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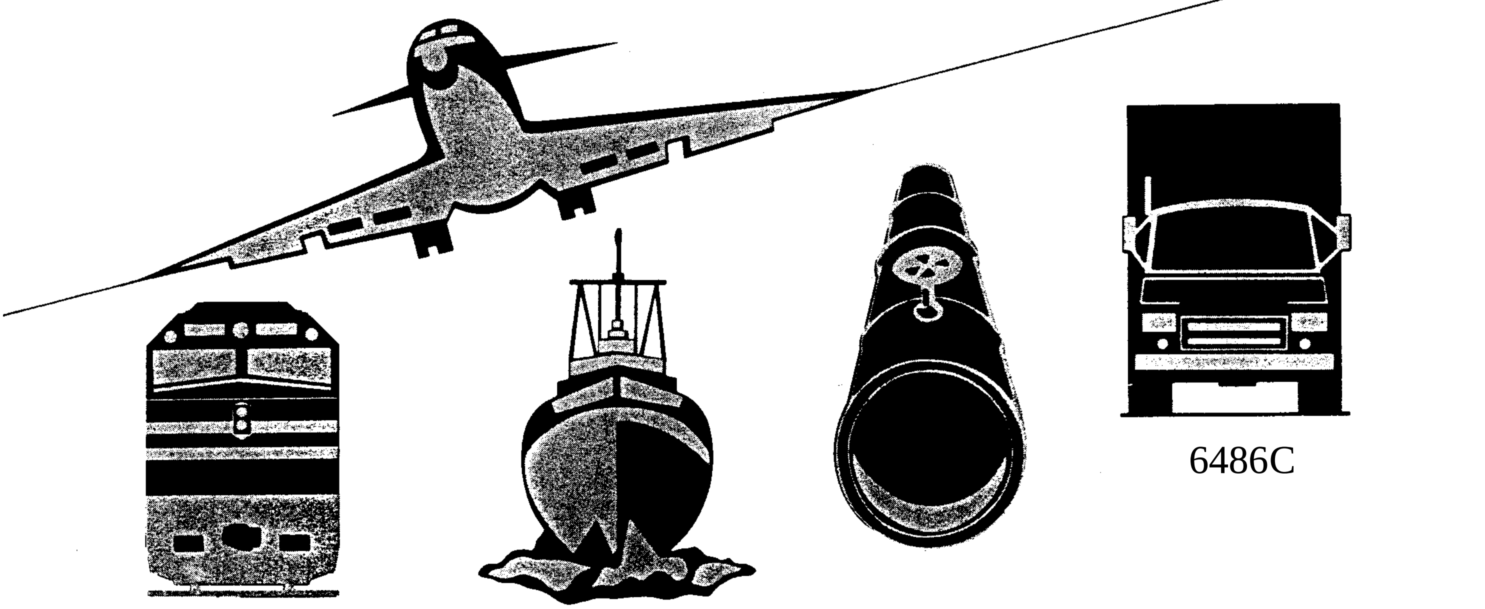
NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

IN-FLIGHT ICING ENCOUNTER AND LOSS OF CONTROL
SIMMONS AIRLINES, d.b.a. AMERICAN EAGLE FLIGHT 4184
AVIONS de TRANSPORT REGIONAL (ATR)
MODEL 72-212, N401AM
ROSELAWN, INDIANA
OCTOBER 31,1994

VOLUME 1: SAFETY BOARD REPORT



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MODEL 72-212, N401AM
ROSELAWN, INDIANA
OCTOBER 31, 1994

Adopted: July 9, 1996
Notation 6486C

Abstract: Volume I of this report explains the crash of American Eagle flight 4184, an ATR 72 airplane during a rapid descent after an uncommanded roll excursion. The safety issues discussed in the report focused on communicating hazardous weather information to flightcrews, Federal regulations on aircraft icing and icing certification requirements, the monitoring of aircraft airworthiness, and flightcrew training for unusual events/attitudes. Safety recommendations concerning these issues were addressed to the Federal Aviation Administration, the National Oceanic and Atmospheric Administration, and AMR Eagle. Volume II contains the comments of the Bureau Enquetes-Accidents on the Safety Board's draft of the accident report.

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September 13, 2002
The National Transportation Safety Board adopted revisions to the findings and probable cause for this accident, as summarized below.

For more information, see the full Response to Petition for Reconsideration.

Findings 21, 23, 24, 25, 26, 35, and 36 (and the corresponding text on pages 177, 178, 179, 179-80,181, 193, and 194, respectively) are revised as follows:

21. ~~Prior to~~ *Before* the Roselawn accident, ~~ATR recognized the reason for the aileron behavior in the~~ previous incidents ~~and determined~~ *demonstrated* that ice accumulation behind the deice boots, at an [angle of attack] sufficient to cause an airflow separation, would cause the ailerons to become unstable. Therefore, *it would have been prudent for* ATR *to examine the combinations of icing conditions and airplane configurations that could produce the performance, stability, and control characteristics (including aileron hinge moment shifts) exhibited in the prior incidents, and the possible repercussions of such aileron hinge moment shifts* ~~had sufficient basis to modify the airplane and/or provide operators and pilots with adequate, detailed information regarding this phenomenon~~.

23. ATR's proposed post-Mosinee AFM/FCOM changes, ~~even if~~ *which were not* adopted by the DGAC and the FAA, would not have provided flightcrews with sufficient information to identify or recover from the type of event that occurred at Roselawn~~, and the actions taken by ATR following the Mosinee incident were insufficient~~.

24. The 1992 ATR All Weather Operations brochure ~~was misleading and minimized~~ *did not adequately communicate* the ~~known~~ catastrophic potential of ATR operations in freezing rain.

25. *Information provided b*y ~~ATR failed to disseminate adequate warnings and guidance~~ to operators *after the late 1980s and early 1990s about ice-related incidents did not give adequate warnings and guidance to operators* about the adverse characteristics of, and techniques to recover from, ice-induced aileron hinge moment reversal events~~; and ATR failed to develop additional airplane modifications, which led directly to this accident~~.

26. *Prior to the Roselawn accident,* the DGAC failed to require ATR to *examine the combinations of icing conditions and airplane configurations that could produce the performance, stability, and control characteristics (including aileron hinge*

moment shifts) exhibited in the prior incidents, and the possible repercussions of such aileron hinge moment shifts; ~~take additional corrective actions, such as performing additional icing tests, issuing~~ *to issue* more specific warnings regarding the aileron hinge moment reversal phenomenon~~,~~*;* ~~developing additional airplane modifications,~~ and ~~providing~~ *to provide* specific guidance on the recovery from a hinge moment reversal.~~, which led directly to this accident.~~

35. Because the DGAC did not require ATR~~, and ATR did not~~ *to* provide to the operators of its airplanes, information that specifically alerted flightcrews to the fact that encounters with freezing rain could result in sudden autopilot disconnects, aileron hinge moment reversals, and rapid roll excursions, or guidance on how to cope with these events, the crew of flight 4184 had no reason to expect that the icing conditions they were encountering would cause the sudden onset of an aileron hinge moment reversal, autopilot disconnect, and loss of aileron control.

36. ~~Neither the flight attendant's presence in the cockpit nor the flightcrew's conversations with her contributed to the accident. However, a~~*A* sterile cockpit environment would probably have reduced flightcrew distractions and could have promoted a more appropriate level of flightcrew awareness for the conditions in which the airplane was being operated.

The probable cause is amended as follows:

The National Transportation Safety Board determines that the probable ~~causes~~ *cause* of this accident ~~were~~ *was* the loss of control, attributed to a sudden and unexpected aileron hinge moment reversal, that occurred after a ridge of ice accreted beyond the deice boots ~~because: 1) ATR failed to completely disclose to operators, and incorporate in the ATR 72 airplane flight manual, flightcrew operating manual and flightcrew training programs, adequate information concerning previously known effects of freezing precipitation on the stability and control characteristics, autopilot and related operational procedures when the ATR 72 was operated in such conditions;~~ *while the airplane was in a holding pattern during which it intermittently encountered supercooled cloud and drizzle/rain drops, the size and water content of which exceeded those described in the icing certification envelope. The airplane was susceptible to this loss of control, and the crew was unable to recover.*

Contributing to the accident were 1) ~~2)~~ the French Directorate General for Civil Aviation's (DGAC's) inadequate oversight of the ATR 42 and 72, and its failure to take the necessary corrective action to ensure continued airworthiness in icing conditions; *2)*~~3)~~the DGAC's failure to provide the FAA with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions~~, as specified under the Bilateral Airworthiness Agreement and Annex 8 of the International Civil Aviation Organization. Contributing to the accident were: 1)~~ *3*) the Federal Aviation Administration's (FAA's) failure to ensure that aircraft icing certification requirements, operational requirements for flight into icing conditions, and FAA published aircraft icing information adequately accounted for the hazards that can result from flight in freezing rain ~~and other conditions not specified in 14 Code of Federal Regulations (CFR) Part 25, Appendics C, and 2)~~ *4)* the FAA's inadequate oversight of the ATR 42 and 72 to ensure continued airworthiness in icing conditions; *and 5) ATR's inadequate response to the continued occurrence of ATR 42 icing/roll upsets which, in conjunction with information learned about aileron control difficulties during the certification and development of the ATR 42 and 72, should have prompted additional research, and the creation of updated airplane flight manuals, flightcrew operating manuals and training programs related to operation of the ATR 42 and 72 in such icing conditions.*

The following paragraph is removed from page 75:

~~Hydraulically powered flight controls can overcome high control forces resulting from normal in-flight control surface hinge moments. If properly designed, they can also prevent control surface anomalies from being transmitted back through the control system and into the cockpit. According to ATR engineers, hydraulically powered ailerons were discussed during the preliminary design of the ATR 42. It was determined that adequate lateral control characteristics could be obtained without the additional weight and complexity of a hydraulic system. Hydraulic aileron control was again discussed informally among ATR engineers after an incident involving a Simmons Airlines ATR 42 in Mosinee, Wisconsin, in December 1988. ATR management has since stated that hydraulically powered ailerons have never been "officially" considered for either the ATR 42 or 72.~~

The following sentence is removed from page 117:

~~Also, with respect to Flight 4184, the chief test pilot for ATR testified that the type of roll anomaly the flight crew experienced would not have been recoverable by the average line pilot.~~

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CONTENTS

EXECUTIVE SUMMARY

On October 31, 1994, at 1559 Central Standard Time, an Avions de Transport Regional, model 72-212 (ATR 72), registration number N401AM, leased to and operated by Simmons Airlines, Incorporated, and doing business as American Eagle flight 4184, crashed during a rapid descent after an uncommanded roll excursion. The airplane was in a holding pattern and was descending to a newly assigned altitude of 8,000 feet when the initial roll excursion occurred. The airplane was destroyed by impact forces; and the captain, first officer, 2 flight attendants and 64 passengers received fatal injuries. Flight 4184 was a regularly scheduled passenger flight being conducted under 14 Code of Federal Regulations, Part 121; and an instrument flight rules flight plan had been filed.

The National Transportation Safety Board determines that the probable causes of this accident were the loss of control, attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the deice boots because: 1) ATR failed to completely disclose to operators, and incorporate in the ATR 72 airplane flight manual, flightcrew operating manual and flightcrew training programs, adequate information concerning previously known effects of freezing precipitation on the stability and control characteristics, autopilot and related operational procedures when the ATR 72 was operated in such conditions; 2) the French Directorate General for Civil Aviation's inadequate oversight of the ATR 42 and 72, and its failure to take the necessary corrective action to ensure continued airworthiness in icing conditions; and 3) the French Directorate General for Civil Aviation's failure to provide the Federal Aviation Administration with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions, as specified under the Bilateral Airworthiness Agreement and Annex 8 of the International Civil Aviation Organization.

Contributing to the accident were: 1) the Federal Aviation Administration's failure to ensure that aircraft icing certification requirements, operational requirements for flight into icing conditions, and Federal Aviation Administration published aircraft icing information adequately accounted for the hazards that can result from flight in freezing rain and other icing conditions not specified in 14 Code of Federal Regulations, Part 25, Appendix C; and 2) the Federal Aviation Administration's inadequate oversight of the ATR 42 and 72 to ensure continued airworthiness in icing conditions.

The safety issues in this report focused on communicating hazardous weather information to flightcrews, Federal regulations regarding aircraft icing and icing certification requirements, the monitoring of aircraft airworthiness, and flightcrew training for unusual events/attitudes.

Safety recommendations concerning these issues were addressed to the Federal Aviation Administration, the National Oceanic and Atmospheric Administration, and AMR Eagle. Also, as a result of this accident, on November 7, 1994, the Safety Board issued five safety recommendations to the Federal Aviation Administration regarding the flight characteristics and performance of ATR 42 and ATR 72 airplanes in icing conditions. In addition, on November 6, 1995, the Safety Board issued four safety recommendations to the Federal Aviation Administration concerning the Air Traffic Control System Command Center. In accordance with Annex 13 to the Convention on International Civil Aviation, the Bureau Enquetes-Accidents provided comments on the Safety Board's draft of the accident report that are contained in Volume II of this report.

SELECTED ACRONYMS AND DEFINITIONS

AAS	anti-icing advisory system
AC	advisory circular; provides nonregulatory guidance to certificate holders for a means (but not necessarily the only means) to comply with Federal Aviation (FAA) Regulations
ACARS	automatic communications and recording system
AD	airworthiness directive; FAA regulatory requirement for immediate mandatory inspection and/or modification
ADC	air data computer
AEG	FAA aircraft evaluation group
AIM	Aeronautical Information Manual; a primary FAA publication whose purpose is to instruct airmen about operating in the U. S. National Airspace System
AIRMET	Airman's Meteorological Information; such advisories to flightcrews include, but are not limited to, moderate icing and moderate turbulence
AMM	aircraft maintenance manual
AOA	angle-of-attack ("vane" AOA is about 1.6 times the fuselage AOA for the ATR 72)
AOM	aircraft operating manual
ARTCC	air route traffic control center
ASRS	NASA's Aviation Safety Reporting System
ATCSCC	air traffic control system command center
BAA	Bilateral Airworthiness Agreement
BEA	French Bureau Enquetes-Accidents
CFR	Code of Federal Regulations
CWA	center weather advisories
CWSU	center weather service unit
DGAC	French Directorate General for Civil Aviation
EADI	electronic attitude display indicator indicating pitch and roll attitudes
EDCT	expect departure clearance time
EFC	expect further clearance from ATC
EFIS	electronic flight information system
EHSI	electronic horizontal situation indicator
FAR/JAR	Federal Aviation Regulations/Joint Airworthiness Requirements
FCOM	flightcrew operating manual
G	one G is equivalent to the acceleration due to Earth's gravity
GPWS	ground proximity warning system

HIWAS	hazardous in-flight weather advisory service; continuous recorded hazardous in-flight weather forecasts broadcast to airborne pilots over selected VOR outlets defined as an HIWAS Broadcast Area
ICAO	International Civil Aviation Organization
IFR	instrument flight rules flight plan
IEP	ice evidence probe
KIAS	knots indicated airspeed
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/SLW refer to the amount of liquid water in a certain volume of air
LWD	left wing down
MFC	multi-function computer
MVD	median volumetric diameter; the FAA defines freezing drizzle as supercooled water drops with MVDs between 50 and 300 microns and freezing rain as supercooled water drops with MVDs greater than 300 microns (a micron is 1/1,000 of a millimeter) ("supercooled" is the liquid state of a substance that is below the normal freezing temperature for that substance)
NASA	National Aeronautics and Space Administration (formerly the National Advisory Committee for Aeronautics NACA))
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NAWAU	National Aviation Weather Advisory Unit; renamed Aviation Weather Center subsequent to the accident
OIM	operators information message
OAT	outside air temperature
PIREP	pilot report
POI	FAA principal operations inspector
RWD	right wing down
SAT	static air temperature (synonymous with OAT)
SB	service bulletin supplied by manufacturer
SIGMET	significant meteorological information; such advisories to flightcrews include, but are not limited to, severe and extreme turbulence and severe icing
SPS	stall protection system
STC	supplemental type certificate
TAT	total air temperature

TCAS	traffic alert and collision avoidance system
TRACON	terminal radar approach control
TLU	travel limiter unit, which limits rudder travel
VOR	very high frequency omni-directional radio range navigation aid
Zulu Time	coordinated universal time (UTC), time at the 0^o longitude line that passes through Greenwich, England, and is based on the 24-hour clock

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NATIONAL TRANSPORTATION SAFETY BOARD
WASHINGTON, D .C. 20594

AIRCRAFT ACCIDENT REPORT

IN-FLIGHT ICING ENCOUNTER AND LOSS OF CONTROL

SIMMONS AIRLINES, d.b.a. AMERICAN EAGLE FLIGHT 4184 AVIONS de TRANSPORT REGIONAL (ATR), MODEL 72-212, N401AM ROSELAWN, INDIANA OCTOBER 31, 1994

1. FACTUAL INFORMATION

1.1 History of Flight

On October 31, 1994, at 1559 Central Standard Time,[1] an Avions de Transport Regional, model 72-212 (ATR 72), registration number N401AM, leased to and operated by Simmons Airlines, Incorporated, and doing business as (d.b.a.) American Eagle flight 4184, crashed during a rapid descent after an uncommanded roll excursion. The airplane was in a holding pattern and was descending to a newly assigned altitude of 8,000 feet[2] when the initial roll excursion occurred. The airplane was destroyed by impact forces, and the captain, first officer, 2 flight attendants and 64 passengers received fatal injuries. Flight 4184 was a regularly scheduled passenger flight being conducted under 14 Code of Federal Regulations (CFR) Part 121; and an instrument flight rules (IFR) flight plan had been filed.

The flightcrew reported for duty at 1039 in Chicago, Illinois, departed Chicago's O'Hare International Airport (ORD) as flight 4101, on schedule at 1139, and arrived in Indianapolis, Indiana (IND), at 1242. The trip sequence after IND included a return leg to ORD, followed by a stopover at Dayton, Ohio (DAY), a return trip to ORD, and a final stop in Champaign/Urbana, Illinois (CMI). The captain was scheduled to complete only the first four segments of the first day's schedule while the first officer was to fly all five segments. The accident occurred

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[1]All times herein are Central Standard Time (CST) unless otherwise noted.

[2]All altitudes are expressed in relation to mean sea level (msl) unless otherwise noted.

on the second leg (from IND to ORD), while the first officer was performing the duties of the flying pilot.

Prior to departure, the flightcrew received a company-prepared, combined flight plan release and weather package. The meteorological information provided to the crew did not contain airman's meteorological information (AIRMET)[3] or any information regarding a forecast of light-to-moderate turbulence or in-flight icing conditions along flight 4184's intended route of flight. According to testimony of the Manager of Dispatch for Simmons Airlines, AIRMETs are available to dispatchers for review and can be included in the flight release at the discretion of the dispatcher. AIRMETs are also available for the pilots to review at the departure station. There was no evidence to indicate whether the flightcrew of flight 4184 had obtained this information.

Flight 4184 was scheduled to depart the gate in IND at 1410 and arrive in ORD at 1515; however, due to a change in the traffic flow because of deteriorating weather conditions (by the Traffic Management Coordinator) at ORD, the flight left the gate at 1414 and was held on the ground for 42 minutes before receiving an IFR clearance to ORD. At 1453:19, the ground controller at the IND air traffic control (ATC) tower advised the crew of flight 4184 that, "...you can expect a little bit of holding in the air and you can start 'em up [reference to engine start] contact the tower when you're ready to go." The controller did not specify to the crew the reason for either the ground or airborne hold.

At 1455:20, the IND local control (LC) controller cleared flight 4184 for takeoff. The route for the planned 45-minute flight was to fly directly to IND VOR (very high frequency omni-directional radio range) navigation aid via V-399 (Victor Airway), then to BOILER VOR, directly to BEBEE intersection[4] and thereafter to ORD.

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[3]According to the Aeronautical Information Manual (AIM), AIRMETs (Airman's Meteorological Information) are "in-flight advisories concerning weather phenomena which are of operational interest to all aircraft and potentially hazardous to aircraft having limited capability because of lack of equipment, instrumentation, or pilot qualifications. AIRMETs concern weather of less severity than that covered by SIGMETs." AIRMETs cover large geographical areas similar to a SIGMET [significant meteorological information], and include information regarding "moderate icing, moderate turbulence, sustained winds of 30 knots or more at the surface...."

[4]An intersection is a point defined by any combination of intersecting courses, radials or bearings of two or more navigational aids.

The data from the digital flight data recorder (FDR) indicated that the flightcrew engaged the autopilot as the airplane climbed through 1,800 feet. At 1505:14, the captain made initial radio contact with the DANVILLE Sector (DNV) Radar Controller and reported that they were at 10,700 feet and climbing to 14,000 feet. The DNV controller issued a clearance to the crew to proceed directly to the Chicago Heights VOR (CGT). At 1508:33, the captain of flight 4184 requested and received a clearance to continue the climb to the final en route altitude of 16,000 feet.

At 1509:22, the pilot of a Beech Baron, identified as N7983B, provided a pilot report (PIREP) to the DNV controller that there was "light icing" at 12,000 feet over BOILER, and, at 1509:44, he reported the icing was "trace rime...." According to the DNV controller, because the crew of flight 4184 was on the frequency and had established radio contact, the PIREP was not repeated. The DNV controller received additional PIREPs shortly after the accident.

At 1511:40, prior to flight 4184 establishing radio contact with the BOONE sector controller,[5] the ORD Terminal Radar Approach Control (TRACON) West Arrival Handoff controller contacted the BOONE controller via telephone and said, "...protect yourself for the hold." At 1511:45, the DNV controller contacted flight 4184 and issued a clearance and a frequency change to the BOONE controller. This transmission was acknowledged by the captain. About this same time, the FDR indicated that the airplane was in a level attitude at an altitude of about 16,300 feet and was maintaining an airspeed of approximately 190 knots indicated airspeed (KIAS). About 2 minutes later, the captain of flight 4184 made initial radio contact with the BOONE controller and stated, "...checking in at one six thousand we have a discretion down to one zero thousand forty southeast of the Heights we're on our way down now." The BOONE controller acknowledged the radio transmission and provided the ORD altimeter setting. At 1513, flight 4184 began the descent to 10,000 feet. During the descent, the FDR recorded the activation of the Level III[6] airframe deicing system and the propeller revolutions per minute (RPM) at 86 percent.

At 1517:24, the BOONE sector was advised by the ORD TRACON arrival controller to issue holding instructions to those aircraft that were inbound to

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[5]Refer to Section 1.5.4.3 for further information about the developmental controller and trainer handling aircraft in the BOONE Sector.

[6]Refer to Section 1.6.6 for detailed information about the ATR-72 deicing system.

ORD.[7] At 1518:07, shortly after flight 4184 leveled off at 10,000 feet, the crew received a clearance from the BOONE controller that they were, "...cleared to the LUCIT intersection[8] via radar vectors turn ten degrees left intercept Victor 7 hold southeast on Victor 7 expect further clearance (EFC) two one three zero [Zulu time] [1530 CST]." The captain acknowledged the transmission. About 1 minute later, the BOONE controller revised the EFC for flight 4184 to 1545.[9] This was followed a short time later by several radio transmissions between the captain of flight 4184 and the BOONE controller in which he received approval for 10 nautical mile legs in the holding pattern, a speed reduction,[10] and confirmation of right turns while holding. (See Figure 1 for holding location.)

At 1524:39, the captain of flight 4184 contacted the BOONE controller and reported, "entering the hold." The crew then notified the company via the automatic communications and recording system (ACARS) that they were delayed and that the EFC was 1545. According to the FDR, the first holding pattern was flown at approximately 175 KIAS with the wing flaps in the retracted position. The airframe deice system was deactivated during this time, and the propeller speed was reduced to 77 percent.

Recorded sounds on the cockpit voice recorder (CVR) began at 1527:59, with the sounds of music playing in the first officer's headset and a flight attendant in the cockpit discussing both flight and nonflight-related information with the pilots. At 1533:13, the captain stated, "man this thing gets a high deck angle in these turns...we're just wallowing in the air right now" [FDR data indicated that the vane angle-of-attack (AOA)[11] was 5 degrees]. The following exchange

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[7]Between 1547:59 and 1558:28 there were seven aircraft holding in the BEARZ sector at HALIE intersection located 25 nautical miles northeast of the LUCIT intersection. The aircraft holding were a United Airlines B-757 at 11,000 feet; a United Airlines B-767 holding at 12,000 feet; a USAir DC-9 holding at 13,000 feet; a United Airlines B-737 holding at 14,000 feet; a Northwest Airline Airbus A-320 holding at 15,000 feet; a Dassault Falcon 50 holding at 16,000 feet; and an American Airlines Airbus A-300 holding at 17,000 feet.

[8]Located 18 nautical miles from the Chicago Heights VOR on the 157-degree radial.

[9]Arriving aircraft that preceded flight 4184 were slowed down because of deteriorating weather conditions and an anticipated "rush" of arriving aircraft from the west; as a result, the BOONE sector controller issued two additional EFC's to the flightcrew.

[10]The maximum airspeed for all propeller-driven airplanes (including turbopropeller) in holding is 175 KIAS. According to the FDR data, flight 4184's indicated airspeed varied between 170 and 180 KIAS in the holding pattern.

[11]Vane AOA is herein referred to as "AOA" and is approximately 1.6 times the fuselage AOA, such that at 5 degrees vane AOA, fuselage AOA is approximately 3 degrees.

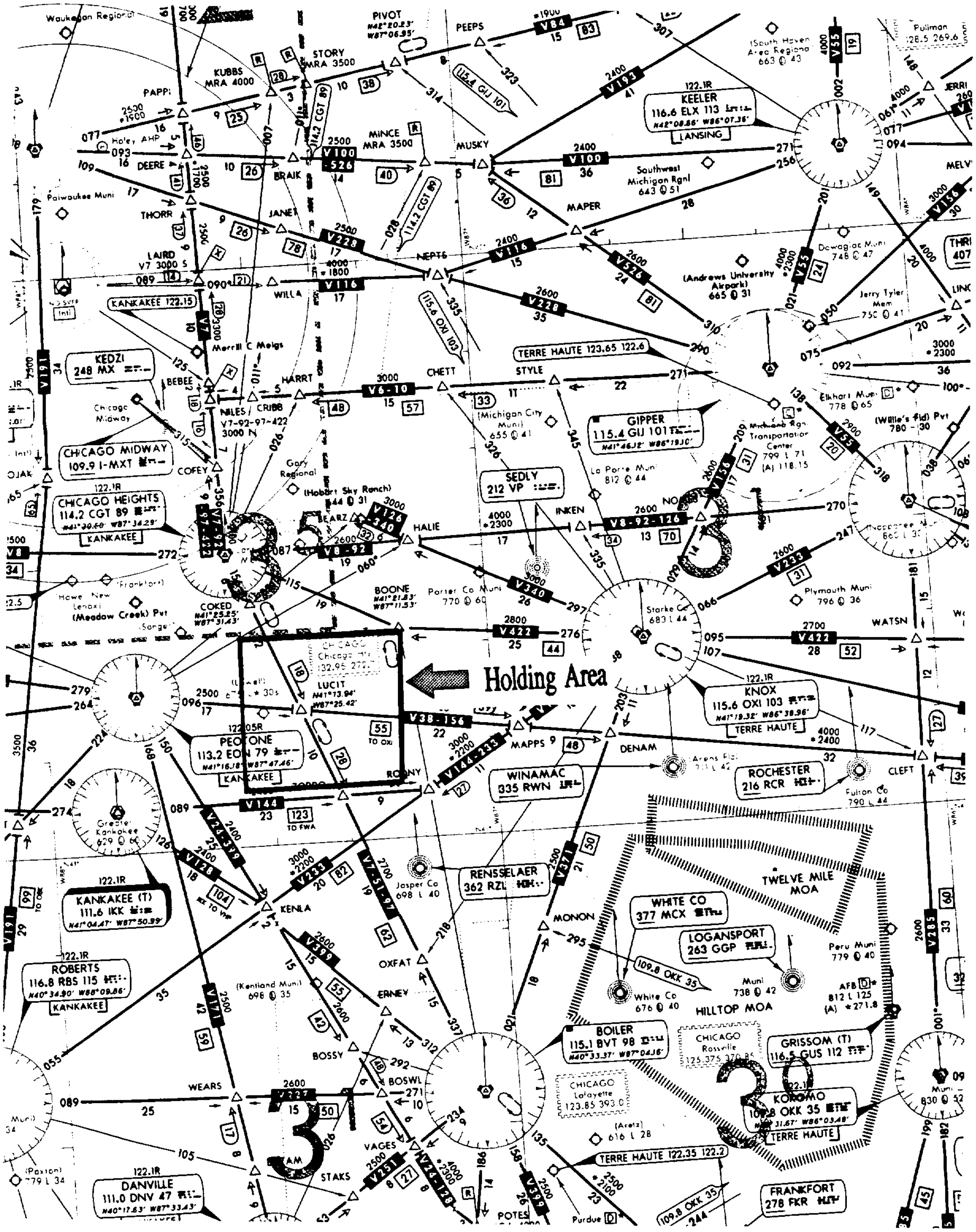

Figure 1.--Holding pattern location; box identifies LUCIT intersection.

of conversation and sounds were recorded on the CVR:[12]

1533:19	First Officer	you want flaps fifteen
1533:21	Captain	I'll be ready for that stall procedure here pretty soon
1533:22	First Officer	sound of chuckle
1533:24	Captain	do you want kick 'em in (it'll) bring the nose down
1533:25	First Officer	sure
1533:26	Sound of several clicks similar to flap handle being moved. [The FDR recorded the flaps moving to the 15-degree position and the aircraft AOA decreasing to approximately 0 degrees].	
1533:34	Sound of "whooler" similar to pitch trim movement	
1533:39	Captain...the trim, automatic trim	
1533:56	Sound of single tone similar to caution alert	

At 1538:42, the BOONE controller issued a revised EFC of 1600 to flight 4184. The captain acknowledged this transmission, and the CVR recorded the flightcrew continuing their discussion with the flight attendant. At 1541:07, the CVR recorded the sound of a single tone similar to the caution alert chime,[13] and the FDR recorded the activation of the "Level III" airframe deicing systems. About 3 seconds later, both the CVR and FDR recorded an increase in the propeller speed from 77 percent to 86 percent.

At 1542:38, during the beginning of the third circuit of the holding pattern, the CVR recorded the flight attendant leaving the cockpit followed by the flightcrew discussing flight-related information. Also, during this time, the crew

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[12]Refer to appendix B for a complete transcript of the CVR.

[13]This caution chime can be activated by any one of numerous aircraft systems, including the aircraft ice detection system. See Section 1.6.6 for more information about the ice detection system.

received information from the company dispatch via the ACARS. The first officer transmitted the updated EFC time and fuel data via the ACARS but was unsuccessful in acknowledging a company-transmitted ACARS message. He succeeded in sending another ACARS message; however, he was still unsuccessful in acknowledging the company's messages.

At 1548:34, the first officer commented to the captain, "that's much nicer, flaps fifteen." About 7 seconds later, the CVR recorded one of the two pilots saying, "I'm showing some ice now." This comment was followed 2 seconds later by an unintelligible word(s). The CVR group could not determine whether the word(s) was spoken by the captain or the first officer. The captain remarked shortly thereafter, "I'm sure that once they let us out of the hold and forget they're down [flaps] we'll get the overspeed."[14]

At 1549:44, the captain departed the cockpit and went to the aft portion of the airplane to use the restroom. During the captain's absence, both he and a flight attendant spoke with the first officer via the inter-communication system (ICS) for about 1 minute. The captain advised the first officer that the restroom was occupied and that he would return shortly. The CVR indicated that the captain returned from the restroom at 1554:13, and upon his return asked the first officer for a status update regarding company and ATC communications. There was no verbal inquiry by the captain about the status of the icing conditions or the aircraft deice/anti-icing systems. At 1555:42, the first officer commented, "we still got ice." This comment was not verbally acknowledged by the captain. The CVR indicated that the flightcrew had no further discussions regarding the icing conditions.

At 1556:16, the BOONE controller contacted flight 4184 and instructed the flightcrew to, "descend and maintain eight thousand [feet]." At 1556:24, the CVR recorded a TCAS[15] alert; however, there was no discussion between the flight crewmembers regarding this alert. This was followed by a transmission from the BOONE controller informing the crew that "...[it] should be about ten minutes till you're cleared in." The first officer responded, "thank you." There were no further radio communications with the crew of flight 4184.

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[14]Reference is to the aural flap overspeed warning that activates if the aircraft speed exceeds 185 knots with the flaps in the 15-degree position.

[15]The traffic alert and collision avoidance system is an airborne collision avoidance system based on radar beacon signals that operate independent of ground-based equipment. TCAS II generates traffic advisories and resolution (collision avoidance) advisories in the vertical plane.

At 1556:51, the FDR showed that the airplane began to descend from 10,000 feet, the engine power was reduced to the flight idle position, the propeller speed was 86 percent, and the autopilot remained engaged in the vertical speed (VS) and heading select (HDG SEL) modes. At 1557:21, as the airplane was descending in a 15-degree right-wing-down (RWD) attitude at 186 KIAS, the sound of the flap overspeed warning was recorded on the CVR. Five seconds later, the captain commented, "I knew we'd do that," followed by the first officer responding, "I [was] trying to keep it at one eighty." As the flaps began transitioning to the zero degree position, the AOA and pitch attitude began to increase.

At 1557:33, as the airplane was descending through 9,130 feet, the AOA increased through 5 degrees, and the ailerons began deflecting to a RWD position. About 1/2 second later, the ailerons rapidly deflected to 13.43 degrees RWD,[16] the autopilot disconnected, and the CVR recorded the sounds of the autopilot disconnect warning (a repetitive triple chirp that is manually silenced by the pilot). The airplane rolled rapidly to the right, and the pitch attitude and AOA began to decrease (see Figures 2 and 3 for graphical depictions of the airplane's flightpath and FDR/CVR data). There were no recorded exchanges of conversation between the flightcrew during the initial roll excursion, only brief expletive remarks followed by the sounds of "intermittent heavy irregular breathing."

Within several seconds of the initial aileron and roll excursion, the AOA decreased through 3.5 degrees, the ailerons moved to a nearly neutral position, and the airplane stopped rolling at 77 degrees RWD. The airplane then began to roll to the left toward a wings-level attitude, the elevator began moving in a nose-up direction, the AOA began increasing, and the pitch attitude stopped at approximately 15 degrees nose down.

At 1557:38, as the airplane rolled back to the left through 59 degrees RWD (towards wings level), the AOA increased again through 5 degrees and the ailerons again deflected rapidly to a RWD position. The captain's nose-up control column force exceeded 22 pounds,[17] and the airplane rolled rapidly to the right, at a rate in excess of 50 degrees per second.

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[16]Maximum designed aileron deflection is 14 degrees in either direction from neutral.

[17]The DFDR records data that indicate when more than 22 pounds of force are applied to the captain's and first officer's control columns in both nose-up and nose-down directions.

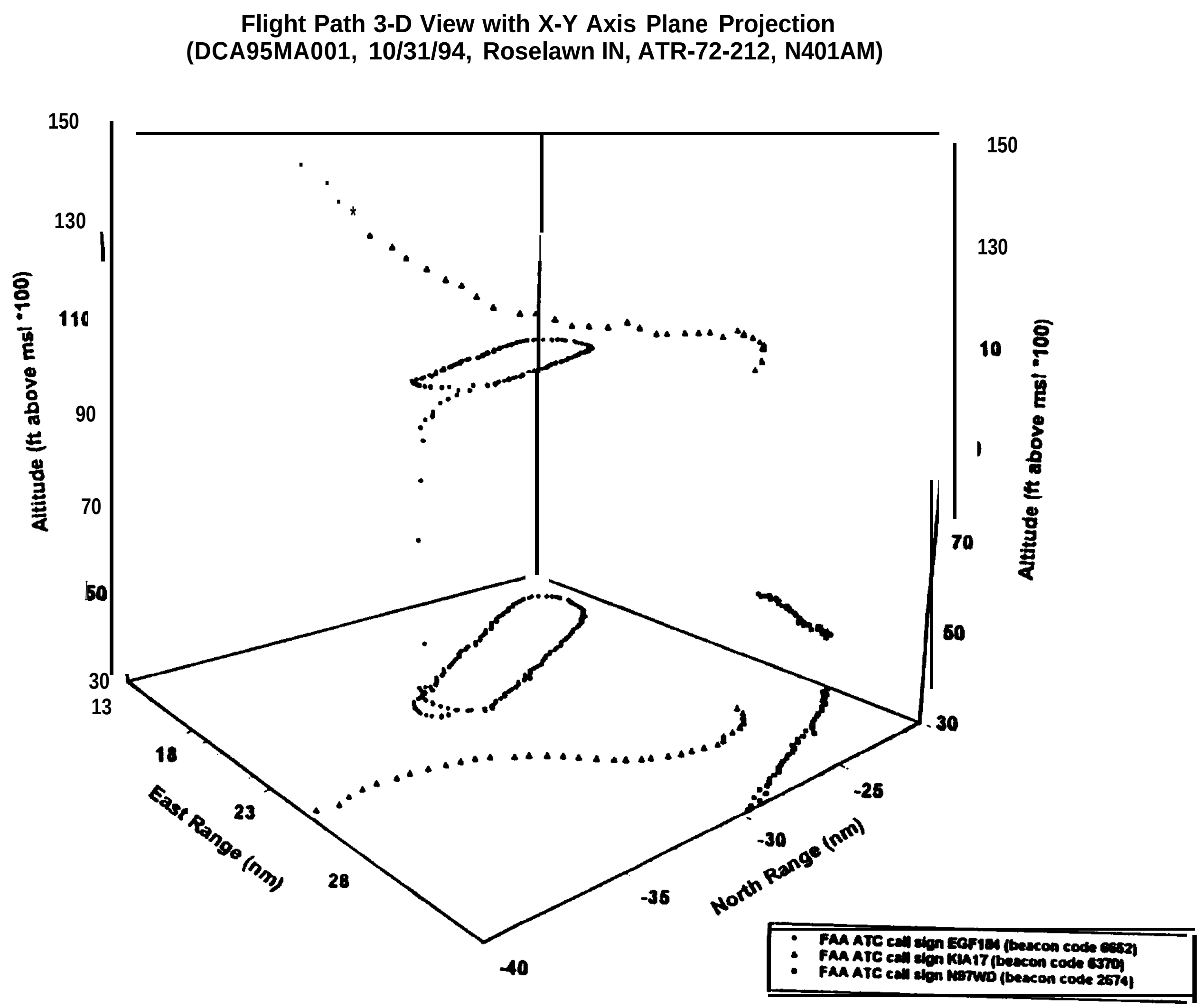

Figure 2.—Flightpath of airplane in holding pattern.

