulence below 15,000 feet msl. The Safety Board examined the PIREPs for the area about the time of the incident; at 1728, an MD-80 flightcrew reported encountering the following icing conditions during its descent 15 miles northeast of Sacramento: light rime icing at 15,000 feet msl; moderate rime icing at 12,000 feet msl; and freezing rain/sleet between 8,000 and 7,000 feet msl.

1.18.2.9.2 Westair Flight 7233 Airspeed Indication and Flight Data Recorder Sensor Information

During postincident discussions, Comair and ALPA representatives advised Safety Board investigators that they frequently observed airspeed differences of up to 10 knots between the captain's and first officer's airspeed indicators.[157] They further indicated that because airspeed information recorded by the FDR is from a different source than the captain's or first officer's airspeed indicators, the airspeed information observed by the Westair pilots in the cockpit (and used by the pilots to maintain safe/assigned airspeeds) might have been significantly different from the airspeeds recorded by the FDR. The incident airplane's maintenance records indicated the following:

- The airplane's most recent air data sensor (ADS) output calibration was accomplished during the FDR system check on December 27, 1997; no discrepancies were noted.
- The airplane's most recent pitot/static system calibration was accomplished on March 12, 1998 (one week after the incident); no discrepancies were noted

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[157] According to FAR Part 25.1323, the maximum allowable airspeed indicator variance (from actual airspeed) is 5 knots or 3 percent, whichever is greater, throughout the airplane's airspeed range.

during this calibration. (The airplane's previous pitot/static system calibration was accomplished in March 1996.)

- A review of the preceding 2 years of maintenance discrepancies for the incident airplane revealed no reported discrepancies involving the accuracy of the pitot/static system, airspeed indication errors, or FDR airspeed input calibration problems.

On April 30, 1998, the Safety Board conducted a postincident demonstration flight to document the observed and recorded airspeeds in the incident airplane. Examination of the flightcrew's airspeed indicators revealed that the indications matched under all tested conditions/airspeeds except one; in the 150 knot test condition, the captain's airspeed indicator showed 150 knots, and the first officer's airspeed indicator showed 148 knots. The FDR data indicated that the recorded airspeed values were within +4/-3 knots of the targeted airspeed in all conditions except one—at 170 knots with a left sideslip condition, the FDR-recorded airspeed was 6 knots higher than the targeted airspeed and the airspeeds indicated by the flightcrew's instruments.

Although there were no sensor discrepancies noted during the FDR system check on December 27, 1997, when the Safety Board reviewed the FDR from the incident airplane, several discrepancies were noted. The rudder pedal position parameter contained numerous data dropouts, and the CWP parameter recorded a constant value throughout the entire incident flight; these anomalous data indicate that the sensors for these parameters were malfunctioning or improperly installed.

1.18.3 Accident-Related Safety Board Recommendations (A-97-31 through –34) and FAA Actions (Notice of Proposed Rulemaking 97-NM-46-AD and Airworthiness Directive 97-26-06)

The FAA partially addressed some of the issues discussed during the March 13, 1997, meeting (see section 1.18.2.3) in its May 7, 1997, NPRM Docket 97-NM-46-AD, in which the FAA required the installation and use of ice detection equipment on EMB-120 airplanes, required EMB-120 operators to adjust their leading edge deicing boot operation procedures, and identified a minimum airspeed for operating in icing conditions. Further, as a result of this accident and the six previous EMB-120 icing-related events, on May 21, 1997, the Safety Board issued Urgent Safety Recommendations A-97-31 through -34 to the FAA. The recommendation letter stated the following, in part:

> Information from the CVR indicates that the flightcrew activated the anti-ice equipment for windshield, propellers, pitot tubes, angle-of-attack vanes, sideslip angle vane, and total air temperature probes. There is no evidence from the CVR, FDR, performance of the aircraft, or aircraft wreckage to determine if the flightcrew activated the de-icing boots. These facts and the airplane's degraded aerodynamic performance strongly suggest that ice had accumulated on the airframe, but may not have been seen or recognized as a hazard by the flightcrew of Comair 3272.

> The NPRM addresses many of the safety issues discussed in this letter. The Safety Board is evaluating whether the proposed 160 KIAS 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 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.

> Therefore, the urgent safety recommendations asked the FAA to do the following:

> 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. (A-97-31)

> Ensure that the de-icing information and procedures in air carrier's EMB-120 operating manuals and training programs are consistent with the revised Embraer EMB-120 airplane flight manual. (A-97-32)

> Direct principal operations inspectors (POIs) to ensure that all EMB-120 operators provide flightcrews with training that emphasizes the recognition of icing conditions and the need to adhere to the procedure for using de-ice boots that is specified in the revised Embraer EMB-120 airplane flight manual. (A-97-33)

> Require that all EMB-120 aircraft be equipped with automated ice detection and crew alerting systems for detecting airframe ice accretion. (A-97-34)

On June 18, 1997, the FAA responded to Safety Recommendations A-97-31 through -34, indicating actions that the FAA was taking in regard to the recommendations. In the June 18, 1997, letter, the FAA said that it would ensure that EMB-120 operating manuals and pilot training programs reflected any changes that might result from the NPRM and that training programs would emphasize the requirements of activation of ice protection systems. On July 1, 1997, the Safety Board commented on NPRM 97-NM-46-AD, and on September 30, 1997, the Safety Board answered the FAA's June 18, 1997, letter. In its September 1997 letter, the Safety Board identified some shortcomings in the NPRM and in the FAA's June 18, 1997, letter and stated that "the NPRM does not address several key issues raised in the Board's recommendations." Further, the Safety Board expressed concern that additional intercycle icing tests "may show that a higher minimum airspeed is required to provide an adequate safety margin. It is also not clear if the…NPRM establishes appropriate minimum speeds for all flap settings and phases of flight." The Safety Board also stated that "all EMB-120 pilots need to be provided updated manuals and training to unlearn old habits and to emphasize the new de-icing procedures." As a result of the shortcomings in the FAA's June 18, 1997, response letter and the NPRM and pending clarification of the FAA's planned actions, the Safety Board classified Safety Recommendations A-97-31 through -33 "Open—Await Response."

The Safety Board's response letter to the FAA strongly supported the FAA's action requiring all EMB-120 operators to install ice detection/alerting systems and make appropriate revisions to their manuals, and based on the actions described in the NPRM, the Safety Board classified Safety Recommendation A-97-34 "Open—Acceptable Response."

The issues contained in the FAA's May 7, 1997, NPRM were subsequently addressed on December 19, 1997, when the FAA issued AD 97-26-06. This AD partially responded to the Safety Board's Safety Recommendations A-97-31 through -34. The AD was issued with an effective date of January 23, 1998, and stated the following:

> This amendment adopts a new airworthiness directive (AD), applicable to all EMBRAER Model EMB-120 series airplanes, that requires revising the Airplane Flight Manual (AFM) to include requirements for activation of the ice protection systems, and to add information regarding operation in icing conditions. This amendment also requires installing an ice detector system and revising the AFM to include procedures for testing system integrity. This amendment is prompted by reports indicating that flightcrews experienced difficulties controlling the airplane during (or following) flight in normal icing conditions, when the ice protection system either was not activated when ice began to accumulate on the airplane, or the ice protection system was never activated. These difficulties may have occurred because the flightcrews did not recognize that a significant enough amount of ice had formed on the airplane to require activation of the deicing equipment. The actions specified by this AD are intended to ensure that the flightcrew is able to recognize the formation of significant ice accretion and take appropriate action; such formation of ice could result in reduced controllability of the airplane in normal icing conditions.

In part, the AD required Embraer and EMB-120 operators to revise the EMB-120 AFM to state that when atmospheric icing conditions exist, flightcrews should activate the leading edge ice protection system "at the first sign of ice formation anywhere on the aircraft," perform daily checks of the ice detection system, and maintain a minimum airspeed (with flaps and landing gear retracted) of 160 knots. The AD further required operators to "[w]ithin 10 months after the effective date of this AD, install an ice detector in accordance with EMBRAER SB No. 120-30-0027, dated May 9, 1997."[158] Excerpts from the AD stated the following:

> --During flight, monitoring for icing conditions should start whenever the indicated outside air temperature is near or below freezing or when operating into icing conditions, as specified in the Limitations Section of this manual.

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[158] In March 1998, during a followup visit to Comair's facilities in Cincinnati, investigators examined several of Comair's EMB-120s; all of the airplanes examined had the ice detection system installed and operational. Full compliance with the ice detector portion of the AD is required by October 1998.

> --When operating in icing conditions, the front windshield corners (unheated areas), propeller spinners, and wing leading edges will provide good visual cues of ice accretion.
>
> --For airplanes equipped with an ice detection system, icing conditions will also be indicated by the illumination of the ICE CONDITION light on the multiple alarm panel.
>
> Visually evaluate the severity of the ice encounter and the rate of accretion and select light or heavy mode [3 minute or 1 minute cycle, respectively] based on this evaluation.
>
> Increase approach and landing speeds…until landing is assured. Reduce airspeed to cross runway threshold at Vref:
>
> Flaps 15—Increase Speed by 10 KIAS…
> Flaps 25—Increase Speed by 10 KIAS…
> Flaps 45—Increase Speed by 5 KIAS….
>
> CAUTION: The ice protection systems must be turned on immediately (except leading edge de-icers during takeoff) when the ICE CONDITION light illuminates…or when any ice accretion is detected by visual observation or other cues.
>
> CAUTION: Do not interrupt the automatic sequence of operation of the leading edge de-ice boots once it is turned ON. The system should be turned OFF only after leaving the icing conditions and after the protected surfaces of the wing are free of ice.

On July 8, 1998, based on the actions taken by the FAA, the Safety Board classified Safety Recommendation A-97-34 “Closed—Acceptable Action.”

On August 13, 1998, the FAA issued a flight standards information bulletin (FSIB) to “ensure that [NTSB] Safety Recommendations A-97-31, A-97-32, and A-97-33 concerning the Embraer EMB-120 airplane have been addressed.” Based on the actions taken in AD 97-26-06, and pending a thorough review of the FSIB, Safety Recommendations A-97-31 through -33 are classified “Open—Acceptable Response.”