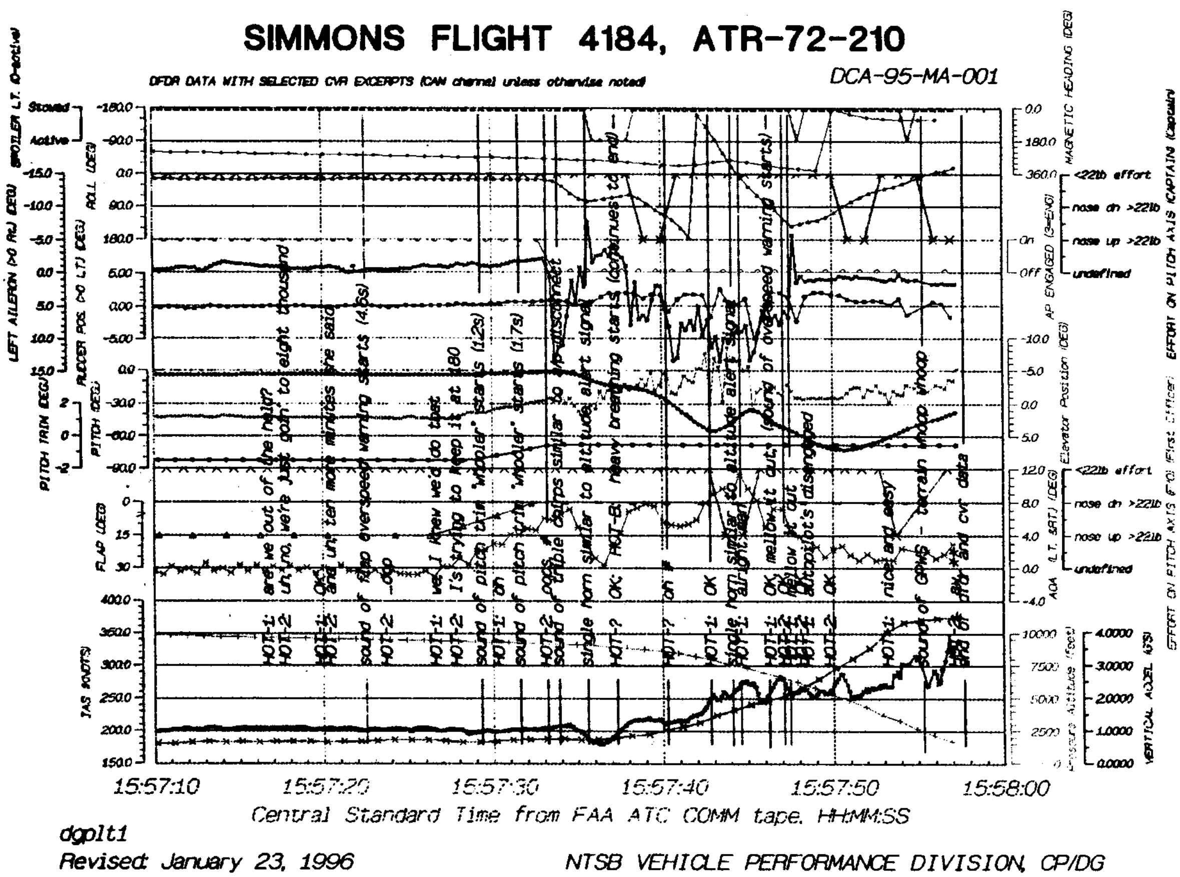

Figure 3.--FDR/CVR data correlation.

According to the FDR data, the captain's nose-up control column force decreased below 22 pounds as the airplane rolled through 120 degrees, and the first officer's nose-up control column force exceeded 22 pounds just after the airplane rolled through the inverted position (180 degrees). Nose-up elevator inputs were indicated on the FDR throughout the roll, and the AOA increased when nose-up elevator increased. At 1557:45, as the airplane rolled through the wings-level attitude (completion of first full roll), the captain said "alright man" and the first officer's nose-up control column force decreased below 22 pounds. The nose-up elevator and AOA then decreased rapidly, the ailerons immediately deflected to 6 degrees LWD and then stabilized at about 1 degree RWD,[18] and the airplane stopped rolling at 144 degrees right wing down.

At 1557:48, as the airplane began rolling left, back towards wings level, the airspeed increased through 260 knots, the pitch attitude decreased through 60 degrees nose down, normal acceleration fluctuated between 2.0 and 2.5 G,[19] and the altitude decreased through 6,000 feet. At 1557:51, as the roll attitude passed through 90 degrees, continuing towards wings level, the captain applied more than 22 pounds of nose-up control column force, the elevator position increased to about 3 degrees nose up, pitch attitude stopped decreasing at 73 degrees nose down, the airspeed increased through 300 KIAS, normal acceleration remained above 2 G, and the altitude decreased through 4,900 feet.

At 1557:53, as the captain's nose-up control column force decreased below 22 pounds, the first officer's nose-up control column force again exceeded 22 pounds and the captain made the statement "nice and easy." At 1557:55, the normal acceleration increased to over 3.0 G, the sound of the ground proximity warning system (GPWS) "Terrain Whoop Whoop" alert was recorded on the CVR, and the captain's nose-up control column force again exceeded 22 pounds. Approximately 1.7 seconds later, as the altitude decreased through 1,700 feet, the first officer made an expletive comment, the elevator position and vertical acceleration began to increase rapidly, and the CVR recorded a loud "crunching" sound. The last recorded data on the FDR occurred at an altitude of 1,682 feet (vertical speed of approximately 500 feet per second), and indicated that the airplane was at an airspeed of 375 KIAS, a pitch attitude of 38 degrees nose down with 5

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[18]Prior to this point, vane AOA remained over 5 degrees, and aileron position had been oscillatory. Aileron position stabilized after vane AOA decreased below 5 degrees.

[19]Normal acceleration, as stated in this report, refers to the acceleration of the center of gravity of the airplane along its vertical axis, which is 90 degrees to the airplane's longitudinal and lateral axes. The values are shown in units of "G" force; and one (1) G is equivalent to the acceleration due to Earth's gravity.

degrees of nose-up elevator, and was experiencing a vertical acceleration of 3.6 G. The CVR continued to record the loud crunching sound for an additional 0.4 seconds. The airplane impacted a wet soybean field partially inverted, in a nose down, left-wing-low attitude.

There were no witnesses to the accident, which occurred during the hours of daylight at 41° 5' 40" north latitude and 87° 19' 20" west longitude. The elevation of the accident site was about 675 feet.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Other	Total
Fatal	2	2	64	0	68
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	--	0
Total	2	2	64	0	68

1.3 Damage to Airplane

The airplane was destroyed by impact forces. The estimated value of the airplane was $12,000,000.

1.4 Other Damage

The airplane struck the ground in a 20-acre soybean field. The field was determined to be an environmental hazard; and the expense of reconditioning the land for agricultural use was estimated at $880,000.

1.5 Personnel Information

1.5.1 The Captain

The captain, age 29, held an Federal Aviation Administration (FAA) Airline Transport Pilot (ATP) certificate, No. 572598812, with a multiengine land airplane rating, and type ratings in the Shorts SD3 and the ATR 42/72. Additionally, he held commercial pilot and flight instructor certificates with single-engine land, multiengine land and instrument airplane ratings. He was issued an FAA First Class Airman Medical Certificate on October 31, 1994, with no limitations.

The captain had gained his initial flying experience (prior to employment with Simmons Airlines) in general aviation aircraft. He was hired by Simmons Airlines on July 1, 1987, as a first officer for the Shorts 360 and progressed to a captain on the Shorts. The captain transitioned to the ATR and attained his type rating in the ATR 72 on March 17, 1993. According to company records, the captain had accumulated 7,867 hours of total flight time as of the date of the accident, with 1,548 hours total time in the ATR. All of the flight time he had accrued in the ATR was as the pilot-in-command. His most recent 14 CFR 121 proficiency check was successfully accomplished on April 25, 1994. He attended recurrent training on October 9, 1994, and satisfactorily completed a line check on June 8, 1994, which was administered by a check airman from the American Eagle Training Center.

A review of the captain's airman certification records and FAA accident/incident and violation histories revealed no adverse information. He held a valid Illinois driver's license with no history of automobile accidents or violations in the preceding 3 years. Interviews with other crewmembers, check airmen and instructors subsequent to the accident described the captain's performance in positive terms. Several pilots stated that he solicited input from first officers, considered their opinions and promoted a relaxed atmosphere in the cockpit.

A review of the captain's activities in the 3 days before the accident showed that he had flown a 3-day trip schedule that ended at 1930 on the day before the accident. He successfully completed an FAA Airman Medical examination on the morning of October 31. According to witnesses, the captain appeared rested. It could not be confirmed through the company's records if this was the first trip pairing for this captain and this first officer.

1.5.2 The First Officer

The first officer, age 30, held a commercial pilot certificate, No. 2316882, with single and multiengine land airplane and instrument ratings. Additionally, he held both ground and flight instructor certificates. He was issued an FAA First Class Airman Medical Certificate on August 8, 1994, with no limitations.

The first officer had gained his flying experience (prior to employment with Simmons Airlines) in general aviation aircraft. He was hired by Simmons Airlines on August 14, 1989, for his current position and, according to company records, had accumulated a total flight time of 5,176 hours as of the date of the accident, with 3,657 hours in the ATR. His most recent 14 CFR Part 121 proficiency check was successfully accomplished on September 7, 1994, and he attended recurrent training on September 9, 1994.

The first officer's airman certification, and FAA accident/incident and violation histories were reviewed and no adverse information was revealed. He held a valid Wisconsin driver's license with no history of automobile accidents or violations in the preceding 3 years. Crewmembers, check airmen and instructors, who were interviewed subsequent to the accident, described the first officer's performance in positive terms.

A review of the first officer's activities in the 3 days preceding the accident showed that he had been off duty and spent the majority of the time at his family's ranch. According to witnesses, the first officer appeared alert during the break period prior to the accident flight.

1.5.3 The Flight Attendants

There were two flight attendants aboard flight 4184 at the time of the accident. The senior flight attendant was employed by Simmons Airlines on January 17, 1988, and received training on the Shorts 360 and the ATR 42/72 airplanes. She successfully accomplished her ATR recurrent training on April 12, 1994.

The junior flight attendant was hired by Simmons Airlines on October 6, 1994, and successfully completed her initial training in October on the Saab 340, Shorts 360 and the ATR 42/72 airplanes. Flight 4184 was the first line trip for the junior flight attendant.

1.5.4 Air Traffic Control Personnel

1.5.4.1 DANVILLE Sector Controller

The controller was employed by the FAA on July 30, 1982. He began his duty at the Chicago air route traffic control center (ARTCC) on October 27, 1982, and became a full performance level (FPL) controller on February 27, 1986. He was issued an FAA Second Class Airman Medical Certificate with no waivers or limitations in February 1994.

1.5.4.2 BOONE Sector Controller

The controller was employed by the FAA on October 30, 1987, and graduated from the FAA Academy in January 1988. He began his duty at the Chicago ARTCC on January 21, 1988, and became an FPL for the South Area on April 8, 1993. He was issued an FAA Second Class Airman Medical Certificate with a limitation to wear corrective lenses for nearsightedness in July 1994. At the time of the accident, he was conducting on-the-job training and instructing the developmental controller.

1.5.4.3 BOONE Sector Developmental Controller

The controller was employed by the FAA on September 26, 1989, and had graduated from the FAA Academy in December of 1989. She began her duty at the Chicago ARTCC on December 20, 1989. She was issued an FAA Second Class Airman Medical Certificate in July 1994, with no waivers or limitations.

At the time of the accident, the developmental controller was receiving on-the-job training at the BOONE Sector radar position and had accumulated 87.16 hours of the allotted 120 hours in this position. She was previously certified at two radar positions (Pontiac and Danville) and seven manual assist positions, including the DANVILLE and BOONE sectors.

1.6 Airplane Information

N401AM, ATR serial number 401, was a pressurized, high wing, two engine, turbopropeller airplane. It was manufactured in Toulouse, France, on February 2, 1994, and at the time of the accident was owned by and registered to AMR Leasing Corporation, a subsidiary of AMR Corporation. N401AM was issued a French Export Certificate and a U.S. Certificate of Airworthiness on March 24, 1994. The airplane was placed into service with Simmons Airlines on March 29, 1994, and was maintained in accordance with the its Continuous Airworthiness and Maintenance Program (CAMP). According to ATR, a total of 154 ATR airplanes are currently in operation in the United States. The total includes 103 ATR 42 airplanes and 51 ATR 72 airplanes.

At the time of the accident, the airplane had accumulated 1,352.5 hours of flight time in 1,671 flights. The maintenance records revealed that the airplane had been in compliance with all applicable airworthiness directives (ADs). On the day of the accident, the airplane had been dispatched with two deferred maintenance items: an inoperative No. 2 bleed valve, and an inoperative cargo door warning system.

The airplane was equipped with a Honeywell Electronic Flight Information System (EFIS) that displays the aircraft attitude, heading, and other flight-related information. The airplane's attitude is displayed on a cathode ray tube (CRT) for each pilot and on a mechanical "standby" attitude display indicator (ADI) located on the center instrument panel. The CRT attitude display is referred to as an Electronic Attitude Display Indicator (EADI), and its operation is such that the horizon sphere symbol moves relative to the airplane symbol to indicate pitch and roll attitudes. The EADI, unlike the mechanically operated ADI, will not tumble or lose its reference during extreme attitude changes. The portion of the sphere that represents the sky is colored blue, and that representing the ground is shaded brown. The pitch scale is marked in 5-degree increments to plus and minus 80 degrees. The roll scale displays 0, 10, 20, 30, 45 and 60 degree orientation marks.

The EADI also displays chevrons that point toward the horizon and are fully visible above a 45-degree nose-up and below a 30-degree nose-down pitch attitude. The chevrons are used to orient the pilot to the horizon and to aid in the recovery from an unusual attitude. The tip of the chevron [below the horizon line] becomes visible at a pitch attitude of approximately 10 degrees nose down. The investigation revealed that these chevrons are not typically visible to the pilot through the "normal" range of pitch attitudes; however, the pilots do see the chevrons when performing emergency descent procedures during training. In addition to the chevrons, the EADI displays an "eyelid," which is shaded either blue or brown, depending on the aircraft's pitch attitude. The system logic was designed so that the eyelid would remain visible when the EADI pitch attitude indication was at or beyond the maximum normal display limits of the horizon reference line. The eyelid horizon symbol and the chevrons are meant to facilitate pilot orientation to the horizon during extreme pitch attitudes.

The Electronic Horizontal Situation Indicator (EHSI) combines several displays on one screen to provide a moving-map depiction of the airplane position. The display shows the airplane's position relative to VOR radials, localizer and glideslope beams, as well as providing real-time information for heading, course selection, distance, groundspeed, desired track, bearings, glideslope or glidepath deviations, and other navigational features. The EHSI also incorporates a four-color weather radar and displays 3 levels of detectable moisture with four separate colors. According to the ATR 72 Flight Crew Operating Manual (FCOM), the following colors are used to depict the various cloud densities:

Level	Weather Mode	Map Mode
Level 0	No Detectable Clouds	Black
Level 1	Normal Clouds	Green
Level 2	Dense Clouds	Yellow
Level 3	Severe Storm	Red

Because this information is not recorded on the FDR, and the flightcrew did not make any comments referencing the weather radar, it could not be determined during the investigation if the weather radar was being used during the accident flight.

1.6.1 Flight 4184 Dispatch Weight and Balance Information

The dispatch information for flight 4184 indicated that it was released from IND at a gross takeoff weight of 45,338 pounds [maximum gross takeoff weight is 47,400 pounds], with a calculated zero fuel weight of 40,586 pounds. The computed weight of flight 4184 included 11,934 pounds for 64 passengers and baggage/cargo, and 5,060 pounds for fuel. The center of gravity was calculated to be 22 percent mean aerodynamic chord (MAC).[20] The calculated gross weight of the airplane at the time of the accident was approximately 43,850 pounds.

1.6.2 ATR 72 Wing Design History

According to the manufacturer, the ATR 72 wing was developed by Aerospatiale, based on a modified National Advisory Committee for Aeronautics (NACA) 43XXX "5 digit series" non-laminar[21] airfoil design. [NACA was renamed the National Aeronautics and Space Administration (NASA) in 1958.] The NACA airfoil designs have been used for airplanes manufactured worldwide.

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[20] The ATR 72 maximum allowable MAC range for flight is 10 to 39 percent.

[21] Laminar flow is the smooth movement of air in parallel layers with very little mixing between layers. Each layer has a constant velocity but is in motion relative to its neighboring layers.

The ATR 72 wing is a non-laminar flow design; thus, the boundary layer airflow was not intended to remain laminar.[22]

1.6.3 ATR 72 Lateral Flight Control System Description

The ATR 72 lateral flight control systems consist of moveable, unpowered[23] ailerons plus hydraulically actuated wing spoilers that supplement the ailerons. The ailerons are aerodynamically balanced through the use of an offset hinge line, geared trailing edge balance tabs, and exposed horns (see figures 4 and 5). The exposed horns, which are also weighted for mass balance of the ailerons, are mounted on the outboard tips of the ailerons and extend spanwise beyond the tips of the wings.

The ailerons are connected to the cockpit control wheels by a series of cables, bellcranks, and carbon-fiber push-pull rods. A tension regulator maintains 20 to 25 deca-newtons (daN)[24] of cable tension. An electric trim actuator motor is connected to the left aileron balance tab. The maximum deflections for the ailerons, control wheels, and the balance tabs are approximately +/-14 degrees, +/-65 degrees, and +/-4 degrees, respectively. The lateral control system is augmented with one hydraulically actuated spoiler on the upper surface of each wing, just inboard of the ailerons. The hydraulic control for each spoiler is controlled mechanically by the aileron control linkage. The hydraulic actuator for each side is designed to activate at an aileron deflection of 2.5 degrees trailing edge up, and spoiler deflection is linear up to 57 degrees for 14 degrees of aileron deflection.

According to ATR engineers, the design of the lateral control system produces roll rates and maximum control wheel forces of less than 60 pounds, as required in 14 CFR Parts 25.143 and 25.147. The control wheel forces required to move unpowered ailerons are a function of aileron hinge moments and mechanical

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[22]Fifty percent of the ATR wing is located in the propeller slipstream, resulting in turbulent airflow along the entire airfoil chord for that portion of the span. The remainder of the wing (outside the propeller slipstream) has a slight airfoil surface discontinuity at the junction of the removable leading edges and center wing section (located at 16 percent chord). This chordwise discontinuity results in boundary layer transition from the laminar regime to the turbulent regime, if it has not already occurred.

[23]Refers to flight controls that are not hydraulically assisted.

[24]According to the ATR 72 Aircraft Maintenance Manual, 10 daN is equivalent to 22.48 [foot] pounds. Thus, 20 to 25 daN would be equivalent to 44.96 to 56.2 [foot] pounds.

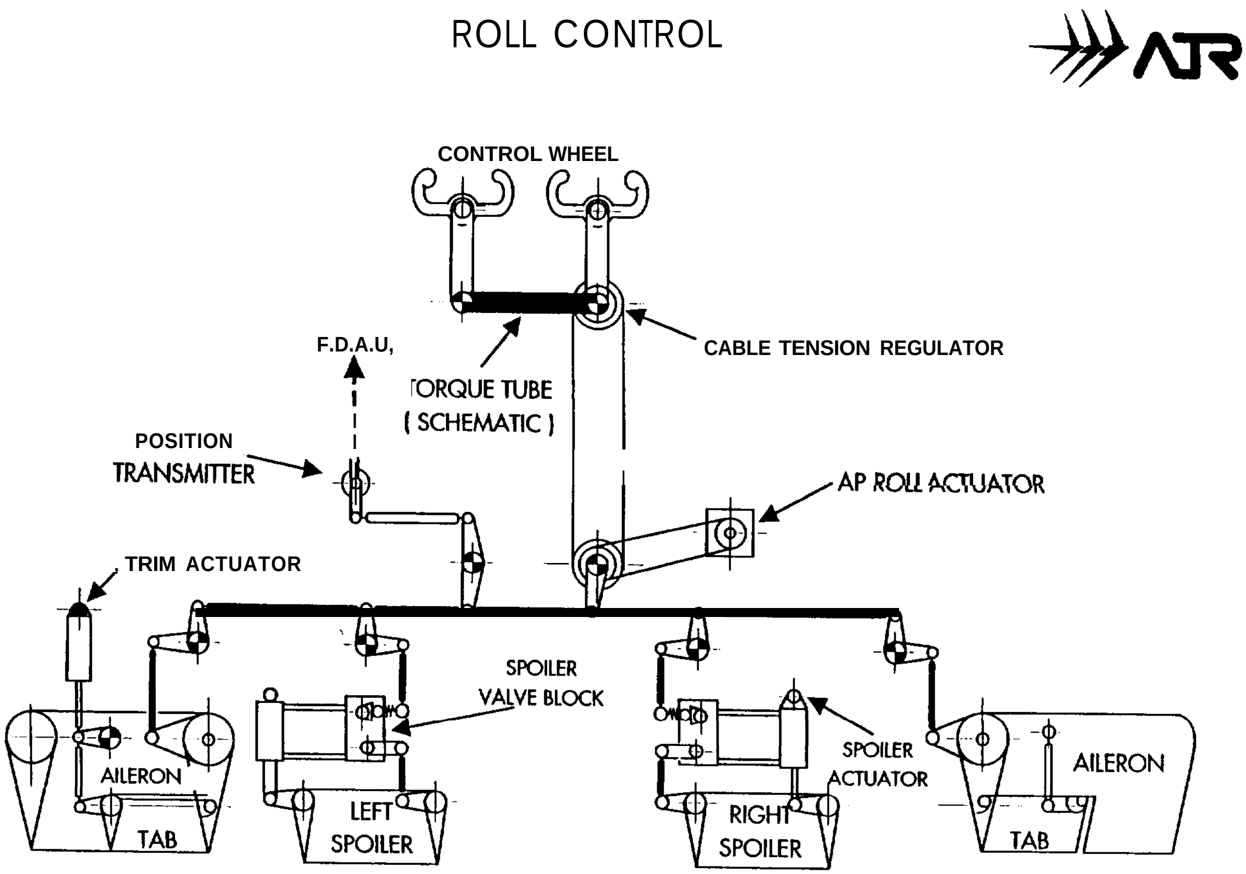

Figure 4.—Roll control diagram.

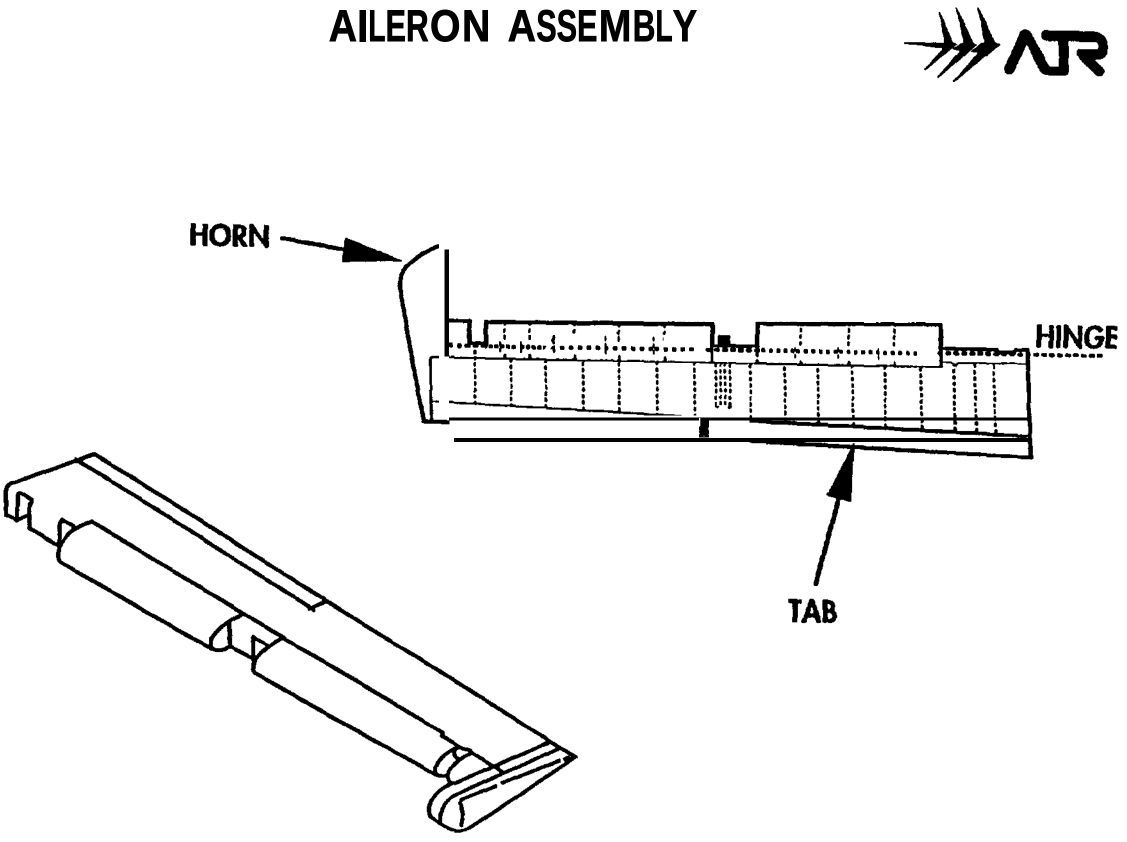

Figure 5.--Aileron assembly.

gearing between the aileron hinges and the cockpit control wheels. 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 aileron hinge line.

The aileron systems on the ATR 42 and 72 utilize the horns and balance tabs to provide an "aerodynamic power assist" in the direction of the deflection, which results in aileron controllability without hydraulic actuators. Under normal airflow conditions, deflection of the ailerons requires a control wheel force that progressively increases as aileron deflection increases. Without the horns and tabs, the control forces in flight would be excessively high. The forward aileron hinge line provides aileron deflection stability, while the balance horns and tabs provide aileron deflection controllability.

Compared to a hydraulically powered aileron system, the ATR's unpowered, aerodynamically balanced aileron control system is light weight, requires a minimal number of components, and is inexpensive to manufacture. However, during some airflow separation conditions, unpowered aileron control systems can be susceptible to undesirable aileron hinge moment changes (including asymmetric hinge moment reversals) and subsequent uncommanded aileron deflections.

1.6.3.1 ATR 72 Directional Flight Control System

ATR 72 directional control is accomplished with the rudder and its associated systems: the Travel Limiter Unit (TLU); the Releasable Centering Unit (RCU); the yaw damper; and the rudder trim system (see Figure 6). The rudder is mechanically connected to the cockpit rudder pedals through a series of cables, springs, bellcranks, and push-pull rods, and has a maximum low speed deflection of 27 degrees each side of neutral.

The TLU limits the rudder travel to about 3 degrees each side of neutral (6 degrees total) at speeds above 185 KIAS, using a "U-shaped" mechanical stop that extends around the lower portion of the rudder. The TLU is normally controlled automatically via the multi-function computer and airspeed data obtained from the air data computer (ADC). The TLU high speed mode occurs when both ADCs sense an indicated airspeed greater than 185 knots. Reversion to the low speed mode (full rudder deflection) occurs when at least one ADC senses an

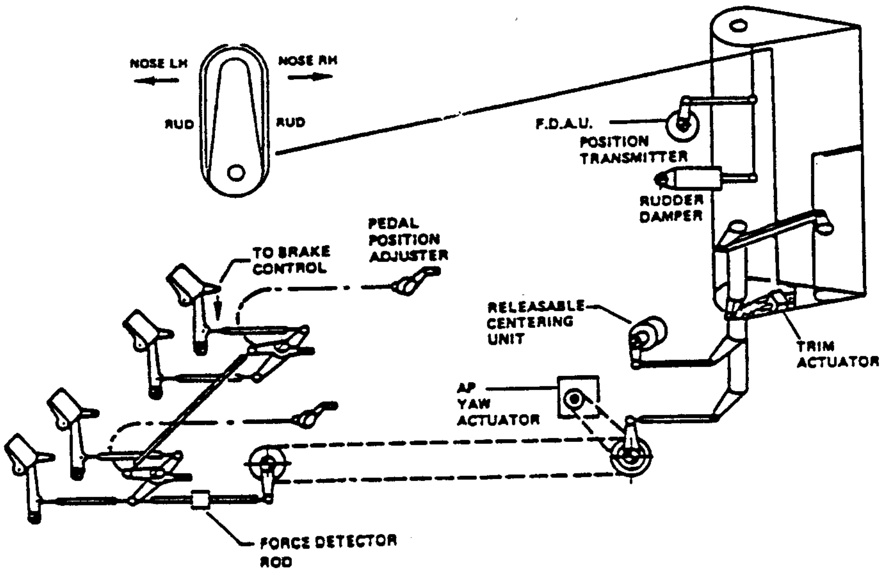

Figure PPLT-3

Rudder Control System

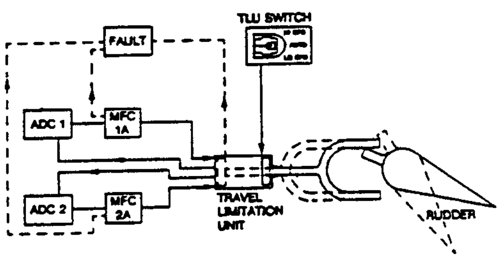

Figure FLT CTL-23

TLU System

Figure 6.--Travel Limiter Unit (TLU) system.

indicated airspeed that is less than 180 knots. The TLU function can be overridden by the pilot through the activation of the TLU override switch located in the cockpit, and full rudder authority will be available 15 seconds after override switch activation.

The Safety Board reviewed operational procedures in both the American Eagle ATR 72 Aircraft Operating Manual (AOM) and the ATR Flight Crew Operating Manual (FCOM). Both publications are identical in their respective description of the "Aileron Jam" procedures and state in the "Comments" section that, "there is no indication of an aileron jam other than an inability to operate the control wheel laterally." The procedures also state that the bank angle is limited to a maximum of 25 degrees "due to reduced roll control efficiency." The procedures do not indicate that the rudder is the primary source of lateral control in the event of jammed ailerons or that the rudder travel is limited to 6 degrees at airspeeds above 185 KIAS. Also, the procedures for both aileron jams and spoiler jams do not indicate the need to use the TLU override switch to restore full rudder authority over 185 KIAS.

1.6.4 ATR 72 Stall Protection System

The ATR 72 stall protection system (SPS) offers the pilot three different devices that provide warnings prior to the airplane reaching AOAs consistent with "clean" and ice-contaminated flow separation characteristics. These devices are: an aural warning and a stick shaker, both of which activate simultaneously when the AOA reaches a predetermined value that affords an adequate margin prior to the onset of adverse aerodynamic characteristic(s); and a stick pusher that activates when the AOA reaches a subsequently higher value that has been determined to be nearer to the onset of stall or aileron hinge moment reversal. The activation of the stick pusher results in an immediate and strong nose-down movement of the control column.

The SPS on the ATR 72 is controlled by two multi-function computers (MFC), each of which uses information from the following sources for activation: the AOA probes; the flap position; engine torque; airplane on-ground/in-flight indication; horn anti-ice status; airplane altitude above or below 500 feet; and the presence or absence of optional deicers on the inner leading edges. The stick pusher, which is mechanically linked to the left control column cable, moves the column to the 8-degree nose-down position when the MFC stick pusher activation criteria are met.

The SPS logic also uses AOA probe information to reduce the triggering threshold when the AOA is rapidly moving toward positive values. According to the aircraft maintenance manual (AMM) for the ATR 72, the phase lead of the triggering threshold has a maximum value of plus 3 degrees AOA and does not intervene when the anti-icing system is engaged.[25] The SPS is designed so that a single failure of any component in the system cannot cause the loss of the stick pusher function, improper activation of the stick pusher, the loss of the aural warning alert, or the loss of both stick shakers.

The SPS on the ATR 72, as well as the ATR 42, has icing and nonicing AOA triggering thresholds for each flap configuration. The SPS activates at lower AOAs when the anti-icing system is activated to account for aerodynamic changes when flying in 14 CFR Part 25, Appendix C, icing conditions. These SPS "icing" AOA thresholds do not account for more adverse aerodynamic changes that may result from flight in freezing drizzle/freezing rain or other icing conditions outside those defined by 14 CFR Part 25, Appendix C.

1.6.5 Autoflight System Description

The ATR 72 is equipped with a Honeywell SPZ-6000 Digital Automatic Flight Control System (DAFCS). The following subsystems are included: the Attitude and Heading Reference System (AHRS), the Air Data System, the Electronic Flight Instrument System (EFIS), the Flight Guidance System (FGS), and the PRIMUS 800 Color Weather Radar System.

The DAFCS is a completely automatic flight control system that provides fail-passive flight director guidance, autopilot, yaw damper and pitch trim functions. The autopilot computers monitor the system continuously and alert the flightcrew to faults that have been detected in the system. The autopilot system design incorporates the use of two in-flight bank angle selections: "HIGH" bank angle (27 degrees) and "LOW" bank angle (15 degrees). These bank angle limits are manually selected by the pilot and are used to control the maximum amount of bank angle executed by the autopilot during turns.

The "limitations" section of the ATR 72 Aircraft Flight Manual (AFM) provides a brief description of the flight regimes during which the autopilot may be

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[25]Refer to Section 1.6.6 for further information regarding the SPS.

operated. Both the ATR and AMR Eagle/Simmons Airlines operating manuals permitted, as of the time of the accident, the use of the autopilot for holding and flight operations in icing conditions. The American Eagle ATR 42/72 Operation Manual, Volume 1, Conditionals Section, stated, in part:

> ...effective management of all flightdeck resources is an absolute necessity for safe and efficient operation of a two crew aircraft. The design features of the ATR, including AFCS Flight Director/Autopilot system, provide the crew an opportunity to effectively manage the flight deck environment during all phases of flight, including abnormal and emergency procedures. However, periodic "hand flying" of the aircraft will ensure basic pilot skills are retained....

The autopilot will disengage automatically if the computer senses any one of a variety of system faults or malfunctions, including the exceeding of a predetermined rate of travel for the ailerons (3.6 degrees per second). If the aileron rate monitor is tripped, power will be removed from the autopilot aileron servo motor and servo clutch, and the flightcrew will receive an aural and visual warning alert in the cockpit.

The MFC also monitors the trailing edge flaps and sounds an alarm if the airplane exceeds an airspeed of 185 knots with the flaps extended at the 15-degree position. If the flaps are in the retracted position, the MFC will inhibit flap extension above an indicated airspeed of 180 knots (KIAS). After this accident, ATR Service Bulletin (SB) ATR 72-27-1039, dated January 12, 1995, provided a means to remove the flap extension inhibit logic so that flightcrews could select flap extensions in emergencies above 180 KIAS.

1.6.6 ATR 72 Ice and Rain Protection Systems

The ATR 42 and 72 ice protection system is a combination of deicing and anti-icing systems. This system consists of the following:

1. a pneumatic system (leading edge inflatable boots) that permits deicing of critical airframe surfaces, i.e., outboard and inboard wing sections, the horizontal stabilizer leading edges, and the vertical stabilizer (optional);

2. a pneumatic system for deicing the engine air intakes;

3. electrical heating for anti-icing of the propeller blades, the windshield and forward portion of the side windows, the pitot tubes, static ports, TAT [total air temperature] probe, and the AOA vanes;

4. electrical heating for anti-icing of the aileron, elevator and rudder balance horns;

5. and a windshield wiping system for the forward windows.

The ice protection systems are controlled and monitored from control panels located in the cockpit. In addition, there is an illuminated Ice Evidence Probe (IEP) located outside and below the captain's left side window. The IEP is visible to both pilots and provides visual information regarding ice accretion. The IEP is molded in the shape of an airfoil with spanwise ridges to increase its ice accretion efficiency and is not equipped with an anti-ice or deice system. The probe is designed to retain ice until sublimation or melting has occurred and is intended to provide the flightcrew with a visual means of determining that other portions of the airframe are either accreting ice or are free of ice.

Additionally, an Anti-Icing Advisory System (AAS), which employs a Rosemont ice detector probe, is mounted on the underside of the left wing leading edge between the pneumatic boots. The AAS provides the flightcrew with a visual[26] and aural alert when ice is accreting on the detector probe. The aural alert chime is inhibited when the deice boots are activated. The visual alert will remain illuminated as long as ice is detected, regardless of whether deice boots are activated. (See Figure 7 for diagram of ATR 72 ice protection system.)

The AAS was designed to enhance ice detection by using the Rosemont ultrasonic (harmonic/vibrating) ice detector probe which senses ice accretions. The AAS warning alarm signal is generated by the probe on the underside of the left wing. It is approximately 1/4 inch in diameter and 1 inch long and vibrates along its axis on a 40 kHz [kilohertz] frequency. The system detects changes in vibration frequency resulting from the increased mass of accumulated

[26]The visual alert consists of an amber light that illuminates on the instrument panel, below the central crew alerting system (CCAS).

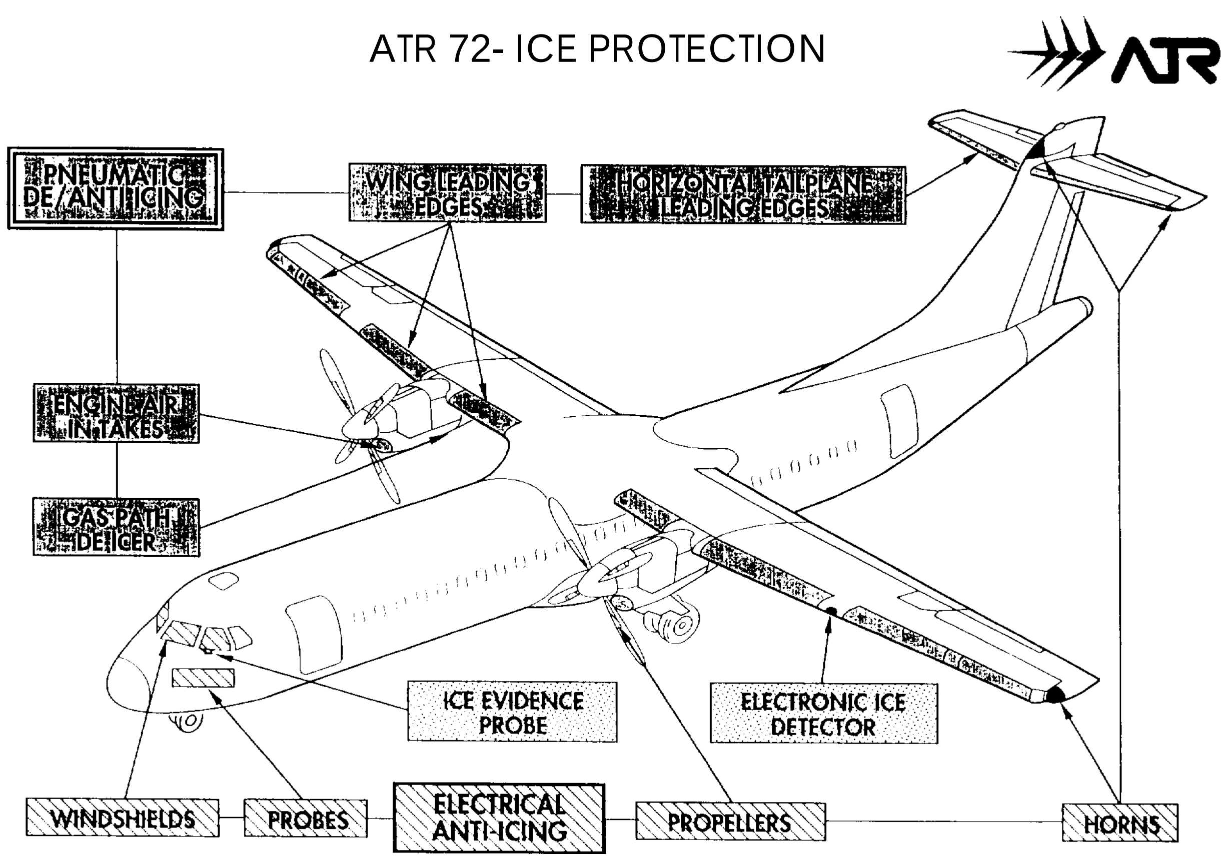

Figure 7.--Ice protection system.

ice, which, in turn, activates the visual and aural ice accretion alerts in the cockpit. If ice is detected, the Rosemont probe will initiate a heat cycle to remove the accretion and start the ice detection process again. According to ATR and the manufacturer of the Rosemont probe, the detection system may not reliably detect large supercooled drops that are near freezing (such as freezing drizzle/freezing rain) because there may not be enough heat transfer to freeze the large water drops that contact the probe. The ATR 72 ice protection system was designed with three levels of operation, and provides the flightcrew with the ability to choose the level(s) of protection based on environmental conditions.

* Level I - activates all probe and windshield heating systems, and, according to the ATR 72 Flight Crew Operating Manual (FCOM), must be in operation at all times after engine start and during flight operations.

* Level II - activates the pneumatic engine intake boots, electric propeller heaters, elevator, rudder and aileron horn heat, and electric side window heaters. According to the American Eagle AOM, the Level II protection must be in operation when atmospheric icing conditions exist.[27] Propeller RPM [revolutions per minute] must be at or above 86 percent during Level II operation to ensure adequate propeller deicing.[28]

* Level III - activates the wing, horizontal and vertical stabilizer leading edge boots (if installed), and must be used at the first visual identification of ice accretion or when alerted to ice accretion by the AAS. Level III ice protection must remain activated for as long as ice is accreting on the

[27]Page 8 of the LIMITATIONS Section of the American Eagle (Simmons) Aircraft Operating Manual, Part 1, states that atmospheric icing conditions exist when the "Outside Air Temperature (OAT) on the ground and for takeoff is at or below 5 degrees C or when the Total Air Temperature (TAT) in flight is at or below 7 degrees C and visible moisture in any form is present (such as clouds, fog with visibility of less than one mile, rain, snow, sleet, and ice crystals)."

[28]According to ATR, the propeller RPM must be increased to 86 percent in icing conditions because the increased rotational speed will prevent the formation of and/or improve the shedding of ice and will subsequently prevent the formation of ice aft of the deice boots in the area of the propeller slipstream. Tests conducted by ATR indicate that operation with propeller RPMs below 86 percent does not affect the formation of ice behind the wing deice boots in front of the aileron, or the airflow over the ailerons.

> airframe. [ATR recommends that flightcrews use the IEP as a means of determining when the airframe is free of ice.]

Activation of the Level II ice protection system causes the SPS to use the lower "icing" AOA threshold and the "Icing AOA" annunciator is illuminated. The ATR 72 aural stall warning and stick shaker AOA threshold decreases from 18.1 degrees to 11.2 degrees in cruise flight, and to 12.5 degrees when either the flaps are extended to 15 degrees or for 10 minutes after takeoff. The stall warning threshold returns to 18.1 degrees when the "Icing AOA" is deselected by deliberate pilot action (does not automatically return to 18.1 degrees when level II is deactivated).

The purpose of the pneumatic deice boot system installed on the ATR 42 and 72 is to remove ice that has accumulated on the leading edges of the wings, horizontal and vertical stabilizers, and engine inlets. This is accomplished mechanically by changing the shape of the leading edge with alternately inflating/deflating tubes within each of the boots. This method of ice protection is designed to remove ice after it has accumulated on the airfoil surface rather than to prevent the accretion on the airfoil surface, such as with an anti-ice system. Most pneumatic deice boot designs have the inflation tubes oriented spanwise. However, the boots used on the ATR 72 are oriented chordwise and cover about 7 percent of the chord of the upper wing surface. The boots consist of two sets of chambers, "A" and "B," that inflate on an alternating schedule to shed ice at selected time intervals. When the boots are not inflated, they are held in a streamlined position conforming to their respective structure by a vacuum. The vacuum is provided by a venturi[29] which uses engine bleed air to create a negative pressure within the boots. Two separate switches mounted in the cockpit control the automatic inflation and cycle modes (FAST and SLOW) of the boots and provide an override capability in the event of a failure of the normal system. The system is designed so that the boots will automatically inflate either on a 1 minute (FAST) or 3 minute cycle (SLOW). There is no provision for manual control by the pilot of the duration of the boot inflation.

[29]A tube or port of smaller diameter in the middle than at the ends. When air flows through such a tube or port, the pressure decreases as the diameter becomes smaller, the amount of the decrease being proportional to the speed of the flow and the amount of the restriction.

1.6.7 ATR 42/72 Type Certification History

1.6.7.1 General

The ATR 42-200 and -300 airplanes were certified under JAR (Joint Airworthiness Requirements) 25 by the DGAC on October 25, 1985. Under the Bilateral Airworthiness Agreement[30] (BAA) with the United States, the ATR 42 was type certificated by the FAA in accordance with 14 CFR Part 25, and began commercial operations with Command Airways on January 24, 1986. Since that time, several derivatives of the ATR 42 (-200,-300,-320) have received certification under the ATR 42 FAA-Type certificate. Additionally, seven models of the ATR 72 (-101, -102, -201, -202, -210, -211, -212), have been certified, some of which initially began operations in the United States with Executive Airlines, on January 10, 1990.

1.6.7.2 ATR 72 Icing Certification Program

The ATR 72 was certificated for flight into known icing conditions in accordance with FAR/JAR Part 25.1419 and Appendix C, and the DGAC Special Condition B6 (SC B6) and its interpretive material. FAR/JAR Part 25.1419, Ice Protection, requires that a manufacturer demonstrate safe operation of the aircraft in the maximum continuous and maximum intermittent icing envelopes specified in Part 25, Appendix C. (See Figure 8 for graph from Appendix C.) Appendix C icing envelopes specify the water drop mean effective diameter (MED),[31] liquid water content (LWC),[32] and the temperatures at which the aircraft must be able to safely operate. The envelopes specify a maximum MED of 50 microns,[33] which, by definition, do not include freezing drizzle or freezing rain.[34] (See figure 9.)

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[30]Refer to Section 1.18.7 for further information regarding the ATR 42 and 72 certification process under the Bilateral Airworthiness Agreement.

[31]According to the FAA, the mean effective diameter is the apparent median volumetric diameter (MVD) that results from having to use an assumed drop size distribution when analyzing data from rotating multi-cylinder cloud sampling devices (old-style technology). Modern cloud sampling devices measure the drop size distributions directly and can determine the actual MVD.

[32]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 (g/m^3). The terms LWC and SLW refer to the amount of liquid water in a certain volume of air.

[33]A micron is 1/1000 of a millimeter (mm). A 0.5 mm mechanical pencil is 500 microns in diameter, or 10 times greater than the largest MED defined in Appendix C.

[34]FAA icing experts have defined freezing drizzle as supercooled water drops with MVD's between 50 and 300 microns and freezing rain as supercooled water drops with MVD's greater than 500 microns.

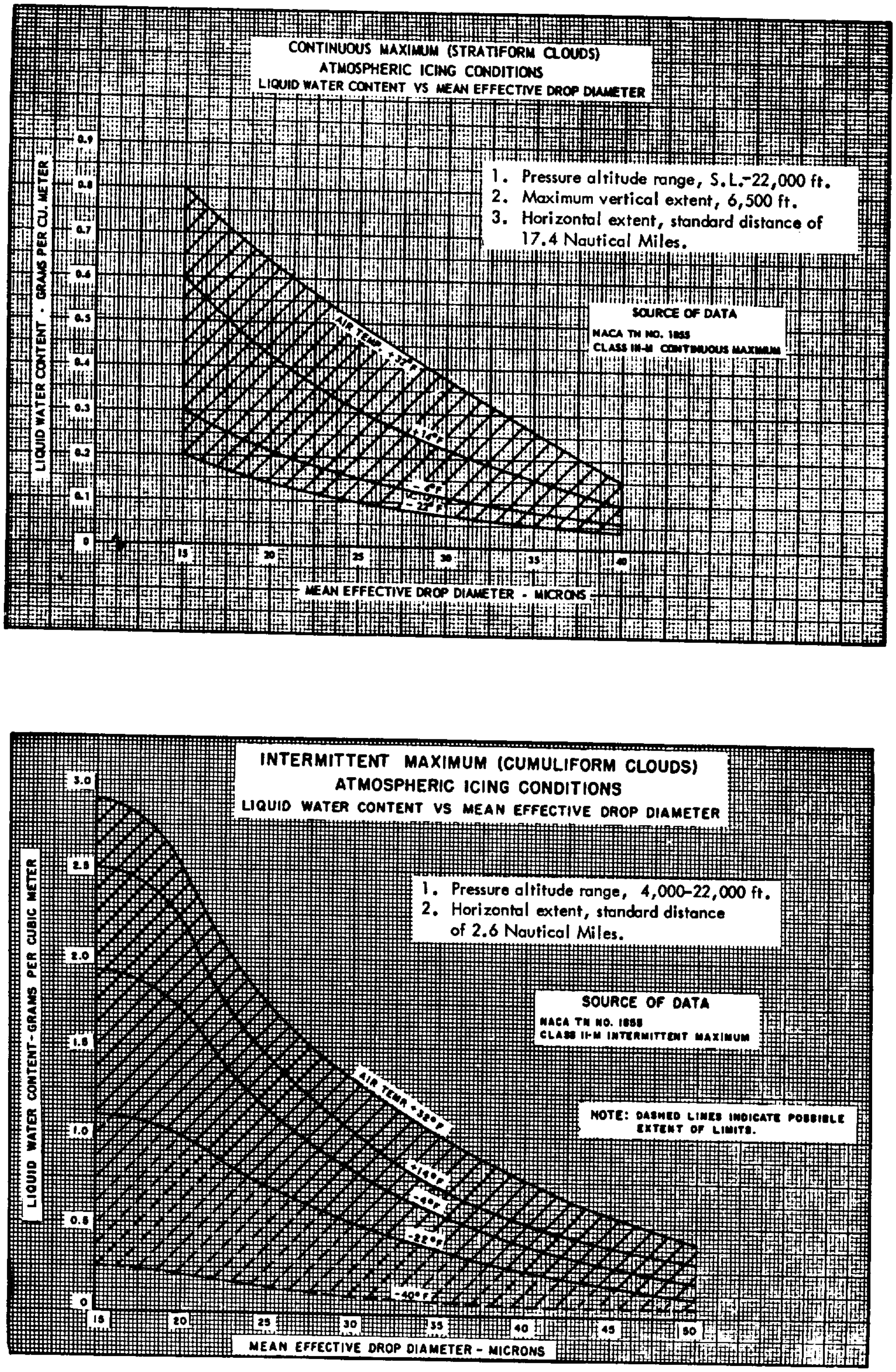

Figure 8.—14 CFR Part 25 Appendix C Icing Envelope.

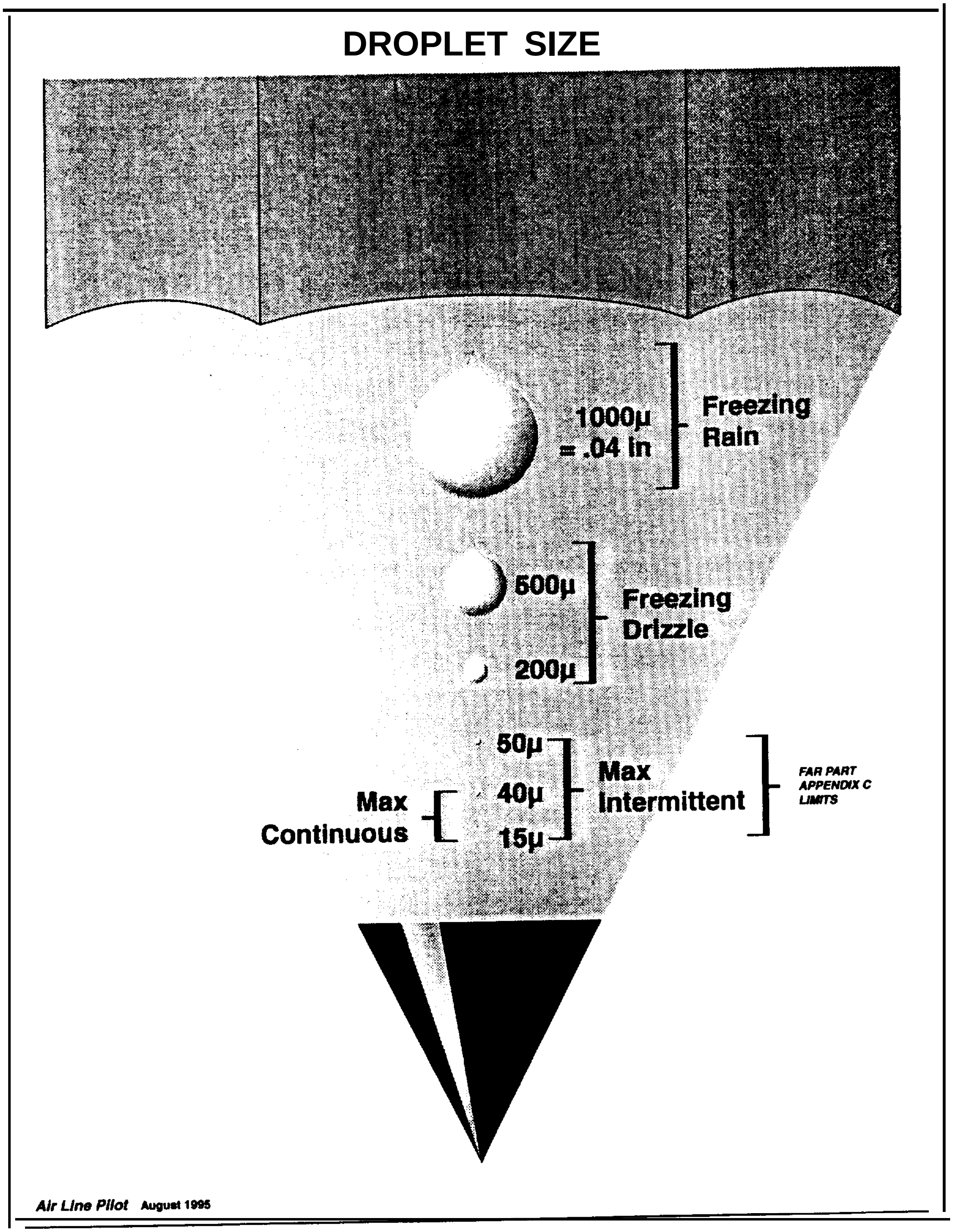

Figure 9.—Drop size diagram.

Compliance with FAR/JAR 25.1419 must be demonstrated through analysis, experimentation, and flight testing.

According to both ATR and the DGAC, SC B6 and its interpretive material were developed by the DGAC to improve airplane icing certification within the FAR/JAR 25 Appendix C envelopes and were first applied to the ATR 72 certification. SC B6 established specific additional icing certification requirements because FAR and JAR 25.1419 do not explicitly require the determination of the effects of ice on aircraft handling characteristics and performance. In addition, FAR/JAR 25.1419 left uncertainties about how to determine performance decrements, how they should be applied to the flight manual, which flight characteristics should be reviewed, and how safe flight in various flight phases should be demonstrated.

SC B6 requires that the effects of ice accretion on protected and unprotected surfaces be evaluated when establishing performance data for takeoff, climb, cruise, descent and landing phases of flight. Performance data for each flight phase should be based on speed, thrust/power, and drag changes related to expected ice accumulations. Any potential performance penalties associated with flight in icing conditions must be added to the airplane flight manuals. Handling characteristics addressed by SC B6 include 1 G stalls, zero G pushovers,[35] stall warnings, changes in takeoff speeds, vibrations, and stability/maneuverability. SC B6 also addresses other issues, such as: ice shapes found in typical flight phases; possible failures or malfunctions of the ice protection system; effects of ice shapes on the performance and handling characteristics; and testing of artificial ice shapes.

FAA aircraft icing certification advisory material includes AC 20-73 and the Aircraft Icing Handbook (AIH). These materials, which provide guidance and are not mandatory, include information on aircraft design, testing, and operational concerns for flight in icing conditions as specified in FAR 25 Appendix C. These publications do not provide design guidance concerning flight in freezing drizzle/freezing rain.

AC 20-73 does state that "Service experience indicates that holding in icing conditions for as much as 45 minutes is an operational condition that may be

[35]A flight maneuver where nose-down elevator input is made to achieve a zero vertical G load. The intent is to evaluate tailplane AOA margins and hinge moment characteristics.

encountered...it is recommended that the tests include a continuous exposure for at least 45 minutes." The AC further states, "The 45 minute holding criterion should be used in developing critical ice shapes for unprotected surfaces of the aircraft for which operational characteristics of the overall airplane are to be analyzed." Both the AIH and AC 20-73 state, in part, "If the analysis shows that the airplane is not capable of withstanding the 45 minute holding condition, a reasonable period may be established for the airplane, but a limitation must be placed in the Airplane Flight Manual." The AIH states that for the 45-minute holding pattern evaluation, an MED of 22 microns and a LWC of 0.5 grams per cubic meter should be used. These values are at the center of the Appendix C envelopes and do not represent worst-case conditions within the Appendix C envelopes. ATR tests with ice shapes resulting from flight in 22 micron/0.5 gram per cubic meter conditions showed that the ATR 42 and 72 could safely fly for at least 45 minutes in those conditions.

According to the FAA team leader for the ATR special certification, prior to beginning the process of certifying an airplane under 14 CFR, Part 25, an aircraft manufacturer and the FAA agree to the icing certification basis/requirements that will be applied to their specific aircraft when the icing certification submissions are reviewed by the FAA. The FAA applies the requirements of 14 CFR, Part 25.1419, as well as additional requirements based on FAA staff experience, advisory circular guidelines, and AIH guidelines. According to FAA icing certification experts, a combination of natural icing condition tests, icing tanker/icing tunnel tests, dry wind tunnel tests, flight tests with artificial ice shapes, and computer analyses are typically performed.

As a part of the ATR 72 icing certification, ATR performed computer analyses of ice accretion characteristics on its airfoils (wings, horizontal and vertical stabilizers) using ice accretion simulation software developed by ONERA.[36] ATR also conducted flight tests using artificial ice shapes, as well as flights in natural icing conditions. The tests conducted by ATR in natural icing conditions did not capture data points near the zero-degree temperature boundary of the Appendix C icing envelopes. The number of data points attained during natural icing tests were limited to available icing conditions.

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[36]ONERA is the French counterpart to the National Aeronautics and Space Administration.

1.6.7.3 Postaccident Certification Review

Subsequent to the accident involving flight 4184, the Safety Board recommended that the FAA conduct a Special Certification Review (SCR) of Model ATR 42 and 72 series airplanes. The Safety Board also recommended that flight tests and/or wind tunnel tests be conducted as part of that review to determine the aileron hinge moment characteristics of the airplanes while operating at different airspeeds and in different configurations during ice accumulation, and with varying AOA following ice accretion.

On December 12, 1994, a 10-person team, including six certification specialists from the FAA and four specialists from the DGAC, began the certification review process.

The SCR team participated in the creation of two telegraphic airworthiness directives (ADs). AD T94-25-51, issued on December 9, 1994, prohibited flight into known or forecast icing conditions for the ATR fleet. AD T95-02-51, issued on January 11, 1995, restored flight in icing conditions upon incorporation of certain flight and dispatch restrictions, and procedures.

On September 29, 1995, the FAA published the SCR report.[37] The team focused on the following major issue areas during its investigation:

> **Certification Basis** - The basic Model ATR 42 was approved by the FAA on October 25, 1985 [Type Certificate (TC) A53EU]. The certification basis for the airplane is 14 CFR Part 25, as amended by Amendment 25-1 through Amendment 25-54, with certain special conditions not related to icing. The basic Model ATR 72 was approved by the FAA on November 15, 1989, as an amendment to TC A53EU. The ATR 72 211/212 model (the accident airplane) was approved by the FAA on December 15, 1992.

> **Review of Certification Practices and Results -** The icing certification program conducted for the ATR 42 and 72 demonstrated the adequacy of the anti-ice and deicing systems to protect the airplane against adverse effects of ice accretion in

[37] See Appendix C for Executive Summary, Conclusions and Recommendations of the FAA SCR Report.

compliance with the requirements of FAR/JAR 25.1419. The wing deicing system has demonstrated acceptable performance in the meteorological conditions defined in the FAR/JAR 25 Appendix C envelope. Additionally, during the icing tanker testing conducted at Edwards Air Force Base (AFB), California, the proper functioning of the wing deicing boots was observed to correlate with Aerospatiale (ATR) test data within the Appendix C envelope. The certification program for the ATR 72-201/202 and ATR 72-211/212 icing systems was documented thoroughly using sound procedures and was processed and conducted in a manner consistent with other FAA icing certification programs. All data reviewed showed compliance with FAR 25/JAR 25.1419. The SCR team concluded that results show a good correlation with Special Condition B6 stall requirements and also with FAR/JAR 25.203 (handling qualities). The ATR 42 and ATR 72 series airplanes were certificated properly in accordance with DGAC and FAA regulations, practices, and procedures.

Autopilot Certification Procedures and Characteristics - The Honeywell Automatic Flight Control System (AFCS) was approved by the DGAC in accordance with the FAA certification basis that existed for each successive ATR series airplane. System design parameters for performance and servo authority meet those specified by FAR 25.1329 and AC 25.1329-1A. The system installation and monitor design is supported by the Aerospatiale Safety Assessment Automatic Pilot System and Honeywell DFZ-6000 Safety Analysis for critical and adverse failure cases. The equipment qualification and subsequent performance and malfunction flight tests that were performed are consistent with acceptable industry practices and procedures and are similarly consistent with practices and procedures accepted by the FAA in the past for other aircraft. The SCR team concluded that the Honeywell AFCS installed in the successive ATR series airplanes was certificated properly to the requirements of the FARs.

Review of Pertinent Service Difficulty Information - While all icing-related accident and incident information was not examined to the full extent of the Roselawn accident due to time and resource limitations, certain important aspects of the event history were studied and some conclusions were possible. Events of unacceptable control anomalies were associated with severe icing conditions such as freezing rain/freezing drizzle, and, in a few cases, the icing was accompanied by turbulence. These other roll anomaly events provided no evidence that the ATR 72 had any problems with any icing conditions for which it was certificated. Appendix 8 contains a tabulation of events that were known to the SCR team.

Environmental Conditions Outside the Appendix C Envelope - Weather observed in the area of the accident appears to have included supercooled water droplets in the size range of about 40 to 400 microns. This weather phenomenon is defined by the SCR team as Supercooled Drizzle Drops (SCDD).

While the physics of formation are not the same, freezing drizzle and SCDD can be considered to present the same icing threat in terms of adverse effects. The difference between them is that freezing drizzle is found at the surface, while SCDD is found aloft with air at temperatures above freezing underneath. Freezing rain contains droplets in the range of 1,000 to 6,000 microns. Collectively, all these large drops are referred to as supercooled large droplets (SLD). When used herein, the aerodynamic effects of SCDD and freezing drizzle are synonymous. While the effects of ice accreted in SLD may be severe, the clouds that produce them tend to be localized in horizontal and/or vertical extent.

The scientific investigation of SCDD and the body of knowledge on this subject are relatively new. SCDD is not universally understood in the aviation community. SCDD may be considered to icing as the microburst is to wind shear. Both have been unrecognized until recent times. Since they may be very severe, but are localized in extent and are difficult to detect until the airplane has encountered the condition, pilot awareness and prompt action to exit the condition are relied upon for now. Some researchers have observed that the effects of ice accreted in SCDD are far more severe than those of freezing rain.

Considering all available data, the SCR team has determined that the icing conditions of the accident environment were well outside the Appendix C icing envelope. This report contains a detailed description of this phenomenon; several short and long term recommendations are made.

Analysis of Aileron Hinge Moment Characteristics - The flight test data and qualitative assessments made by the DGAC during basic certification of the ATR 42 and 72, and the ATR 72-211/212, did not indicate that any unsafe or atypical lateral control wheel force characteristics exist. This conclusion also was based on the comprehensive assessment of the airplane in icing conditions conducted in accordance with Special Condition B6. The original certification test program did lack an evaluation of airplane characteristics with asymmetrical ice shapes; however, such an evaluation is not considered standard practice. Ice asymmetry was considered unlikely due to system design and Airplane Flight Manual (AFM) procedures.

Wind tunnel data and analysis have shown that a sharp-edge ridge on the wing upper surface in front of one aileron only can cause uncommanded aileron deflection. By using a very conservative analysis, these data show that keeping the wings level at 175 knots indicated airspeed (KIAS) takes approximately 56 pounds of control wheel force. These force levels were not seen during any of the icing tanker tests. However, during the first series of tests in the icing cloud behind the tanker, a ridge of ice did build up behind the deicing boots in a similar location to the wind tunnel model, but it was not sharp-edged and only extended spanwise approximately 40 percent in front of the ailerons due to the dimension of the icing cloud. However, these tests indicated that a mechanism existed that could actually produce such a ridge in actual icing conditions. Even though high lateral wheel forces were not seen during the tanker tests, icing specialists indicated that under slightly different conditions of the icing environment, other shapes could develop. Since the ice ridge sheds in a random manner, and in light of the airflow difference over the wings during maneuvering and turbulence or due to aerodynamic effects, an assumption was made that there could be a significant difference in ice accretion between the left and right wings.

Additional flight tests were conducted by Aerospatiale with artificial ice shapes duplicating the ice that accreted during the tanker tests in freezing drizzle conditions. Initially, these shapes were applied in front of the aileron in a random pattern to duplicate the shedding that was observed during the tanker tests. Additionally, a series of flight tests were conducted with ice shapes covering full and partial spans of the wing. The results of these tests coincided with the results obtained from the tanker tests. Further testing by Aerospatiale with more asymmetry and with sharper edge shapes indicated higher lateral control forces, although not as high as those derived from the initial wind tunnel studies.

FAA/Air Force Icing Tanker Testing - Two series of icing tanker tests were performed at Edwards AFB, California, in support of the investigation of the October 31, 1994, accident. A United States Air Force jet airplane (similar to a Boeing Model 707) specially modified to produce an icing cloud was used to simulate the conditions believed to have existed at the time of the accident. Direct results of the icing tanker tests were used to determine possible (1) immediate and long term changes to the aircraft, (2) changes to flight crew operations procedures, (3) changes to the Master Minimum Equipment List (MMEL), and (4) changes to flight crew training.

The first tanker test took place December 13 - 22, 1994; the second test program took place March 4 - 7, 1995. Both test programs were conducted as similarly as possible so that the results of the two tests could be compared directly.

Approval of Modified Deicing Boots - Aerospatiale developed a modification that consists of an increase in coverage of the active portion of the upper surface of the outer wing deicing boots from 5 percent chord on the ATR 42 and 7 percent chord on the ATR 72 to 12.5 percent chord for both airplane models. These enlarged wing deicing boots were certificated by extensive dry air and icing wind tunnel tests, and by dry air and natural icing flight tests conducted by Aerospatiale and FAA flight test pilots. In addition, an ATR 72 fitted with the modified boots was flown behind the icing tanker at Edwards AFB. The results of all these tests revealed that the modified boots perform their intended function within the icing requirements contained in Appendix C of Part 25 of the Federal Aviation Regulations. All U. S.-registered Model ATR 42 and ATR 72 series airplanes were modified with the new boots prior to June 1, 1995.

Aerospatiale developed the deicing boot modification to provide an increased margin of safety in the event of an inadvertent encounter with freezing rain or freezing drizzle (SLD). With the ability to recognize that an inadvertent encounter had occurred, flight crews would be afforded an increased opportunity to safely exit those conditions. However, even with improved boots installed, Model ATR 42 and 72 airplanes, along with all other airplanes, are not certificated for flight into known freezing drizzle or freezing rain conditions.

Operational Considerations that May Require Changes - Several recommendations regarding operational considerations for the turboprop transport fleet were made. These recommendations include changes to flight crew and dispatcher training, expanded pilot reports, Air Traffic Control and pilot cooperation regarding reporting of adverse weather conditions, flight crew training in unusual attitude recovery techniques, aircraft systems design and human factors, and MMEL relief.

Changes to the Certification Requirements (Appendix C) - The FAA recognizes that the icing conditions experienced by the accident airplane, as well as other airplanes involved in earlier accidents and incidents (see Appendix 8), may not be addressed adequately in the certification requirements. Therefore, the FAA has initiated the process to create a rulemaking project under the auspices of the Aviation Rulemaking Advisory Committee (ARAC). The ARAC will form a working group, made up of interested persons from the U.S. aviation industry, industry advocacy groups, and foreign manufacturers and authorities. The ARAC working group will formulate policy and suggested wording for any proposed rulemaking in the area of icing certification.

According to the SCR report, the team concluded, based on their review and evaluation of the data, that:

1. The ATR 42 and ATR 72 series airplanes were certificated properly in accordance with the FAA and DGAC certification basis, as defined in 14 CFR parts 21 and 25 and JAR 25, including the icing requirements contained in Appendix C of FAR/JAR 25, under the provisions of the BAA between the United States and France.

2. The Roselawn accident conditions included SCDD outside the requirements of 14 CFR Part 25 and JAR 25. Investigations prompted by this accident suggest that these conditions may not be as infrequent as commonly believed and that accurate forecasts of SCDD conditions do not have as high a level of certitude as other precipitation. Further, there are limited means for the pilot to determine when the airplane has entered conditions more severe than those specified in the present certification requirements.

The SCR team also made the following recommendations:

- The current fleet of transport airplanes with unboosted flight control surfaces should be examined to ascertain that inadvertent encounters with SLD will not result in a catastrophic loss of control due to uncommanded control surface movement. The following two options should be considered:

    1. The airplane must be shown to be free from any hazard due to an encounter of any duration with the SLD environment, or

    2. The following must be verified for each airplane, and procedures or restrictions must be contained in the AFM:

        a. The airplane must be shown to operate safely in the SLD environment long enough to identify and safety exit the condition.

b. The flight crew must have a positive means to identify when the airplane has entered the SLD environment.

c. Safe exit procedures, including any operational restrictions or limitations, must be provided to the flight crew.

d. Means must be provided to the flight crew to indicate when all icing due to the SLD environment has been shed/melted/sublimated from critical areas of the airplane.

- FAR 25.1419, Appendix C, should be reviewed to determine if weather phenomena which are known to exist where commuter aircraft operate most often should be included...;

- Rulemaking and associated advisory material should be developed for airplanes with unpowered flight control systems to address uncommanded control surface movement characteristics that are potentially catastrophic during inadvertent encounters with the SLD environment. Discussions about these new criteria should consider the criteria already contained in the certification requirements...;

- Existing criteria used for evaluation of autopilot failures [should] be used to evaluate the acceptability of the dynamic response of the airplane to an uncommanded aileron deflection. Moreover, since both of these events (failure/hardover aileron deflection) can occur without pilots being directly in the loop, the three-second recognition criteria used for cruise conditions also should be adopted;

- Policy should be developed to assure that on-board computers do not inhibit a flightcrew from using any and all systems deemed necessary to remove an airplane from danger;

- Airplane Flight Manuals (AFM) should be revised to clearly describe applicable icing limitations;

- The FAA/JAA harmonization process for consideration of handling qualities and performance of airplanes while flying in icing conditions should be accelerated...;

- Evaluate state-of-the-art ice detector technology to determine whether the certification regulations should be changed to require these devices on newly developed airplanes;

- Flightcrew and dispatcher training related to operations in adverse weather should be reevaluated for content and adequacy;

- Flightcrews should be exposed to training related to extreme unusual attitude recognition and recovery;

- Pilots should be encouraged to provide timely, precise, and realistic reports of adverse flight conditions to ATC. The tendency to minimize or understate hazardous conditions should be discouraged;

- An informational article should be placed in the Winter Operations Guidance for Air Carriers, or airline equivalent, which explains the phenomenon of uncommanded control surface movement and the hazard associated with flight into SLD conditions;

- MMEL relief for all aircraft, particularly items in Chapter 30 (Ice and Rain Protection), should be reviewed for excessive repair intervals; and

- Methods to accurately forecast SLD conditions and mechanisms to disseminate that information to flightcrews in a timely manner should be improved.

1.7 Meteorological Information

1.7.1 General

At the time of the accident, there was no significant meteorological information (SIGMET)[38] indicating the existence of icing conditions, and stations along flight 4184's route of flight were not reporting any freezing precipitation. The only relevant in-flight icing weather advisory (AIRMET "Zulu") indicated, "light to occasional moderate rime icing in clouds and in precipitation freezing level to 19,000 feet." There were no additional reports of any significant weather phenomenon in the vicinity of the LUCIT intersection.