1.18.4 Previous Icing-Related Recommendations and Information

The Safety Board’s concern about the hazards of operating airplanes in icing conditions dates back more than 20 years. On September 9, 1981, following a series of accidents that involved in-flight icing encounters, the Safety Board published a report entitled “Aircraft

Icing Avoidance and Protection,"[159] which included six safety recommendations regarding icing-related issues. The Board's report stated, in part, that the "icing criteria for aircraft certification as defined in 14 CFR 25 are based upon research done by NASA in the late 1950's with the transport aircraft of that period. Although the results of this research and the ensuing practices and regulations that came out of it are still basically valid, there have been changes in aircraft, deicing/anti-icing equipment, and improvements in the instruments used to measure atmospheric icing parameters." As a result, one of the recommendations issued by the Safety Board was Safety Recommendation A-81-116, which recommended that the FAA do the following:

> Review the icing criteria published in 14 CFR Part 25 in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and expand the certification envelope to include freezing rain and mixed water droplet/ice crystal conditions, as necessary.

In the years since that report was published, the Safety Board has issued numerous additional safety recommendations regarding icing operations issues. The recommendations have addressed issues such as icing standards for aircraft certification, weather forecasting/dissemination, aircraft performance in icing conditions, and methods for flightcrews to positively determine when they are in icing conditions that exceed the limits for aircraft certification. Despite these efforts, icing-related incidents and accidents continue to occur. Based on its concerns, the Safety Board included this safety issue when it adopted the "Most Wanted" Transportation Safety Improvements program in 1990. The issue continues to be included on the "Most Wanted" list.

As a result of the recommendations included in the Safety Board's "Aircraft Icing Avoidance and Protection" report, in 1982 the FAA published a report entitled, "A Report on Improving Forecasts of Icing Conditions for Aviation." Further, the Aircraft Icing Program Counsel was established in 1984 to continue the study of icing forecast methods. In 1986, the FAA published another report entitled, "National Aircraft Icing Technology Plan," which also addressed the improved aircraft icing detection technologies on current generation aircraft. This plan also promoted the development of aircraft ice detection technology that would be needed by 1995 to meet the goals set for the new generation of aircraft that were in development. (Details of the FAA's current three-phase plan are addressed in section 1.18.4.1.)

Although the FAA's various reports and actions indicate an inclination towards a favorable response, over time, not all of the FAA's actions/responses were favorable. For example, the Safety Board considered the FAA's initial response to Safety Recommendation A-81-116 to be unfavorable, and, in 1983, classified it "Open—Unacceptable Response." However, in 1986, the FAA sent a followup letter to the Safety Board, which stated that it had "reconsidered the issue of considering freezing rain and drizzle as a criterion of aircraft for flight in icing conditions. …current research and development efforts…will provide the data needed to form a basis for determining the feasibility of any rulemaking action." As a result of the FAA's

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[159] See National Transportation Safety Board. 1981. *Aircraft Icing Avoidance and Protection, September 9, 1981*. Safety Report NTSB-SR-81-1. Washington, DC.

reconsideration and pending the Board's review of the final action taken by the FAA, in March 1987, the Safety Board classified Safety Recommendation A-81-116 "Open—Acceptable Response." Additional correspondence between the FAA and the Safety Board resulted in Safety Recommendation A-81-116 being reclassified "Open—Unacceptable Response" in April 1990.

In May 11, 1994, the Manager of the FAA's Small Airplane Directorate, Aircraft Certification Service issued a memo to the Manager of the Aircraft Engineering Division, in which he stated, "[w]e understand that continued research on freezing rain and freezing drizzle may be discontinued for lack of apparent support. I believe there is a need for this work and request consideration be given to continuation of that work as resources and competing projects allow." The memo addressed, in part, the need for expanding the Part 25 appendix C icing envelope to include SLD and other known critical icing conditions and stated the following: "We do not see abatement…of susceptibility to this hazard. There is substantial interest in the international community in this subject….I believe a rational research and development effort leading toward a better understanding of the environment is appropriate." On September 8, 1994, the Manager of the Aircraft Engineering Division responded in a memo, stating, "[c]onsidering the research resources and desire for less regulations, this does not appear to be a program that should be supported at this time." The Safety Board received additional correspondence from the FAA regarding Safety Recommendation A-81-116 on September 16, 1994, which stated the following, in part:

> The FAA has reviewed the research and development projects that have been conducted on various icing issues and especially with respect to the adequacy of the icing criteria published in 14 CFR Part 25.…The FAA has concluded that the icing criteria published in 14 CFR Part 25 is adequate with respect to the issues outlined in Safety Recommendation A-81-116.
>
> The FAA's correspondence further stated the following:
>
> The FAA has put in place major programs in recent years which have addressed various anti-ice and deicing issues. At the same time the FAA has sponsored or collaborated on numerous icing programs…However, none of this work has established the foundation or justification to revise 14 CFR Parts 25, 91, or 135.

Forty-five days after the Safety Board received the FAA's letter, on October 31, 1994, the ATR-72 accident occurred at Roselawn, Indiana. On July 12, 1995, the Safety Board's response letter to the FAA stated the following:

> In light of the accident on October 31, 1994…in which structural icing may have been involved, the Safety Board believes the issue of icing criteria, as related to the design and use of transport-category aircraft, warrants reexamination by the FAA and the aviation industry. …the Safety Board classifies Safety Recommendation A-81-116…"Open—Unacceptable Response," pending further action by the FAA on this matter.

On August 28, 1995, the FAA responded, stating the following, in part:

> The…FAA has taken actions to address the ATR 72 aircraft design and operation in icing conditions. …[and] is currently evaluating similar aircraft designs to ensure there are no adverse characteristics when operating in icing conditions. The final phase of this evaluation is to review the current certification requirements, applicable operating regulations, and forecasting methodologies associated with ice under varying environmental conditions. The FAA plans to conduct an international meeting in the spring of 1996 with representatives from airworthiness authorities, the aviation industry, the NTSB, and other interested parties. This meeting will include a comprehensive review of all aspects of airworthiness when operating in icing conditions and determine where changes or modifications can be made to provide an increased level of safety.

The Safety Board responded to the FAA on November 20, 1995, and indicated that although the Board supported the FAA's multi-phase plan to address icing concerns, the Safety Board was disappointed that the FAA did not amend the icing certification regulations as recommended by the Board in 1981. The Safety Board reclassified Safety Recommendation A-81-116 "Closed—Unacceptable Action/Superseded" and superseded it by issuing Safety Recommendation A-96-54 (issued with the Board's ATR-72 accident report) to the FAA, which stated 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 and use of aircraft. Also, expand Appendix C icing certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary.

On October 30, 1996, the FAA responded, stating that it would assign an ARAC working group the task of developing certification criteria for the safe operation of airplanes in icing conditions that are not covered by the current certification envelope. It further stated that "pending availability of funds," the FAA would support a research effort to gather SLD data; lead an effort to collect, consolidate, and analyze existing SLD data; and undertake a study to determine the magnitude of the hazard posed by operations in mixed-phase icing conditions. On August 20, 1997, the Safety Board stated that it "strongly encourages the FAA to make every effort to fund these important in-flight icing research projects." Pending completion of the aforementioned actions, the Board classified A-96-54 "Open—Acceptable Response."

The FAA responded again on July 1, 1998, stating that the agency has tasked the ARAC to form an Ice Protection Harmonization Working Group. In October 1997, the ARAC approved a "terms of reference" document (published in the *Federal Register* on December 8, 1997) that identified several tasks assigned to the Ice Protection Harmonization Working Group. One of the identified tasks stated, "define an icing environment that includes [SLD], and devise requirements to assess the ability of aircraft to safely operate either for the period of time to exit or to operate without restriction in SLD aloft, in SLD at or near the surface, and in mixed phase conditions if such conditions are determined to be more hazardous than the liquid phase icing environment containing supercooled water droplets."

The FAA further stated that data from the following research activities will be provided to the Ice Protection Harmonization Working Group in support of the identified task to define an icing environment:

1. A research effort to gather SLD data in the Great Lakes region was accomplished during the winters of 1996-1998. The data from this effort are to be analyzed and forwarded to the ARAC working group in the second quarter of fiscal year (FY) 1999.
2. An effort to collect, consolidate, and analyze existing SLD data is underway. The FAA plans to provide the results of this effort to the ARAC in the first quarter of FY 1999.
3. The FAA completed a draft report, which surveys publicly available evidence bearing on the possible safety hazards posed by operation in mixed-phase conditions. The FAA plans to provide ARAC with a final report in the third quarter of FY 1998.

The FAA stated that it would keep the Board informed of its progress. Based on the FAA's continued efforts to work with its ARAC on this issue, Safety Recommendation A-96-54 remains classified "Open—Acceptable Response."

The Safety Board also issued Safety Recommendation A-96-56 in the ATR-72 report, which stated the following:

> 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.

On October 30, 1996, the FAA responded, stating that although it did not believe that the icing certification regulations needed to be changed for operation in icing conditions defined by Part 25 appendix C, it acknowledged that airplanes may encounter icing conditions outside the Part 25 appendix C envelope, for which there are no established certification criteria. The FAA's response indicated that the ARAC working group would be tasked to consider development of a regulation that requires the installation of ice detectors, aerodynamic performance monitors, or another acceptable means to warn flightcrews of ice accumulation on critical surfaces. On August 20, 1997, the Safety Board stated that "such devices would provide a reliable means for flightcrews to assess in-flight conditions to positively determine when they are flying in icing conditions that may be beyond the airplane's capabilities or exceed certification limits." Pending completion of the FAA's planned actions, the Safety Board classified Safety Recommendation A-96-56 "Open—Acceptable Response."

1.18.4.1 FAA's Multi-Phase Plan to Address Icing-Related Concerns

As a result, in part, of the previously discussed Safety Board recommendations, increased industry concerns regarding the hazards of severe icing after the Roselawn accident, and its own concerns, the FAA initiated a program to address icing-related issues. In May 1996, the FAA held a conference on in-flight icing; in October 1996, the FAA published its "In-Flight Icing Product Development Plan: FY97 & FY98," and in April 1997, the FAA published its "…Inflight Aircraft Icing Plan." (Excerpts from the FAA's Inflight Aircraft Icing Plan are included in appendix I.) According to FAA personnel,[160] the program was structured as follows:

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

According to the FAA, Phase I was completed by the following means: (1) all ATR-42/-72 airplanes are now equipped with extended deicing boots (nearly doubling the coverage on the upper surface of the outer wings) to minimize the hazard during inadvertent exposure to SLD icing conditions, (2) visual cues were identified to help pilots detect when the airplane is operating in SLD icing conditions (after ATC has been advised that SLD icing is identified, they are required to expedite the airplane's egress from those conditions), and (3) pilots are required to turn the autopilot off while operating in SLD icing conditions.