The Safety Board performed an in-depth study of the environmental conditions to define the weather phenomenon in which flight 4184 was operating until the time of the accident. Because of the complexity of the environmental conditions, it was necessary to collect and document data from numerous sources, and to determine the pertinent weather products, services, and actions of agencies and individuals involved. In addition to information received from the FAA, National Weather Service (NWS), and Simmons/AMR Eagle, numerous individuals were interviewed, including pilots operating in the area of the LUCIT intersection at the time of the accident. Also, data were collected from the WSR-88D Doppler weather radar sites located in Romeoville, Illinois, and Indianapolis, Indiana.

The Safety Board also sought additional input to define the meteorological environment encountered by flight 4184 from scientists of several organizations, including the National Oceanic and Atmospheric Administration (NOAA), the National Center for Atmospheric Research (NCAR), and the University of Wyoming. The Safety Board also received multispectral digital data from the Geostationary Operational Environmental Satellite (GOES 8), and reviewed the data on the Safety Board's Man computer Interactive Data Access System (McIDAS) Computer Workstation.[39]

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[38]SIGMET is defined as significant meteorological information. It is an in-flight advisory for the en route environment, indicating weather phenomenon severe enough to represent a concern to all categories of aircraft. Among other weather phenomena, the SIGMET includes information about severe icing which affects an area of at least 3,000 square miles.

[39]McIDAS is an interactive meteorological analysis and data management computer system. McIDAS is administered by personnel at the Space Science and Engineering Center at the University of Wisconsin, Madison, Wisconsin.

1.7.2 Flight 4184 Dispatch Weather Information

FAA Order 8400.10, Chapter 7, Section 2, paragraph 1423, "Operational Requirements - Flightcrews," provides guidance to POI's regarding the weather information that a carrier should provide to its pilots. The Order states, in part:

> Flightcrews need accurate weather information to determine the present and forecast weather conditions on any planned operation. For example, for adequate flight planning, flightcrews should know existing and expected weather conditions at the departure airport, along the planned route of flight, and at destination, alternate, and diversionary airports.
>
> A. Preflight Planning: Operational flight planning decisions require consideration of the following weather information:
>
> - Area Forecasts
> - AIRMETs, SIGMETs, and Convective SIGMETs
> - Icing (location, type and severity)
> - Center Weather Advisories (CWA) are not specified in this Order[40]

At Simmons Airlines, the flightcrew's primary source of weather information is provided by the dispatch office and is typically presented in the flight release paperwork. The Manager of Dispatchers at Simmons testified at the Safety Board's public hearing that at the time of the accident, it was standard policy at Simmons to provide the flightcrew with surface weather observations, terminal

[40]A CWA is issued by the meteorologist located in the ARTCC for significant meteorological hazards i.e., icing or turbulence.

forecasts, and SIGMETs. AIRMETs and CWAs are not normally included in the flight release but may be included at the discretion of the dispatcher. AIRMETs are continually available at the dispatcher's station while CWAs must be requested.

According to the Manager of Dispatchers, although a flightcrew is only provided selected weather information, it is the duty and responsibility of the dispatcher to review all of the available weather information, including area forecasts, station forecasts, airport weather observations, AIRMETs, SIGMETs, and a variety of computer-generated prognostic charts, to ensure that the flight release is "current, accurate and pertinent to the planned route of flight." Upon completion of the flight release, it is provided to the flightcrew approximately 60 to 75 minutes prior to departure. The flightcrew receives significant weather information (i.e., thunderstorms, turbulence, icing, etc.) updates, as necessary, and, at the discretion of the dispatcher, via the ARINC ACARS [Aeronautical Radio Inc., Automatic Communications and Recording System].

The following is a partial summary of weather information that was included in the Flight Release prepared for the crew of Flight 4184 at 1255:

Surface weather observations for ORD and IND...

IND...1251...Measured ceiling 1,300 feet overcast; visibility 5 miles; fog; temperature 61 degrees F; dew point 57 degrees F; winds 160 degrees at 7 knots; altimeter setting 29.73 inches of Hg., rain ended 1204.

ORD...1250...1,100 feet scattered, measured ceiling 2,500 feet overcast; visibility 4 miles; moderate rain, fog; temperature 47 degrees F; dew point 45 degrees F; winds 050 degrees at 16 knots; altimeter setting 29.89 inches of Hg.

Terminal Forecast for IND...Prepared by the National Weather Service indicated that from 1200 to 1600...clouds at 800 feet scattered, a ceiling at 1,500 feet overcast, with a visibility of greater than 6 miles; the winds would be from 130 degrees at 8 knots; and it could be expected that occasionally the ceiling would be 800 feet broken; and visibility would be 4 miles, with light rain, fog.

> The Terminal Forecast for ORD prepared by American Airlines Weather Services staff indicated that from 1300 to 1700 the clouds would be 1,500 feet scattered, with a ceiling at 3,500 feet overcast; visibility 6 miles; light rain; winds 050 degrees at 12 knots gusts to 22 knots; occasional ceiling 500 feet broken, 1,200 feet overcast; visibility 2 miles; moderate rain showers; fog.

The Flight Release also contained the following description of weather conditions, valid from 0900 on October 31 to 0300 on November 1. The following summarized information was prepared by American Airlines Weather Services:

> A surface low located Southern Missouri will move into Ohio by 0300 on November 1. A quasi-stationary front located central New Jersey, Southern Ohio, Southern Missouri will become a warm front and move to Ohio, Southern New York by 0300 November 1. A cold front out of the surface low Missouri, Northwest Arkansas will move to Ohio Central Kentucky, Southern Louisiana by 0300 November 1. Scattered to occasional moderate broken showers will fall over portions of Missouri, Arkansas, Iowa, Wisconsin, Illinois today spreading and intensifying into Indiana, Michigan, Ohio. Some flurries light snow showers will develop tonight over the Western Great Lakes portions of Wisconsin, Michigan, possibly Illinois. Thunderstorm Outlook...Isolated becoming widely scattered to scattered along the cold front Southern Missouri moving eastward with the front to Southern Illinois, Indiana, Ohio....

The following wind and temperature deviation[41] information was also included in the Flight Release:

- Boiler VOR at 10,000 feet wind 220 degrees at 19 knots temperature deviation 0 degrees C;

[41]The difference between the actual temperature and the temperature in the Standard Atmosphere for a given altitude.

- LUCIT Intersection at 10,000 feet wind 230 degrees at 11 knots temperature deviation minus 1 degrees C;

- Chicago Heights VOR at 10,000 feet 230 degrees at 8 knots temperature deviation minus 1 degrees C.

There were no Terminal SIGMECs[42] issued by American Airlines Weather Service staff for ORD in effect for the time of the accident. The Terminal SIGMECs are issued when conditions exist for moderate or greater icing, low level turbulence, low level windshear, and/or thunderstorm activity in the vicinity of the terminal area. These reports are valid for the terminal area, which is defined as about a 25 nautical mile radius of the airport. The Terminal SIGMECs are produced by American Airlines meteorological specialists and forwarded to the Simmons flight dispatch center for release among their crews.

In addition, the Safety Board found that there are neither FAA regulations, ATC procedures, nor Simmons' policies that would prohibit aircraft from holding in known or forecast icing conditions.

1.7.3 Weather Synopsis

The surface weather and upper air conditions for the area of Roselawn, Indiana, were summarized from the National Weather Service (NWS) Weather Depiction Chart recorded at 1600. The charts revealed a low pressure center in the area of west central Indiana and "...cloud ceilings of less than 1,000 feet and/or visibilities of less than 3 miles, in rain," occurring in northern Indiana. Further, a "moderate" cold front extended from the low pressure center and extended in a southwesterly direction. A moderate stationary front was also present and extended eastward from the center of the low pressure area. In addition, precipitation in the form of rain and rainshowers associated with this system were occurring to the north (ahead) of the stationary front and west (behind) of the cold front. The accident site was north of the stationary front, where surface temperatures of plus 7° C were being reported.

The NWS's 1800 analysis of the 850 millibar data (recorded about 5,000 feet msl) indicated an area of low pressure with the center located in west

[42]The SIGMEC is a weather product issued exclusively by the American Airlines weather service staff.

central Indiana; and a northerly flow over northern Illinois and southwesterly flow over eastern Indiana. The temperatures were near 3 degrees C with moisture evident in the area where flight 4184 was holding. The 1800 analysis of the 700 millibar data (recorded about 10,000 feet msl) indicated an area of low pressure, with the center located in northern Illinois, and a southwesterly flow over the accident area. Temperatures were near minus 4 degrees C with moisture evident in northern Indiana. At 500 millibars (about 18,000 feet), the center of the low pressure area was located in northeastern Iowa and had a southwesterly flow over the area of the accident. Temperatures were near minus 18 degrees C with moisture evident in the area.

Surface weather observations surrounding the accident site were as follows:

Gary, Indiana (GYY) [located 32 miles north of the accident site]: 1545...Record...800 feet scattered, estimated ceiling 1,700 feet overcast; visibility 7 miles; light rain showers; temperature 44 degrees F; winds 020 degrees at 13 knots gusts 30 knots; altimeter setting 29.68 inches of Hg.; [remarks] pressure falling rapidly; ceiling ragged.

1645...Record...800 feet scattered, estimated ceiling 1,700 feet overcast; visibility 5 miles; light rain showers, fog; temperature 43 degrees F; winds 020 degrees at 18 knots gusts to 43 knots; altimeter setting 29.65 inches of Hg.; [remarks] ceiling ragged.

South Bend, Indiana (SBN) [located about 58 nautical miles northeast of the accident site]: 1552...Record...Measured ceiling 1,400 feet overcast; visibility 3 miles; moderate rain; temperature 44 degrees F; dew point 43 degrees F; winds 050 degrees at 11 knots; altimeter setting 29.71 inches of Hg.

1652...Record...Measured ceiling 1,400 feet overcast; visibility 4 miles; light rain, fog; temperature 44 degrees F; dew point 42 degrees F; winds 050 degrees at 11 knots; altimeter setting 29.65 inches of Hg.; [remarks] precipitation very light.

Chicago, O'Hare Airport (ORD) [located about 60 nautical miles north-northwest of the accident site]: 1550...Record...sky partly obscured, measured ceiling 1,100 feet broken, 2,500 feet overcast; visibility 2 1/2 miles; moderate rain; fog; temperature 44 degrees F; dew point 43 degrees F; winds 020 degrees at 20 knots gusts to 30 knots; altimeter setting 29.81 inches of Hg.

1650...Record special...sky partly obscured; measured ceiling 1,100 feet broken, 2,500 feet overcast; visibility 3 miles; moderate rain, fog; temperature 42 degrees F; dew point 41 degrees F; winds 010 degrees at 22 knots gusts 30 knots; altimeter setting 29.80 inches of Hg.

Lafayette, Indiana (LAF) [located about 44 nautical miles south-southeast of the accident site]: 1545...Record...measured ceiling 600 feet broken, 1,000 feet overcast; visibility 2 1/2 miles; light rain, fog; temperature 47 degrees F; dew point 46 degrees F; winds 060 degrees at 16 knots; altimeter setting 29.57 inches of Hg.; [remarks] pressure falling rapidly.

1645...Record...measured ceiling 400 feet overcast; visibility 1 mile; light rain showers, fog; temperature 48 degrees F; dew point 47 degrees F; winds 070 degrees at 12 knots gusts to 18 knots; altimeter setting 29.53 inches of Hg.

Indianapolis, Indiana (IND) [located about 94 nautical miles south-southeast of the accident site]: 1455...Record...1,600 feet scattered, estimated ceiling 9,500 feet broken, 18,000 feet overcast; visibility 6 miles; fog; temperature 65 degrees F; dew point 57 degrees F; winds 130 degrees at 9 knots; altimeter setting 29.64 inches of Hg.; pressure falling rapidly.

1551...Record...measured ceiling 9,500 feet broken, 20,000 feet overcast; visibility 6 miles; fog; temperature 64 degrees F; dew point 58 degrees F; winds 130 degrees at 10 knots; altimeter setting 29.59 inches of Hg.; few stratocumulus.

The weather conditions reported by the airport operator at the Lowell Airport, located about 12 nautical miles northwest of the accident site, were: clouds approximately 1,400 feet broken, 3,000 feet overcast; the winds were estimated to be from the southwest at 20 knots and "gusty;" and there was light drizzle falling. The time of the report was unknown; however, it was estimated that the observation was made about 30 minutes after the accident.

At Demotte, Indiana, which is about 9 miles north-northeast of the accident site, no precipitation was recorded between 1500 and 1545, and 0.1 inch of precipitation was recorded between 1545 and 1600.

Upper air information recorded from onboard sensors from six aircraft operating within about an 80 nautical miles radius of Chicago between the hours of 1430 and 1800 were reviewed. Three of the aircraft were approaching or departing to the southwest through the southeast of Chicago, and three of the aircraft were approaching or departing through the east of Chicago. The following is a summary of the information prepared by investigators:

> For all aircraft, at approximately 3,000 feet, the temperature varied between 1.5 to .5 degrees C, and at approximately 6,000 feet, the temperature varied between about minus 2 and minus 3 degrees C. At approximately 10,000 feet, the temperature varied between about minus 3 to minus 4 degrees C for the aircraft flying to the southwest through the southeast of Chicago, and between minus 5 to minus 6 degrees C for aircraft flying to the west and east of Chicago. From an aircraft flying to the northwest of Chicago the temperature was about minus 7.5 degrees C.
>
> At 1742, an aircraft recorded the wind and temperature at 10,000 feet as 170 degrees at 25 knots and about minus 4 degrees C, respectively. This aircraft was located about 45 nautical miles north-northwest of the accident site.
>
> At 1437, a second aircraft recorded the wind and temperature at 10,000 feet to be about 180 degrees at 20 knots and about minus 4 degrees C, respectively. This aircraft was located about 50 nautical miles north-northwest of the accident site.

Static Air Temperatures (SAT) in degrees C calculated from Total Air Temperatures recorded during the final moments of flight 4184 are as follows:

<u>Height (Feet)</u>	<u>SAT (Degrees C)</u>

15,100	minus 9.0
14,100	minus 7.0
13,800	minus 9.0
12,800	minus 8.0
11,800	minus 6.0
11,500	minus 5.0
11,200	minus 4.0
10,800	minus 3.0
10,500	minus 2.5
10,200	minus 2.5
9,800	minus 2.0

Upper level wind data were obtained from the WSR-88D Doppler Weather Radar (located at Romeoville, Illinois (KLOT), about 46 nmi and 312 degrees from the accident site) velocity azimuth display (VAD) vertical wind profile (VWP) product.[43] The product is based on data obtained within a 22 nmi radius of the KLOT radar site. Weather radar images from KLOT for 1530 to 1600, at the elevation angles of 1.5, 2.4, 3.4, and 4.3 degrees were also reviewed. At an elevation angle of 1.5 degrees, the radar beam center is located about 9,500 feet msl, in the area where flight 4184 was holding. The images showed a changing pattern of weather radar echoes. The weather radar echo intensities varied from weak to moderate at the 1.5 degree elevation angle, and the radar echoes recorded at this angle revealed movement to the northeast. About 5,000 feet, the movement of the echoes was determined to be from 190 degrees at 25 knots; at about 10,000 feet, the echo movement was from 200 degrees at 40 knots; and at about 14,000 feet, the echo movement was from 195 degrees at 50 knots. A "bright band"[44] was not evident in the data recorded east of the radar, although a bright band could be seen in the data to the north through west of KLOT. The radar images (1.5 degrees elevation) with the ground track of flight 4184 superimposed are contained in Appendix F of this report.

The GOES 8 data were displayed and reviewed on the Board's McIDAS Workstation. The Longwave Infrared (LWIR) Imager data showed radiative[45] temperatures in the area of the LUCIT intersection of about minus 13 degrees C at 1432 and 1445. At 1515, colder radiative temperatures (higher cloud tops) were noted to the south and east of LUCIT. Radiative temperatures of about minus 35 degrees C

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[43]Refer to Appendix E for VAD VWP information.
[44]Bright band refers to the enhanced radar echo of snow as it melts to rain.
[45]Radiative temperatures pertain to atmospheric temperatures sensed by the GOES 8 satellite.

were noted in the area of LUCIT at 1532, with an area of colder radiative temperatures to the north of LUCIT at 1545. At 1602, an area of relatively warm radiative temperatures were recorded in the area of the LUCIT intersection. The upper air data from Peoria (PIA) for 1800, which was in the colder air mass, showed that a temperature of minus 35 degrees C corresponded to an approximate cloud height of about 27,000 feet. Radiative temperatures (GOES 8 LWIR data) and estimated cloud heights for the location of the accident are as follows:

Time	Temperature (degrees C)	Height (feet)[46]
1432	minus 13	17,100
1445	minus 12	16,600
1515	minus 20	20,600
1532	minus 38	29,200
1545	minus 17	19,100
1602	minus 21	21,100

Looping[47] of the GOES 8 LWIR data indicated cloud movement towards the northeast. The GOES 8 visible image showed brighter clouds about 5 nautical miles west of the accident site at 1532. The clouds moved to about 9 nautical miles north of the accident site at 1545, and, at 1602, the brighter clouds were located about 25 nautical miles to the north of the accident site. The visible data also showed multiple cloud layers in the area of the accident and the presence of rolling wave cloud features called Kelvin-Helmholtz Waves. These wave cloud tops were estimated from GOES 8 LWIR data to be about 17,000 feet. These waves are present in the atmosphere and are generated by windshear.

1.7.4 Pilot Reports (PIREPs) and Other Weather Information

A review of the numerous PIREPs revealed that there were about 13 reports that referenced icing conditions within an approximately 100 nautical mile radius of Roselawn from 1500 to 1700. These reports were provided by the pilots of various types of aircraft, at altitudes of between 4,000 and 21,000 feet msl. Of these reports, six indicated "light rime or mixed" icing, four specified "light to

[46] The cloud heights were estimated from a combination of SAT data from flight 4184 and PIA upper air data for 1800.

[47] Displaying the satellite images one frame at a time on a video monitor to produce a continuous motion picture.

moderate icing," one specified "moderate mixed icing," two indicated "light mixed icing," and two indicated no icing conditions. The following reports were from pilots operating near the Boiler VOR, which is located approximately 35 nmi south-southeast of the accident site: at 1510, a Beech Baron reported light rime icing at 12,000 feet; at 1617, a Saab 340 reported light to moderate rime icing at 15,000 feet; and at 1657, a Saab 340 reported light to moderate rime icing at 13,000 to 16,000 feet. One pilot, whose airplane was located about 100 nautical miles west of the accident site, reported "freezing rain" and "negative icing" at an altitude of 4,000 feet msl.

1.7.4.1 Witness Descriptions of Weather Conditions

Pilots in flight.--The captain of a Northwest Airlines Airbus A-320 stated in an interview after the accident that he had been holding in the area of HALIE intersection (located about 26 nautical miles north-northeast of the LUCIT intersection) between 1610 and 1640 and encountered icing conditions. The captain stated that the icing began in the descent from about 14,000 feet at HALIE, and continued to approximately 2,000 feet msl while on approach to ORD.

The captain said that he noticed light precipitation and light visible moisture; however, the size of any drops were unknown. He said that there were no drops "splattering" on the windshield, only frozen particles characterized as light snow, and light sleet. He stated further that he estimated the intensity of the rime icing to be light to moderate, and that the icing did not present a problem for the airplane anti-icing systems. He also said that only light precipitation was showing on the airborne weather radar.

The captain also estimated that between 1/2 to 3/4 inch of ice accumulated rapidly on the icing probe and that it remained until they were on "short final" into ORD (about 2,000 feet msl). He said that they had been in the icing conditions about 30 minutes, and that the shape of the ice was "jagged to bumpy." These conditions were reported by the captain to ATC as "light rime."

The captain of a Boeing 727 (KIWI flight 17) that was also in close proximity to the Roselawn area at the time of the accident stated that his aircraft had been in clouds that contained rain and "light to moderate icing and light turbulence." He estimated that the icing levels existed between 5,000 and 15,000 feet. The captain did not provide this information as a PIREP to ATC.

About 1611, the BOONE sector controller solicited a PIREP from the crew of a second Boeing 727 (KIWI flight 24), which was located about 10 nautical miles east of the accident site and heading northbound at an altitude of about 9,000 feet. The following pilot report was recorded:

> ...well we're in and out of some pretty heavy rain with some sleet in it...started about fourteen thousand feet and it's continuing still.

During the interview with the crew of KIWI flight 24 after the accident, they described the precipitation as being "more like rain and snow mixed" and not "ice pellets" or "frozen rain."

On October 31, 1994, there were no SIGMETs or Convective SIGMETs in effect at the time and for the area of the accident. Also, there were no Chicago Center Weather Service Unit (CWSU) Center Weather Advisories in effect at the time and for the area of the accident. Convective SIGMET 14C[48] (issued at 1355 and valid until 1555), for an area over 100 nautical miles west/southwest of the Indianapolis Airport, was valid while flight 4184 was holding on the ground. FAA Order 7110.65, "Air Traffic Control," Chapter 2, "General Control," Section 6, "Weather Information," states, in part, that "...the controller shall advise pilots of hazardous weather that may impact operations within 150 nautical miles of their sector of jurisdiction....Tower cab and approach control facilities may opt to broadcast...alerts only when any area described is within 50 nautical miles of the airspace under their jurisdiction." The BOONE and the DANVILLE sector controllers issued weather information at 1454 and 1456, respectively, approximately 20 minutes prior to flight 4184 arriving on their radio frequencies.

The following summarized AIRMETs (updates 2 and 3), issued at 0845 and 1445, respectively, and valid until 1500 and 2100, respectively, included the route from Indianapolis, Indiana (IND) to ORD:

> AIRMET Sierra Update 2 for IFR indicated occasional cloud ceilings below 1,000 feet and visibility below 3 miles in precipitation and fog.

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[48]Developing line of embedded thunderstorms 15 miles wide, moving from 250 degrees at 30 knots, cloud tops to 30,000 feet.

AIRMET Tango Update 2 for turbulence indicated occasional moderate turbulence below 12,000 feet.

AIRMET Zulu Update 2 for Icing and Freezing Level indicated that light to occasional moderate rime icing in cloud and in precipitation - freezing level to 19,000 feet. Also, the freezing level was estimated to be from 2,000 to 5,000 feet, sloping to the north, and up to 8,000 feet, on along a line that was defined as Oswego, Kansas, to Burlington, Iowa, to Detroit, Michigan.

AIRMET Sierra Update 3 for IFR indicated occasional cloud ceilings below 1,000 feet and visibility below 3 miles in precipitation and fog.

AIRMET Tango Update 3 for turbulence indicated occasional moderate turbulence below 12,000 feet.

AIRMET Zulu Update 3 for Icing and Freezing Level indicated light to occasional moderate rime icing in cloud and in precipitation, freezing level to 19,000 feet. The freezing level was estimated to be 4,000 to 5,000 feet in the northern portion of area, sloping to 8,000 to 11,000 feet in the southern portion of area.

The AIRMETs issued at 0845 and valid until 1500 were not included in the flight release provided to the crew of flight 4184. Also, the updates to the AIRMETs were not provided to the crew prior to flight 4184's departure from Indianapolis.

The AIRMETs, which were issued by the National Weather Service's National Aviation Weather Advisory Unit (NAWAU)[49] in Kansas City, Missouri, covered a large geographical area that encompassed several states. The Manager of the weather advisory unit stated during the Safety Board's public hearing that the notation, "icing in precipitation," contained in the icing AIRMETs, indicated the possibility of freezing rain and/or freezing drizzle from the freezing level to 19,000 feet. He stated that "...it is our intent as forecasters that 'in precip' includes...what's been characterized in earlier statements here as the freezing drizzle

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[49]Subsequent to this accident, the NAWAU was renamed the Aviation Weather Center (AWC).

regime, and/or freezing rain for that matter." The notation, "Icing in Precipitation" is not defined in the Aeronautical Information Manual (AIM), in AC-00-45C, or in any other documentation readily available to pilots, and is routinely cited in AIRMETs.

1.7.5 Hazardous In-flight Weather Advisory Service (HIWAS)

The HIWAS provides continuous recorded hazardous in-flight weather forecasts to in-flight pilots over selected VOR frequencies. The HIWAS broadcast consists of a summary of weather products, including AIRMETs, SIGMETs, and Center Weather Advisories.

The HIWAS broadcast recorded by the Kankakee, Illinois, Automated Flight Service Station (AFSS) at 1500 included information that light to occasional moderate rime icing was forecast in the clouds and in precipitation. The affected altitude of this forecasted icing condition extended upward from the freezing level to FL190 (19,000 feet). In addition, occasional moderate turbulence was forecast below 12,000 feet. The HIWAS broadcast was relevant for an area that was within a 150 nautical mile radius of the ORD, Pontiac, Illinois (PNT), Polo, Illinois (PLL), and Burlington, Iowa (BRL) VORs. The area identified as affected by forecast turbulence and forecast icing conditions encompassed the accident site location.

In addition, the HIWAS broadcast recorded at 1507 by the Terre Haute, Indiana, AFSS for the area extending 150 nautical miles radially from the Nabb, Indiana (ABB), Pocket City, Indiana (PXV), Shelbyville, Indiana (SHB), and Terre Haute, Indiana (HUF) VORs reported AIRMETs for "occasional moderate turbulence" below 12,000 feet throughout the area, as well as icing conditions above the freezing level. This same broadcast was recorded at 1506 for the area extending radially from the Lafayette, Indiana (BVT) VOR.

1.7.6 Information About Freezing Rain/Freezing Drizzle and General Icing Conditions

Estimates of Liquid Water Content (LWC) for the flightpath of flight 4184 were made using the available meteorological data, including the data from the KLOT Doppler weather radar. Based on the KLOT WSR-88D radar data, LWCs ranging from less than .01 to 0.7 gram per cubic meter were estimated for the time that flight 4184 was in the hold at LUCIT. Using the Safety Board Program ICE4A,[50] the

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[50] A computer program developed by the Safety Board to estimate liquid water content in the atmosphere.

LWC was estimated to be about 0.74 gram per cubic meter for an altitude of about 10,000.

A second method of estimating the LWC, found in the Forecasters' Guide on Aircraft Icing, published by the Air Force, indicated a LWC of about 0.59 gram per cubic meter at an altitude of approximately 10,000 feet. A scientist from NCAR indicated that given the conditions that existed in the area at the time of the accident, Supercooled[51] Liquid Water (SLW) contents of between 0.3 to 1 gram per cubic meter were reasonable assumptions. In addition, estimates of LWC for this time period were also made by the French Bureau Enquetes-Accidents (BEA) that showed they ranged from 0.3 to 0.7 gram per cubic meter. (See Appendix G.)

The water droplet sizes were estimated using the data from the KLOT Doppler weather radar. These drop sizes were determined using an assumed LWC of 0.1 to 1 gram per cubic meter and the measured reflectivity in the area of the LUCIT intersection. These calculations indicated that the drop sizes ranged from about 100 to 2,000 microns in diameter.

The icing conditions associated with SLW droplets with diameters of 50 microns to 500 microns have been defined by both the FAA and the icing research community as freezing drizzle, while those with drop diameters greater than 500 microns are referred to as freezing rain. The NCAR scientist testified that the presence of freezing drizzle/freezing rain in the atmosphere is "difficult to forecast" and "usually not detected." Additionally, because of its insidious nature, the ice that results from freezing drizzle/freezing rain is not always apparent to pilots; thus, avoidance is not always possible. The ice that forms from freezing drizzle/freezing rain accretes not only on the protected surfaces of the aircraft but also aft of the protected surfaces. Though ice accretions on the protected surfaces can be removed using conventional aircraft deice/anti-ice systems, the ice that has accreted behind the protected surfaces remains on aircraft until it is removed naturally through sublimation, melting, aerodynamic force, or a combination of these factors.

A research professor at the University of Wyoming provided testimony at the Safety Board's public hearing regarding the environmental conditions necessary for freezing drizzle/freezing rain to exist. He stated that cloud drops, drizzle drops, and rain drops are defined according to the size of the water droplets. These

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[51]Supercooled is the liquid state of a substance that is below the normal freezing temperature for that substance. Regarding airframe ice accretion, supercooled rain drops, freezing rain, supercooled drizzle drops and freezing drizzle are considered synonymous terms.

definitions are the basis for determining the type of freezing moisture conditions and the severity of the resulting icing phenomenon. The research specialist defined the following drop sizes: Cloud drops are typically less than 50 microns in diameter and fall at speeds of less than 5 centimeters per second (cm/s); drizzle drops are typically 50 to 500 microns in diameter and fall at speeds of between 5 and 60 cm/s; rain drops are typically greater than 500 microns in diameter and fall at speeds greater than 160 cm/s.

According to the scientist from NCAR, the formation process for freezing rain or freezing drizzle can be divided into two basic categories. In the first category, the atmospheric temperature must be below 0 degrees C throughout the majority of the altitudes, with an embedded layer of air in which temperatures are greater than 0 degrees C. The process begins with snow formed in the clouds above the layer of warm air, and, as it falls through the layer of warm air, it melts and forms drizzle or rain. The resulting droplets continue to fall and reenter the layer(s) of cold air (temperatures less than 0 degrees C) but remain in their liquid state. The drizzle or rain drops, depending upon their size, freeze on contact with various surfaces.

The second category does not involve an ice phase in the formation of freezing rain or freezing drizzle. The process begins when the water droplets grow to either drizzle or rain drop size without having evolved from a snow flake and melting. The droplets are formed at cloud-drop size (less than 50 microns) and continue to grow at a slow rate through a process known as "condensational growth." However, the droplet growth is often accelerated considerably through a second process known as "collision coalescence," which results when cloud size water drops that are larger than their neighbors begin to fall. These drops fall at different speeds, collide with other cloud drops and coalesce with them, thereby increasing their mass at a faster rate than condensation alone. As the drops increase in weight, they continue to fall at an accelerated rate, colliding with more water droplets, thereby creating drizzle or rain.

The freezing drizzle or freezing rain can occur either near the earth's surface or further aloft in the atmosphere. This process is not temperature dependent and can occur in clouds that are colder than 0 degree C, as long as the clouds do not contain a significant amount of ice (since the presence of ice tends to deplete the SLW in the cloud). According to the professor from the University of Wyoming, about 25 percent of the time freezing rain or freezing drizzle is produced by the collision-coalescence process. This is based on data for freezing precipitation that falls to the ground.

1.7.7 Classification of Icing Conditions

The FAA addresses the reporting of icing conditions in the AIM. According to AIM Section 7-1-25, Meteorology, Paragraph 7-20, "PIREPs Relating to Airframe Icing," it states, in part:

a. The effects of icing on aircraft are cumulative - thrust is reduced, drag increases, lift lessens and weight increases. The results are an increase in stall speed and a deterioration of aircraft performance...it takes but 1/2 inch of ice to reduce the lifting power of some aircraft by 50 percent and increases in the frictional drag by an equal percentage;

b. A pilot can expect icing when flying in visible precipitation, such as rain or cloud droplets, and the temperature is 0 degrees Celsius or colder. When icing is detected, a pilot should do one of two things (particularly if the aircraft is not equipped with deicing equipment), he should get out of the area of precipitation or go to an altitude where the temperature is above freezing....Report icing to ATC/FSS, and if operating IFR, request new routing or altitude if icing will be a hazard. The following describes how to report icing conditions:

   1. **Trace -** Ice becomes perceptible. Rate of accumulation is slightly greater than the rate of 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).

2. **Light** - The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deice/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used.

3. **Moderate** - The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or flight diversion is necessary.

4. **Severe** - The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

In addition, the following are the AIM definitions of the two different types of ice:

Rime Ice - rough, milky, opaque ice formed by the instantaneous freezing of small supercooled water droplets;

Clear Ice - a glossy, clear or translucent ice formed by the relatively slowly freezing of large supercooled water droplets. The large droplets spread out over the airfoil prior the complete freezing, forming a sheet of clear ice.

The AIM does not define "Mixed Ice;" however, a definition is found in AC-00-45C, Aviation Weather Services, as a combination of clear and rime ice. The FAA Aircraft Icing Handbook defines mixed icing conditions as, "a subfreezing cloud composed of snow and/or ice particles as well as liquid droplets."

1.7.8 Forecasting of In-flight Icing Conditions

According to information received from NCAR and the NWS, icing forecast techniques are currently predicated on relative humidity and temperature fields. This method enables a forecaster to determine the potential for icing conditions and typically covers large areas. However, these forecasts do not include SLW (Supercooled Liquid Water) content or provide explicit water droplet sizes. According to the NCAR scientist, it is not possible, using temperature and humidity data, to accurately determine the severity of the icing conditions that may exist. The scientist stated, "severity depends in the liquid water content of the clouds, how much water mass you are actually intercepting with your airplane, how large the droplets are and the temperature."

One icing forecast produced after the accident, using a state-of-the-science atmospheric model developed by NOAA and NCAR, provided no indications of freezing rain or freezing drizzle in the Roselawn area for the time of the accident. The NCAR scientist stated, "...models aren't perfect. Forecasts aren't perfect...even though it's current state-of-the-art atmospheric modeling." She also said that, with continuing deployment of Radar Wind Profilers, the use of WSR-88D and terminal Doppler weather radar (TDWR), multispectral satellite data, aircraft-transmitted atmospheric reports, and the sophisticated mesoscale atmospheric models, it is possible to refine the current icing forecasts.

The FAA-sponsored research and development program for forecasting icing conditions has focused primarily on the creation of new mathematical algorithms that enhance the weather information received from weather forecasting models in operation at the National Meteorological Center. The FAA's Advanced Weather Product Generator (AWPG) program was intended to be a comprehensive automated aviation weather warning display for the CWSU, Flight Service Station (FSS) and other related system users, capable of generating and displaying icing forecasts and icing data. The AWPG program was canceled in 1994, "due to prioritization, based upon severe budget constraints...." According to the NCAR scientist, although the majority of the development work has been accomplished and in-flight icing research is continuing, the program funding will cease in 1996. The scientist also stated that the "freezing rain" and "freezing drizzle" algorithms were informally reviewed and tested during the winters of 1993, 1994, and 1995 but that they have not been validated.

On May 3, 1995, the Safety Board received a letter from the FAA regarding its ongoing activities involving the forecasting of in-flight icing. The FAA stated, "In-flight icing forecast research is currently being performed...this research is intended to develop methodologies for determining the location of supercooled liquid in clouds which produces icing conditions...Additional research is planned and on-going to enable the determination of icing severity and to diagnose icing in real time."

1.8 Aids to Navigation

Not Applicable

1.9 Communications

Not Applicable

1.10 Aerodrome Information

Not Applicable

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

N401AM was equipped with a Fairchild model A-100A CVR, Serial Number 60753. The recorder was transported to the Safety Board's audio laboratory on November 1, 1994. The CVR group convened on November 2, 1994, and again on December 7, 1994.

Examination of the CVR revealed that the exterior received minor structural damage that consisted of several small dents in the outer casing. The interior of the recorder, including the magnetic tape, was intact and did not sustain heat or impact damage. The recording consisted of three channels of good quality audio information. One channel contained the cockpit area microphone audio signal. The other two channels contained the captain and first officer audio panel signals. The timing on the tape was established using the known time of a specific air traffic control transmission recorded on a cassette tape provided by the FAA.

The audio portion of the recording started at 1527:59 and continued uninterrupted until 1557:57,[52] when electrical power was removed from the unit. The CVR group, consisting of representatives from the parties to the investigation, collectively transcribed the tape in its entirety and had the opportunity to review the transcript. About 8 minutes of nonaviation-related conversation between the flightcrew and a flight attendant were not included in the transcript made available

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[52]The CVR and FDR times were correlated.

to the public. However, the transcript does specify the time when these discussions began and ended (identified as "non-pertinent pilot and flight attendant conversation") and it includes all other conversations and sounds recorded on the CVR.

The final 2 minutes of the recording were reviewed using a sound spectrum analyzer. The data obtained from the spectrum analysis were used to complete the verification of certain cockpit sounds and to determine the elapsed time between key events.

1.11.2 Digital Flight Data Recorder

The airplane was also equipped with a Loral/Fairchild flight data recorder, model F800, Serial Number 4838. The recorder was capable of recording 25 hours of operational data and was configured to record approximately 115 parameters. The recorder was transported to the Safety Board's FDR laboratory on November 1, 1994, for readout and evaluation.

The FDR sustained extreme impact damage to both external and internal components. However, the crash-survivable memory module unit was found intact with no evidence of internal damage to the recording medium. All of the recorded information, with the exception of the last second of operational data, was recovered and analyzed.

1.12 Wreckage and Impact Information

1.12.1 General Wreckage Description

The airplane impacted the ground in a nose-down, partially inverted position at a high rate of speed. Fragmented airplane wreckage was found in and around three impact craters. A complete survey of the accident scene and aircraft structure was accomplished; however, the severity of the damage precluded a complete accounting of all the airplane structure. (See Figure 10a.)