During Phase II the FAA examined the lateral controllability characteristics (handling qualities, control wheel forces) of turbopropeller-driven airplanes that have pneumatic deicing boots and unpowered ailerons and are used in scheduled passenger service (19 airplane models, including the EMB-120), to determine whether they were susceptible to roll upsets when operating in SLD icing conditions. According to the FAA's Inflight Aircraft Icing Plan (published in April 1997), in April 1996, the FAA issued 18 ADs requiring the revision of operators' flight manuals to provide flightcrews with recognition cues for, and procedures for exiting from, SLD icing conditions.[161]

Phase III of the FAA's program was intended to encompass all aircraft and the freezing rain/freezing drizzle environment (and has since been expanded to include "sandpaper-

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[160] This information was presented to the Safety Board during a January 1998 meeting held at the Safety Board's headquarters in Washington, D.C. The information is also addressed in the previously discussed article entitled "Pilots Can Minimize the Likelihood of Roll Upset in Severe Icing." (See section 1.18.1.)

[161] The FAA's Inflight Aircraft Icing Plan states that the FAA will propose similar rulemaking to address these issues for Part 25 and Part 23 airplanes that have not been addressed in the previous ADs; the FAA published final ADs in this area in 1998.

type" icing conditions, which fall within Part 25 appendix C, but have not typically been represented during certification flight tests). Phase III was intended to bring icing experts together to review available data, determine what changes need to be made, and develop plans and tasks to enact those changes. This phase was initiated at an FAA-sponsored conference in May 1996, during which six areas were identified for additional research and revisions; these six areas included 1) operations regulations, procedures, and guidance material; 2) forecasting and in-flight detection of icing conditions; 3) certification regulations and guidance materials; 4) icing simulation methods; 5) ice accretion and its effects on performance/stability and control; and 6) SLD characterization and mixed phase icing conditions assessment. Some of the work areas had projected completion dates extending beyond the year 2000.

In January 1998, the FAA's Environmental Icing NRS briefed Safety Board personnel regarding the status of various activities described in the FAA's April 1997 Inflight Aircraft Icing Plan (Phase III work), which he summarized as follows:

- Operations regulations, procedures, and guidance material—Proposed changes to procedures regarding flightcrew activation of ice protection systems raised questions concerning bridging; the FAA and NASA co-sponsored a bridging conference; work in this area will/may result in changes in pilot training, procedural guidance contained in company manuals, ATC priorities, autopilot usage, etc. (The bridging conference will be discussed in more detail in section 1.18.4.2.)
- Weather forecasting and in-flight detection of icing conditions—Weather research is being conducted in many areas, with goals of improving weather predicting capabilities (optimally, to provide 5 minute advance notification for flightcrews) and to better define weather conditions.
- Certification regulations and guidance materials—FAA personnel are, in part: reviewing airplane icing certification requirements, attempting to determine whether they need to require ice detection equipment on all airplanes, reviewing autopilot disconnect systems on airplanes. The FAA is developing an advisory circular to provide guidance regarding the susceptibility of a horizontal tail to stall. The FAA is also developing advisory circulars and rulemaking to address icing certification changes to Part 23/25 and appendix C.
- Icing simulation/modeling methods—The FAA is working to ensure that the computer coding/programming used for engineering simulations are valid and reliable, and that the ice shapes and airfoils used in wind tunnel testing reflect real-world conditions—dynamic conditions (changes in angle of attack, flow separations, etc.) on wings with flight controls.
- Ice accretion (various types and locations) and its effects on performance/stability and control—The FAA formed working groups to examine the following: 1) categories of ice accretion (including sandpaper ice, inter-cycle ice, rime ice, glaze ice, SLD ice accretions beyond the predicted

impingement area, etc.),[162] 2) manufacturers' criteria for certification ice shapes, and 3) to research the effects of tailplane icing and spanwise accretion of large droplet ice.

- SLD characterization and mixed phase icing conditions assessment.

1.18.4.2 FAA/NASA Airplane Deicing Boot Ice Bridging Workshop

According to the FAA's Environmental Icing NRS, the practice of early activation of deicing boots encountered resistance with pilots and operators around the world because of the longstanding theory that early activation of leading edge deicing boots could result in "ice bridging." According to FAA and NASA icing experts, although the practice of delaying activation of the ice protection system until ice thicknesses between ¼ inch to 1½ inches had accumulated did not result in ice bridging, that practice has also "contributed to…losses of airplane performance and maneuver margins, departures from controlled flight, and may have contributed to one or more accidents."

In September 1995, the United Kingdom (U.K.) Civil Aviation Authority (CAA) published a safety study (paper 95007) entitled "Ice Detection for Turboprop Aircraft," which also addressed pilots' concerns regarding ice bridging, and stated the following, in part:

> Discussions with technical personnel employed by the manufacturers of pneumatic de-icing boots, indicated that they do not believe that ice bridging occurs for turboprop aircraft with fully serviceable boot systems. From the interviews with pilots, although they frequently observed residual ice on the boots, the only reported ice bridging incident happened to a light twin piston engined aircraft. Piston engined aircraft have a pneumatic system which operates from an engine driven pump, rather than engine bleed air. This means that compared to a turboprop aircraft, the system pressures are lower and the boot inflation times are longer. These differences may be crucial and may explain why ice bridging does not appear to occur for turboprop aircraft. The aviation community needs to decide whether or not ice bridging is a real possibility for turboprop aircraft. If it is not, the need for accurate measurement of ice thickness disappears, and the issue becomes one of detecting airframe ice.
>
> Ice bridging may still be a problem for turboprop aircraft when the pressure in the de-icing boots [is] low. This may be due to a puncture/leak in the system,

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[162] A representative from the "Working Group on Categories of Ice Accretion" gave a presentation at a June 1998 icing conference that Safety Board staff attended. He stated that the group's charter required it to "Develop guidance material, working methods, and recommendations for the criticality of ice accretion characteristics on aircraft aerodynamic performance and handling qualities useful for certification." He stated that the group's work would "provide the basis for guidance based on current technology and knowledge, as well as describe research that could improve the relevant knowledge base and technology." He indicated that the group's goal was to have surveyed and assessed the available data and complete a final report (published by the FAA) with recommendations by early 1999.

> but one manufacturer did comment on the difficulty of always maintaining adequate pressure at low engine pressure settings (e.g. on approach).
>
> If ice bridging is not an issue, this fact should be communicated to pilots, so that the recommended ice thicknesses for boot operation can be viewed as approximate rather than absolute. In addition, if ice bridging does not occur, it may then be possible to use pneumatic boots on turboprop aircraft as anti-icing devices. However use as an anti-icing system will increase the number of boot cycles when compared with use as a de-icing system.

In an attempt to answer the questions and address the concerns expressed by pilots and operators regarding the relative hazards of ice bridging associated with activating the leading edge deicing boots at the initial detection of in-flight icing, in November 1997, the FAA and NASA co-sponsored the Airplane Deicing Boot Ice Bridging Workshop, an industry forum for investigating the existence of the ice bridging phenomenon.[163] Evidence presented at the workshop indicated that concern regarding ice bridging in turbopropeller-driven airplanes appeared to be based on "myth or anecdotal incidents," dating back to earlier deicing boot designs (which typically consisted of long, larger-radius tubes, operated at slower inflation/deflation speeds and lower pneumatic pressures) or based on experiences in reciprocating engine-driven airplanes (with engine-driven pumps providing pressure to operate deicing boots). Because the deicing boots installed on reciprocating engine-driven airplanes and earlier design turbopropeller-driven airplanes might have contributed to ice bridging when they were activated with only thin layers of ice accumulated, pilots, manufacturers, and operators began to allow ice to accumulate to a greater thickness before activating the deicing boots.

According to the information presented at the workshop, there is no factual evidence that bridging is a problem in modern turbine-powered airplanes. Modern deicing boots are made up of smaller expansion tube segments, which are inflated/deflated at faster rates and at higher air pressures (typically operated by pneumatic pressure from turbine engine bleed air), and appear to have reduced the potential for ice bridging. Representatives from Embraer, Cessna, and Aerazur (foreign airplane manufacturer) presented evidence obtained from their wind tunnel and flight tests. Based on the data developed during these tests, and the lack of reported instances in recent history, the manufacturers independently concluded that ice bridging does not appear to be a significant hazard for turbopropeller-driven aircraft with modern, properly designed, maintained, and operating pneumatic deicing boot systems. The airframe and deicing boot manufacturers reported that deicing boots activated at the onset of ice accumulation were capable of shedding ice effectively; further, they noted that any ice that was not shed during the initial inflation cycle would simply continue to increase in thickness and shed with subsequent inflation cycles. Additionally, B.F. Goodrich personnel stated that "if the de-icers are activated when ice thickness is less than the recommended thickness, the shed will not be as clean (by area). However, even if this occurs, the ice layer will eventually shed."

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[163] The Airplane Deicing Boot Ice Bridging Workshop was conducted in Cleveland, Ohio, on November 18, 1997. Attendees included representatives from the FAA, NTSB, NASA, UIUC, Wichita State University, Transport Canada Aviation, ALPA, Comair, AMR Eagle, Inc., de Havilland Inc., Aerazur, Aerospatiale Aircraft Division, CASA, Embraer, Cessna Aircraft, Mitsubishi Heavy Industries, Boeing, SAAB Aircraft of America, Raytheon Aircraft Company, Innovative Dynamics, Inc., and B.F. Goodrich.

B.F. Goodrich personnel further stated that they had seen no indication of ice bridging during wind tunnel and natural icing tests with modern pneumatic deicing boots and concluded that "classical ice bridging may be extremely 'rare' or may not exist as traditionally defined." However, they cautioned that deicing boot system maintenance was critical to ensure optimum ice removal performance[164] and that each airplane and flight condition (airspeed, temperature, moisture content, AOA, etc.) was unique.

Despite the lack of evidence that ice bridging is a problem in modern turbopropeller-driven aircraft, the FAA's EMB-120 Aircraft Certification Program Manager and Environmental Icing NRS indicated that many pilots and operators have deeply ingrained beliefs that they should delay deicing boot activation to avoid ice bridging. The FAA's EMB-120 Aircraft Certification Program Manager stated that initially, even within FAA ACO and AEG personnel, the deicing boot procedural change was controversial because of ice bridging concerns. She told Safety Board staff that before revision 43 was approved by the FAA/CTA, there were many discussions and debates regarding the procedural change; however, after talks with Embraer, B.F. Goodrich, and other industry personnel eased those concerns, the FAA approved revision 43. In addition, recent (spring 1998) discussions with ALPA and other EMB-120 pilots indicated that many pilots may still be resistant to the deicing boot procedural change. According to the FAA's Environment Icing NRS, the FAA, NASA, and ALPA are organizing an industry-wide pilot training campaign in an attempt to update the pilots' (and operators') perceptions and understanding regarding the ice bridging phenomenon and safe deicing boot procedures.

1.18.5 Previous Safety Board Recommendations Regarding Autopilot-Related Upset Events

During the past 15 years, the Safety Board has made several safety recommendations to the FAA regarding autopilot-related (autopilot-masked) upset events that involved air carrier airplanes. There is evidence that pilots' previous experience with autopilot systems (the autopilot's reliability and ability to consistently control the airplane as commanded) can result in an increased level of confidence in the autopilot system, which may lead to less vigilant flightcrew monitoring of the airplane's performance while operating with the autopilot engaged. Researchers Parasuraman and Riley[165] stated the following:

> Operators may not sufficiently monitor the inputs to automated systems in order to reach effective decisions should the automation malfunction or fail….[although gross] autopilot failures are relatively easy to detect because they are so salient, "slow-over" rolls, in which the autopilot rolls the aircraft gradually and smoothly, are much less salient and can go undetected until the aircraft wings are nearly vertical.

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[164] B.F. Goodrich personnel estimated that even an effective deicing boot cycle might leave 20 to 25 percent residual ice coverage.

[165] Parasuraman, R. and Riley, V. 1997. "Humans and Automation: Use, Misuse, Disuse, Abuse." *Human Factors,* 39, 230-253.

In May 1992, the Safety Board issued several recommendations as a result of safety issues that were identified while the Board assisted the Transportation Safety Board of Canada in the investigation of such a "slow-over" roll and upset event. The upset incident occurred on December 12, 1991, and involved an Evergreen International Airlines Boeing 747 night cargo flight. The airplane was in autopilot-controlled cruise flight at FL 310 when the pilots noted the inertial navigation system FAIL light had illuminated. When they crosschecked their flight instruments, they observed that the airplane was in a steep right bank in a nose-down pitch attitude. The pilots initiated the recovery by disengaging the autopilot, rolling wings level, and adding back pressure on the control column to pull the nose up. However, the airplane exceeded 90° of bank, lost about 10,000 feet of altitude, and approached supersonic airspeeds before the recovery was accomplished. The Board issued Safety Recommendations A-92-31 through -35, which asked the FAA to do the following:

- Review the Boeing 747 series autopilot system designs and installations to identify all possible failure modes that could generate autopilot flight control commands that would cause the airplane to initiate an uncommanded roll. Following the completion of the review, implement design changes to prevent or limit excursions of the airplane as a result of any autopilot system malfunctions or failures. (A-92-31)

- Issue an airworthiness directive to require the installation of devices in Boeing 747 series airplanes that provide aural and visual warnings of bank angles that exceed normal flight attitudes. (A-92-32)

- Issue an air carrier operations bulletin to principal operations inspectors to advise Boeing 747 operators of the potential for a slow roll input in the event of an autopilot system failure. (A-92-33)

- Review in-flight incident data for all transport-category airplanes in an effort to determine if similar potential autopilot failure conditions exist with other airplanes and issue the appropriate directives. (A-92-34)

- Revise Advisory Circular 25.1329-1A to add guidance regarding autopilot failures that can result in changes in attitude at rates that may be imperceptible to the flightcrew and thus remain undetected until the airplane reaches significant attitude deviations. (A-92-35)

The FAA's responses to Safety Recommendations A-92-31, -33, and -34 resulted in the Safety Board classifying these recommendations "Closed—Acceptable Action" on October 4, 1995. Further, in its May 13, 1996, response letter, the FAA indicated that it had tasked the FAA/Joint Airworthiness Authorities Working Group to review proposed changes to AC 25.1329-1A, to include guidance stipulated in Safety Recommendation A-92-35; pending final publication of the revised AC 25.1329-1A, the Safety Board classified Safety Recommendation A-92-35 "Open—Acceptable Response" on June 5, 1996. However, the FAA's April 14, 1997, response letter indicated a less favorable response to Safety Recommendation A-92-32. The

FAA stated that autopilot-related Boeing 747 roll incidents occurred "at a rate below the design goal of 1 per 100,000 flight hours"[166] and "far less than the regulatory requirements for the system." Further, the FAA noted that Boeing installs a GPWS that provides an aural warning to the flightcrew when a preset bank angle threshold is exceeded in its new production 747 airplanes.[167] Consequently, the FAA's April 14, 1997, response letter indicated that "an airworthiness directive to require the installation of a bank angle exceedence device on Boeing 747 series airplanes is not warranted," and the FAA planned no further action; on January 21, 1998, the Safety Board classified Safety Recommendation A-92-32 "Closed—Unacceptable Action."

The Safety Board also addressed the issue of autopilot use in icing conditions in its report regarding the ATR-72 accident near Roselawn, Indiana, in which it noted that autopilot control of an airplane in icing conditions can hinder pilot recognition of alterations in performance/flightpath that may result from ice accretions. On November 4, 1994, the Safety Board issued Safety Recommendation A-94-184, which recommended that the FAA do the following:

> Provide guidance and direction to pilots of ATR 42 and ATR 72 airplanes in the event of inadvertent encounter with icing conditions by the following actions: (1) define optimum airplane configuration and speed information; (2) prohibit the use of autopilot; (3) require the monitoring of lateral control forces; (4) and define a positive procedure for reducing angle of attack.

On November 16, 1994, the FAA issued telegraphic AD T94-24-51, which, in part, prohibited pilots of ATR-42 and ATR-72 airplanes from using the autopilot in icing conditions or in moderate or greater turbulence. The FAA addressed other aspects of the recommendation in AD 96-09-28, which it issued on April 24, 1996. Based on the FAA's responses, on January 27, 1997, the Safety Board classified Safety Recommendation A-94-184 "Closed—Acceptable Action."

1.18.6 Standard Air Traffic Control Procedures/Separation/Wake Turbulence

According to DTW ATCT Order 7110.9D, when the ILS to runway 3 is being used, the standard procedure is for ARTCC personnel to position arrival traffic at 11,000 (turbopropeller-driven aircraft) and 12,000 feet msl (turbo-jet aircraft) before they are handed off to TRACON at or around MIZAR. According to FAA Order 7110.65J, "Air Traffic Control," controllers should separate radar-identified aircraft by 3 miles when they are less than 40 miles from the radar antenna or by 5 miles when the aircraft are 40 miles or more from the radar antenna. (These minima apply when Broadband Radar System or ASR-9/Full Digital Terminal Radar System are used. DTW used ASR-9 radar at the time of the accident, and Comair flight

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[166] According to the FAA's letter, "[t]his design goal is predicated on the pilot's responsibility to monitor cockpit instruments and to detect any rare occurrences of control upset."

[167] The FAA's response letter stated that "while the new ground proximity warning computer is a more efficient system and a safety enhancement, it is not required for safe flight or to meet certification standards."

3272 and Cactus 50 were within 40 miles of the radar antenna when the accident occurred.) FAA Order 7110.65J also contains a note, which states, "Wake turbulence procedures specify increased separation minima required for certain classes of aircraft because of the possible effects of wake turbulence." In addition, under the heading "Wake Turbulence Application," FAA Order 7110.65J states the following, in part:

> [S]eparate an aircraft landing behind another aircraft on the same runway…by ensuring the following minima will exist at the time the preceding aircraft is over the landing threshold:
>
> 1. Small behind large—4 miles
> 2. Small behind a B757—5 miles
> 3. Small behind heavy—6 miles.

According to the AIM (pages 7-3-1 through 7-3-3 discuss wake turbulence), "vortices from larger…aircraft sink at a rate of several hundred feet per minute, slowing their descent and diminishing in strength with time and distance behind the generating aircraft….vertical separation of 1,000 feet may be considered safe."

On July 16, 1996, the FAA issued Notice 7110.157, "Wake Turbulence," which stated that controllers should apply wake turbulence separation procedures to aircraft as follows:

> For the purposes of Wake Turbulence Separation minima, the weight classification definitions of Heavy, Large, and Small are as follows:
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> (1) Heavy. Aircraft capable of takeoff weights of more than 255,000 pounds whether or not they are operating at this weight during a particular phase of flight.
> (2) Large. Aircraft of more than 41,000 pounds maximum certificated takeoff weight, up to 255,000 pounds.
> (3) Small. Aircraft of 41,000 pounds or less maximum certificated takeoff weight

The EMB-120 has a maximum takeoff weight of less than 41,000 pounds. Cactus 50 was an Airbus 320, which has a maximum takeoff weight of more than 41,000 pounds, and less than 255,000 pounds.

Examination of radar data revealed that at 1552, Cactus 50 was descending through 5,500 feet msl at the point where the airplanes' flightpaths would later converge; about 2 minutes later, when Comair flight 3272 reached that point, the accident airplane was leveling at 4,000 feet msl. At 1554, the separation between Cactus 50 and Comair flight 3272 was 4.03 miles and increasing. Radar data indicated that by 1554:24.725 (the time of the upset), the airplanes were more than 5 miles apart. The Safety Board's wake vortex sink rate calculations indicated that during the 2 minutes that separated Cactus 50 and Comair flight 3272 at the point of the upset, Cactus 50's wake vortices could not have sunk below 4,500 feet msl. The Board sought the assistance of an expert in wake vortices from NASA, who (upon review of the radar and meteorological data) stated that based on known wake vortex movements, he was unable to generate circumstances that would have allowed Cactus 50's wake to sink to 4,000 feet in the 2 minutes that separated the airplanes. He further stated that "[I]f the radar data is correct, that would rule out a vortex encounter."

1.18.7 Information Regarding Tailplane Icing

The Safety Board has investigated several icing-related accidents that have involved tailplane icing, including the December 29, 1989, accident involving United Express flight 2415, a British Aerospace 3101 (BA-3101), that crashed while conducting an instrument approach to the airport at Pasco, Washington, and the January 20, 1991, accident involving a CC Air[168] BA-3101 that crashed while conducting an instrument approach to the airport at Beckley, West Virginia.[169] Evidence from these accidents indicated that both airplanes pitched nose down and crashed on or near the runway after the flaps were extended from an intermediate setting to the landing flaps setting. In addition, the BA-3101 that crashed at Beckley, West Virginia, had been operating in icing conditions with inoperative deicing boots.