Two smaller impact craters, consistent with the size of the left and right engines, were found on both sides of the larger, main impact crater (the size and orientation of the three craters, identified as crater 1, crater 2A, and crater 2B, are shown in Figure 10b). Most of the human remains, as well as portions of the

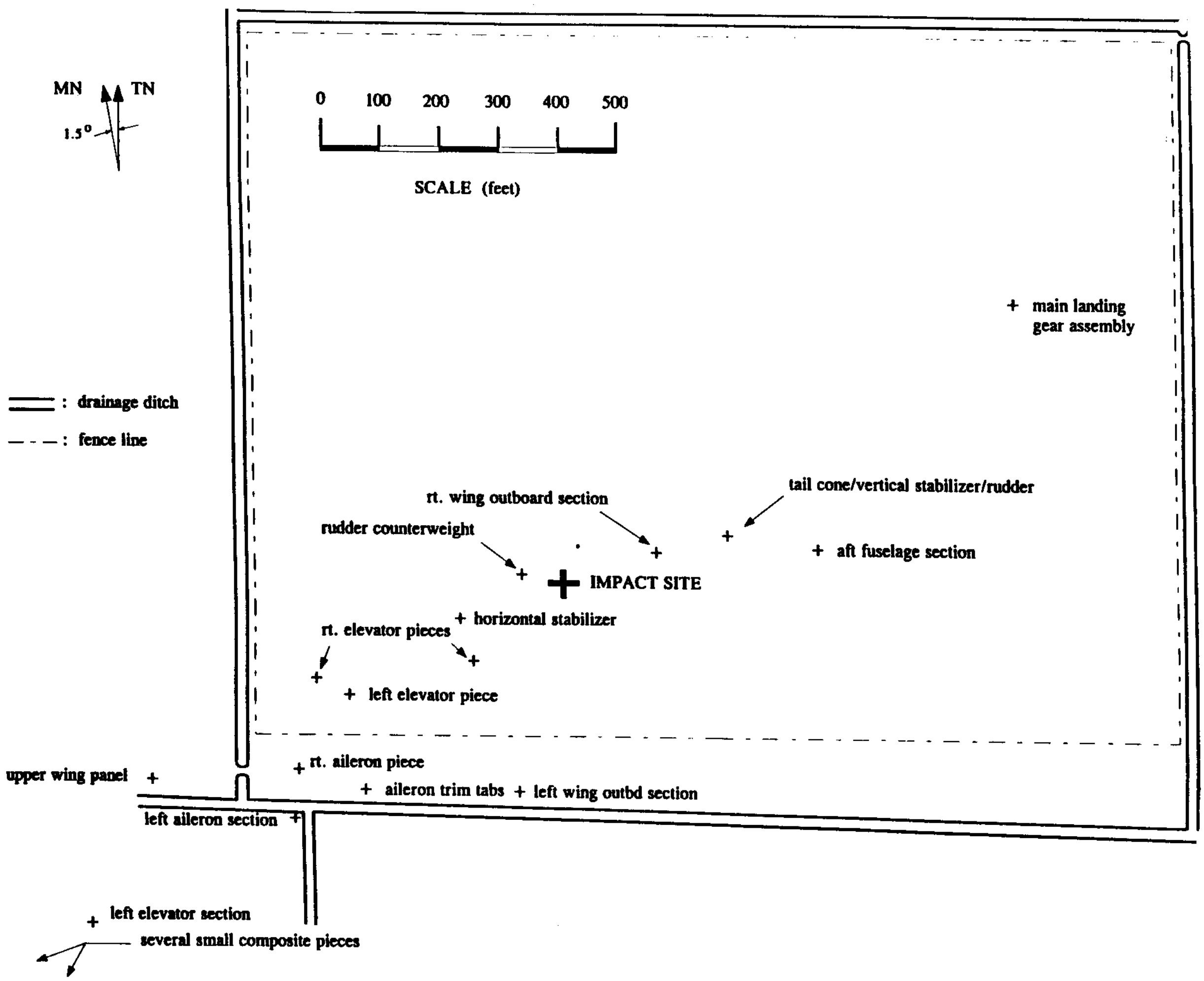

Figure 10a.--Wreckage distribution diagram.

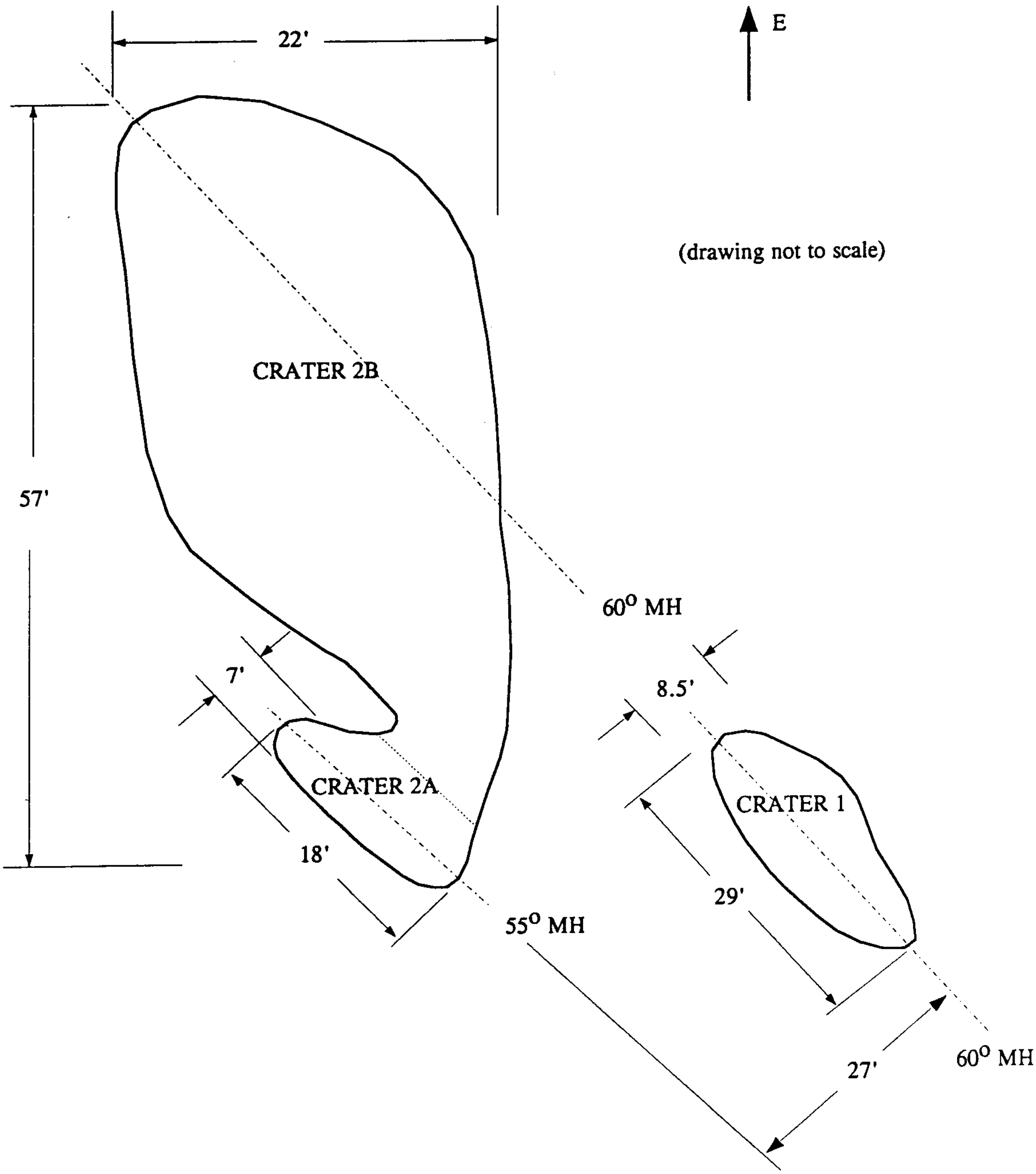

Figure 10b.--Impact craters.

airplane structure and components, were located to the east-northeast of the impact craters. Portions of the wings and empennage were found to the south and southwest of the craters. The first major airplane structure found in the debris field, located farthest southwest from the impact craters, was a portion of the left elevator. Numerous small lightweight pieces of composite material were found about 1,000 feet southwest of the elevator. The last pieces in the debris field, farthest northeast from the impact craters, consisted of a main landing gear assembly (main landing gear wheel and tire) a portion of the flightcrew/passenger oxygen bottle, and two hydraulic pumps located in the lower section of the airplane.

An outboard portion of the left wing was found south of crater 1. The horizontal stabilizer was found west-southeast of the impact craters, and portions of the left elevator and left aileron were found southwest of the creek bordering the field.

The majority of the fuselage disintegrated into small unidentifiable pieces with only the aft end of the fuselage, the horizontal and vertical stabilizers, and both wing tips located as intact assemblies at the site. The forward fuselage and cockpit had been completely destroyed. Portions of all flight controls were found in the debris field, some of which were located nearly 1,000 feet from the impact craters.

A section of the left wing rear spar approximately 7 1/2 feet long (inboard and outboard of wing rib No. 13), several engine accessories, and portions of the engine mount frame were found in crater 1. Numerous other pieces of the left wing and left engine were found northeast of the main impact crater. Engine accessory components were found in crater 2A, and parts from the right engine were found northeast of craters 2A and 2B.

The balance horns for the elevators, ailerons, and the rudder and portions of all flight controls and doors were found in the debris field.

1.12.2 The Wings

The outboard portions of both wings were found to have separated approximately 10 feet inboard from their respective tips. On both outboard wing sections, the upper skin extended almost 2 feet farther inboard than the lower skin. The wing structure is constructed of a composite material outboard of wing rib

No. 13, and no definitive failure modes were determined from the fracture surfaces of the outboard wing pieces.

The outboard portion of the left wing was found 390 feet from the southwest edge of crater No. 1. The outboard attach fitting for the left aileron was found in an approximate 3-foot-long depression adjacent (northeast) to the wing section. Another large portion of the left wing was found approximately 75 feet northeast of crater 2B. The majority of the leading edge was found with the wing section but was partially separated. The outboard third of the rear spar and a portion of the outboard lower skin had separated.

The right wing sustained substantially more damage than the left wing, especially in the area of the flap. The outboard section of the right wing was found approximately 80 feet east of crater 2B. Other than this piece, only a few small portions of the right wing were recovered.

Examination of the leading edges of the left and right outboard sections of the wings revealed minor damage, and the deicing boots were intact and properly bonded. The filler in the spanwise seam between the leading edge and the upper skin surface was found to be intact and flush on both outboard wing sections. All of the vortex generators on the left wing were found mounted in their normal positions. The upper surface of the outboard portion of the right wing sustained impact damage, and only six vortex generators were found mounted in their normal positions. Impact-related damage to the right wing in the area of the vortex generators precluded complete documentation.

The leading edges of both wings on the ATR 72, inboard of the engines, contain a piano hinge along the lower surface, with the upper surface attached to the wing structure by screws. The forward half of the hinge is normally attached to the leading edge and the aft portion of the hinge is attached to a flange on the wing lower skin. The hinge pin is held in place by a hinge pin stop on each end. The stop on the right end of the hinge (as viewed from above) consists of a plug inserted into the aft half hinge. The stop at the left end of the hinge (as viewed from above) consists of a plate riveted onto the forward half hinge and includes a solid hinge tooth that blocks movement of the pin after the plug and the pin are first installed.

Examination of the airplane wing structure revealed that a 44-inch portion of the forward half hinge was found attached to a piece of the left wing leading edge that measured about 51 inches in length, including the outboard edge. The outboard 31 inches of the 44-inch hinge section was straight, and the hinge pin stop was attached. A 38-inch portion of the corresponding aft half-hinge remained attached to the lower flange and left wing skin. Dirt was found embedded in the pin "through-holes" in the hinge teeth. Further examination of the inside of the through-holes revealed no evidence of smearing damage; however, two through-holes at the inboard end of the forward half hinge were elongated. The hinge pin was absent from the left wing hinge pieces. Fretting damage[53] was observed on inboard and outboard faces of several hinge teeth.

The left wing piano hinge section, mated to a portion of the left wing structure, was transported to the Safety Board's laboratory for examination. The examination revealed that the through-holes bore evidence that was indicative of the pin having been in its normal mounted position at the time of impact.

Except for the four outboard teeth on the forward (leading edge) half hinge, the full span of the right wing hinge was found in three pieces, with the largest measuring 75 inches long. A portion of the lower flange and leading edge corresponding to the longest hinge piece was also found. The hinge pin was found in the two longest hinge pieces, and the teeth on the forward half hinge of these pieces were broken at the base. The smallest of the three hinge pieces was attached to the wing flange and consisted of the outboardmost two teeth. The "plug-type" hinge pin stop was not found, but there was a circular area void of white paint where the pin stop had been installed. The "plate-type" hinge pin stop was not located, nor was the lower flange inboard of the two hinge teeth.

The ailerons from both wings were recovered. Two pieces of the left aileron with its balance horn, and the mating inboard portion, measuring approximately 57 inches, were found embedded leading-edge-down on the south side of the creek, approximately 700 feet southwest of the impact craters.

The left outboard aileron hinge fitting was found in a small ground depression beside the left wing tip. The web of the fitting between the aileron and the wing rear spar was broken near the location of the rear spar, and the forward end of the broken web was bent inboard. The fractures where the outboard aileron

[53]According to the American Society for Metals definition of metallurgical terms, fretting is the "action that results in surface damage…when there is relative motion between solid surfaces in contact under pressure."

hinge fitting had separated from the wing and the aileron bore evidence indicative of tensile overload.

Marks consistent with impact from the upper and lower aileron stops were observed on the middle aileron hinge fitting. The white paint and green primer were missing from the center of the lower stop, although both were present near the edges. The paint and primer were found on the upper stop, although the center of the stop was slightly darker in color than the surrounding surface.

The right aileron and the balance horn were found in several pieces near the impact craters. The largest portion of the aileron was the inboard portion, which measured approximately 54 inches long. The outboard portion measured approximately 50 inches but only consisted of the leading edge and front spar. Both of these pieces were crushed aft. The forward outboard edge of the counterweight horn was crushed downward and aft. The forward inboard edge was crushed outboard, and the right aileron trim tab had broken into two spanwise pieces but was complete.

The outboard aileron hinge fitting was found attached to the wing. Marks consistent with impact from the upper and lower aileron stops were observed on the middle aileron hinge fitting, and no white paint or green primer was observed at the center of either aileron stop or on the surrounding surface.

The majority of both wing flaps was recovered, and evidence found on the flap tracks and other parts connected to the wing indicated that the flaps were attached to their respective wing structure at the time of impact. Further examination revealed that the interconnect rod and the mushroom-shaped pin between the inboard and outboard flaps of both the left and right wings were intact. The flap interconnection shaft between the left and right wings was found in numerous pieces.

The trailing edge fairings from both wings between the flaps and the ailerons were recovered. Because of a previously identified problem (addressed by an airworthiness directive) of aileron interference with the wing flap, the right fairing and the outboard piece of the right outboard flap were examined at the Safety Board's laboratory to determine if the right flap might have contacted the right aileron during flap retraction. The examination revealed no evidence of fiberglass carbon fibers (the flap is constructed of composite material) embedded in the fiberglass composite fairing. The electronic flap control switch, located under the center pedestal in the cockpit, was found in an intermediate position, between the second and third selections of the flap control lever, with a twisted shaft.

1.12.3 Empennage

Large portions of the tailcone and the vertical stabilizer, with the rudder attached, were found connected to a portion of the aft fuselage, located approximately 200 feet east of crater 2B.

The horizontal stabilizer was found intact, approximately 165 feet west of crater No. 1. The stabilizer leading edge and deicing boot received minor damage, including a puncture of the lower surface of the left horizontal stabilizer near midspan. Both sides of the horizontal stabilizer bore evidence of wrinkling in the upper skin. Depressed areas were also observed in the upper skin between the ribs, mostly in the outboard portion of the horizontal stabilizer. All vortex generators were intact and attached. The deicing boot material was relatively intact and exhibited cuts and scratch marks that were consistent with ground impact.

The horizontal stabilizer fittings that attach the horizontal stabilizer to the vertical stabilizer consist of six attachment lugs, three on each side of centerline. Examination of this area revealed that the left side lugs had pulled through the bottom, and the fractures on the left lugs were indicative of tensile overload. The right lugs were intact, and no deformation was observed on the right forward lug. The middle and aft lugs were bent outboard, with greater deformation on the aft flange.

The left elevator was found in three pieces, and the left elevator trim tab was found in two pieces. Both elevator sections were broken in the same approximate location as the elevator trim tab center hinge. The entire right elevator was found in four pieces. The right elevator trim tab was found in two pieces and had broken near the center hinge.

Both elevators exhibited damage to the stops consistent with over-travel impact. The left elevator contained damage to the upper and lower surfaces of the attach fitting cutout at the locations of the middle and outboard fittings, consistent with over-travel impact with the fitting.

The right side of the vertical stabilizer had a vertical break in the skin, approximately 4 feet long and located aft of frame 44 (aft pressure bulkhead location). The upper left side of the stabilizer had an L-shaped break (approximately 10 inches by 12 inches) in the skin in the same general area. The vortex generators on each side of the vertical stabilizer were intact and attached.

The vertical stabilizer fittings (attaching the vertical and the horizontal stabilizer) consist of six double-flange lugs, three on each side of centerline. The left lugs were intact, and the bolts and spherical bearings were attached. The outboard flange of the right lugs had broken off at the base, and the three bearings were missing. The bolts on the forward and aft fittings remained; the bolt at the middle fitting was missing.

The rudder was found attached to the vertical stabilizer. Pieces of separated rudder skin were found in the beginning of the debris field near the left elevator piece. Both sides of the attach fittings for the rudder contained gouges, and rudder skin on both sides aft of each fitting was damaged consistent with impact with the fittings. The upper fitting at the lower rudder hinge point was broken.

1.12.4 Engines and Propellers

The two Pratt & Whitney PW-127 engines and their respective Hamilton Standard propellers were found separated from their airframe engine mounts and located in the vicinity of craters 2A and 2B. The engines and propellers were removed from the accident site for further examination and disassembly.

The Engines.--Both engines sustained impact damage that fragmented portions of the engines forward of the high pressure diffuser case. Examination of the first stage power turbine blades revealed evidence of circumferential rubbing with corresponding smears due to radial contact with the shroud. The second stage power turbine blades were deformed and fractured in a direction opposite to normal rotation.

The remaining internal components of both engines also revealed evidence of rotational smearing, rubbing and blade fractures in a direction opposite to their normal rotation. The damage sustained by these components indicated that at the time of impact, the engines were producing power.

The Propellers.--The eight composite propeller blades sustained various degrees of impact damage. The majority of one blade was found mounted in the propeller hub that was located on the north side of the impact crater.

Numerous pieces of blade were scattered near the impact crater, and all eight blades were identified and recovered. The damage sustained by the propellers was consistent with rotation under power at the time of impact.

1.13 Medical and Pathological Information

Due to the catastrophic destruction of the airplane, identification of the flight crewmembers was conducted using deoxyribonucleic acid (DNA) protocols at the Armed Forces Institute of Pathology (AFIP) in Washington, D.C. Following the identification, muscle tissue samples from both pilots were forwarded to the FAA's Civil Aeromedical Institute (CAMI) for toxicological analysis. Both pilots tested negative for alcohol and other drugs.

1.14 Fire

Not Applicable

1.15 Survival Aspects

The accident was not survivable because the impact forces exceeded human tolerances, and no occupiable space remained intact. The Newton County Coroner's Office investigative report stated that the occupants sustained fatal injuries due to, "multiple anatomical separations secondary to velocity impact of aircraft accident."

The emergency response by the Newton County Sheriff's Department, the Lincoln Township Volunteer Fire Department and the Indiana State Police was initiated by several telephone calls to the emergency dispatch service about 1600. The aircraft wreckage site, which covered approximately 20 acres, was declared a "biohazard" area, and access to the site was restricted to essential personnel. The monitoring of the site and access control were conducted by the Sheriff's department. The procedures imposed for working in this type of environment required the Safety Board's investigative team, including the party members, to wear personal protective gear while working on the site.

1.16 Tests and Research

1.16.1 ATR 42/72 Lateral Control System Development History

The Safety Board reviewed historical information regarding the development of the ATR 42 and 72, including a presentation by ATR engineering personnel on the development of the ATR 42 and 72 lateral control systems.

ATR engineers stated that the initial ATR 42 aileron system development included multiple balance/hinge moment-related configuration changes to achieve the desired roll efficiency, hinge moment characteristics, and roll trim characteristics. Several ATR 42 developmental aileron configurations produced aileron hinge moment reversals at low AOAs. According to ATR engineers, the final ATR 42 aileron design was a "compromise of acceptable roll rates and hinge moments," and resulted in the aileron hinge moment reversals being delayed to about 25 degrees AOA. ATR indicated that the aileron hinge moment reversals were linked to aerodynamic stall. The susceptibility to hinge moment reversal from aerodynamic stall is a characteristic of aerodynamically balanced control surfaces at high AOAs, and the characteristics can vary among configurations.

According to ATR officials, the ATR 42 SPS was designed to provide a margin between "normal" aircraft operations and the higher AOAs found to be associated with undesirable handling characteristics, including, but not limited to, aileron hinge moment reversals. SPS AOA thresholds were established for both a "clean" and "iced" airplane. The SPS threshold values for the airplane with ice contamination were established based upon the AOAs at which undesirable handling characteristics, including aileron hinge moment reversals, occurred during the icing certification handling tests. This SPS design was carried forward during the development of the ATR 72.

During the ATR 72 development stages, efforts were made to achieve the needed roll and AOA performance by various means. Initial aileron configurations resulted in hinge moment reversals at AOAs deemed to be too low by ATR. Vortex generators were then added to the upper wing surface of the ATR 72, in front of the ailerons, which delayed the aileron hinge moment reversal to 25 degrees vane AOA. The installation of the vortex generators, which proved effective in postponing the flow separation in the area of the ailerons and the resulting aileron hinge moment reversal, prompted ATR to develop similar aileron vortex generators for the ATR 42 as a product improvement.

Further performance enhancements desired for the ATR 72, series 210, required an increase in maximum AOA capability. ATR subsequently added more vortex generators of a different design (co-rotative) in front of the ailerons. This change increased the aileron hinge moment reversal AOA to 27 degrees.

Hydraulically powered flight controls can overcome high control forces resulting from normal in-flight control surface hinge moments. If properly designed, they can also prevent control surface hinge moment anomalies from being transmitted back through the control system and into the cockpit. According to ATR engineers, hydraulically powered ailerons were discussed during the preliminary design of the ATR 42. It was determined that adequate lateral control characteristics could be obtained without the additional weight and complexity of a hydraulic system. Hydraulic aileron control was again discussed informally among ATR engineers after an incident involving a Simmons Airlines ATR 42 in Mosinee, Wisconsin, in December 1988. ATR management has since stated that hydraulically powered ailerons have never been "officially" considered for either the ATR 42 or 72.

The Safety Board reviewed graphical data from developmental test flights in which aileron hinge moment reversals were encountered during flight test stall demonstrations. The graphs indicated that aileron hinge moment reversal occurred at or above the current "clean"[54] airplane stick pusher activation AOA. The stall speeds noted on the graphs where the hinge moment reversals occurred were about 100 knots indicated airspeed (KIAS), and the flight test pilot indicated that the control forces required to counteract the uncommanded aileron deflections were "not excessive." ATR engineers agreed in principle that airfoil contamination, such as icing, could tend to lower the AOA at which the aileron hinge moment reversal occurs, and that icing conditions beyond those specified for certification could lower the AOA at which the aileron hinge moment reversals occur to below the certified icing stall protection system (SPS) AOA thresholds.

1.16.2 Previous ATR 42 and 72 Incidents/Accidents

The service histories of the ATR 42 and 72 airplanes were examined by the Safety Board, with an emphasis placed on previous roll control incidents. Twenty-four roll control incidents were found to have been reported since 1986, all

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[54]"Clean" refers to a wing surface that is free of any contamination, such as ice.

of which involved the ATR 42.[55] The Safety Board determined that 13 of the 24 roll control incidents were related to icing conditions. Of these 13 icing-related incidents, the following 5 occurred in weather conditions consistent with freezing drizzle/freezing rain, and involved varying degrees of uncommanded aileron deflections with subsequent roll excursions:

- AMR Eagle/Simmons Airlines at Mosinee, Wisconsin, December 22, 1988;
- Air Mauritius over the Indian Ocean, April 17, 1991;
- Ryan Air over Ireland, August 11, 1991;
- Continental Express at Newark, New Jersey, March 4, 1993;
- Continental Express at Burlington, Massachusetts, January 28, 1994.

All five of these incidents were investigated by either the Safety Board, the French Bureau Enquetes - Accidents (BEA), or ATR/Aerospatiale. The Safety Board conducted investigations of the incidents that occurred at Mosinee, Wisconsin, and Newark, New Jersey. The BEA participated in the investigation of the Mosinee incident and received information from ATR regarding the incidents in Ireland and over the Indian Ocean. The FAA participated in the investigation of the Mosinee and Newark incidents, and ATR participated in the investigation of all five incidents.

ATR used available data from the incidents and its six degrees-of-freedom (6 DOF) numerical simulation to study the airplane performance and identify any abnormal aerodynamic characteristics. In each incident, ATR identified significant drag increases, and, in some cases, found significant decreases in lift coefficient. ATR attributed the drag increases primarily to propeller ice accretions that resulted from the propellers being operated at speeds of 77 percent, rather than the required 86 percent.

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[55] See Appendix H for a listing of ATR 42/72 incidents/accidents in icing conditions or roll control problems.

In the case of the accident involving flight 4184, the Aerospatiale 6 DOF simulations have indicated intermittent periods of moderate drag increase well prior to the event, imperceptible (less than 3 percent) drag increase just prior to the event, a slight right roll and yaw increment just prior to the event, and normal aileron effectiveness throughout the departure, climb, and initial descent.

Based on the available information, the Safety Board determined on June 6, 1990, that the probable cause of the December 22, 1988, ATR 42 incident at Mosinee was "a stall induced by the accretion of moderate to severe clear icing."

According to ATR, the DGAC and the FAA were provided copies of the ATR analysis of the Mosinee incident. The Safety Board was not provided a copy of this analysis until after the Roselawn accident. The ATR analysis of the Mosinee incident contained the following conclusions:

- The autopilot disengagement occurred owing to its internal safety devices. The ailerons tended to adopt the zero hinge moment position in the absence of pilot reaction. The maximum deflection reached was minus 12.5 degrees. This deflection introduced a high roll rate which added to the wing drop to take the aircraft to an 80 degree bank attitude;

- Two other roll excursions corresponding to increasing AOA were checked by the control surfaces. The increased engine power and descending flightpath made the aircraft fly at an AOA such that the roll excursions disappeared and/or could be easily controlled by the pilot;

- It should be noted that throughout the incident, i.e., 30 seconds in all, the control surfaces remained effective and, owing to their action alone, enabled the aircraft to recover a normal attitude, although control stability was affected, owing to the changes in hinge moment according to angle of attack, which were probably due to the presence of ice on the airfoil beyond the deicers, as is the case on all aircraft in freezing rain conditions.

The Safety Board compared the December 22, 1988, incident at Mosinee, Wisconsin, to the Roselawn accident, and the following similarities have been noted:

- both events occurred with the autopilot initially engaged, while operating in icing conditions consistent with freezing drizzle/freezing rain;

- both airplanes were turning with the AOA increasing, when the ailerons began to deflect in the direction of the turn;

- in both events, the autopilot disconnected automatically prior to SPS activation and the ailerons immediately deflected rapidly to nearly their full travel limit at rates in excess of pilot input or autopilot capabilities;

- both airplanes rolled in the direction of the aileron deflection;

- in both events, the aileron deflection was rapid and oscillatory at elevated AOAs, and was stable at lower AOAs.

The Safety Board also noted the following differences between the Mosinee incident and the Roselawn accident:

- the ATR involved at Mosinee had a significant loss of speed due to ice accretion prior to the incident; conversely, the Roselawn accident only showed small, intermittent speed losses;

- at Mosinee, the initial uncommanded aileron deflection occurred at 11.5 degrees vane AOA and 154 KIAS, while at Roselawn, the aileron deflection occurred at approximately 5.2 degrees vane AOA and 184 KIAS;

- at Mosinee, the airspeed and vertical acceleration did not exceed 190 KIAS and 1.7 G after the event, while at Roselawn, the airspeed and vertical acceleration exceeded 370 KIAS and 3.0 G after the event;

- at Mosinee, the ice accretion and uncommanded aileron deflection occurred at flaps 0, while at Roselawn, ice accreted with the flaps set at 15 degrees, and the aileron deflection occurred when the flaps were retracted to 0 degrees;

- the Mosinee flightcrew did not use the Level III deicing system before the event, while at Roselawn, the FDR data indicate that Level III ice protection was activated 17.5 minutes before the event.

The Mosinee flightcrew filed a report with NASA's Aviation Safety Reporting System (ASRS) regarding the incident and indicated that they had encountered clear ice that they were unable to see on the airframe. The crew's report did not mention side window icing, but it did state, "...to keep this airplane safe we need some indicator to let us know we have ice on the airframe we cannot see."

In addition, ATR sent an “Operators Information Message” (OIM) in January 1989, regarding the Mosinee incident. The message characterized the event as follows:

> The A/C was submitted to freezing rain. This freezing rain affected control forces on the ailerons in such a manner that the autopilot was no longer able to maintain the bank angle in the procedure turn. As a consequence, the A.P. [autopilot] was normally disconnected by its monitoring system. The A/C rolled to a large bank angle until the pilot took over the control manually. From that point the response of the A/C to pilot aileron inputs was correct except that the wing heaviness was present for about 20 seconds as long as incident [AOA] was not significantly reduced. The rest of the flight was uneventful including the landing on an ice covered runway. Taking into account the information presently available the A/C manufacturer considers that nothing needs to be changed on the A/C or in the operating procedures. This position has the agreement of the French airworthiness authority….
>
> It is emphasized that aircraft ice protection systems are designed basically to cope with the supercooled cloud environment (not

> freezing rain). Supercooled cloud water droplets have median volumetric diameter (MVD) of 5 to 50 microns. Freezing rain MVD is as great as 1300 microns. Large droplets of freezing rain impact much larger areas of aircraft components and will in time exceed the capability of most ice protection equipment. Flight in freezing rain should be avoided where practical.

On February 8, 1989, ATR provided Flight Safety International (FSI) with an ATR 42 icing model for implementation in the FSI ATR 42 simulators. This was followed on June 26, 1990 by a similar icing model for the FSI ATR 72 simulators. These icing simulation packages provided demonstration of low, medium and high ice accretion rates, resulting in loss of airspeed (the rate of these losses were dependent upon the ice accretion rate selected) that flightcrews were intended to recognize and activate the deice boots. The airspeed losses cease upon activation of the deice boots. The simulation induces a roll to the right or left (random) after the AOA has increased beyond the stick shaker activation AOA (11.2 degrees vane AOA if the Level II anti-icing is selected). These icing simulations do not include any change that would demonstrate rapid and uncommanded aileron and control wheel deflections to near their full travel limits with high, unstable control wheel forces.[56]

In 1990, ATR added vortex generators forward of the ailerons on all ATR 42 airplanes. According to ATR statements provided to the Safety Board after the Roselawn accident, the vortex generators increased the AOA at which the airflow separation occurred and would provide an additional AOA margin of several degrees between the normal operating AOA and the aileron hinge moment reversal AOA. In 1990, the DGAC provided the FAA with the certification documentation necessary for the installation of the vortex generators on the ATR 42. Subsequently, on September 18, 1992, the FAA issued AD 92-19-01 requiring the installation of the vortex generators as terminating action for AD 89-09-05 (AFM limitations prohibiting the use of the autopilot in icing conditions). In the discussion section of the Notice of Proposed Rulemaking (NPRM) for AD 92-19-01, the FAA stated that:

> …flight testing and analysis have demonstrated that installation of vortex generators on the upper surface of the Model ATR 42 wing significantly improves the effectiveness of the ailerons, which

[56]ATR’s post-Roselawn “freezing drizzle” simulation package, provided to FSI on January 30, 1996, demonstrates these characteristics.

> reduces the severity of the roll upset that can occur with asymmetric ice accumulations resulting from icing conditions such as freezing rain…. The FAA has determined that long term continued operational safety will be better assured by design changes to remove the source of the problem rather than by repetitive inspections or special operating procedures. Long term special operating procedures may not be providing the degree of safety assurance necessary for the transport airplane fleet….

ATR had also developed the Anti-Icing Advisory System (AAS) for the ATR 42 and 72. The DGAC issued CN 89-120-023B, which required the installation of the AAS and SPS by October 1, 1989. The FAA subsequently issued AD 89-24-07, which required the installation of the AAS on U.S.-registered ATR airplanes.

In an August 28, 1989, response letter to the FAA regarding the Notice of Proposed Rule Making (NPRM), the Air Line Pilots Association (ALPA) expressed its concerns to the FAA about the installation of the AAS on ATR airplanes. ALPA stated that "...we question whether or not the modifications proposed will solve the problem...." Additionally, ALPA stated in this letter that:

> ...We are also concerned with the premise that this aircraft was not certified for flight into freezing rain. The FAA has not gone far enough in outlining the procedures pilots should take when confronted with the possibility of flight into freezing rain....Since freezing rain cannot be predicted with any reasonable certainty, should pilots refrain from flight into any icing conditions? How can pilots determine if their aircraft will be subjected to freezing rain? And if their aircraft are subjected to unexpected freezing rain, will the modifications proposed in the AD be effective in ensuring the continued safe flight of this aircraft? All other aircraft types were not certificated for flight into freezing rain as well, yet these same aircraft have not experienced the serious loss of control incidents as the ATR 42 has. Perhaps anti-ice/deice systems of other aircraft types have been more thoroughly designed to compensate for operations in all icing conditions thus recognizing the inability of predicting freezing rain.

On July 9, 1991, ATR made the following conclusions after its investigation of the April 17, 1991, Air Mauritius incident:

> During Air Mauritius flight MK121 on Wednesday 17th April 1991, performed in potential icing conditions (external temperature minus 3 degrees C, presence of clouds), ATR 42 s/n 208 registered 3BNAP, started a moderate roll excursion at flight level 160 on AP disconnection;
>
> The crew had previously observed an appreciable speed decrease. After manual take over, the flight was continued without any anomaly;
>
> Analysis of the DFDR and the simulations made afterwards lead [ATR] to believe that this aircraft was subjected to ice accretion which downgraded drag and lift performance, and was not reproducible by the certificated ice simulation models and not detected by the crew and the ice detector (transparent ice, location...;)
>
> The ice accretion caused dissymetry ("heavy wing") which was difficult to control by the autopilot. The unusual control forces then encountered by the crew on disconnection led to a 40 degree roll excursion. Use of roll control then allowed the normal situation to be quickly restored;
>
> The propeller speed directive for potential icing conditions - Np greater than 86 percent was not respected; this contributed significantly to the thrust/drag deficit;
>
> The modifications decided upon as a result of the incident on aircraft 23 [ATR 42 operated by Executive Airline, San Juan Puerto Rico], in particular as [it] regards indication of roll out of trim and which will be retrofitted in the medium term of the fleet, would certainly have made it possible to limit the roll excursion on autopilot disconnection....As these control forces may be unusual, it would be desirable for the crews to be trained to face these roll out-of-trim situations.

On November 13, 1991, ATR made the following conclusions from its investigation of the August 11, 1991, Ryan Air incident:

> On Sunday, August 11, 1991, at 1440, in cruise, during flight RYR 123, ATR 42 SN 161 RYAN AIR (EI-BYO), stalled in icing conditions at FL [flight level] 180 [18,000] after prolonged deceleration at cruise power. After manual control recovery, the flight continued at FL 140 without any further incident;
>
> An analysis of the weather conditions in the area showed that the aircraft probably flew in the cold frontal zone where the air temperature was minus 10 degrees C at FL 180....The extra moisture may have triggered off the severe ice conditions;
>
> FDR information shows that the stall warning threshold (angle of incidence 11.5 degrees) is reached at the same time of the AP disconnection; this leads us to think that the AP was disconnected by the stall warning;
>
> FDR information shows that the airframe de-icing system was switched on only 2 minutes and 30 seconds before the incident; the anti-icing systems (propellers, horns, side windows) were selected without setting Np at 86 percent;
>
> This incident is the consequence of non-observance by the crew of procedure and limitation as described in the ATR 42 AFM, probably in severe icing conditions, namely: late activation of ice protection systems, propellers left at Np=77 percent (minimum allowed 86 percent), no immediate speed recovery initiated at stall warning activation (the elevator remains in pitch up position during 12 seconds leading the aircraft to the stall);
>
> ATR has decided to launch a new campaign of information for the crews related to icing conditions and to introduce in the ATR 42 checklist an "icing conditions" checklist.

ATR's analysis also stated, "Crew noticed ice on side window...." The Ryan Air flightcrew had reported that a "large sudden accretion of ice was observed on windscreen...."

In December 1992, ATR sent all ATR operators a brochure entitled All Weather Operations, (See Appendix I) which addressed the operation of ATR airplanes in various weather conditions, including icing. This brochure also contained a section dedicated to discussing freezing rain and stated, in part, "Although freezing rain is not part of certification cases, it must be taken into account for operations in icing conditions." The brochure also provides a discussion of the following items:

- the physics of freezing rain;
- meteorological conditions conducive to freezing rain (temperature inversions);
- the potential for ice accretion aft of the leading edges of airframe components;
- the potential for asymmetric wing lift and "associated increased aileron forces necessary to maintain coordinated flight before aerodynamic stall;"
- the difficulty in visually detecting the presence of associated clear ice (transparent, shiny);
- the need to avoid freezing rain where practical;
- ways of avoiding freezing rain (reviewing weather charts, PIREPs, AIRMETs, SIGMETs, monitoring outside air temperature data for temperature inversions);
- operating procedures for freezing rain encounters (monitor the autopilot for roll retrim messages, increase speed as much as possible, extend flaps as close as possible to VFE [design flap limiting speed], avoid excessive maneuvering);
- alternative actions for exiting freezing rain conditions (climb or alter course);

- procedures to follow in the event of a roll axis "anomaly:" "disconnect AP holding control stick **firmly**. Possible abnormal rolls will be better felt when piloting manually."