After the accident in Beckley, West Virginia, a series of BA-3101 flight tests were conducted using varying flap configurations and ice accumulations on protected surfaces (to simulate leading edge deicing systems that were not activated or were not operating properly). Flight tests conducted with 50° of flaps extended and 1 inch of ice on the leading edges (at varying airspeeds) revealed that during 0.5 G maneuvers the control column exhibited a tendency to move forward if unrestrained. The Safety Board's report stated that "…the results and…the pilots' [observations indicated that]…higher speeds gave more adverse characteristics in that the reduction in stick forces were more pronounced." The Safety Board's analysis of the Pasco, Washington, accident stated that "[o]ne of the most insidious hazards of ice contamination is that the aerodynamic stall can occur at an airspeed that the pilot perceives as safe and at a corresponding AOA that is below that at which the stall protection devices activate." Further, it stated that "an accretion of ice on the leading edge of the stabilizer that degrades its aerodynamic efficiency can significantly affect its ability to maintain stabilized flight.…The pitchover of the airplane upon selection of 50° [of] flaps can be explained by a sudden reduction in the down force produced by the horizontal stabilizer."

The Safety Board's report further stated that British Aerospace and the regulatory authorities responded to this information by reducing the maximum operating airspeed with 50° of flaps extended from 153 knots to 130 knots and limiting the landing flap setting to 20° "when there is any visible ice accretion on any part of the aircraft." As a result of the accident at Pasco, in 1991, the Safety Board issued 5 icing-related recommendations to the FAA, including Safety Recommendations A-91-87 and A-91-88, which asked the FAA to do the following:

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[168] Carolina Commuter, Inc.

[169] Both accidents are discussed in National Transportation Safety Board. 1991. *NPA, Inc., dba United Express flight 2415, British Aerospace BA-3101, N410UE, Tri-Cities Airport, Pasco, Washington, December 29, 1989.* Aircraft Accident Report NTSB/AAR-91/06. Washington, DC.

- Amend the icing certification rules to require flight tests wherein ice is accumulated in those cruise and approach flap configurations in which extensive exposure to icing conditions can be expected, and require subsequent changes in configuration, to include landing flaps. (A-91-87)
- Review the airframe icing certification data for existing Part 23 and Part 25 airplanes to verify that the flight profiles examined included ice accumulated at those cruise and approach flap configurations in which extensive exposure to icing conditions can be expected, with subsequent changes in configuration, to include landing flaps. Require additional flight tests as necessary. (A-91-88)

As a result of these recommendations, on April 29, 1994, the FAA issued a policy memo to all ACOs describing the tailplane stall phenomenon and defining a flight test maneuver (zero-G pushover maneuver) to identify susceptibility to ice-contaminated tailplane stall, implemented a program to screen and rank the turbopropeller airplane fleet based on the tailplane stall margin under certain aerodynamic and ice accretion conditions, and indicated that it intended to revise the icing-related certification regulations and advisory circulars and to issue NPRMs and ADs, as appropriate, to ensure adequate icing certification of the existing fleet. Based on the FAA's responses (dated January 31, 1992 and February 13, 1996), Safety Recommendation A-91-87 was classified "Open—Acceptable Alternate Response," and Safety Recommendation A-91-88 was classified "Open—Acceptable Response," pending receipt of the pertinent revisions, NPRMs and ADs. In the Safety Board's July 19, 1996, letter to the FAA Administrator, the Board stated, "[a]lthough the Safety Board is pleased with the generally positive response by the FAA…the Board is concerned that there is no final action yet on these recommendations that were issued more than 4 years ago." In an e-mail dated August 18, 1998, the FAA's Director of Aircraft Certification Services advised the Safety Board that the FAA has "issued all but the Lockheed Electra AD;" subsequently, the FAA provided the Safety Board with a list of eight ADs and an NPRM (for the Lockheed Electra) that the FAA indicated were actions taken in response to Safety Recommendation A-91-88. Further, the Safety Board has been informed that the FAA is preparing another letter setting forth the actions the FAA has take in response to this recommendation. Pending receipt of that letter, Safety Recommendations A-91-87 and -88 remain classified "Open—Acceptable Alternate Response" and "Open—Acceptable Response," respectively.

2. ANALYSIS

2.1 General

The pilots were properly qualified and certificated to perform the flight during which the accident occurred, and each crewmember had received the training and off-duty time prescribed by the Federal regulations. There was no evidence of any preexisting medical or behavioral conditions that might have adversely affected the flightcrew's performance.

The airplane was certificated, equipped, and dispatched in accordance with Federal regulations and approved Comair procedures. There was no evidence of preexisting mechanical malfunction or other failure of the airplane structure, flight control or other systems, powerplants or propellers that would have contributed to the accident. (The absence of conductive edge sealer on some leading edge deicing boot segments will be discussed in section 2.4.1)

Although postaccident examination of the leading edge deicing boot system components revealed no evidence of preimpact malfunction or failure (missing patches, holes, etc.), impact damage to the deice system switches and timers made it impossible to determine switch positions at the time of impact. However, a postaccident statement obtained from the first officer who flew the accident airplane during the preceding flight indicated that the airplane's leading edge deicing boot system operated normally during that trip segment. Further, the cockpit voice recorder (CVR) did not record any flightcrew references to leading edge deicing boot failure during the accident flight. Therefore, the Safety Board concludes that it is likely that the leading edge deicing system was capable of normal operation during the accident flight.

The Detroit terminal radar approach (TRACON) controllers who were involved with flight 3272 were properly qualified and certificated. A review of air traffic control (ATC) and facility procedures revealed that the controllers followed applicable air traffic and wake turbulence separation rules, and air traffic separation was assured during flight 3272's approach to the runway.

Although the radar ground tracks of Cactus 50 and Comair flight 3272 converged near the accident site, the Safety Board's review of winds aloft and wake vortex sink rates indicated that Cactus 50's wake vortices would have been above and northeast of Comair flight 3272's flightpath near the upset location. Thus, Comair flight 3272 was separated from the vortices vertically and horizontally, and, therefore, wake turbulence was not a factor in the accident.

After summarizing the accident sequence, this analysis will address the weather conditions that Comair flight 3272 encountered, the aerodynamic effect of thin rough ice, possible factors in the left roll tendency that the accident airplane exhibited during the seconds before the autopilot disengaged, flightcrew actions, including the use of ice protection equipment and airplane airspeed/flap configuration, the airspeed guidance available to the flightcrew, the operation of the stall warning/protection system, autopilot warnings and use in icing conditions, FAA oversight, icing certification standards and continuing airworthiness issues, flight data recorder (FDR) sensor information, and the lack of available icing-related pilot reports (PIREPs).

2.2 Summary of Accident Sequence

According to CVR and 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. FDR and radar data indicated that the airplane's descent from the en route cruise altitude of flight level (FL) 210 to 4,000 feet 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[170] before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down (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.[171] The roll and control wheel

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[170] 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.

[171] 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. See section 1.16 in its entirety and sections 2.3 and 2.4 for further discussion of the ice accretion and its effects.

position (CWP) 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. (For further discussion of the airplane's tendency to roll left, see section 2.4.1.)

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;[172] 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 (see section 2.4.1). 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.

2.3 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 (see section 1.16.1.1). 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

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[172] 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 (see section 2.4.1) .

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.

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-SLD [supercooled large droplets], 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 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.

2.4 Aerodynamic Effect of the Ice Accretion on Comair Flight 3272

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 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[173] 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. (See section 1.16.1.2.) Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,[174] and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the Part 25 appendix C envelope (see section 1.6.1) 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),[175] 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. (The effects of these ridges will be discussed later in this section.) 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. NASA-Lewis's scientists 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

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[173] 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.

[174] 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.

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

record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.[176]

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, whereas 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 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

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[176] According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel); however, the B.F. Goodrich impingement study and NASA's LEWICE program (see section 1.16.2) 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. (See section 2.5.1.) 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.

stitchlines. 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 MAC) 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 implications of this finding for FAA icing certification criteria are discussed in section 2.6.2.

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 (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[177] 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. As previously noted, 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.

2.4.1 Possible Factors in Left Roll Tendency

Although the accident airplane's entire airframe was exposed to roughly equivalent icing conditions, making it theoretically possible that ice accumulation would be symmetrical, icing research and wind tunnel tests revealed that ice accumulation (especially ice accumulated at near freezing temperatures, as occurred in this accident) is rarely totally symmetrical, either physically or aerodynamically. FDR information showed that, from the time the airplane leveled at 4,000 feet msl, and then began the left turn, the airplane exhibited an increasing left roll tendency. The Safety Board identified several factors that might have contributed in varying degrees to the left roll, asymmetric conditions, and loss of control observed in this accident. These possible factors included the following:

- asymmetrical ice accumulation effects, possibly caused by ice self-shedding. NASA's IRT tests indicated that the TAT present at the time of the accident was likely to result in asymmetrical ice self-shedding. Increased vertical acceleration values might have exacerbated the ice self-shedding because of wing bending.
- the aerodynamic effects of aileron deflections on airfoils with an ice contaminated leading edge (after the left bank was established, the autopilot commanded right-wing-down aileron deflections—left aileron down, right aileron up—to resist the steepening left roll) during the left turn. Computational two-dimensional studies and wind tunnel research indicated that at higher AOAs the downward aileron deflection could initiate a localized flow separation, which resulted in a decrease in lift on the left wing. The

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[177] 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.

localized flow separation occurred at a lower AOA on the downward deflecting aileron than the upward deflecting aileron, thereby considerably reducing (or even reversing)[178] the rolling moment induced by the wheel inputs. The studies showed that this effect was most pronounced when a leading edge ridge of ice was present.

- differences in local airflow over left and right wings because of propeller thrust—both propellers rotating in a clockwise direction results in asymmetrical thrust and a left yaw tendency.
- the airplane leveling off at its assigned altitude and slowing to its assigned airspeed resulted in an increased AOA and movement of the stagnation point on the leading edge of both wings, which might have exacerbated the effects listed above.
- left yaw resulting from the asymmetrical engine power application that occurred less than 3 seconds before the autopilot automatically disengaged. Flight simulations that varied the timing and symmetry of the engine power application indicated that when power was applied earlier and/or more symmetrically, the simulator's bank did not exceed the autopilot's command limit, the autopilot did not abruptly disengage, and the upset did not occur. However, flight simulations indicated that the asymmetrical engine power application observed in the accident FDR data would not have resulted in an upset if the aerodynamic degradation from ice was not present. (See sections 1.16.1.2 and 2.2.)
- the effects of the autopilot disengagement—when the autopilot (which had been commanding RWD aileron to resist the left roll) automatically disengaged, the sudden absence of resistance resulted in a significant increase in the left roll and roll rate. (See section 2.5.4.)