An investigation of an incident involving an ATR 42 operated by Continental Express in Newark, New Jersey, on March 4, 1993, was commenced by the Safety Board on March 5, 1993. The pilots of the Continental Express flight provided the following ASRS report regarding the events:

> Apparently our problem was caused by ice formation on top of the wing in an unprotected area...Ice was noted accumulating on the side windows. The outside temp was fluctuating between 0 and minus 3 degrees C throughout the descent...Passing approximately 7 NM and approaching the final fix the FO [first officer] began a power reduction in order to reduce speed so that the aircraft could be configured in the normal landing profile. It was at this time during the speed reduction the autopilot disconnected and the aircraft immediately rolled to the right...Both pilots immediately grabbed the controls to bring the wings level and nose back up. It took full aileron travel to do so. The aircraft returned to normal flight and was now being hand flown by the FO. Shortly after, the same flight characteristic was observed and the aircraft once again was recovered. At this time, the trims were checked and were found to be normally positioned. The same flight characteristics were then observed for a third time. The captain took control of the aircraft. The trims were checked a second time along with the spoiler lights on the overhead panel, again found to be normally positioned. On the fourth roll, it was observed that prior to the roll, the flight controls became spongy and rough air disturbance could be felt over the ailerons. The aircraft was recovered again, and the captain observed that there was approximately 3 inches of ice aft of the leading edge boots spanning the entire length of the wing. The ice extended back as far as could be observed....

ATR participated in the investigation of the Newark incident and concluded in its March 25, 1993, "Preliminary Report"[57] that:

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[57] This was the only report provided by ATR regarding the Newark incident.

> ATR 42 MSN 259 operated by CONTINENTAL AIRWAYS encountered a sudden lateral jerk reaching a peak of 52 degrees bank angle. Aircraft was flying at a speed of 170 knots in heavy turbulent atmosphere conditions; recorded TAT was close to 0 degrees C; selected configuration was flap 0. After the anomaly, pilot quickly recovered normal aircraft attitude and flightpath; he then performed safe landing after normal selection of flap 15 and flap 30.

ATR further described the "anomaly" that had occurred, and stated, in part:

> ...banking tendency to the right; right hand bank angle increases (delta = 10 degrees). AP disconnects. At the time of the disconnection, local AOA of 7 degrees and VC = 170 knots; immediately after the disconnection, rapid left aileron deflection is observed (7 degree increase - right bank order). Simultaneously the right bank angle goes further to the right; a strong input to the left (to the aileron stop - equal to 14 degrees) stops the roll excursion at 52 degrees. Converging oscillation in bank angle is then observed.

The analytical descriptions made by ATR are consistent with the FDR data. However, the Safety Board has delayed the issuance of a probable cause pending the results of the investigation involving flight 4184.

Continental Express did not, nor were they required to, notify the Safety Board of the ATR 42 incident in Burlington, Massachusetts, on January 28, 1994. However, Continental Express did notify ATR of the incident, and also sent the airplane's FDR to ATR for readout and analysis. ATR’s March 17, 1994, analysis concluded the following:

> ...roll excursion on autopilot disconnection was observed on ATR 42 N15818 (MSN 153) operated by Continental Express. The aircraft was then in cruise, at flight level 160, at 144 knots, in icing conditions with propeller/horn anti-icing and wing/engine de-icing selected, Np at 86 percent. There was a quick takeover by the pilot and the flight continued without any other problems at flight level 120;

> AP disconnection by the STALL warning as the local angle of attack was greater than 11.2 degrees (threshold in icing conditions). The local angle of attack went on increasing and reached a maximum of 12.4 degrees. On AP disconnection negative deflection (probably not commanded) of the LH aileron (minus 10.5 degrees), with the control column not held, which accentuated the roll movement to the left (30 degrees per second) which was quickly countered by the pilot who deflected the aileron positively on to its stop (right turn). The maximum bank angle reached was 54 degrees to the left;
>
> This incident revealed an evolution in drag (and lift) which was incompatible with the most severe assumptions envisioned by the certification regulations (conventional icing, leading edge shapes). This type of evolution was similar to the one observed in the incidents concerning aircraft 161 and 208 and for which the assumption of a low pollution [contamination], but covering the major part of the chord, had been made. This assumption was associated with the turbulence generated by operation at Np = 77 percent in icing conditions, which was not the case for this flight. This type of evolution which was characterized by a continuous considerable reduction in the cruise speed - with constant power lever position - was tolerated by the crew without reaction and resulted in activation of the stall warning and automatic AP disconnection just after the first sign of natural stalling. Takeover of the aircraft by the crew was quick and easy.

In each of the five prior incidents, the airplanes accreted ice while in a flaps 0 configuration, pitched nose up as airspeed decreased (resulting from drag increase), and experienced roll excursions immediately following the disengagement of the autopilot and an uncommanded deflection of the ailerons. In each case, the flightcrews were able to regain full control of the aircraft and complete the flight successfully by either increasing power, reducing the pitch attitude or extending the flaps to 15 degrees, which reduced the AOA.

In addition to the installation of vortex generators, the installation of an anti-icing advisory system (AAS), the development of icing simulator training packages, and the distribution of the <u>All Weather Operations</u> brochure, ATR also took the following actions in response to the prior icing incidents:

- issued "All Operators Messages" to inform ATR operators of its conclusions with regard to some of the investigated icing incidents, related airframe modifications, and changes to operating procedures; and

- conducted operational visits to ATR operators to respond to specific concerns expressed by the pilots and operators.

ATR's knowledge of the aileron hinge moment behavior and the associated autopilot behavior of the ATR 42 in freezing rain conditions, as discussed in its incident analyses and 1992 All Weather Operations brochure, was not explicitly incorporated into the ATR airplane flight manuals, aircraft operations manuals or pilot training programs. Also, the DGAC and FAA did not recommend or require ATR or its operators to include this information in the specific aircraft manuals or pilot training programs.

1.16.3 Communications of Airworthiness Information Between FAA, DGAC and ATR

According to ATR, the DGAC and BEA were provided copies of the ATR analyses for each of the five prior icing incidents. Testimony provided by two FAA staff members indicated that the FAA had not been provided ATR's analyses of these icing-related incidents. ATR stated that the FAA was provided a copy of the analysis for the Mosinee incident shortly after it was completed, but could not verify that the FAA had been provided copies of its analyses of the other four icing incidents. FAA staff members also testified that based on their understanding of the Bilateral Airworthiness Agreement (BAA), it was both ATR's and the DGAC's responsibility to provide the FAA with such information.

The Special Assistant to the Director, FAA Aircraft Certification, testified that the BAA is the "foundation of the FAA's aircraft certification system...[and] is a technical agreement between governments." He said that the BAA was intended to be, among other things, a means for establishing a direct link between the FAA and a foreign airworthiness authority. The Special Assistant also stated that under the BAA, both contracting parties [the U.S. and France] are required to "keep the other party informed" of "information concerning continued airworthiness." The BAA does not specifically require the DGAC or any other airworthiness authority to provide the FAA with the manufacturer's incident/accident analyses.

The standards set forth in the International Civil Aviation Organization's (ICAO) Annex 8, Part II, paragraph 4, "Continuing airworthiness of aircraft," state, in part;

> 4.2.2 The State of Manufacture of an aircraft shall transmit any generally applicable information which it has found necessary for the continuing airworthiness of the aircraft and for the safe operation of the aircraft (hereinafter called mandatory continuing airworthiness information)....
>
> Note 1. - In 4.2, the term "mandatory continuing airworthiness information" is intended to include mandatory requirements for modification, replacement parts or inspection of aircraft and amendment of operating limitations and procedures. Among such information is that issued by Contracting States in the form of airworthiness directives.

On April 27, 1995, the Safety Board investigated a Northwest Airlines Airbus A320 that had experienced severe pilot-induced roll oscillations of 30 degrees while on final approach to runway 18 at Washington National Airport, Washington, D.C. The Safety Board learned that a temporary revision to a procedure in the Airbus flightcrew operating manual had been reviewed by the DGAC and that the DGAC had determined that regulatory action was not required. The investigation also revealed that the FAA did not perform a review of this information to determine if regulatory action was required. The Safety Board concluded that information regarding undesirable flight characteristics in the A320 had not been "effectively disseminated from the manufacturer to the different airworthiness authorities, operators and flightcrews." Furthermore, the Safety Board expressed its concern that, "...other useful and perhaps critical information of a similar nature is not being effectively communicated," and on November 14, 1995, recommended to the FAA that it and the DGAC "establish policy and procedures to assure effective dissemination of all essential information regarding airworthiness problems and corrective actions in accordance with ICAO Annex 8, Part II, paragraph 4. ([Safety Recommendation] A-95-109)."

In its response of January 29, 1996, to the Safety Board, the FAA stated, in part, that it was:

> ...working closely with the French [DGAC] to determine the adequacy of Airbus Industrie's reporting process for information concerning continued airworthiness and safe operation of its aircraft...[and that] ...appropriate certificate management offices, principal maintenance inspectors, and the Seattle aircraft evaluation group have also been asked to review the procedures that Airbus Industrie uses to disseminate continued airworthiness information to its operators....

In a letter dated March 20, 1996, the Safety Board noted that:

> [t]he FAA's actions are only partially responsive to A-95-109, because they are limited to the problems noted with Airbus Industrie. Safety Recommendation A-95-109 was directed at the broad policy and procedures issues for effective dissemination of essential airworthiness information between the FAA and the DGAC, not merely Airbus Industrie's reporting processes. The intent of A-95-109 was to gain improvements in the overall reporting system. Further, similar concerns about adequate dissemination of critical airworthiness information have arisen during the investigation of the American Eagle ATR-72 accident at Roselawn, Indiana….

Based on the understanding that the FAA would submit a more complete reply to the recommendation, it was classified "Open--Await Response" pending further evaluation of the issues and clarification of the FAA's planned actions.

In a letter dated May 7, 1996, the FAA further responded to the recommendation by stating:

> Under the United States/French agreement regarding Certificates of Airworthiness for Imported Aircraft, all essential information related to airworthiness problems and corrective actions on all imported French aeronautical products come to the [FAA] through the French [DGAC]. Currently, the United States and France are completing a new agreement regarding the Promotion of Aviation Safety. The new agreement, which is scheduled for completion by June 1996, will replace the current agreement regarding Certificates

of Airworthiness for Imported Aircraft. Under the new agreement, the FAA and the DGAC will codevelop procedures to define the roles and responsibilities of the FAA and the DGAC. The FAA intends to define the information to be made available on continuing airworthiness and corrective actions. It is anticipated that the procedures will be fully implemented by mid-1997.

In addition to this effort, the FAA will meet with the DGAC to discuss the importance of transmitting any generally applicable information found necessary for the continuing airworthiness of and for the safe operation of imported French aircraft. The FAA will also discuss with the DGAC the feasibility of having access to the DGAC electronic data base containing reports of failures, malfunctions, defects, and incidents of French-designed aircraft models which are on the U.S. registry.

By letter dated May 15, 1996, the Safety Board classified Safety Recommendation A-95-109 “Open--Acceptable Response,” pending implementation and review of the agreement regarding the Promotion of Aviation Safety.

1.16.4 Investigation of Lateral Control System Behavior

During the investigation, the Safety Board examined the possible reasons for flight 4184's rapid right-wing-down aileron deflection at the point of autopilot disengagement. The aileron deflection rate, which was in excess of 50 degrees per second, exceeded the deflection rate capability of a pilot (determined to be about 30 degrees per second), the autopilot servo motor (determined to be about 9 degrees per second), and a runaway aileron trim (determined to be 37 degrees per second). The FDR data indicated that the autopilot servo motor disconnected at the time of the rapid aileron deflection, and the aileron trim was in the neutral position and had not moved since the initial climb phase of the flight.

The Safety Board also examined other possible mechanisms (both mechanical and nonmechanical) that would have resulted in this type of aileron deflection behavior. They included aerodynamic forces that would have resulted in unbalanced aileron hinge moments between the left and right ailerons, a spoiler system force input that would have "back driven" the aileron control rods, and ice contamination of the flap leading edges that could have impinged on the aileron control rods. These possibilities were examined thoroughly. Based on the consensus of the party participants, all of the possibilities were discounted by analysis, except for the aerodynamic force/unbalanced aileron hinge moment scenario. This aerodynamic force/unbalanced hinge moment phenomenon was found to have been cited by ATR in its written analysis of the 1988 Mosinee, Wisconsin, ATR 42 incident. ATR attributed this aileron behavior to the accretion of ice, aft of the wing de-ice boots and in front of the ailerons, as a result of flight in freezing rain.

In consideration of all available information, the Safety Board requested that ATR perform wind tunnel tests to determine the type and location of arbitrary artificial ice shape(s) that would result in similar aileron and airplane behavior exhibited by flight 4184. The wind tunnel tests revealed that one ice shape, similar to a 3/4-inch-high wooden "quarter-round" molding, induced an aileron hinge moment reversal at very low AOAs. This shape also resulted in low drag when mounted on the upper wing surface, in a limited span, forward of the aileron.

ATR conducted high-speed taxi tests with these simulated ice shapes mounted on the upper surface of the wing of an ATR 72. The tests were performed at airspeeds up to 100 KIAS. The tests revealed that asymmetric placement of the shapes induced an asymmetric aileron hinge moment reversal with control wheel forces remaining within the certification limits (40 pounds continuous, and 60 pounds maximum) at this airspeed.

ATR also conducted similar high speed taxi tests with these simulated ice shapes mounted on a Fokker F-27, a Saab 340, and an Embraer 120. They reported that these airplanes also exhibited aileron hinge moment responses similar to the ATR 72, but with varying wheel force magnitudes that were specific to each airplane. The results were qualitatively evaluated by ATR; and no numerical data were recorded.

1.16.5 Postaccident NASA Icing Research

During the course of this investigation, the Safety Board requested and received the assistance of aircraft icing specialists assigned to NASA's Lewis Research Center in Cleveland, Ohio. The NASA Lewis icing specialists provided technical guidance during the initial review of the Roselawn FDR data, meteorological data, and ATR icing certification data. They subsequently supported the Safety Board's investigation by performing icing tunnel tests on an airfoil section very similar to that of the ATR 72, by performing computer simulations of the ice accretion characteristics of the ATR 72 airfoil, and by performing computer simulations of the airflow about the ATR 72 airfoil with various ice accretions found in the icing tunnel tests.

In the icing tunnel tests, the specialists varied the icing conditions and airfoil AOAs parametrically to document general ice accretion trends in various icing conditions, including those consisting of large water droplets at near freezing temperatures.[58] The results of the tests are summarized in the Safety Board's Icing Tunnel Test, Icing Computer Simulation, and Airflow Simulation Factual Report. The tests indicate that by increasing either the mean volumetric diameter (MVD), the Liquid Water Content (LWC), or the Total Air Temperature (TAT), the aft chordwise accretion limit increased on the upper and lower surfaces of the airfoil, until such time that the amount of water or heat was too great to permit sufficient heat transfer to form ice (liquid water runs off the trailing edge of the airfoil).

The tests also found that there was an increase in the aft chordwise accretion limit that occurred between 34 and 35°F TAT, regardless of the MVD/LWC combination tested, with significant random, chordwise sliding and shedding of the ice accretions at different points along the span of the airfoil section. This sliding and shedding could result in spanwise asymmetry between left and right wings on a complete airplane (these tests were performed on a limited-span wing section). Additionally, it was found that decreasing the AOA increased the aft chordwise accretion limit on the upper surface of the airfoil and decreased the aft chordwise accretion limit on the lower surface. Conversely, increasing the AOA increased the aft chordwise accretion limit on the lower surface of the airfoil and decreased the aft chordwise accretion limit on the upper surface.

The tests also showed that ice accretions on the negative pressure side (upper surface for a typical wing in flight -- lower surface for a typical horizontal tail in flight) of the airfoil would result in airflow separation on the negative pressure side starting at the trailing edge and moving forward as the AOA increased. If a hinged control surface is located at the trailing edge of an airfoil section that is

[58]This was NASA Lewis' first research effort specifically involving water drop size distributions that are considerably larger than those specified in 14 CFR Part 25, Appendix C, and in temperatures that are near freezing. Consequently, the results of this research should be used with caution pending further research and validation.

experiencing airflow separation on the negative pressure side, the moment about the hinge of the control surface could tend to deflect the trailing edge towards the negative pressure side. The magnitude of this hinge moment is a function of the pressure gradient about the control surface and the chordwise location of the hinge line.

The NASA Lewis research further revealed that ice accretions of large supercooled water drops could extend beyond the active portion of the deice boot on the ATR 72 wing, and trailing edge airflow separations could occur at lower than normal AOAs. The tests also found that such ice accretions at near freezing temperatures could shed randomly, resulting in spanwise ice shape asymmetry.

1.16.6 ATR 72 Icing Tanker Tests

A series of flight tests were conducted by ATR at Edwards Air Force Base, California, in December 1994. The flight tests utilized an Air Force NKC-135A tanker that was flown ahead of the ATR 72, and a Learjet that was fitted with instrumentation that measured drop size, LWC and temperature. The tanker was equipped with a boom diffuser and interchangeable nozzles to produce a range of icing conditions. These tests were conducted to confirm that the ATR 72 met the certification standards specified in 14 CFR Part 25, Appendix C, and to evaluate the ATR 72 ice accretion characteristics when exposed to large, supercooled droplets at near freezing temperatures (conditions outside of the Appendix C envelope).

During the icing tanker testing, static air temperatures (SAT) at altitude were varied from minus 9.2 degrees Celsius to minus 0.4 degrees; water drop MVDs were varied between 24 and 140 microns, and LWCs were varied between 0.20 and 0.89 grams per cubic meter. The test procedure involved establishing the desired air temperature and airspeed, sampling the tanker cloud with the instrumented Learjet, and exposing the ATR 72 to the tanker cloud for the planned period of time, followed by maneuverability checks and 1 G decelerating stalls by the ATR 72. The decelerating stalls were performed to observe the control wheel force/aileron hinge moment behavior at AOAs up to stick pusher with each type of accretion.

The icing tanker test results indicate that in icing conditions representative of those specified in 14 CFR Part 25, Appendix C, the ATR 72 accretes ice within the active area of the deice boots, in both the flaps 0 and 15 configurations. These tests showed that the deice boots shed the ice effectively during normal boot cycling, with no resulting aileron hinge moment reversals occurring prior to stick pusher.

The tests in conditions that exceeded 14 CFR Part 25, Appendix C, icing conditions (freezing drizzle) showed that the ATR 72 accreted ice both within and aft of the active area of the deice boots, in both the flaps 0 and 15 configurations. The deice boots shed the ice in the active area effectively during normal boot cycling, but developed a jagged, spanwise ridge of ice near the aft edge of the boot, on the upper wing surface (8 percent chord at flaps 0, 9 percent chord at flaps 15). The aft limit of the upper surface accretion extended back to approximately 14 percent chord with decreasing ice thickness. Intentional 1 G decelerating stall maneuvers resulted in aileron hinge moment reversals that occurred at AOAs of 12 degrees for flaps 15 accretion followed by flaps 15 stall maneuver and at 7 to 11 degrees AOA for flaps 15 accretion followed by flaps 0 stall maneuver.

The tests also revealed that there were distinct, recognizable ice accretion patterns on the aft portion of the side windshield, which exceeded the 14 CFR Part 25, Appendix C, icing conditions. Also, there was very little change in ice accretion characteristics with "ice-phobic" chemicals applied.[59]

The postaccretion 1 G decelerating stall maneuvers were performed starting at approximately 175 KIAS. The icing stall protection system (SPS) AOA schedule for stick shaker and pusher at flaps 0 are 11.2 degrees and 15.3 degrees AOA, respectively. At flaps 15, the icing SPS AOA shaker/pusher schedule is 12.5 degrees and 16.4 degrees AOA, respectively. In all of the 104 through 140 micron MVD tests (outside FAR 25 Appendix C envelope) during which ice accretion occurred and the subsequent stall maneuvers were performed at flaps 0, the hinge moment reversals occurred between shaker and pusher AOA. In all of the 104 to 140 micron MVD tests (outside of the 14 CFR Part 25 Appendix C envelope) during which ice accretion occurred at flaps 15, the subsequent stall maneuver resulted in hinge moment reversals prior to or at shaker AOA, regardless

[59] Ice phobic chemicals are used to prevent the accretion of ice on the surface of a wing. The chemicals are typically dispensed in liquid form from outlets on the wing surface.

of whether the maneuver was performed at flaps 15 or 0. Control wheel forces subsequent to the aileron hinge moment reversals averaged 30 to 40 pounds, with a maximum momentary peak of 77 pounds occurring during one test.

The ice accretions documented in the NASA icing tunnel tests performed for the Safety Board were similar in some aspects to those observed in the tanker tests. The FAA, NASA and ATR concluded that the differences in these accretions were significant enough to warrant further development of the icing tunnel and icing computer simulation capability with respect to icing conditions outside of the 14 CFR Part 25 Appendix C envelope.

ATR subsequently developed artificial ice shapes based on the findings of the Edwards AFB tanker tests. Flight tests at flaps 0 with the "flaps 15" artificial ice shapes resulted in airplane behavior consistent with the autopilot disconnect, uncommanded aileron deflection, and initial roll excursion identified in the data from flight 4184. ATR's flight tests with these artificial shapes resulted in the following ATR conclusions:

- control wheel forces subsequent to an aileron hinge moment reversal did not vary significantly with airspeed;

- an ice shape height of one-half inch or more was required to induce a premature aileron hinge moment reversal. Increasing the ice shape to a height more than one-half inch only slightly increased the severity of the aileron hinge moment reversal;

- sharp edges on the ice shapes reduced the AOA at which the aileron hinge moment reversal occurred, and increased the resulting control wheel forces;

- aileron hinge moment reversals induced by full span ice shapes were not significantly more severe than those resulting from partial span ice shapes;

- the most severe aileron hinge moment reversals were encountered with "flaps 15" ice shapes flown in a flaps 0 configuration;

- moving the ice shape location from 5 percent to 13 percent chordwise reduced the magnitude of the control wheel forces resulting from the aileron hinge moment reversals.

During both series of icing tanker tests at Edwards AFB, it was determined that two generally accepted methods of calculating MVD and LWC provided significantly different results. One method was developed by Particle Measuring Systems, the manufacturer of the instruments used to measure the icing conditions, and the other method was developed by NCAR. It was found that when processing any given set of raw icing data collected behind the icing tanker, the two methods provided MVD and LWC results that differed by as much as a factor of 2. These results are attributed to the different mathematical equations used by the two methods.

Following these flight tests, ATR designed extended chord deice boots for the area of the wing outboard of the engines, which included the area in front of the ailerons. ATR conducted a second series of icing tanker flight tests at Edwards AFB with the new deice boots. In simulated icing conditions, consistent with those estimated to have existed in the Roselawn area at the time of the accident, no ice accreted aft of the new extended chord deice boots. (See Appendix D for photographs from both Edwards AFB tanker tests.)

In early 1995, ATR also published the ATR Icing Conditions Procedures brochure. The brochure described the icing tanker tests conducted at Edwards AFB and summarized its findings. In addition, the brochure provided recommended procedures for flight in freezing rain or drizzle. These procedures provided for the identification of visual cues, established recommended airplane configurations, and defined actions related to lateral trim and autopilot functions.

1.16.7 Historical Aspects of Aircraft Icing Research and Aircraft Icing Certification Requirements

The existing FAA/JAA aircraft icing certification requirements are based on envelopes defined by the minimum and maximum values of mean effective water drop size, liquid water content, and air temperature. The boundaries of the 14 CFR Part 25, Appendix C icing envelopes are based upon recommended values cited in the National Advisory Committee for Aeronautics (NACA) Technical Note (TN) 1855 (March 1949), and are statistical boundaries derived from hundreds of hours of in-flight icing data collected by NACA in the United States from the late 1940s to the early 1950s. NACA TN 2738 (July 1952) shows that these data were collected and categorized by geographical location within the United States, namely, the eastern U.S. region, the plateau region, and the pacific coast region. The data were further categorized by cloud type during the icing encounter (layer or cumulus) and probability of encounter.

NACA TN 2738 shows that the drop sizes and liquid water contents of the pacific coast region were considerably greater than those of the plateau or eastern U.S regions. For example, the maximum mean effective drop size shown for cumulus clouds at a probability of 0.001[60] was determined to be over 80 microns for the pacific coast region, and about 57 microns for the plateau region, whereas there was no cumulus recorded data for the eastern U.S. region. The respective regional values for layer clouds are: 78 microns, 53 microns, and 46 microns.

The Safety Board compared the existing 14 CFR Part 25 1419, Appendix C icing envelopes with the NACA TN 2738 data and found that the Appendix C Maximum Continuous icing envelope coincides approximately with the eastern U.S. layer cloud icing data having a probability of 0.001, and the Appendix C Maximum Intermittent icing envelope coincides approximately with the pacific coast cumulus cloud icing data having a probability of 0.001. The NACA data indicate that the pacific coast layer cloud maximum drop size (78 microns) was 70 percent larger than that of the eastern U.S. layer cloud (46 microns), and the associated liquid water contents in the pacific coast cloud data were 3 times higher than that of the eastern U.S. cloud data of 40 microns. These larger pacific coast layer cloud drops at higher liquid water contents are not represented in the NACA TN 1855 or Appendix C envelopes.

NACA TN 1855 provides a recommended envelope for freezing rain icing conditions, citing a temperature range of 25 to 32 degrees F, a liquid water content of 0.15 grams per cubic meter, a drop size of 1,000 microns, and a horizontal extent of 100 miles. The authors of the NACA TN 1855 wrote, in regards to freezing rain, "observational data are not available for this class, since, in the only case in which data have been taken, the water content of the rain was

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[60]The maximum drop size in the NACA TN 2738 statistical data occurs at an LWC of 0 and at a temperature of 32 degrees Fahrenheit.

too low to measure in the presence of the clouds through which it was falling. For this reason, the values for the proposed conditions were calculated....based on an assumed rate of rainfall of 0.10 inch per hour, with drops 1 millimeter in diameter." The NACA TN 1855 concludes:

> It is not intended that each icing condition tabulation should be specified as a design requirement for all components of the airplane, but rather that each condition be considered as a possible meteorological situation to be encountered and, therefore, worthy of some attention. For example, the designer, having a certain component of the airplane in mind, should review the listing to determine which icing condition would probably affect that component and, therefore, should be included in the design calculation. For his part, the operator should consider the listing as indicative of the wide variations of conditions through which his aircraft might be called upon to operate.

The existing FAA icing advisory material, including AC 20-72, and the recently revised FAA Aircraft Icing Handbook, do not contain any design or certification guidance concerning freezing drizzle or freezing rain. The predecessor to the FAA's Aircraft Icing Handbook, the Engineering Summary of Airframe Icing Technical Data (ADS-4, issued December 1963), discusses designing for exposure to freezing rain in several instances, and concludes, "flight through freezing rain can have adverse effects on aircraft performance....In any aircraft design, the effect of freezing rain should be considered in addition to the current design procedures for normal (small droplet) icing conditions."

In 1981, the Safety Board published the finding of its safety study entitled Aircraft Icing Avoidance and Protection.[61] Based on the findings of the study, the Safety Board recommended to the FAA, among other things, that it revise the 14 CFR Part 25, Appendix C, icing certification envelopes to include freezing rain. Further, in 1983, Dr. Richard Jeck (then of the Naval Research Lab; with the FAA since 1990) published a report[62] for the FAA in which he noted that although icing research and commercial aircraft continue to encounter icing conditions outside of the Appendix C envelope (such as freezing drizzle and

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[61] National Transportation Safety Board, Safety Report, NTSB-SR-81-1, September 9, 1981.

[62] A New Database of Supercooled Cloud Variables for Altitudes Up to 10,000 Feet AGL and the Implications for Low Altitude Aircraft Icing, Dr. Richard Jeck, August 1983, DOT/FAA/CT-83/21 (NRL Report 8738).

freezing rain), "...Data on freezing rain or freezing drizzle are essentially absent from the Icing Data Base at this writing...." Dr. Jeck's 1983 report also contained the following findings that are of significance to the accident flight 4184:

> In addition to the engineering concerns, there have been calls for improved icing forecasts and for redefining the icing severity classifications in terms of quantitative LWC values instead of the relative and ambiguous, "trace," "moderate," etc, that is now in use....
>
> In 1952, after the NACA researchers became aware of the seriousness of the runoff errors for measurements at temperatures just below 0 degrees C, they must have reexamined their data and concluded that not more than about 5 percent of the reported measurements would be affected....
>
> [NACA researchers recalled] that severe icing was observed on the windshield of their C-46 research aircraft with only 0.15 grams per cubic meter of LWC when the MVD was an unusually large 50 microns, which apparently led the author [NACA] to stress the potential importance of the larger MVD's because of the greater collection efficiencies associated with them....
>
> The accreted rime [from rain] usually breaks away in 1 to 3-inch wide pieces at random positions along the wing. The instances noted by the author [Politovich and Sands] all occurred at ambient temperatures of not more than 2 or 3 degrees Celsius below freezing so that softening of the ice may have been expected anyway. In addition, the efficiency of this impact-assisted deicing is probably a function of speed....

1.17 Organizational and Management Information

1.17.1 Simmons Airlines

Simmons Airlines originated as a small commuter airline based in Marquette, Michigan, in 1979. The airline provided scheduled commuter service with 5-passenger Piper Aerostars and eventually expanded into larger aircraft: Piper Navajos, Embraer Bandeirantes, and the Shorts. Simmons Airlines joined the

American Eagle system as an independent airline on April 16, 1986, and provided principal air transportation from smaller communities to the hubs of American Airlines.

On August 8, 1988, Simmons Airlines was purchased by AMR Eagle, a subsidiary of AMR Corporation, the parent company of American Airlines. In December 1992, AMR acquired Metro Airlines and merged it with Simmons. Simmons Airlines serves 30 cities from its Chicago hub and 31 cities from its Dallas/Ft. Worth hub. At the time of the accident, Simmons employed approximately 3,300 employees, operated a fleet of 79 aircraft, including 32 Saab 340s, 25 ATR 42s and 22 ATR 72s, and dispatched approximately 565 flights per day.

1.17.2 AMR Eagle Organization

The senior management of Simmons Airlines is comprised of the President (who reports to the President of AMR Eagle); a Vice President of Flight Operations; a Vice President of Maintenance and Engineering; a Vice President of Finance/Administration; a Vice President of Airline Services; and a Director of Personnel. The flight operations management structure consists of the Vice President of Flight Operations who oversees the following:

Director of Flight Operations
Manager of Dispatch
MQT Technical Publications
Chicago (ORD) Chief Pilot
Dallas/Ft. Worth (DFW) Chief Pilot
ATR Fleet Manager
Saab Fleet Manager
Manager of Crew Scheduling

The management structure of AMR Eagle consists of the Chairman, who reports to the President of AMR Corporation; a President, to whom the four individual carriers report; a Vice President; Director of Flight Operations; Director of Maintenance and Engineering; a Manager of Crew Planning; a Senior Systems Analyst and the Director of the American Eagle System Operations Control Center (AESOCC).

AMR Eagle owns three other airlines: Executive Airlines, headquartered in San Juan, Puerto Rico; Wings West Airlines, headquartered in San Luis Obispo, California; and Flagship Airlines, headquartered in Nashville, Tennessee. These airlines conduct operations under the auspices of AMR Eagle but maintain their individual FAA operating certificate identities. They operate in accordance with their respective FAA operating specifications, and the compliance of each is overseen by an FAA Principal Operations Inspector (POI).

While AMR Eagle does not hold an FAA air carrier operating certificate, its corporate organization and responsibilities are similar to those of an operating air carrier. It also performs the following functions for each of the four carriers:

Pilot Recruitment and Hiring
Pilot Training and Checking
Crew Planning and Aircraft Acquisition
Airline Planning and Marketing

In addition, AMR Eagle has centralized the crew scheduling, flight dispatch, and pilot training of each of the carriers by collocating them at the AMR facility in Ft. Worth, Texas. However, the dispatch and crew scheduling remain a function of individual carriers, and pilot training is conducted by employees from each carrier. AMR Eagle also coordinates the route planning, development of aircraft operating procedures and the related manuals, and allocation of aircraft among the individual carriers. The flight operations, in-flight services and recordkeeping are the responsibility of the individual carrier.

At the Safety Board's public hearing, the Vice President stated that the AMR Eagle organization serves as a coordinator between the four Eagle carriers and that the AMR Eagle staff interacts with the staff of the carriers to facilitate a joint decision to "standardize those decisions as much we can." He also stated that AMR Eagle does not exercise operational control over the individual carriers and that the "objective of AMR Eagle is to ensure the consistency of operations and encourage the airlines to operate at the highest level of safety possible." Additionally, the Vice President stated that American Eagle is a "generic name...[with] no organizational entity...[and] it [AMR Eagle] exists for several purposes. Number one, it exists to provide technical support to those airlines that operate as American Eagle. It also exists to provide some oversight to ensure that it complies with the Federal Aviation Regulations and with the company policies and procedures." AMR Eagle, as part of its technical support function, gathers both the aircraft and crewmember data from the airline, the manufacturer and the FAA, and consolidates and publishes the pertinent operating manuals and documents.

1.17.3 FAA Oversight of Simmons Airlines/AMR Eagle

The FAA certificate holding office for Simmons Airlines was transferred from the FAA's Grand Rapids, Michigan, Flight Standards District Office (FSDO) to the DFW Certificate Management Office (CMO) in October of 1992. The transfer of the certificate occurred 2 days after the Grand Rapids FSDO rejected Simmons' ground deicing program.[63]

The American Eagle Training Center (AETC) in Dallas is overseen by the FAA Program Manager at the DFW CMO. The FAA "Focal Point" coordinator in Dallas is the repository for information flowing between AMR Eagle, the four AMR Eagle carriers, and the FAA. The FAA coordinator's role is to assist in the facilitation of "standardization" between the four AMR Eagle carriers and their respective FAA POIs. The POI for Simmons Airlines characterized the relationship between AMR Eagle and the individual carriers as one in which AMR Eagle tried to implement changes without the carriers' knowledge or understanding. He also said that the "Focal Point" coordinator routinely disseminated information to the individual carriers to determine whether they had a complete understanding of the proposed changes.

1.17.4 FAA Partnership in Safety Program

The Partnership in Safety Program was introduced to a portion of the aviation industry by the President of AMR Eagle in June 1994, during the Safety Board's Public Forum on Commuter Airline Safety. The following is an excerpt from the AMR presentation at the forum:

> AMR Eagle makes extensive use of comprehensive internal audit programs using company evaluators to conduct ongoing inspections to ensure the standards of American Eagle are maintained. This

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[63]The FAA's certificate holding offices for the other AMR Eagle carriers (with individual oversight responsibility) are located in San Juan, Puerto Rico (Executive Airlines); San Jose, California (SJC) (Wings West Airlines); and Nashville, Tennessee (BNA) (Flagship Airlines).

> commitment to internal evaluation programs is made in concert with the FAA Partnership in Safety Program -- a program that is designed to achieve the highest possible level of carrier and FAA communication and coordination on issues relating to daily operations, aircraft manufacturer information, and internal FAA guidance. This program serves both the FAA and the carrier by insuring a high degree of regulatory compliance, and at the same time insuring the carrier's ability to use its assets effectively in its operation.

On February 8, 1995, at the request of the Safety Board, the FAA provided documentation describing of the Partnership in Safety Program. The written material outlined general program structure that could be used to implement an internal safety program; however, there were no specific goals or expectations cited to assess the success or failure of the program. The Safety Board requested more specific information from the FAA regarding the Partnership in Safety Program, and, on May 12, 1995, the Safety Board received a response that "...no written documentation on this program currently exists."

FAA AC-120-59 provides guidance to 14 CFR Part 121 air carriers for the establishment and conduct of an internal audit program. The POI for Simmons Airlines testified that Simmons Airlines did not have a formal internal evaluation program at the time of the accident, but that AMR Eagle had contracted with the American Airlines Safety department to conduct annual safety audits. He said that the audits that he was familiar with did not reveal any "irregularities." The FAA Program Manager for the AMR Eagle Training Center testified that he was familiar with the safety audits that were conducted and while the "training center does not have a dedicated internal evaluation program that you could identify with an advisory circular," an internal evaluation is performed as part of the carriers' internal evaluation program.

1.17.5 Simmons Airlines/AMR Eagle Pilot Training

1.17.5.1 General Training Information

Simmons Airlines and the other AMR Eagle carriers conduct ATR pilot ground and simulator training at the AMR Eagle Training Center in Ft. Worth, Texas, and ATR 42/72 simulator training in Houston, Texas, and Wilmington, Delaware. The Ft. Worth training center is staffed by a program manager, and instructors from Simmons Airlines and the other three Eagle carriers.