The Safety Board also considered the possibility that the absence of conductive edge sealer[179] on the left wing leading edge segments (see section 1.12.2) might have contributed to an asymmetrical ice accretion that would have increased the left roll tendency. Postaccident examination revealed that the leading edge segments that did not have the conductive edge sealer applied were as smooth to the touch as any other part of the deicing boot/leading edge; further, there was no roughness, cracking, splitting, or delamination observed in the area where the conductive edge sealer should have been. Safety Board staff asked the scientists at NASA-Lewis

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[178] NASA's two-dimensional studies indicated that such a reversal is possible at small aileron deflections and higher AOAs; FDR data indicated that during the last minute before the upset, the aileron deflection and AOA was frequently changing.

[179] It was not possible to determine when and/or how the conductive edge sealer came to be missing; whether it eroded or wore off during flight, during the accident sequence, as a result of application of ICEX, or whether the conductive edge sealer was not applied properly during deicing boot installation. The left wing leading edge deicing boot segments were most recently replaced in July 1996—it strains credibility to presume that the pilots and mechanics who examined the airplane's leading edges during preflight and maintenance inspections between July 1996 and the day of the accident did not observe inconsistently applied conductive edge sealer. Further, during postaccident interviews, Comair's maintenance personnel appeared to be very familiar with the conductive edge sealer application.

whether the lack of conductive edge sealer on the upper wing surface at the aft edge of the leading edge deicing boot had potential to act as a preferred ice accumulation location. The NASA-Lewis scientists stated that it was unlikely because there were no perceivable tactile differences (gaps, edges, roughness, etc.) between the leading edge deicing boot and the wing skin to trigger ice accumulation. More importantly, the NASA-Lewis scientists stated that IRT tests had demonstrated that ice accretion that far aft on the upper wing surface would be unlikely to occur in a non-SLD icing environment—it would be more likely to occur in larger SLD droplet sizes, because of the resultant runback and secondary ice accumulation.

The Safety Board concludes that the accident airplane's left roll tendency was precipitated by a thin layer of rough ice that accumulated on the leading edge of the wing during the airplane's cruise descent and was then affected by some or all of the following factors: the autopilot-commanded left roll, asymmetrical ice self-shedding, aileron deflection effects (localized airflow separations), the effects of engine/propeller thrust, the asymmetrical engine power application, and the disengagement of the autopilot. It is unlikely that the absence of conductive edge sealer on the left wing leading edge deicing boot segments was a factor in the airplane's excessive left roll.

2.5 Flightcrew Actions

2.5.1 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 Detroit Metropolitan/Wayne County Airport (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.[180] This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is +5° C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which

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[180] 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.

used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging]." Thus, at the time of the accident, Comair's (and most other EMB-120 operators') guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed ¼ inch to ½ inch ice accumulation, despite Embraer's FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation (see discussion later in this section).

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 (see section 1.18.4.2). The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.[181] 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.

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[181] 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.

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 "Winter Operating Tips," and the October 1996 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 the 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,[182] 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. As previously noted, 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;

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[182] 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.

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 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.

2.5.2 Airspeed and Flap Configuration Information

Simulator studies conducted during the investigation revealed that the accident airplane's decreasing airspeed in icing conditions was critical in the development of the accident scenario. According to FDR data, the airplane began to exhibit signs of departure from controlled flight as it decelerated from 155 to 156 knots. Because the pilots accepted an ATC instruction to slow to 150 knots and maintained a flaps-up configuration, the Safety Board evaluated the guidance that Comair provided to its EMB-120 pilots on minimum airspeed in the flaps-up configuration, the Comair flight 3272 flightcrew's acceptance of this airspeed without adjusting the airplane's configuration, and the FAA's requirements for airplane manufacturers with regard to minimum airspeeds.

2.5.2.1 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°

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})[183] 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 (memo) and a flight standards bulletin (FSB) that contained guidance advising EMB-120 pilots to maintain higher airspeeds than 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 a flight standards bulletin (FSB) or a revision to the Comair EMB-120 flight standards manual (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

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

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.[184] 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 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.

2.5.2.2 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

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[184] 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.

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. Though 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° of flaps and still complied with ATC's airspeed assignment. Further, there was no safety or operational reason to avoid extending the flaps.[185]

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[185] 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° 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 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° 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.

2.5.2.3 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 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

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The Safety Board was unable to determine whether the pilots believed they had extended the flaps at any subsequent time.

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 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 (see section 1.18.7).

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.

2.5.3 Stall Warning/Protection System

The stall warning systems that are required by 14 Code of Federal Regulations (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° and the AOA at which the airplane actually stalled would be 18°, providing a margin of about 8°. 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,[186] thus decreasing the margin between 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

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[186] 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° or 6°.

a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

2.5.4 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 (EADIs) 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^o, and the roll angle did not exceed 30^o (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 LWD 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° 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° 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 discussed in section 1.18.5), 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.

2.5.5 Flightcrew's Ability to Recover From the Upset

Although the FDR data indicated that the pilots responded to the upset within 1 second of the autopilot disengagement, and the airplane responded somewhat to the control wheel inputs, the airplane did not respond normally or promptly. This is likely because the airplane's flight handling characteristics were altered by ice accumulation and the highly dynamic nature of the subsequent maneuvers. The pilots of Comair flight 3272 had received unusual attitude training, including rolls into extreme attitudes and recoveries, which the Safety Board advocates for all air carrier pilots. However, because of the degraded lateral and longitudinal control response (and the unknown degree to which these controls were degraded), the Safety Board was unable to determine the extent to which the unusual attitude training received by the pilots (or any other variant of this training) might have allowed them to affect a recovery. Although the pilots reacted promptly to the autopilot disengagement and applied control wheel inputs to counter the resultant abrupt left roll, they were not able to regain control of the airplane because of the airplane's extreme unusual attitude, the highly dynamic nature of the subsequent maneuvers, the presence and effect of ice on the wings, and the low altitude at which the loss of control occurred. The airplane entered an extreme nose-down pitch attitude from which it did not recover.

2.6 FAA Oversight Issues

The Safety Board's investigation of this accident raised concerns about the FAA's continuing airworthiness oversight of the EMB-120 and the agency's oversight of icing-related incidents and accidents involving turbopropeller-driven transport airplanes, the adequacy of existing FAA regulatory requirements for the certification of transport-category airplanes for flight into icing conditions (specifically 14 CFR Part 25 appendix C and Section 25.1419), the FAA's policies for AFM and air carrier operating manual revisions, and the sharing of information related to such revisions between the FAA's certification and flight standards personnel.

2.6.1 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.[187] 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.

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[187] 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.

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 (see section 1.18.2.3).

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 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 (see section 1.18.1), 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 (see section 1.18.7) 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.[188] 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.

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[188] As discussed in section 1.18.1.1, 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.

2.6.2 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.

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.[189] 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.[190]

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

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[189] 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).

[190] 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.

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). As discussed in section 2.4, 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. 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.[191] (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

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[191] 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.

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.

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[192] 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

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

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 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.
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> (The status of these recommendations is discussed in section 1.18.3.)

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. (See section 1.17.2.2.) 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;[193] 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 ARAC working groups to accomplish, in part, the following: to establish criticality of ice accretions on airplane performance and handling 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 advisory circulars (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,

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[193] 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.

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).

2.6.3 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 (see section 1.17.2.2). 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.

2.6.4 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 CWP 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),[194] 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 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.

2.7 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

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[194] See section 1.11.2.1, and 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.

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 TRACON 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.

3. CONCLUSIONS

3.1 Findings

1. The pilots were properly qualified and certificated to perform the flight during which the accident occurred, and each crewmember had received the training and off-duty time prescribed by the Federal regulations. There was no evidence of any preexisting medical or behavioral conditions that might have adversely affected the flightcrew's performance.

2. The airplane was certificated, equipped, and dispatched in accordance with Federal regulations and approved Comair procedures. There was no evidence of preexisting mechanical malfunction or other failure of the airplane structure, flight control or other systems, powerplants or propellers that would have contributed to the accident.

3. It is likely that the leading edge deicing system was capable of normal operation during the accident flight.

4. The Detroit terminal radar approach controllers who were involved with flight 3272 were properly qualified and certificated. A review of air traffic control and facility procedures revealed that the controllers followed applicable air traffic and wake turbulence separation rules, and air traffic separation was assured during flight 3272's approach to the runway.

5. Although the radar ground tracks of Cactus 50 and Comair flight 3272 converged near the accident site, the Safety Board's review of winds aloft and wake vortex sink rates indicated that Cactus 50's wake vortices would have been above and northeast of Comair flight 3272's flightpath near the upset location. Thus, Comair flight 3272 was separated from the vortices vertically and horizontally, and, therefore, wake turbulence was not a factor in the accident.

6. The airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

7. 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 supercooled large droplet icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet mean sea level.

8. 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 mean sea level (msl) to 4,000 feet msl in

icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

9. The suggestion in current Federal Aviation Administration publications that “trace” icing is “not hazardous” can mislead pilots and operators about the adverse effects of thin, rough ice accretions.

10. 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.

11. The accident airplane’s left roll tendency was precipitated by a thin layer of rough ice that accumulated on the leading edge of the wing during the airplane’s cruise descent, and was then affected by some or all of the following factors: the autopilot-commanded left roll, asymmetrical ice self-shedding, aileron deflection effects (localized airflow separations), the effects of engine/propeller thrust, the asymmetrical power application, and the disengagement of the autopilot. It is unlikely that the absence of conductive edge sealer on the left wing leading edge deicing boot segments was a factor in the airplane’s excessive left roll.

12. 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.

13. 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 operational bulletin 120-002/96 and revision 43 to the EMB-120 airplane flight manual, 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.

14. 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.

15. 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.

16. 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, supercooled large droplets, thin, rough ice accumulations, etc.).

17. 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.

18. 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.

19. Whether the pilots perceived ice accumulating on the airplane or not, they should have recognized that operating in icing conditions at the air traffic control-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.

20. Minimum airspeed information for various flap configurations and phases and conditions of flight would be helpful to pilots of all passenger-carrying airplanes.

21. 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.

22. 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.

23. Had the pilots been flying the airplane manually (without the autopilot engaged) they likely would have noted the increased right-wing-down 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.

24. 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.

25. If the pilots of Comair flight 3272 had received a ground proximity warning system, 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.

26. Despite the accumulated lessons of several major accidents and (in the case of the EMB-120) the specific findings of a staff engineer, the Federal Aviation Administration 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.

27. 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.

28. The work conducted by the Federal Aviation Administration Environmental Icing National Resource Specialist and the Aviation Rulemaking Advisory Committee's icing-related working groups is of crucial importance to the future safety of icing operations.

29. 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.

30. The current Federal Aviation Administration policy allowing air carriers to elect not to adopt airplane flight manual operational procedures without clear written justification can result in air carriers using procedures that may not reflect the safest operating practices.

31. At the time of the Comair flight 3272 accident, pertinent flight standards personnel (specifically, the principal operations inspector 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 airplane flight manual revision 43 or any alternatives proposed by air carriers.

32. The Federal Aviation Administration's current EMB-120 flight data recorder system inspection procedure is inadequate because it allows existing flight control sensor anomalies to go undetected, and thus uncorrected.

33. 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.

34. The Federal Aviation Administration air traffic control 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 automatic terminal information service broadcasts so that all arriving and departing pilots can become aware of icing conditions in the area.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the FAA's 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.

Contributing to the accident were the flightcrew's decision to operate in icing conditions near the lower margin of the operating airspeed envelope (with flaps retracted), and Comair's failure to establish and adequately disseminate unambiguous minimum airspeed values for flap configurations and for flight in icing conditions.

4. RECOMMENDATIONS

As a result of the investigation of this accident, 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)

--to the National Aeronautics and Space Administration:

With the Federal Aviation Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-107)

With the Federal Aviation Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.
(A-98-108)

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)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JAMES E. HALL
Chairman

ROBERT T. FRANCIS**
Vice Chairman

JOHN HAMMERSCHMIDT
Member

JOHN J. GOGLIA
Member

GEORGE W. BLACK, JR.
Member

November 4, 1998

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

5. APPENDIXES

APPENDIX A—INVESTIGATION AND HEARING

1. Investigation

The National Transportation Safety Board was initially notified of this accident by the FAA's Communications Center in Washington, D.C., about 1700 eastern standard time on January 9, 1997. A full go-team from Safety Board headquarters in Washington, D.C., was dispatched to Monroe, Michigan, about 2000 that evening. In addition, three Safety Board employees from the North Central Regional Office in Chicago, Illinois, and one employee from the Northwest Field Office in Anchorage, Alaska, were dispatched to the accident site to assist with the investigation. The following investigative groups were formed: operations/human performance, structures, systems, powerplants, maintenance records, air traffic control, weather, aircraft performance, witness, cockpit voice recorder, and flight data recorder. Member John Hammerschmidt traveled separately from his home and joined the investigative team at the accident site. Chairman James Hall also visited the accident site. Additionally, one public affairs staff member and three family assistance staff members traveled to the accident site.

An accredited representative appointed by the Center for the Investigation and Prevention of Accidents of Brazil (state of manufacture of the airplane) participated and provided assistance throughout the investigation. Transportation Safety Board of Canada (state of manufacture of the engines), did not appoint an Accredited Representative to participate in the investigation.

Parties to the investigation were the Federal Aviation Administration, COMAIR, Inc., Empresa Brasileira de Aeronautica, S/A, the Pratt and Whitney Canada and Hamilton Standard Divisions of United Technologies Corporation, the National Weather Service, the National Air Traffic Controllers' Association, and the Air Line Pilots Association.

2. Public Hearing

No public hearing was held in connection with this accident.

APPENDIX B—COCKPIT VOICE RECORDER TRANSCRIPT

LEGEND

CAM	Cockpit area microphone
HOT	Crewmember hot microphone
RDO	Radio transmission from accident aircraft
-1	Voice (or position) identified as Captain
-2	Voice (or position) identified as First Officer
-3	Voice identified as Flight Attendant
-?	Unidentifiable voice
COM	Misc. radio communications or aircraft aural warnings heard on crewmember CVR channels
ZID	Indianapolis Air Route Traffic Control Center
ZOB	Cleveland Alr Route Traffic Control Center
DTW	Detroit Metro ATCT
OPS	Airline Operations
CACT50	America West Airlines Flight Fifty
*	Unintelligible word
#	Expletive deleted
...	Pause
( )	Questionable text
[]	Editorial insertion
.	Break in continuity

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1523:37 CAM	[start of recording]		
1523:37 CAM	[start of transcript]		
		1523:39 RDO-1	thanks.
1523:41 INT-2	he's gotta use the phone.		
		1523:49 ZID	comair thirty-two seventy-two climb maintain flight level two one zero.
		1523:52 RDO-1	flight level two one zero comair thirty-two seventy-two, thank you.
1523:57 INT-2	twenty-one.		
1523:59 INT-1	set once and set twice.		
1525:44 CAM	[sound of three tones similar to that of the altitude alerter]		
		1526:59 ZID	comair ah thirty-two seventy-two any improvements ah with the climb there?

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1527:03 RDO-1	comair thirty-two seventy-two affirmative ... it's ah smooth here at two one oh .. we're getting ah occasional light chop at one nine oh cause we were right at the tops.
		1527:11 ZID	right at the tops .. appreciate it, thanks.
1528:54 INT-1	well, ready for cruise?		
1528:56 INT-2	yup, thanks.		
1529:09 CAM	[sound similar to that of slight decrease in propeller rpm frequency]		
1529:13 CAM	[sound of several unknown clicks]		
1529:52 INT-1	power and NP set, pressurization check, cruise check complete.		
1530:52 CAM	[sound of unknown squeaks]		
		1531:22 ZID	comair thirty-two seventy-two contact cleveland one two three point niner.
		1531:28 RDO-1	one two three point niner comair thirty-two seventy-two, good day.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1531:31 ZID	so long.
		1531:32 COM	[sound of tone similar to that of frequency change]
		1531:34 RDO-1	good afternoon cleveland center, comair thirty-two seventy-two .. flight level two one zero.
		1531:39 ZOB	comair thirty-two seventy-two cleveland center, roger.
		1533:05 ZOB	comair thirty-two seventy-two how's your ride there?
		1533:08 RDO-1	comair thirty-two seventy-two it's smooth.
		1535:37 ZOB	comair thirty-two seventy-two descend and maintain one two thousand .. the ah detroit altimeter two nine two one.
		1535:44 RDO-1	two nine two one .. descend and maintain one two twelve thousand comair thirty-two seventy-two.
1535:52 INT-2	yeah there's twelve .. gotta go [sound of human whistle]		
1535:57 INT-1	down.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1536:07 ZOB	comair thirty-seven I'm sorry .. thirty-two seventy-two contact cleveland one two zero point four five.
		1536:13 RDO-1	one two zero point four five comair thirty-two seventy-two, good day.
		1536:18 ZOB	*.
		1536:18 COM	[sound of tone similar to frequency change]
1536:43 INT-2	might get a speed warning here.		
		1536:46 RDO-1	good afternoon cleveland center comair thirty-two seventy-two .. flight level one nine oh .. descend and maintain one two twelve thousand.
		1536:52 ZOB	thirty-two seventy-two cleveland center roger .. no delay down to twelve for traffic.
		1536:56 RDO-1	comair thirty-two seventy-two wilco.
1537:04 INT-2	dive, dive.		
1537:09 HOT-2	whoop whoop dive [sound of human whistle].		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1538:03 INT	[sound of chime similar to that of flight attendant chime]		
1538:07 INT-1	need anything?		
1538:08 INT-?	sure don't.		
1538:09 INT-2	no thanks.		
1538:14 HOT-1	would you be kind enough to get me an ice refresher .. just add some to that.		
1538:18 HOT-3	[unintelligible female voice]		
1538:18 HOT-2	no thanks .. doing great.		
1538:20 HOT-3	are we already on the descent?		
1538:21 HOT-1	yes ma'am .. you told them an hour but it's only forty minutes today.		
1538:27 HOT-3	(forty minutes).		
1538:27 HOT-1	didn't I .. I think I told you forty-five.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1538:30 HOT-3	(oh that's right you did it).		
1538:32 HOT-1	I go okay .. well she just knows we're gonna probably have to hold now.		
1538:35 HOT-3	[sound of laughter]		
1538:55 HOT-1	yeah we're only seventy-five miles out right now.		
1538:57 HOT-3	okay great, thanks.		
1538:58 HOT-1	so -		
1538:58 HOT-3	here's your drink.		
1539:00 HOT-1	fifteen ... fifteen minutes about.		
1539:03 HOT-3	okay.		
1539:04 HOT-1	thank you very much for the ice.		
		1539:07 ZOB	comair thirty-two seventy-two continue descent to one one thousand then fly heading of ah zero three zero to rejoin the mizar arrival off of detroit.