All training at the Ft. Worth Training Center is conducted in accordance with the FAA "Approved Training Manual" (ATM). Any changes to the ATM or the training curriculum must be accomplished through a process that includes approval from the management of each of the four AMR Eagle carriers operating that equipment, their respective POIs and AMR Eagle management.

The instructor who provided the captain and first officer of flight 4184 with ground instruction during their training session prior to the accident discussed the dissemination of information. He stated that operating bulletins from the manufacturer [ATR] were provided to AMR Eagle but not directly to the training center instructors, and that "typically" the information from the bulletins was passed down by "word of mouth." The manufacturer bulletins that are received by AMR Eagle are evaluated and approved by the individual carriers and the FAA. Once a bulletin change has been approved, it is incorporated into the airplane operations manual, disseminated to all the AMR Eagle airlines and incorporated into the training curriculum.

The instructor also stated that ground school instructors were not included on the company's computer "E-mail" system and that information from the company in Dallas was disseminated through their supervisors. Also, the instructor stated that one of the other ground instructors, who is also a line pilot, often provided the remaining instructors with aircraft operations messages that had been distributed to the line pilots by the company. The Safety Board found that the special holding procedure developed after the accident involving flight 4184 was initially disseminated to flightcrews with the flight releases for the AMR Eagle ATR flights. This procedure was also conveyed to all AMR Eagle pilots and those training center instructors responsible for teaching flight-related procedures via the company's "E-mail" system. All AMR Eagle pilots and training center instructors are required to read the E-mail promulgated by the company.

According to Simmons Airlines training personnel, both the initial and recurrent pilot training programs include a review of prior incidents and accidents involving the ATR 42 and 72. Simmons had not provided guidance to the instructors about the previous ATR icing incidents, and ATR did not provide specific findings about all of the icing incidents to AMR Eagle or its airlines.

However, ATR had provided some information[64] via ATR-generated "Operator Information Messages" (OIM). In addition, the Safety Board interviewed several flightcrew members, some of whom stated that they had not received any information about the previous ATR icing incidents during their respective ground school sessions.

1.17.5.2 AMR Eagle Flight Training

The ATR simulators utilized by American Eagle are classified "Level C".[65] Currently, there are no simulators capable of projecting specific exterior visual cues for ice accretions; thus, the pilot's simulator training relies on the Anti-ice Advisory System (AAS) for icing identification. According to the American Eagle ATR 42 and 72 Operating Manual, Volume II, the Anti-ice Advisory System (AAS) is considered a secondary means for ice detection, while crew "vigilance" and visual detection is primary. Flightcrew members are taught that there are several primary visual cues that can be used to confirm ice accretions on the airplane. They include the formation of ice on the propeller spinners and/or the ice evidence probe located near the left side window.

The training center check airman, who had performed the accident captain's line check, stated that he had observed other pilots operate the ATR in icing conditions. He stated that the pilots he observed typically activated the level three ice protection when icing was detected by the AAS, but that he had also seen pilots activate the system when ice was visually observed on the aircraft but not yet detected by the AAS.

Several pilots were interviewed subsequent to the accident regarding their understanding of airframe ice detection. One pilot stated that the captains with whom he was familiar "usually" waited until they received the AAS alert before they activated the level three ice protection. Another pilot said that the AAS "rarely came on" before the crew visually detected the icing conditions.

A review of the AMR ATR pilot training curriculum, as well as other related information received from AMR Eagle, revealed that simulator sessions on operations in icing conditions included information about the identification of icing

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[64] See section 1.16.2, Previous ATR 42 and 72 Incidents/Accidents, for further information.

[65] Level C simulators incorporate full motion with full visual graphics.

conditions, both visually and with the automated systems on the airplane, and the operation of the anti-ice/deicing systems. AMR Eagle stated, in part, the following regarding the simulator training sessions:

> …at the time of the accident, every other training flight in the simulator [was] conducted in an icing environment condition….A demonstration of stalls to stick pusher activation is made when these maneuvers are first introduced to ensure the crewmember has good operational knowledge of pusher operation and appropriate recovery procedures….Crewmembers are taught to initiate recovery at the first indication of any of the following: stick shaker, stall "cricket" (aural warning), airframe buffet or stick pusher….If the simulation is set for icing conditions, a crewmember is not permitted to perform stall maneuvers without the appropriate [ice protection] equipment being turned on. Permitting training in an incorrect configuration would be classified as negative training…we [AMR Eagle] were never informed by ATR of any simulator icing package which would provide special or unique handling characteristics during icing simulations, or which might be cause for modifying any of the industry standard training procedures….In our extensive experience in using these simulators, there have never been indications or reports of roll off characteristics when the anti-ice/deice equipment is being operated in accordance with prescribed procedures.

1.17.6 Flight and Airplane Operating Manual

The manuals that were issued to Simmons Airlines ATR pilots, and that were in effect at the time of the accident, include the American Eagle/Simmons Airlines, Inc., ATR 42/72 Airplane Operating Manual Volumes I and II (AOM), the Flight Manual - Part 1, (FM), and Jeppesen Airway Manuals. The American Eagle/Simmons Airlines, Inc., ATR-42/72 Operating Manual (AOM) Volume I and the ATR FAA-approved Airplane Flight Manual (AFM) are required to be onboard the airplane.

Section 4 of the American Eagle Flight Manual - Part 1, presents, among other things, the company's policy on flight crewmembers leaving their stations during a flight. This section also quotes a portion of 14 CFR §121.542, which describes the nonessential duties of a flight crewmember during critical phases of flight:

> (a) No certificate holder shall require, nor may any flightcrew member perform, any duties during a critical phase of flight except those duties required for the safe operation of the aircraft. Duties such as company required calls made for such non-safety related purposes as ordering galley supplies and confirming passenger connections...are not required for the safe operation of the aircraft;
>
> (b) No flight crewmember may engage in, nor may any pilot in command permit, any activity during a critical phase of flight which could distract any flight crewmember from the performance of his or her duties or which could interfere in any way with the proper conduct of those duties. Activities such as eating meals, engaging in nonessential conversations within the cockpit and nonessential communications between the cabin and cockpit crew, and reading publications not related to the proper conduct of the flight are not required for the safe operation of the aircraft;
>
> (c) For the purpose of this section, critical phase of flight includes all ground operations involving taxi, takeoff and landing, and all other flight operations conducted below 10,000 feet, except cruise flight. A critical phase of flight may also include any other phase of a particular flight as deemed necessary by the captain.

According to testimony provided at the public hearing by both AMR Eagle and FAA personnel, since flight 4184 was holding at 10,000 feet, this phase of flight is not considered "critical," and the sterile cockpit rule was not in effect.

The guidance provided by AMR Eagle/Simmons Airlines to their pilots regarding flight operations in icing conditions is described in the American Eagle Flight Manual - Part 1, Section 9, Weather and Section 6, En-route. The company requires their pilots to provide PIREPs "…when encountering inflight icing conditions," and use specific terminology (extracted from the FAA's AIM) when providing icing conditions PIREPs to either ATC or an FSS. The PIREPs provided by company pilots are required to be made "as soon as practicable" and expressed in terms of "trace, light, moderate, and severe, rime and clear" with the type of aircraft in which these conditions were encountered also identified.

A review of the air traffic control conversations with the flightcrew of flight 4184 revealed that neither crewmember provided a PIREP about the icing conditions they were encountering during the holding pattern circuits.

Aviation Weather AC 00.6A provides information on conditions favorable to the formation of structural icing. It states, "The condition most favorable for very hazardous icing is the presence of many large, supercooled water drops. Conversely, an equal or lesser number of smaller droplets favors a slower rate of icing."

The American Eagle ATR 42/72 Airplane Operating Manual, Volume 1, Limitations Section, in effect at the time of the accident, provided pilots with the following information regarding atmospheric icing conditions:

Atmospheric Icing Conditions Exist When: OAT [Outside Air Temperature] on the ground and for takeoff is at or below 5 degrees C or when the TAT [Total Air Temperature] in flight is at or below 7^{o} C and visible moisture in any form is present (such as clouds, fog, with visibility of less than one mile, rain, snow, sleet and ice crystals).

Operations In Icing Conditions: For Operations in atmospheric icing conditions:

Np [Propeller speed] below 86 % is *prohibited*

- Horns, propellers, side windows and engine anti-icing must be selected ON.

- Eng[ine] start rotary selector must be placed to CONT[inuous] RELIGHT.

- Airframe deicing must be selected ON at first indication of ice accretion.

The American Eagle ATR 42/72 Airplane Operating Manual Vol. I, "Conditionals" section, pages 41 and 42, outlined the use of the anti-ice/deice systems. The manual states that Level I ice protection must be selected for all flight operations. Also, for all takeoffs and flight operations in atmospheric icing conditions, Level II protection must be selected in addition to Level I, and whenever ice is building on the airframe, Level III protection must also be selected. The American Eagle ATR 42/72 AOM, Volume II, cautions pilots that "some types of ice accumulation might not be detected by the Anti-ice Advisory System (AAS)."

Guidance provided to pilots in the American Eagle ATR 42/72 Airplane Operating Manual states that it is not necessary to have ice buildup on the leading edges of the wing and stabilizer surfaces prior to activation of the Level III ice protection system. It states that the Level III system, "must be selected "ON" as soon as, and as long as, ice accretion develops on the airframe."

The American Eagle Flight Manual, Part 1, Section 3, Dispatch, Icing Dispatch Policy and Procedures, pages 25 and 26, discussed the company policy regarding dispatch of aircraft into icing conditions. The policy stated, in part:

B. No aircraft shall be dispatched, continue to operate en route or land when in the opinion of the captain or dispatcher icing conditions are expected that might adversely affect safety.

1. When freezing precipitation is reported at the time of departure at the departure airport, and the surface temperature is at or below freezing, no aircraft shall be dispatched except in strict compliance with the approved ground deicing program, including compliance with the appropriate hold-over restriction.

2. When freezing rain is reported or anticipated at the estimated time of arrival at the destination, or alternate airport(s), the aircraft shall be dispatched and operated so as to avoid flight into freezing rain conditions.

C. In making the decision to operate in freezing precipitation, special consideration should be given to:

- surface temperature
- temperature aloft and depth of any temperature inversion
- intensity of precipitation
- types of de-ice/anti-ice fluids available
- anticipated turn around and taxi times
- SIGMET information regarding in-flight icing
- PIREPs indicating the presence of in-flight icing

D. If current weather reports and briefing information indicate that forecast icing conditions that would otherwise prohibit the flight will not be encountered, the flight may be dispatched.

On January 10, 1994, AMR Eagle issued an information bulletin that addressed the company policy regarding release or departure of aircraft during icing conditions. The bulletin stated, in part, the following:

> The AFM [FAA-Approved ATR Flight Manual] will not specify '...light or moderate icing only...', and furthermore, there are generally no AFM restrictions prohibiting flight in a certain type of ice (i.e. rime ice, clear ice, freezing rain, etc.). The only existing exception is the ATR 42/72 AFM's which state that flight in freezing rain...should be avoided.... (emphasis added)

The January 10 bulletin highlighted information contained in Part 1 of the AMR Eagle Flight Manual, which stated, in part, "...strict compliance with the policies, procedures, and regulations as covered in this manual is required." The aforementioned bulletin was not required by AMR Eagle to be incorporated into the flight manual and "...could be retained or discarded at the pilot's option." This information was not added to the "limitations sections" of either the ATR 42 or ATR 72 AFMs. There was a statement, in the Normal Procedures/Flight Conditions section of the ATR 42 AFM, section 3-02, page 1, dated March 1992, "Operation in freezing rain must be avoided."

A review of the Normal Procedures/Flight Conditions section of the ATR 72 AFM, and the ATR Flightcrew Operating Manuals (FCOM) for both the ATR 42 and ATR 72 aircraft revealed that neither publication contained the statement, "Operation in freezing rain must be avoided." Additionally, these manuals did not contain any information prohibiting flight in freezing rain, or any limitation when operating in such conditions. At the Safety Board's public hearing, the ATR Vice President, Flight Operations for North America, testified that the omission of this information from the manuals was "not intentional."

As mentioned earlier, ATR published a brochure in 1992 entitled, All Weather Operations, which contained information regarding the operation of the ATR airplanes in various weather conditions that included icing. In this brochure, ATR stated on page 24, "...flight in freezing rain should be avoided where practical." The brochure also provided information to pilots on how to recognize freezing drizzle and freezing rain conditions and stated, "...as soon as possible, leave freezing rain conditions. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course." The brochure was provided by ATR as general information and was not a required addition, substitution, or revision to any of the FAA-approved ATR flight or operating manuals. ATR distributed the All Weather Operations brochure to all ATR operators, including Simmons Airlines, and also attempted to send a copy to all ATR pilots directly. Simmons Airlines/AMR Eagle did not distribute the brochure to its pilots because some of the information was contrary to Federal Aviation Regulations and some of the operational information was more permissive than the approved Aircraft Operating Manual (AOM). Also, Simmons Airlines/AMR Eagle indicated that while it did use some of the information from the brochure to enhance the AOM, the ATR All Weather Operations brochure consolidated information that already existed in the various ATR and Simmons Airlines/AMR Eagle flight manuals, specifically in the "Conditional" section of the Aircraft Operating Manual (AOM).

The American Eagle Flight Manual, Part 1, stated that the dispatch of airplanes "shall be" conducted so as to avoid flight into freezing rain conditions. Neither the Flight Manual, Part 1, nor the AOM state that flight in freezing rain "should" or "must" be avoided, as stated in the ATR 42 AFM.

Also, the American Eagle ATR 42/72 AOM, "Conditionals" section, contains guidance for pilots regarding winter operations. The AOM states, in part:

> **Cruise -** Crew vigilance in observing formation of ice is the primary means of determining the aircraft has entered ice accretion conditions. Visual indication can usually be detected on such surfaces as windshield wipers, prop spinners [model 42], ice evidence probe [model 72] and wing leading edges and engine inlets.
>
> In conditions of potential clear icing, periodic cycling of the airframe boots will cause any clear ice to crack making its visual detection much easier.
>
> In extended or severe icing conditions, a noticeable decrease in the level of performance or significant vibrations may occur due to propeller residual icing....

Further review of the AMR Eagle and Simmons Airlines guidance material available to flightcrews revealed that there are no definitions or explanations for the terms "extended" or "indeterminate," as it equates to time. The FAA AC-00-45C, entitled <u>Aviation Weather Services</u> does not include the terms "extended" or "indeterminate," but it does state that a "prolonged" period of time in icing conditions is considered to be "over one hour."

The Manager of Flight Standards for the American Eagle Training Center testified at the Safety Board's public hearing that the company does not have a policy that states a specific period of time in which an airplane can remain in icing conditions before an alternate course of action is to be taken by the flightcrew. In addition, he stated that it is "...a crew decision based on the environment that he may be in at the time. He may be in between layers but still in the icing environment. He may be just accumulating light rime ice. The most important thing to me as a pilot after I've been in a hold for some time would be my fuel supply."

On January 23, 1989, Simmons Airlines distributed a memorandum to its pilots entitled, “Loss of Aircraft Stability,” which summarized the December 22, 1988, Simmons ATR 42 incident at Mosinee, Wisconsin. The memorandum provided a summation of the Aerospatiale/ATR OIM concerning the Mosinee incident, as well as a copy of the January 6, 1989, Simmons Airlines memorandum entitled, “Flight Into Icing Conditions.” The January 6 memorandum stated, in part:

> …if icing or adverse weather is experienced, make a PIREP so your fellow pilot may benefit from your experience…This is important if the weather is better or worse than forecast…The temperature range favorable for ice formation is generally 0 to -15 degrees Celsius. However, supercooled water droplets in liquid form in temperatures above freezing, can freeze on impact with the aircraft. Exercise caution when operating your aircraft near the freezing level in visible moisture. Freezing rain may also form ice on an aircraft that is operating near the freezing level (+\- a few degrees above and below the OAT 0 degrees Celsius). This phenomena is usually associated with a temperature inversion. If freezing rain is encountered, you should exit the condition immediately. This diversion should consist of a turn toward better conditions and/or a climb to warmer altitude. Freezing rain and clear ice can be very difficult to recognize on an aircraft, therefore it is strongly recommended when operating in conditions favorable to this type of icing that an extra vigilance be maintained. This should include periodic cycling of the wing boots to aide in the detection of ice…The weather radar may also be useful when operating in visible moisture, near the freezing level. The use of weather radar may help identify areas of greater precipitation. An aircraft may be dispatched into forecast freezing rain. However, our aircraft are not to be operated in known freezing rain or severe ice….

On November 15, 1991, the Director of Operations (DO) for Simmons Airlines distributed a memorandum to the company pilots entitled, Flight Operations in Freezing Rain. The memorandum provided guidance to the pilots regarding the operation of the ATR aircraft in freezing rain and freezing drizzle conditions. The memo stated in part:

> A) No aircraft shall dispatch through known or probable icing conditions unless the requirements of the Minimum Equipment Manual are met....
>
> B) Intentionally Left Blank.
>
> C) It is emphasized that aircraft ice protection systems are designed to cope with the supercooled cloud environment

> (not freezing rain). Large droplets (1,300 microns, large rain droplets) of freezing rain impact much larger areas of the aircraft components and will in time exceed the capability of most ice protection equipment. Therefore, flight in freezing rain should be avoided where practical. Simmons aircraft are certified for flight into freezing drizzle and light freezing rain as long as the aircraft meets the requirements of paragraph A above.

The Simmons DO testified that the memorandum had been rescinded because it was in conflict with the approved AFM. According to Simmons officials, the rescinding documentation was electronically distributed (via computer E-mail) and that a copy of the document (requested by the Safety Board at the public hearing) cannot be located.

The Simmons DO also testified about several information bulletins highlighting practices or procedures contained in Part 1 of the American Eagle Flight Manual. One specific bulletin stated in part, "...If planned routing to the destination or alternate will allow the aircraft to avoid areas of freezing rain during the approach and landing, note that light freezing rain shall be given the same consideration. However, freezing drizzle does not require the same restrictions." The DO stated that it was his understanding, based on the guidance "...per this bulletin here, it indicates that you would be allowed to fly in freezing drizzle...."

The American Eagle Flight Manual - Part 1, Chapter 6, En-route, page 8, describes the use of the anti-icing/deicing system. The manual states, in part:

> Flight crews and dispatchers shall recognize anti-ice/deicing equipment as an aid in descending or ascending through and during <u>emergency flight</u> in severe icing conditions. Operations requiring anti-ice/deicing use shall be based on the consideration that such equipment will permit <u>extended</u> operations only in light ice. (emphasis added)

The Safety Board also reviewed the AMR Eagle guidance and procedures for pilots when holding. According to the Flight Manual - Part 1, Section 8, Communications:

> Pilots shall, except in an emergency, and then when possible, comply with ATC clearances and instructions. This does not preclude a pilot from questioning any clearance or instruction-on the contrary, the company expects its pilots, in the fulfillment of their responsibilities, to question any clearance or instruction received that in their opinion is unreasonable or not in compliance with good operating procedure...

The Flight Manual - Part 1, Chapter 6, En-route, states that the maximum holding speed for a turboprop is 175 KIAS. The manual encourages the pilot to request a deviation from ATC if a higher speed is required. The AMR Eagle ATR 42/72 Operating Manual, Volume 3, states that the airspeeds depicted in the holding charts are predicated on the aircraft in a "clean"[66] configuration and a holding speed of V_MHBO (minimum control speed, high bank mode, zero flap configuration) in icing conditions.

A newly trained Simmons first officer interviewed by the Safety Board said that if the speed of the airplane was above V_MHBO upon entering the holding, he was trained to extend the flaps to slow the airplane. Another first officer estimated that before the accident, 65 percent of the captains with whom he was familiar typically extended flaps while holding in clear air and 100 percent of the captains extended the flaps while holding in icing conditions. A line/proficiency check airman stated that the use of flaps in holding is not prohibited and that some pilots use flaps because it "makes the aircraft more stable and drops the nose."

In the December 1993, issue of the Simmons Flight Operations News Letter, the section entitled “Aircraft Ice” states, in part:

> …Anytime ice accumulates on the aircraft during flight it must be treated seriously. Not only does the performance deteriorate, but any encounter with severe ice - including freezing rain - for a prolonged period of time may cause control problems beyond that of the intended design. When it is possible stay out of icing conditions. Delaying a descent into a cloud layer or requesting an alternate altitude or route to stay clear of known ice will decrease the amount

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[66] "Clean" refers to the aircraft being in a minimum drag configuration, e.g., landing gear in the up position and the flaps fully retracted.

> of total ice build-up and any potential problem related to ice accumulation….

1.17.7 Unusual Attitude and Advanced Maneuvers Training

The FAA defines an "unusual attitude" as "...any airplane attitude not normally required for instrument flight." According to the Instrument Flying Handbook published by the Department of Transportation and the FAA, an unusual attitude may result from:

> ...a number of conditions, such as turbulence, disorientation, instrument failure, confusion, or preoccupation with cockpit duties....Since unusual attitudes are not intentional maneuvers during instrument flight...they are often unexpected, and the reaction of an inexperienced or inadequately trained pilot to expect abnormal flight attitudes is usually instinctive rather than intelligent and deliberate....

A review of the AMR Eagle training syllabus that was in effect prior to the accident for both the ground and simulator training programs revealed that there were no formal "advanced maneuvers" or "unusual attitude" training sessions being conducted. Also, there were no company documents available to indicate whether any AMR Eagle ATR pilots had been shown an unusual aircraft attitude on the EADI [electronic attitude display indicator]. At the time of the accident, there were no FAA requirements for air carriers operating under 14 CFR Part 121 to conduct training involving the recovery from an unusual attitude or the performance of advanced maneuvers. Moreover, there were no data or algorithms to support roll anomalies in the ATR 42/72 simulators. Also, with respect to flight 4184, the chief test pilot for ATR testified that the type of roll anomaly the flightcrew experienced would not have been recoverable by the average line pilot.

The FDR data from flight 4184 revealed that primarily nose-up elevator inputs (never exceeding 8 degrees) were made throughout the roll excursions, including those periods when the airplane was in an inverted or nearly inverted attitude. The FDR data also revealed that left rudder inputs were made throughout the upset; however, because the airspeed was in excess of 185 KIAS, the travel limiter unit (TLU) limited the rudder deflection, and the rudder travel did not exceed 2.3 degrees.

1.18 Additional Information

1.18.1 Air Traffic Control

1.18.1.1 Chicago Area Airspace

In 1994, Chicago's O'Hare International Airport was classified as the busiest airport in the United States, with 882,000 flights. The airspace extending beyond a 40-mile radius of O'Hare is controlled by the Chicago Air Route Traffic Control Center (ARTCC). The airspace within that 40-mile radius is controlled by the Chicago Terminal Radar Approach Control (TRACON).

The airspace controlled by the Chicago ARTCC consists of approximately 109,000 square mile in five states. The airspace is further divided into seven areas: north; northeast; east; southeast; south; southwest and northwest. The south area is again divided into seven sectors, five low altitude sectors, 0 to 10,000 feet; and two high altitude sectors, above 10,000 feet. The five low altitude sectors include the BOONE sector, which is approximately 1,400 square miles and is supported by three air route surveillance and two airport surveillance radars (ASR).

1.18.1.2 Air Traffic Control System Command Center

The predecessor to the FAA's Air Traffic Control System Command Center (ATCSCC) was the Central Flow Control Facility (CFCF), originally located at the FAA Headquarters in Washington, D.C. The CFCF was established with the objective of balancing aircraft flow to minimize delays to the user (primarily airlines) without exceeding controller capacity. The CFCF was renamed the Air Traffic Control System Command Center (ATCSCC) and was relocated to Herndon, Virginia, on March 26, 1994.

The basic mission of the ATCSCC is to manage the flow of air traffic throughout the National Airspace System (NAS), and to achieve the optimum use of the navigable airspace while minimizing the effect of air traffic delays on the user without exceeding operationally acceptable levels of traffic. The ATCSCC consists of the following five operational units:

1) the Traffic Management Function (TMF), which is responsible for coordination and approval of all major inter-center flow control restrictions on a system basis in order to obtain maximum utilization of the airspace;

2) the Central Altitude Reservation Function, which is responsible for coordinating, planning, and approving special user requirements;

3) the Airport Reservation Office, which is responsible for approving IFR [instrument flight rules] flights at designated high density airports (John F. Kennedy, LaGuardia, O'Hare, and Washington National) during specified hours;

4) the ATC Contingency Command Post, which is a facility that enables the FAA to manage the ATC system when significant portions of the system's capabilities have been lost or are threatened; and

5) the Central Flow Weather Service Unit (CFWSU) which is staffed by National Weather Service personnel and provides 24-hour service to the ATCSCC and users as needed.

The ATCSCC is operational 24 hours a day. Generally, two controllers and one supervisor are assigned to midnight shifts, and seven crews (with eight controllers per crew) rotate to work the day shifts. Personnel at the facility are typically full performance level (FPL) air traffic controllers and are normally assigned to the facility for 2 or 3 years. The controllers are provided training about standard operating procedures (SOPs) during 80 hours of classroom training.

All operating positions at the ATCSCC are linked through the Apollo computer system which enables communications between all ATC en route facilities and specific terminal facilities. The flow control workload is typically distributed to specialists at the ATCSCC by dividing the country into two geographical areas, east and west. The east area includes the boundaries of Boston, New York, Cleveland, Washington, Atlanta, Jacksonville, Memphis, Indianapolis, and Miami Air Route Traffic Control Centers (ARTCC). The west area includes:

Seattle, Salt Lake City,Denver, Oakland, Los Angeles, Albuquerque, Minneapolis, Chicago, Fort Worth, Houston, and Kansas City ARTCCs. The sectors can be reassigned as necessary to utilize the system to the fullest extent. In conjunction with the ATCSCC, the CFWSU and the Airport Reservation Office also provide services for each sector area. The primary function of the CFWSU is to provide meteorological expertise and advice to senior level air traffic flow managers/controllers. Meteorological support is also provided to the 20 ARTCCs and high traffic volume facilities.

The ATCSCC specialists have several tools available for monitoring traffic, one of which is the aircraft situation display (ASD). The ASD is a computer system located in Cambridge, Massachusetts, that receives radar track data from all 20 contiguous ARTCCs via satellite link, organizes the data into a mosaic display, and presents digital information on a computer screen. The ASD is not a radar display and only updates approximately every 3 minutes. The visual display provides the traffic management coordinator with multiple methods of selecting and highlighting either individual aircraft or groups of aircraft for analysis. The user also has the option of superimposing selected aircraft positions over any number of background displays, which include ARTCC boundaries, any stratum of en route sector boundaries, navigational fixes, airways, military and other special use airspace, airports, and geopolitical boundaries. All ARTCCs, the 26 terminal facilities, and some users, such as American Airlines, are equipped with ASD stations. By using the ASD, the traffic coordinator can monitor any number of individual aircraft flow situations or view the entire system-wide traffic flows. Each ATCSCC specialist maintains direct contact with the facilities in his or her area so that special traffic flow programs can be implemented if necessary.

According to FAA Order 7110.65, Air Traffic Control Handbook, Pilot/Controller Glossary, the Control Departure Time (CDT) program is the "flow control process whereby aircraft are held on the ground at the departure airport when delays are projected to occur in either the en route system or the terminal of intended landing. The purpose of these programs is to reduce congestion in the air traffic system or to limit the duration of airborne holding in the arrival center or terminal area. A CDT is a specific departure slot shown on the flight progress strip as an expected departure clearance time (EDCT)."

Controllers maintain an awareness of the expected hourly demand in a given area or airport, based on information published in the Official Airline Guide (OAG). When a situation requires the implementation of a traffic flow program, the computer will arbitrarily assign EDCTs to the affected flights. If a nonscheduled flight, such as a military or general aviation aircraft, requests a clearance to a destination with a program in effect and has not been assigned an EDCT, the controller is required to request a time from the Command Center.

One of the duties of the ATCSCC specialist is to retrieve a "Verification and Analysis Report" from the computer every 2 hours, as well as at the end of the program to determine its effectiveness. The verification and analysis report lists all of the aircraft that departed a given airport and the actual departure time. This information is used by the controller to verify that the specific flight did depart during the EDCT time. Tracking of a specific aircraft is not required unless that aircraft has been holding for longer than 15 minutes. Subsequent holds of 14 minutes or less by various sectors are not recorded. Thus, an aircraft can move from one ARTCC to the next, or from controller to controller, holding each time for up to 14 minutes with no recorded delays.

The crew of flight 4184 was directed to hold on the ground by the Indianapolis ground controller because a ground delay program was in effect for the flights into O'Hare due to deteriorated weather conditions at O'Hare. As a result, flight 4184 held on the ground approximately 42 minutes prior to receiving a takeoff clearance, and then because the weather at O'Hare had deteriorated further, held again in flight for approximately 35 minutes because of multiple expect further clearances (EFCs). In testimony provided by the South Area Supervisor for the Chicago ARTCC, he stated that proper notification to the Traffic Management Coordinator (TMC) of the excessive holding time experienced by flight 4184 (greater than 15 minutes) had not occurred, as required. Additionally, the TMC stated in an interview after the accident that when flight 4184 was released from IND, there were no flights holding for landing at O'Hare. However, in anticipation of a "rush" of arriving aircraft from the west, she informed the controllers to "expect holding on the east side [of the sector]." In addition, the TMC stated that she had not been informed that the BOONE sector was in a holding status at the time of the accident.

According to the National Traffic Management Officer (NTMO) on duty at the ATCSCC during the periods before and after the accident:

> The purpose of the EDCT is to permit aircraft to sit on the ground then arrive at the destination with no delay except what is needed en

route (spacing requirements) to reduce airborne holding and save fuel. Center controllers use "call for release" option to keep the flow. It is common to use both EDCT's and call for release simultaneously.

During the course of the on-scene portion of the investigation, Safety Board investigators made a request to the FAA to hold all ATCSCC documentation regarding flow control that was related to the accident. However, this was interpreted as a request to hold the data from the Chicago Traffic Management Unit. The policy regarding requested information that was in effect at the ATCSCC only required the retention of certain facility paperwork for 15 days. The Safety Board reiterated its request in writing on November 15, 1994; however, this request was not forwarded to the ATCSCC until November 17, 1994. As a result, the data pertaining to flight 4184 was not held by the facility and could not be recovered.

1.18.2 FAA Aircraft Certification

The Safety Board reviewed the FAA's organizational units responsible for aircraft certification and oversight. The Aircraft Certification Directorates are described in FAA Order 8000.51, dated February 1, 1982, which contains the duties, responsibilities and authority of each Directorate. The order specifies the need for "timeliness" in "monitoring continuing airworthiness" issues and states that the Aircraft Evaluation Group (AEG) will be responsible for providing all applicable technical services to the Flight Standards Division and Aircraft Certification Offices.

The FAA Air Transportation Inspector's Handbook, Order 8400.10, directs Flight Standards personnel responsible for the investigation of aircraft incidents and accidents to contact the AEG office for assistance and background information. The Order generally describes the AEG office as a unit of the Flight Standards (FS) office, collocated with the Aircraft Certification Office (ACO). The ACO is responsible for providing initial operational evaluation of each aircraft type for FS approval in the aircraft certification process. The AEG, which consisted of 12 specialists, is responsible for monitoring the fleet service history of an aircraft to fulfill the responsibilities of maintaining continued airworthiness. According to the Order, AEG responsibilities also include performing operational evaluations of the aircraft, providing guidance relating to its airworthiness, the receipt and maintenance of service difficulty reports (SDRs), and the evaluation of supplemental type certificates (STCs). The AEG specialists are fully qualified FS aviation safety inspectors in the areas of operations, airworthiness, and avionics.

The Aircraft Certification Directorate procedures are outlined in FAA Order 8100.5, Paragraph 305(b), which states that each Aircraft Certification Office is responsible for keeping the Directorate informed of significant accidents and incidents as referenced in chapter 7 of the Order. Chapter 7 of the Order, entitled Service Difficulties, describes the issuance of airworthiness directives, and section 702 of the chapter, "Accident Investigations," has been "reserved," and provides no information or guidance regarding the proper procedures for reporting the findings of the accidents and incidents to the Directorate. The Washington Headquarters Directives Checklist, Order WA 0000.4T, dated February 2, 1995, lists FAA Order 8100.5, issued October 1, 1982, as being a current order:

The Operations Unit Supervisor for the FAA AEG testified that they:

> ...cover approximately 60 airplanes in the U.S. inventory [and] perform several functions. We have a sister organization that's an airworthiness organization that performs MRB (maintenance review board) activities, which is analyzing the initial maintenance program on newly type [certificated] airplanes. And we do, in the operations unit, we do two Boards; the Flight Standardization Board and the Flight Operations Evaluation Board....We do continuing airworthiness activities in concert with the certification offices...and we participate in in-service history - following an aircraft from...its type certificate until it's taken out of revenue service.

The unit supervisor also testified that the AEG office does not maintain a data base for incident/accident history for specific aircraft. He said "...we're not that sophisticated. We do obviously keep records, especially within the Flight Standardization Board...but we don't particularly have a database."

There was no formal tracking system available from which to obtain background information regarding the incident/accident history of the ATR airplanes in icing conditions. The Safety Board was provided a briefing paper entitled, <u>ATR-42 Icing History</u>, written to the Manager, Seattle Aircraft Evaluation

Office, from the Manager, Seattle Aircraft Evaluation Group,[67] on March 25, 1989. According to the briefing paper, it was believed that the ATR 42 had an "...apparent inability to carry ice or at least perform reliably in icing conditions." The briefing paper also stated, in part:

> ...As of this date there are 10 icing-related incidents, reasonably well documented, in which abnormal flight characteristics were demonstrated by the airplane. A continuing airworthiness statement[68] ...the subject of which was "ATR 42 Icing Problems," prepared by Robert McCracken, ANM-113, annotates 5 of those 10 incidents and summarizes, briefly, the evolution of concern with those incidents. As a result of the incidents prior to the December 22, 1988, incident with Simmons Airlines, the manufacturer in concert with the [FAA's] Brussels Office has published revision No. 6 to the ATR 42 AFM....
>
> We feel that revision 6, as far as it goes, is a definite step in the right direction, however, it is our understanding that the manufacturer has not expressed an interest in mandating the aircraft changes....
> All along there has been a perceived reluctance on the part of the manufacturer to accept the fact there is an icing problem with the ATR 42. They have continually questioned the competence of the aircrews and the training programs in dealing with flight in icing conditions....
>
> It is thought that control forces are building up due to lift distortions on the wing caused by ice build-up, and when the build-up of control forces exceed those which the autopilot can handle, the autopilot disconnects and aileron displacement causes the aircraft to pitch left....

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[67]The Aircraft Evaluation Group evolved from the consolidation of the Flight Standardization Board (FSB) and the Flight Operations Evaluation Board.

[68]The "continuing airworthiness statement" referenced in the briefing paper was requested by Safety Board investigators. The FAA responded that there "is no official document called a continuing airworthiness statement in FAA terminology." The author of the requested document indicated "I do not remember preparing the specific document...I could well have done so, and suspect that it was a briefing paper prepared to alert management to possible problem areas regarding the ATR 72 airplane."

> Pragmatically we feel that the design of the wing has been the singular problem. It has been our observation on line operations that this wing is very efficient, and it follows that any distortion of airflow would be extremely disruptive. Operators and the industry as a whole are used to operating aircraft of the size and general type as the ATR 42 with heavy thick airfoils that will carry a "ton of ice." This wing will not....
>
> Another problem seems to have been that the aircraft was certificated under the Bilateral Agreements, which in this case made it difficult to collate, coordinate, and disseminate information between the manufacturer, regulatory entities, and operators....
>
> In the context of problem solving we would like to see flight tests on the ATR series aircraft with irregular ice shapes emulating "run-back" i.e., small distortions that have not been test flown to date. Intuitively, it seems that a high performance wing and boots do not go together.

The unit supervisor who generated the 1989 briefing paper testified at the Safety Board's public hearing that he made the statement regarding the "...perceived reluctance on the part of the manufacturer to accept the fact that there is an icing problem with the ATR 42" because he was "not familiar with the ATR manufacturer." He stated, "I had noticed, however, with some of the past [ATR] incidents, that there was...often a mention of a crew following improper procedures...and coming from a training background, I took note of that." The unit supervisor also testified that as he became more familiar with people from ATR, "I found that they were in fact not reluctant. That they were doing a lot to deal with these issues." He also stated that "it appeared, however, that when I wrote the letter [briefing paper] that that was [not] the case."

The unit supervisor also testified that he perceived "another problem" existed with the ATR's certification under the bilateral [airworthiness] agreement. He said:

> ...[under the bilateral airworthiness agreement] it's more difficult for us. For instance, we do not have an operational bilateral...and what this does when you're working in a bilateral situation, it does

> impede in a certain sense information flow. And in the AEG, we being a small part of the flight standards, deal in the information. We collect information in the field. We supply it to the certification office, and vice versa. That process was difficult for me as I got involved....I think we could do more to smooth out the lines of communication within the bilateral...."