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1539:14 RDO-1	descend and maintain one one eleven thousand and heading zero three zero to join the arrival comair thirty-two seventy-two.
1539:24 INT-2	okay, there's ah there's eleven and out of detroit we're looking at ah .. two thirty-nine radial.		
		1540:09 COM	detroit metropolitan airport information hotel .. two zero two six zulu special .. wind zero seven zero at six .. visibility one .. light snow .. six hundred scattered .. ceiling one thousand four hundred broken .. two thousand one hundred overcast .. temperature minus three .. dew point minus four .. altimeter two niner two one .. remarks .. A02 .. tower visibility one and one half .. papa zero zero zero zero .. ILS approach in use runway three right .. departing runway three center .. notices to airmen .. runway two one right, three left closed .. runway two seven left, nine right closed .. runway two seven right, nine left closed .. taxiway yankee eleven closed .. braking action advisories in effect .. (local) de-ice procedure in effect .. gate hold procedure in effect for newark, kennedy, chicago o'hare, philadelphia, st. louis, GRR airports .. advise on initial contact you have information hotel.
1540:35 INT-1	so what what do you got set up here?		
1540:38 INT-2	I've got detroit.		
1540:46 INT-2	let's see which one of those lines we hit first.		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1540:48 CAM	[sound of three tones similar to that of the altitude alerter]		
1540:49 INT-1	okay.		
1541:16 CAM	[sound of audio interrupt similar to that of tape splice]		
		1542:32 COM	[sound of tone similar to that of frequency change]
1542:43 HOT-2	[sound of yawn]		
		1542:51 ZOB	comair thirty-two seventy-two detroit one two four point niner seven.
		1542:54 RDO-1	one two four point niner seven comair thirty-two seventy-two, good day.
		1542:58 COM	[sound of tone similar to that of frequency change]
		1543:03 RDO-1	good afternoon detroit approach .. comair thirty-two seventy-two one one eleven thousand hotel.
		1543:07 DTW	comair thirty-two seventy-two detroit approach .. depart mizar heading zero five zero vector to ILS runway three right final approach course .. runway three right braking action reported poor by a DC niner.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1543:16 RDO-1	roger depart mizar heading zero five zero comair thirty-two seventy-two.
		1544:11 DTW	comair thirty-two seventy-two maintain one niner zero knots .. if unable advise.
		1544:15 RDO-1	roger, one niner zero knots comair thirty-two seventy-two.
1544:44 INT-1	I think there's your -		
1544:46 INT-2	ah thanks.		
1544:48 INT-2	whoops.		
1544:49 INT-1	stand by.		
1544:50 INT-2	and five miles for ah ... for ah mizar.		
		1545:46 DTW	comair thirty-two seventy-two descend and maintain seven thousand.
		1545:49 RDO-1	seven thousand comair thirty-two seventy-two.
1545:53 INT-1	and seven's in the altitude alerter.		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1545:56 INT-2	seven's verified .. there's mizar and we're turning zero five zero.		
		1546:12 DTW	comair thirty-two seventy-two turn left heading zero three zero vector for sequencing.
		1546:14 RDO-1	zero three zero comair thirty-two seventy-two.
		1546:57 DTW	northwest two seventy-two information alpha is current .. winds zero six zero at six .. visibility one and one half .. light snow .. ceiling six hundred broken one thousand one hundred broken .. two thousand one hundred overcast .. altimeter's two niner one niner .. runway three right RVR three thousand five hundred .. braking action reported poor by DC niner.
1547:17 CAM	[sound of three clicks]		
		1547:18 DTW	comair thirty-two seventy-two turn right heading zero five five.
1547:20 CAM	[sound of two clicks]		
		1547:21 RDO-1	zero five five comair thirty-two seventy-two.
1547:32 INT-2	[sound similar to that of a human sniffle]		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1547:47 INT-2	let's run the descent check.		
1547:49 INT-1	ice protection?		
1547:51 INT-2	windshield, props, standard seven.		
1547:53 INT-1	ignition?		
1547:54 INT-2	auto.		
1547:55 INT-1	pressurization?		
1547:55 INT-2	it's ah reset for landing in detroit .. six thirty-nine .. looks good.		
1548:01 INT-1	altimeters?		
1548:03 INT-2	ah twenty-one.		
1548:04 INT-1	set left.		
1548:05 INT-2	set right.		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1548:06 INT-1	landing lights?		
1548:06 INT-2	landing lights on.		
1548:07 INT-1	seatbelt sign?		
1548:08 INT-2	on.		
1548:09 INT-1	PACKs and bleeds?		
1548:10 INT-2	four lows.		
1548:11 INT-1	crossfeed?		
1548:12 INT-2	crossfeed's off.		
1548:12 INT-1	that completes that.		
1548:14 INT-2	okay .. a thousand to go .. uhm .. we're going to do an ILS to runway three right .. it'll be a coupled approach .. flaps twenty-five .. frequency is one one one point five .. that's set .. might as well set that in there .. inbound course is zero three five.		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1548:38 CAM	[sound of three tones similar to that of the altitude alerter]		
1548:43 INT-2	we're gonna intercept the top somewhere ah whatever altitude he gives us .. ah .. twenty-seven hundred's the intercept to the glide slope.		
		1548:47 DTW	comair thirty-two seventy-two turn right heading zero seven zero.
		1548:50 RDO-1	zero seven zero comair thirty-two seventy-two.
1548:55 CAM	[sound similar to increase in engine/prop noise]		
1549:13 INT-2	it's ah two hundred foot approach with the decision altitude of eight thirty-three .. you've already got that set in there .. missed approach will be published climb to eleven hundred .. and a climbing right turn to three thousand direct to the ah DM locator outer marker "Spencer" * which is ah two twenty-three that's set .. and hold .. that will be a teardrop entry .. questions, comments.		
1549:38 INT-1	no questions .. twenty-one, fourteen, and forty-three are your bugs.		
1549:43 INT-2	twenty-one, fourteen, forty-three .. set.		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1549:48 INT-1	autofeather?		
1549:50 INT-2	armed.		
1549:51 INT-1	nav radios.		
1549:53 INT-2	nav radios are ah set eleven point five.		
		1549:54 DTW	comair thirty-two seventy-two turn right to a heading of one four zero .. reduce speed to one seven zero.
		1549:59 RDO-1	heading one four zero speed one seven zero comair thirty-two seventy-two.
1550:11 INT-1	I'll be on two.		
1550:11 INT-2	alright.		
		1550:15 RDO-1	good afternoon detroit .. comair thirty-two seventy-two.
1550:28 INT-1	nobody likes to answer me .. I'm back.		
		1550:28 DTW	comair thirty-two seventy-two contact approach one two five point one five so long.

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1550:32 RDO-1	one two five point one five comair thirty-two seventy-two, good day.
		1550:36 COM	[sound of tone similar to that of frequency change]
1550:38 INT-2	maybe you should try being abusive with them.		
1550:40 INT-1	huh?		
1550:41 INT-2	gotta try being abusive with them.		
1550:43 INT-1	that's right.		
1550:43 INT-2	answer the phone, dummy.		
1550:44 INT-1	yeah.		
		1550:45 RDO-1	good afternoon detroit approach comair thirty-two seventy-two seven thousand.
		1550:49 DTW	comair thirty-two seventy-two detroit approach .. reduce speed to one seven zero and maintain six thousand.

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1550:54 RDO-1	speed one seven zero .. descend and maintain six thousand comair thirty-two seventy-two.
1550:57 CAM	[sound of three tones similar to that of the altitude alerter]		
1551:00 INT-1	six.		
1551:00 INT-2	six thousand.		
		1551:14 DTW	comair thirty-two seventy-two fly heading one four zero.
		1551:17 RDO-1	one four zero comair thirty-two seventy-two.
1551:20 INT-2	wonder what plane he's looking at?		
1551:25 INT-1	ah the one ah that's not going one four zero.		
		1551:27 OPS	thirty-two seventy two you calling detroit?
		1551:30 RDO-1	yes sir we're in range .. ah positive fuel .. we'll be at the gate in approximately nine minutes and forty-eight seconds.
		1551:38 OPS	approximately, huh?

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1551:39 RDO-1	approx-, of course.
		1551:41 OPS	do you guys know if you have any special assistance coming in?
		1551:44 RDO-1	I can't recall anyone coming out so I thi- I think we're all good there .. all all we'll need is just fuel.
		1551:51 OPS	roger that ah bravo * three.
1551:53 CAM	[sound of three tones similar to that of the altitude alerter]		
		1551:54 RDO-1	roger that .. and how many do we have going back so I know how many seats to give you?
		1551:58 OPS	ah, you're booked to twenty-eight right now.
		1552:01 RDO-1	okay that'll be our load then .. we can take them all .. thanks.
1552:07 INT-1	took 'em a while but they came back to me.		
1552:13 INT-2	that's good news .. no changes while you were away.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1552:13 DTW	comair thirty-two seventy-two descend and maintain four thousand.
		1552:16 RDO-1	four thousand comair thirty-two seventy-two.
1552:20 INT-1	four's in the altitude alert.		
1552:23 INT-2	four thousand verified.		
		1553:03 DTW	cactus fifty zero six zero to intercept three right.
		1553:05 CACT50	zero six zero okay .. you got any windshear reports on the final?
		1553:09 DTW	ah no .. I haven't had anything ah .. just ah slick runways and ah low visibilities.
		1553:15 CACT50	okay .. yeah it's two thirty-seven at thirty-two up here.
		1553:18 DTW	ah you'll pick up a head wind once you get down ah probably oh two thousand feet or so.
		1553:25 DTW	comair thirty-two seventy-two turn right heading one eight zero .. reduce speed to one five zero.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		1553:29 RDO-1	heading one eight zero .. speed one five zero comair thirty-two seventy-two.
1553:42 CAM	[sound of three tones similar to that of the altitude alerter]		
		1553:42 DTW	comair thirty-two seventy-two reduce speed to one five zero.
		1553:45 RDO-1	speed one five zero comair thirty-two seventy-two.
1553:52 INT-2	this guys got -		
1553:53 INT-1	they gotta always tell us twice.		
1553:55 INT-2	he's got short term memory disorder I think.		
1553:57 INT-1	is that what that is?		
1553:58 INT-2	yeah, he's got alzheimer's .. that's what it is.		
		1553:59 DTW	comair thirty-two seventy-two now turn left heading zero nine zero .. plan a vector across the localizer.
		1554:04 RDO-1	heading zero niner zero comair thirty-two seventy-two.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1554:10.9 CAM	[sound of click]		
1554:13.2 CAM	[sound of faint click]		
1554:14.4 CAM	[sound of several unidentified thumps fade in and out]		
1554:15.9 CAM	[sound of several "whirring" noises, similar to that of the elevator trim servo]		
1554:16.0 CAM	[sound of increase in discrete high frequency noise similar to that of power increase]		
1554:17.1 CAM	[significant reduction in background ambient noise]		
1554:20.8 INT-1	looks like your low speed indicator.		
1554:20.9 INT-2	* *.		
1554:23.6 INT-1	power.		
1554:23.9 CAM	[sound similar to that of stickstaker starts]		
1554:24.1 INT-2	thanks.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1554:24.1 CAM	[sound of three chimes and "auto-pilot" aural warning]		
1554:25.9 CAM	[sound similar to that of stickshaker stops]		
1554:26.1 INT-2	oh.		
1554:26.1 INT-1	oh #.		
1554:26.8 CAM	[sound of increase in background noise similar to that of power increase]		
1554:29.0 CAM	[sound of GPWS “bank angle” aural warning]		
1554:29.1 CAM	[sound of three chimes and "auto-pilot" aural warning]		
1554:31.0 CAM	[sound similar to that of stickshaker starts and continues to the end of tape]		
1554:33.3 INT-?	[sound of single human breath]		
1554:34.3 CAM	[sound of three chimes and "auto-pilot" aural warning]		
1554:35.3 CAM	[sound of GPWS “bank angle” aural warning]		

INTRA-COCKPIT COMMUNICATION		**AIR-GROUND COMMUNICATION**	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
1554:37.1 INT-1	[nonpertinent exclamation]		
1554:38.2 CAM	[sound of three chimes and "auto-pilot" aural warning]		
1554:39.1 INT-1	[nonpertinent exclamation]		
1554:40.1 CAM	[end of tape]		

Appendices C through I are contained in separate files.

They may be obtained from
http://www.ntsb.gov/publictn/1998/AAR9804_links.htm