1.18.3 Previous Safety Board Recommendations Regarding In-flight Icing

On September 9, 1981, the Safety Board published a report entitled Aircraft Icing Avoidance and Protection. The primary issues discussed in the report included icing standards for aircraft certification, weather forecasting/dissemination, and aircraft performance in icing conditions. The report targeted general aviation, air taxi and commuter size aircraft as those most vulnerable to "aircraft structural icing" because they are regularly flown at altitudes that are conducive to atmospheric icing conditions. The Safety Board's report indicated that during the period 1976 through 1979, there were no commercial aviation accidents in the United States attributed to aircraft icing. This successful period was due in part to the fact that the majority of the flights were being conducted by large aircraft that were capable of "...operating above the prevalent icing regimes," with "relatively sophisticated deicing and anti-icing equipment on those aircraft."

The report reflected the Safety Board's concerns about aircraft operations in icing conditions and the varying consequences that ice accretions had on different aircraft types. Based on its findings, the Board stated that "...a forecasting system is needed which will allow the pilot to determine the icing effects on his or her particular aircraft at any of the various stages of his or her flight and to prepare from this a safe flight plan." Thus, the Safety Board issued to the Federal Coordinator for Meteorological Services and Supporting Research, Safety Recommendations A-81-113 and -114, which stated, in part, respectively:

> A-81-113
> …develop instruments to measure temperature, liquid water content, drop size distribution, and altitude in the atmosphere, on a real-time basis, that are economical to use on a synoptic time and grid scale and;

A-81-114
Use the developed instrumentation to collect icing data on a real-time basis on a synoptic grid and, in turn, develop techniques to forecast icing conditions in terms of liquid water content, drop size distribution, and temperature.

On May 12, 1994, the Safety Board classified both recommendations, "Closed--Acceptable Alternate Action" because the issues discussed in the recommendations were addressed in a report published in 1982, 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, a second report was published 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.

Also, based on the findings of the study, the Safety Board issued Recommendations A-81-115 through -118 to the FAA. The first recommendation stated:

A-81-115
Evaluate individual aircraft performance in icing conditions in terms of liquid water, drop size distribution, and temperature, and establish operational limits and publish this information for pilot use.

The FAA initially responded to the Board's recommendation on December 21, 1981, and cited in its correspondence that:

> Full implementation of this recommendation would be dependent upon prior implementation of Safety Recommendations A-81-113 and -114...For a pilot to utilize operational limits in terms of liquid water content, drop size distribution, and temperature, information on icing forecasts and actual conditions must be available to him in terms of these parameters. We can envision that implementation of this concept would entail considerable expense, both in measuring the atmospheric parameters and in providing information for pilot

> use in aircraft flight manuals. During certification in icing, the aircraft is evaluated in terms of liquid water content, drop size distribution and temperature to establish adequacy of the ice protection system and to demonstrate the capability of the aircraft to operate safely in the defined atmospheric conditions. Limited certification in terms of liquid water content, drop size distribution, and temperature is not permitted. As there are no limitations in terms of these parameters for an aircraft certificated in icing, there would be little or no need to provide such information to pilots. (The exception to this is freezing rain, freezing drizzle, and mixed conditions...). We believe the present icing certification philosophy and criteria are basically sound and this is reflected in the accident statistics....In view of this, the cost of implementing Recommendation A-81-115, and the fact that icing certification does not allow limitations in terms of atmospheric icing parameters, the FAA cannot concur.…

The Safety Board emphasized in its April 16, 1982, response to the FAA that, "...the basic concept of enabling an operator to determine the effects of icing conditions, stated in parametric terms, upon a specific aircraft is valid. Forecasts issued in terms of intensity levels ('light,' 'moderate,' 'severe') do not apply equally to all aircraft, for example moderate icing to a large transport aircraft might be severe to a small general aviation aircraft…."

The FAA's June 7, 1982, response to the Safety Board stated, in part:

> The present FAA icing standards require an ice protection system which permits flight in <u>maximum</u> icing conditions. The rules do not allow certification for less extreme conditions...because variables such as liquid water content, droplet size and outside air temperature are not controllable by the pilot. These conditions may change so rapidly that diversion to areas where less severe icing conditions exist may not be possible....Providing icing forecasts and airplane operating limits in parametric terms...could therefore prove hazardous for an aircraft with only a limited capability to operate safely in icing conditions....To allow certification with operating limitations in terms of the above parameters would therefore degrade the level of safety....Forecasts issued or icing conditions

> described in terms of intensity levels...should not affect the capability of icing certified aircraft to operate safely in icing conditions regardless of the size or category of the aircraft. This is because icing-certified aircraft are evaluated to the full icing envelope expected in nature and defined in 14 CFR 25, Appendix C.

The FAA closed the correspondence with, "...We believe implementation of A-81-115 would involve considerable expense with little or no tangible benefit being realized...."

The Safety Board reiterated its position in its October 24, 1983, written response to the FAA, which stated, in part:

> We maintain the position that pilots, particularly those involved in general aviation, air taxi, and commuter aircraft need more information concerning the potential severity of icing and its effect upon aircraft that they are flying.

The Safety Board's stated in its October 2, 1987, follow-up response to the FAA:

> ...in both Advisory Circulars, 29-2 and 23.1419-1, it is recommended that a statement be included in the flight manuals that the prescribed flight test environment does not include freezing rain and/or mixed conditions and that these conditions may exceed the capabilities of an ice protection system.
>
> The Board believes that a pilot flying into known or forecast icing conditions needs more information than is presently provided.

Based on the FAA's unfavorable response of June 7, 1982, the Safety Board classified Recommendation A-81-115, "Open--Unacceptable Response."

In its December 11, 1989, final response to the Safety Board, the FAA cited Advisory Circular 29-2 and Advisory Circular 23.1419-1 (subsequently superseded by AC-23.1419-2 on January 3, 1992), which provide a description of the effects of icing on aircraft performance and flight characteristics. The information and actions contained in the ACs do not include flight testing in conditions that extend beyond those specified in Appendix C, such as freezing drizzle and freezing rain.

In the Safety Board response to the FAA, dated April 11, 1990, it stated:

> ...Considerable important research has been conducted, and the results have been published in research and academic papers, as well as discussed with pilots at FAA safety seminars. However, because the FAA has not related this information to individual aircraft, pilots have not benefited completely from this information. Because this information has not been effectively used, Safety Recommendation A-81-115 has been classified as "Closed--Unacceptable Action."

The Safety Board's 1981 icing report also identified the need for the FAA to review and revise the icing certification criteria in 14 CFR Part 25, Appendix C, based on the fact that this criteria was determined by, and established for, aircraft in use some 40 years ago. The Safety Board believed that because of advancements in technology, i.e., "deicing and anti-icing equipment, and improvements in the instruments used to measure atmospheric icing parameters," it was necessary for the FAA to also advance the criteria to keep pace with technology. Thus, it issued Safety Recommendation A-81-116, to the FAA, which stated:

> Review the icing criteria published in 14 CFR 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; and expand the certification envelope to include freezing rain and mixed water droplet/ice crystal conditions, as necessary. (Class III, Longer Term Action) (A-81-116)

The FAA initially responded to the recommendation with a discussion about the "low probability of occurrence" in such conditions as freezing drizzle, freezing rain and mixed water droplet/ice crystals. They also stated, in part, "...indications are that it would be excessively penalizing and economically prohibitive to require compliance with such criteria as part of a normal icing certification."

The Safety Board responded to the FAA on April 16, 1982, and "took exception" to the FAA's position that certification requirements for these conditions (freezing rain, freezing drizzle and/or mixed) should be elective. The Safety Board believed that "operation in freezing rain, freezing drizzle and mixed conditions occurs often enough to warrant inclusion of such conditions in the certification criteria, especially considering their hazardous nature."

The Safety Board sent a follow-up response to the FAA's June 7, 1982, letter on October 24, 1983, and stated, in part:

> ...In a recent analysis of an annual compilation of icing accidents, 28 percent were found to involve freezing rain. Consequently, such an occurrence cannot be considered a rare event. Freezing rain also is the most likely condition to be encountered during VFR flight in that it is often encountered below the clouds in relatively good visibility at altitudes most frequently utilized by smaller aircraft.

Based on the FAA's unfavorable responses, the Safety Board continued to classify A-81-116 as "Open--Unacceptable Response."

In 1986, the FAA sent a follow-up letter to the Safety Board stating that:

> The FAA has reconsidered the issue of considering freezing rain and drizzle as a criterion of aircraft for flight in icing conditions. The FAA has concluded that current research and development efforts...will provide the data needed to form a basis for determining the feasibility of any rulemaking action....

The Safety Board responded to the FAA in March of 1987, and stated that, "while the Safety Board is concerned about the lack of action since this recommendation was issued, it is encouraging that the FAA has reconsidered…. Pending the Board's review of the final action taken, Safety Recommendation A-81-116 has been classified as "Open--Acceptable Response."

Additional correspondence between the FAA and the Safety Board resulted in Safety Recommendation A-81-116 being reclassified as "Open--Unacceptable Response" in April 1990. The FAA's most recent response before the accident was received on September 16, 1994, and stated, 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 and A-81-118. Thus, the FAA has met the intent of the safety recommendation.

The Safety Board responded to the FAA on July 12, 1995, and indicated that although the Board noted that the FAA had reviewed the icing criteria published in 14 CFR Parts 25, 91 and 135, and concluded that they were adequate with respect to the issues outlined in Safety Recommendations A-81-116 and -118, the Board did not agree with the FAA's conclusions.

Further, information gleaned from the icing study prompted the Safety Board to issue recommendation A-81-118 to the FAA because it was believed that the definition of "severe icing" as found in the Aeronautical Information Manual (AIM) was not consistent with its use in the Federal Aviation Regulations. The recommendation asked the FAA to:

> Reevaluate and clarify 14 CFR 91.209(c) and 135.227(c) to insure that the regulations are compatible with the definition of severe icing established by the Federal Coordinator for Meteorological Services and Supporting Research as published in the Airman's Information Manual. (Class II, Priority Action) (A-81-118)[69]

The FAA's initial response in December 1981 was favorable and acknowledged that:

[69] 14 CFR Part 91.209(c) was changed to 14 CFR Part 91.527(c); and 14 CFR Part 135.227 (c) was changed to paragraph "(d)."

> ...the content of the rules in Parts 91 and 135 are not consistent with the definition of severe icing contained in the Airman's Information Manual and used by the National Weather Service. Accordingly, we agree that clarification of the current regulation is necessary. This incompatibility will be corrected in both Sections 91.209(c) and 135.227(c) in the next major review of these rules.

On June 7, 1982, the FAA responded to the Safety Board with a proposed amendment to the definition of "severe" icing found in the AIM. This amendment was believed to be "more compatible" with the language of 14 CFR 91 and Part 135. The Safety Board took exception in its October 23, 1983, response and stated, in part, "...This is in fact changing the established definition of severe icing and stating in effect that there are no conditions so severe that a properly certificated aircraft cannot safely fly in them."

In April 1990, the Safety Board sent a follow-up response to the FAA and expressed "disappointment" with its failure to "implement this Safety Recommendation [A-81-118] after 8 years." However, in consideration of the on-going research by the FAA, the Safety Board stated that it would monitor the progress of this issue and reclassified the recommendation "Open--Acceptable Response," pending further response.

The most recent FAA response to the Safety Board before the accident was received on September 16, 1994, and said, 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 reviewed the study of aviation requirements described in the "National Plan to Improve Aircraft Icing Forecasts." The FAA has also analyzed extensive in-flight icing data that were obtained from various European agencies as well as from research projects in the United States. As a result...the FAA has concluded that 14 CFR 91 and 14 CFR 135 are adequate to ensure that the intent of this safety recommendation is addressed, and I plan no further action.

The FAA concluded its response letter as follows:

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 as requested by these safety recommendations...I [the FAA Administrator] consider the FAA's actions to be complete on the safety recommendations.

The Safety Board's July 12, 1995, response letter to the FAA stated:

The Safety Board notes that the FAA has reviewed the icing criteria published in 14 CFR Parts 25, 91, and 135 and has concluded that they are adequate with respect to issues outlined in Safety Recommendations A-81-116 and -118. The Safety Board does not agree. The content of 14 CFR 91.527(c) and 14 CFR 135.227(e) still is not consistent with the provisions defined in section 34, Appendix A, of 14 CFR Part 135. Under certain ice protection provisions defined in section 34 Appendix A of 14 CFR Part 135, flight into known severe icing conditions is permitted. However, severe icing, as currently defined, includes hazardous environmental conditions that existing deicing/anti-icing equipment is unable to reduce or control, and immediate diversion is necessary.

In light of the accident on October 31, 1994, near Roselawn, Indiana, involving a Simmons Airlines ATR-72-210 airplane 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. Investigation, testing, and analysis following the ATR-72 accident, and testimony at the Safety Board's associated public hearing for that accident, have underscored the need to amend the icing criteria as they pertain to 14 CFR Parts 25, 91, and 135. Accordingly, the Safety Board classifies Safety Recommendations A-81-116 and -118 "Open--Unacceptable Response," pending further action by the FAA on this matter.

The FAA responded to the Safety Board on August 28, 1995, in regard to Safety Recommendations A-81-116 and -118, and stated:

> The Federal Aviation Administration (FAA) has taken actions to address the ATR-72 aircraft design and operation in icing conditions. The FAA 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 current certification requirements, applicable operating regulations, and forecast 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 the Board notes and supports the FAA's intention to convene an international meeting of representatives from foreign airworthiness authorities, the aviation industry, and other interested parties in 1996. However, the Safety Board maintains its position that in light of the accident involving flight 4184 and the subsequent flight testing and analysis, the issues raised in Safety Recommendations A-81-116 and -118 underscore the need to amend the icing certification regulations. Thus, the Safety Board classified recommendations A-81-116 and -118, "Open--Unacceptable Response," pending further actions by the FAA. Based on a new recommendation issued with this report, the Safety Board classifies recommendations A-81-116 and -118 as "Closed—Unacceptable Action/Superseded."

The Safety Board's 1981 icing report also cited information about the causes of various icing conditions and the detrimental effects that such conditions have on aircraft performance. The report provided a description of the formation and effects of "clear ice," and cited, in part:

> Clear ice is a glossy, clear-to-translucent accumulation formed by large water droplets or raindrops which spread and freeze on

> contact, forming a sheet of smooth ice. It is a hazardous icing condition because it accumulates rapidly and is dense and heavy. It often spreads beyond the effective area of deicing or anti-icing surfaces and adheres strongly to the aircraft's surfaces.

Based on this information, the Board issued Safety Recommendation A-81-117, to the FAA, encouraging it to:

> Establish standardized procedures for the certification of aircraft which will approximate as closely as possible the magnitudes of liquid water content, drop size distribution, and temperature found in actual conditions, and be feasible for manufacturers to conduct within a reasonable length of time and at a reasonable cost. (Class III, Longer Term Action) (A-81-117)

After several follow-up letters between the two agencies, the FAA again responded in regards to Safety Recommendation A-81-117 on October 24, 1983, and stated that it was reviewing the icing criteria for normal icing certification. This review was to include the consideration of freezing rain and freezing drizzle; however, the FAA believed that the latter would be considered "elective" rather than a requirement of the normal icing certification.

The FAA provided a final response to the Safety Board on December 1, 1986, and stated that it had reconsidered the issue of including freezing rain and freezing drizzle as a criterion in the certification of aircraft for flight in icing conditions. The response letter also stated that research and development data was needed to determine the basis for rulemaking action, and that once the data was received, the FAA would determine the appropriate course of action. Based on this response, on March 12, 1987, the Safety Board classified Safety Recommendation A-81-117 "Closed--Acceptable Action."

1.18.4 Previous Safety Board Recommendations Regarding Unusual Attitude Training for Pilots

The Safety Board has addressed the issue of "unusual attitude" recognition and recovery training for transport-category pilots four times in the past 27 years. One recommendation resulted from the investigation of an accident in a United Airlines Boeing 727 that occurred on November 16, 1968, near the Detroit

Metropolitan Airport. The Safety Board issued Safety Recommendation A-70-021 to the FAA, which encouraged the FAA to require commercial airlines to provide additional training to flightcrews regarding unusual attitudes, and require the pilot to demonstrate periodically, proficiency in the area of recovery from unusual attitudes. It was also recommended that aircraft simulators be utilized to provide flightcrew familiarization in the following areas: 1) The various instrument displays associated with and resulting from encounters with unusual meteorological conditions; 2) The proper flightcrew response to the various displays; and 3) Demonstration of and recovery from possible ensuing unusual attitudes.

The FAA did not respond favorably, and, on August 17, 1972, the Safety Board classified recommendation A-70-021, "Closed--Unacceptable Action."

On September 15, 1972, the Safety Board issued Safety Recommendation A-72-152, following an accident on March 31, 1971, at Ontario, California, involving a Boeing 707/720B which crashed after the flightcrew lost control while attempting a 3-engine missed approach on a proficiency check flight.[70] Although the Safety Board attributed the probable cause of the accident to the failure of the aircraft's rudder actuator, the Board expressed concern regarding the flightcrew's ability to rapidly assess the situation and effect a recovery.

Safety Recommendation A-72-152 asked that the FAA require pilots to demonstrate their ability to recover from abnormal regimes of flight and unusual attitudes solely by reference to flight instruments. The use of simulators was recommended for this purpose. The Safety Board noted that if current simulators were not capable of being used for this purpose, the simulators should be modified. The FAA's response to the safety recommendation stated:

> The simulator is not capable of simulating certain regimes of flight which go beyond the normal flight envelope of the aircraft. Further, since an aircraft simulator is not required as part of an air carrier training program, the FAA cannot require that it be replaced or modified to simulate regimes of flight outside the flight envelope of the aircraft.

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[70] Aircraft Accident Report—"Western Air Lines, Inc., Boeing 720-0478, N3166, Ontario International Airport, Ontario, California, March 31, 1971" (NTSB/AAR-72-18)

The Safety Board was disappointed that the FAA declined to implement A-72-152, and, on January 16, 1973, classified this safety recommendation, "Closed--Unacceptable Action."

On July 10, 1991, the Safety Board investigated an accident involving a L'Express Airlines, Beech 99[71] that crashed while conducting an instrument landing system approach to runway 5 at the Birmingham Airport (BHM), Birmingham, Alabama. The Safety Board found that the current Federal regulations do not require instrument-rated pilots to maintain proficiency in the ability to recognize and recover from unusual aircraft attitudes. It also found that the difficulty the L'Express flightcrew had controlling the airplane may have been exacerbated because they had not received unusual attitude recognition and recovery training from the company. Based on this accident, the Safety Board issued Safety Recommended A-92-20 to the FAA which stated:

> Require recurrent training and proficiency programs for instrument rated pilots to include techniques for recognizing and recovering from unusual attitudes.

> The FAA's July 9, 1992, response to the Safety Board stated, in part:

> ...the FAA believes that pilot flight crewmembers must be proficient in the recovery from unusual flight attitudes and has designed the flight training requirements to address this skill. Recovery from unusual flight attitudes is required in order for individuals to receive a private pilot certificate. Additionally, the instrument rating practical test standards require pilots who obtain an instrument rating to be proficient in the recovery from unusual flight attitudes. Likewise, the practical test standards for an airline transport pilot require pilots to recover from specific flight characteristics for a particular type aircraft.

The Safety Board was disappointed with the FAA's response and responded with a second letter reiterating the importance of such training. The Safety Board believed that instrument-rated pilots should receive recurrent training

[71]Aircraft Accident Report--"L'Express Airlines, Inc., Flight 508, Beech 99, N7217L, Weather Encounter and Crash Near Birmingham, Alabama, July 10, 1991" (NTSB/AAR-92/01)

in techniques for recognition and recovery from unusual attitudes because this training would greatly enhance a pilot's ability to safely recover from an unusual attitude. Therefore, the Safety Board classified recommendation A-92-20 on January 26, 1993, "Closed--Unacceptable Action."

On June 25, 1991, the Safety Board issued Safety Recommendation A-93-72, following the accident involving a Beech 1900 that crashed near Block Island, Rhode Island, on December 28, 1991.[72] The recommendation asked the FAA to:

> Consider an amendment to 14 CFR Part 135 to require that commuter air carriers perform certain hazardous training, testing, and checking maneuvers, such as engine-out operations, and recovery from unusual flight attitudes, in approved flight simulators to the maximum extent feasible.

The FAA stated in its response to A-93-72, that it was considering new air carrier training requirements, in particular, requiring certain 14 CFR Part 135 air carriers to conduct their pilot training in accordance with the standards set forth in 14 CFR Part 121.

On August 29, 1995, the Safety Board classified Safety Recommendation A-93-72, "Closed--Acceptable Action," based on the FAA's February 3, 1995, response in which it stated that rulemaking (NPRM) actions were in progress to require pilots of scheduled 14 CFR Part 135 air carriers operating aircraft that required two or more pilots, or seated 10 or more passengers, to receive training under the provisions of 14 CFR Part 121. The proposed rule would permit the use of sophisticated aircraft simulators to conduct the training. The FAA's final rule was adopted in December 1995.

On August 16, 1995, the FAA disseminated a new Flight Standards Handbook Bulletin (HBB) for Air Transportation (HBAT), HBAT 95-10, entitled Selected Event Training, to its POIs. The bulletin contains "...guidance and information on the approval and implementation of 'Selected Events Training' for operators training under 14 CFR Part 121, who use flight simulation devices as part of their flight training programs."

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[72] National Transportation Safety Board, Safety Report (NYC-92-F-A053)

The bulletin states that the selected events training is "voluntary flight training in hazardous inflight situations which are not specifically identified in FAA regulations or directives." Some of the examples of these selected events include: false stall warning at rotation; excessive roll attitude (in excess of 90 degrees); and high pitch attitude (in excess of 35 degrees). The bulletin further states that this training program was developed jointly by the FAA and the aviation industry in response to previously issued Safety Board recommendations addressing the need for unusual events and unusual attitude training for Parts 135 and 121 air carrier pilots.

1.18.5 Previous Safety Board Recommendations Regarding the Performance of ATR Airplanes and the Air Traffic Control System Command Center

As a result of this accident, on November 7, 1994, the Safety Board issued the following safety recommendations to the FAA:

A-94-181
Conduct a special certification review of the ATR 42 and ATR 72 airplanes, including flight tests and/or wind tunnel tests, to determine the aileron hinge moment characteristics of the airplanes operating with different airspeeds and configurations during ice accumulation and with varying angles of attack following ice accretion. As a result of the review, require modifications as necessary to assure satisfactory flying qualities and control system stability in icing conditions. (Class II, Priority Action)

A-94-182
Prohibit the intentional operation of ATR 42 and ATR 72 airplanes in known or reported icing conditions until the effect of upper wing surface ice on the flying qualities and aileron hinge moment characteristics are examined further as recommended in A-94-181 and it is determined that the airplane exhibits satisfactory flight characteristics. (Class I, Urgent Action)

A-94-183
Issue a general notice to ATC personnel to provide expedited service to ATR 42 and ATR 72 pilots who request route, altitude,

or airspeed deviations to avoid icing conditions. Waive the 175 knot holding speed restriction for ATR 42 and ATR 72 airplanes pending acceptable outcome of the special certification effort. (Class I, Urgent Action)

A-94-184
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. (Class I, Urgent Action)

A-94-185
Caution pilots of ATR 42 and ATR 72 airplanes that rapid descents at low altitude or during landing approaches or other deviations from prescribed operating procedures are not an acceptable means of minimizing exposure to icing conditions. (Class I, Urgent Action)

In a letter dated December 2, 1994, the FAA responded positively to all of the recommendations. The Safety Board evaluated the FAA's reply and classified the FAA's responses to each of the recommendations in a letter dated January 9, 1995.

With regard to Safety Recommendation A-94-181, the FAA stated that it agreed with the recommendation and that it had established a special certification review (SCR) team, comprised of representatives from the FAA and the French DGAC, to:

> conduct a special certification review of the ATR-42 and ATR-72 series airplanes. The team will also require flight tests and/or wind tunnel tests as necessary to determine control system performance, particularity in roll of airplanes operating with different airspeeds and configurations during ice accretion. Included in the review will be an evaluation of aileron hinge moment characteristics. As a result of the review, the FAA will require modifications, as necessary, to ensure satisfactory flying qualities and control system

stability in icing conditions. The team is expected to prepare a formal report by February 1, 1995. On November 16, 1994, the FAA issued telegraphic airworthiness directive (AD) T94-24-51 applicable to all model ATR-42 and ATR-72 series airplanes. The AD requires a revision to the FAA-approved airplane flight manual to prohibit operation of the autopilot in icing conditions when the airplane is operated in moderate or greater turbulence, or if any unusual lateral trim situation is observed.

The FAA advised the Safety Board that the certification review team expected to complete its formal report by February 1, 1995. Based on these actions, on January 9, 1995, the Board classified A-94-181 "Open--Acceptable Response," stating that the Board was waiting for completion of the work of the special certification team and that it looked forward to receiving the results contained in its formal report.

In a letter dated April 19, 1996, the FAA advised the Safety Board that it had conducted an SCR of the ATR 42 and ATR 72 airplanes. On September 29, 1995, the team issued its final report, a copy of which was provided to the Safety Board. Based on its review of the SCR report and the verification of the viability of the flight operations restrictions imposed on ATR 42 and ATR 72 airplanes, the Safety Board classifies Safety Recommendation A-94-181 "Closed—Acceptable Action."

With regard to Safety Recommendations A-94-182 and A-94-184, in a letter dated December 2, 1994, the FAA outlined several actions that had been taken since the accident. Those actions included a meeting of ATR operators, FAA representatives, pilot and industry organizations, and the airframe manufacturer and the issuance of telegraphic AD T94-24-51 on November 16, 1994, which prohibited the use of the autopilot on the ATR 42/72 in icing conditions or moderate or greater turbulence, and specified certain procedures in the event of unusual trim situations. The actions also included the issuance of Flight Standards Information Bulletin (FSIB) 94-16, ATR 42 and ATR 72 Operating Procedures in Icing Conditions, on November 18, 1994, that directed the POIs for ATR operators to ensure that several actions were accomplished immediately. Those actions included verification that the procedures in AD T94-24-51 were accomplished, that an attached list of pilot procedures were immediately distributed to all operators and flightcrews of ATR airplanes, and that special dispatch procedures for icing operations were in place.

Further, the FAA conducted followup teleconferences to verify that the provisions of FSIB 94-16 had been implemented, and special surveillance procedures, including a substantial increase in en route inspections, were implemented to verify that the revised procedures were in place and being used.

Before the Safety Board had formally responded to the FAA's actions relevant to A-94-182 and A-94-184, on December 9, 1994, the FAA issued AD T94-25-51 applicable to the ATR fleet to prohibit flight into icing conditions. On January 9, 1995, the Safety Board classified A-94-182 and A-94-184 "Open—Acceptable Response," pending any corrective actions based on the SCR, as recommended in A-94-181.

In a letter dated January 18, 1995, the FAA responded further to Safety Recommendations A-94-182 and A-94-184 stating that on January 11, 1995, it had issued AD T95-02-051 and FSIB 95-01, ATR 42 and ATR 72 Airworthiness Directive T95-02—51 Compliance Procedures.

On February 24, 1995, the Safety Board classified A-94-182 and A-94-184 "Open—Acceptable Action," pending notification from the FAA that terminating actions (to correct the characteristics that led to the special flight restrictions on the airplanes) had been taken and that the results of the SCR team had been published.

Based on the results of the SCR, which was enclosed with a letter from the FAA dated April 19, 1996, and the verification of the viability of the flight operations restrictions imposed on the ATR airplanes, the Safety Board classifies A-94-182 "Closed—Acceptable Action."

With reference to A-94-184, in the April 19, 1996, letter, the FAA advised the Safety Board that it had issued a supplemental notice of proposed rulemaking (NPRM) on January 19, 1996, to require revised flightcrew procedures with respect to flight in large droplet freezing precipitation (freezing drizzle) conditions, and that these revised procedures for the ATR were identical for all other affected airplanes. In addition, the FAA stated that it will issue one final regulatory document incorporating the NPRM and supplemental NPRM. The Safety Board looks forward to receiving this information. Consequently, A-94-184 remains classified “Open—Acceptable Action.”

With regard to A-94-183, the FAA responded on December 2, 1994, that it had issued GENOT (general notice) RWA 4/85, dated November 11, 1994, that directed air traffic personnel to provide priority handling to pilots of ATR 42 and ATR 72 airplanes when they requested route, altitude or airspeed deviations to avoid icing conditions. The GENOT also advised that air traffic personnel should be aware that the normal holding airspeeds for the ATR 42 and ATR 72 airplanes have been waived and that, when speeds in excess of 175 knots (as published in the Aeronautical Information Manual for turbopropeller airplanes) are used, the airplanes may not remain within the confines of the holding pattern airspace. In a letter to the FAA, dated January 9, 1995, the Safety Board classified A-94-183 "Closed—Acceptable Action."

With regard to A-94-185, on December 2, 1994, the FAA advised the Safety Board that its FSIB 94-16:

> cautions pilots that rapid descents at low altitude or during landing approaches or any deviations from these approved procedures as a means of minimizing exposure to icing condition should be avoided. Strict adherence to AD limitations and approved procedures is required.

In a reply to the FAA dated January 9, 1995, the Safety Board noted:

> that the FAA has included in FSIB 94-16 specific precautions to pilots not to use rapid descents at low altitudes or during instrument approaches as a means to minimize exposure to icing conditions. It also urged strict adherence to AD limitations regarding the use of autopilot and other approved procedures. The Safety Board is aware that the FAA has taken actions to verify pilot understanding and compliance by conducting en route inspections and visiting airline operations. Therefore, the Safety Board classifies A-94-185 "Closed--Acceptable Action."

In addition, as a result of this accident, the Safety Board issued the following safety recommendations to the FAA on November 6, 1995:

<u>A-95-103</u>
Require the Air Traffic Control System Command Center to retain all flow control-related facility documents for 15 days, regardless of title, name or form number, for reconstruction purposes. (Class II, Priority Action)

<u>A-95-104</u>
Develop a list of documents to be completed by the Air Traffic Control System Command Center personnel in the event of an incident or accident. (Class II, Priority Action)

<u>A-95-105</u>
Revise Order 8020.11, “Aircraft Accident and Incident Notification, Investigation and Reporting,” to include the Air Traffic Control System Command Center (DCC) facility. Ensure that the SCC facility is assigned specific requirements to be included in an accident/incident package. (Class II, Priority Action)

<u>A-95-106</u>
Revise FAA Order 7210.3, “Facility Operation and Administration,” Chapter 3, “Facility Equipment,” Section 4, “Recorders,” paragraph 3-41, “Assignment of Recorder Channels,” to include the Air Traffic Control System Command Center facility, listing the recorded positions and their priority. (Class II, Priority Action)

On February 2, 1996, and on May 1, 1996, the FAA responded to the Safety Board concerning Safety Recommendations A-95-103 through A-95-106. In its reply to the FAA on June 13, 1996, the Safety Board noted the following:

> The Safety Board notes that the FAA developed a list of documents that will be retained by the DCC facility for 15 days and will be provided to investigators in the event of an incident or accident. Therefore, the Safety Board classifies Safety Recommendations A-95-103 and -104 "Closed—Acceptable Action."
>
> The Safety Board notes that the FAA reviewed the requirements of the DCC and issued a general notice that revised Order 8020.11 to

include the facility. Therefore, the Safety Board classifies Safety Recommendation A-95-105 "Closed—Acceptable Action."

The Safety Board notes that the FAA revised Order 7210.3 to include the DCC positions and their priority. Therefore, the Safety Board classifies Safety Recommendation A-95-106 "Closed—Acceptable Action."

1.18.6 Government Accounting Office (GAO) and Department of Transportation Inspector General (DOT/IG) Investigation of the Federal Aviation Administration

In September 1993, the General Accounting Office (GAO) published a report, at the request of Congressman James Oberstar, former Chairman of the House Subcommittee on Aviation, regarding the adequacy of the FAA's aircraft certification process and design criteria for transport category aircraft to ensure that the FAA met all applicable safety standards. The following is an excerpt from the findings discussed in the GAO's report:[73]

> 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. The report stated that the FAA now delegates up to 95 percent of the certification activities to manufacturers without defining (1) critical activities in which FAA staff should be involved, (2) guidance on the necessary level and quality of the oversight of designees, and (3) standards to evaluate staff members' performance. 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. Because FAA has increased delegation over the last 13 years, its ability to effectively oversee

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[73]United States General Accounting Office. 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.

> and add value to the certification process as well as understand new technologies has been questioned by internal reviews and FAA and industry officials.

The GAO found, for example, that between fiscal years 1990 and 1992, only 1 of the 12 FAA engineers responsible for approving aircraft computer software attended a software-related training course. The GAO said that FAA officials acknowledged that inadequate training over the last decade had limited the certification staff's ability to understand areas of dramatic technological advancement. As a result, the FAA developed a new training program intended to improve the competence of the staff; however, the program was found to lack the necessary structure to establish specific training requirements for staff in their areas of responsibility.

The GAO's report issued 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, require an expert's involvement early in the certification process and at other key junctures, establish specific training requirements, and identify training in new technologies that is available at universities, industry, and other government agencies.

In addition, the GAO report stated:

> ...After maintenance and design problems with a McDonnell Douglas DC-10 aircraft were found to have contributed to an accident resulting in 273 fatalities, in 1979, the Secretary of Transportation established a "blue-ribbon" committee to assess the adequacy of the FAA's certification program. Under the direction of the National Academy of Sciences, the committee 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, such as approving all test proposals, for its own staff.[74] The report warned however, that the FAA's technical competence was falling far behind the DERs to the point that the agency's oversight was becoming superficial. The Academy called on the FAA to establish a "higher esprit de corp" by hiring, retaining, and training highly competent engineers....

...Acknowledging that its staff was falling behind industry in technical competence, the FAA established a program in 1979 to increase staff members' knowledge of state-of-the-art technologies. Under the National Resource Specialist (NRS) Program, the FAA identified a need for expertise in 23 areas, including crash dynamics, fuel and landing gear systems, advanced materials, advanced avionics, and <u>the effects of such environmental factors as ice</u>. [emphasis added] Experts in the program were to be responsible for maintaining the highest level of expertise in their particular specialty and acting as advisers to staff during the certification process. However, the FAA never fully implemented the program. Of the 23 positions the FAA identified as critical, only 11 were authorized. According to the manager of the NRS program, the FAA intended to authorize all of the positions but did not do so because it could not attract qualified individuals to fill them....

For example, according to the certification staff, <u>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. The effects ice has on different aircraft designs vary greatly, making it imperative that the FAA have an expert in this area,</u> [emphasis added] according to the acting manager of the Propulsion Branch at the Los Angeles Aircraft Certification Office (AC). 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, he stated....

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[74] <u>Improving Aircraft Safety: FAA Certification of Commercial Passenger Aircraft</u>, National Academy of Sciences, National Research Council, Committee on FAA Airworthiness Certification Procedures (June 1980).

Comments from the FAA's Aircraft Certification Service Director to the GAO indicated that it was the FAA's belief that the staff was not "falling behind in understanding the principles and effects of ice." The Director also stated that the FAA had recently issued regulations governing an airline's ground operations during icing conditions. As a result, the GAO confirmed with the acting manager of the Propulsion Branch at the Los Angeles AC office the accuracy of the point made in the draft report. Although acknowledging that new regulations governing airline operations had been issued by FAA headquarters, the acting manager stated that new certification staff were falling behind in understanding the principles and effects of ice on aircraft designs because the FAA had not hired an NRS on icing to assist staff in understanding those principles and effects.

The GAO recommended that the Secretary of Transportation direct the Administrator of the FAA to formally examine the need to hire NRSs in areas of technological advancement over the last 14 years and to require NRS involvement early in the certification process and at other key certification junctures.

The DOT responded that the FAA does not need to formally examine the need to hire experts in areas of technological advancement because the FAA periodically assesses the NRS Program. However, the GAO report details examples provided by NRS and FAA staff in which the FAA staff has fallen farther behind in some areas because the FAA has not fully staffed the program. In addition, three members of the National Academy of Sciences' committee stated in 1980 that the NRS program has been an inadequate response to the Academy's call for greater competence by the FAA in the certification process, in part because it has been understaffed.

On April 15, 1994, the Office of the Inspector General (IG) of the Department of Transportation published a report entitled the <u>Federal Aviation Administration, Responsiveness to Suspected Aircraft Maintenance and Design Problems</u>. The report stated, in part:

> ...The Office of the Inspector General (OIG), Department of Transportation, conducted an inspection of the Federal Aviation Administration's ability to identify and respond to suspected aircraft maintenance and design problems. This inspection was initiated in

> response to growing concerns about the FAA's ability to correct suspected aircraft problems--particularly after the October 1992 El Al Airlines crash in the Netherlands. During the inspection, we contacted 89 representatives from FAA, the National Transportation Safety Board, aircraft manufacturers, and aircraft operators....

The report also stated that:

> Our review concludes that the FAA's ability to identify, evaluate, and correct suspected aircraft maintenance and design problems is hampered by inadequate oversight of the FAA's engineers' activities and decisions, and insufficient analysis capability. This conclusion applies primarily to the FAA's Transport Airplane Directorate (TAD)...Specifically, TAD's ability to identify and respond to suspected aircraft maintenance and design problems is hampered by inadequate oversight because no normal system exists to ensure aircraft problems do not fall into a "black hole," and no adequate documentation, tracking and reporting archival and research mechanism exists to enable the FAA to recall incidents, other than engineer's memories...TAD makes limited use of, and has no specific requirement for trend analysis.[75]

The Inspector General recommended that the TAD develop and implement a formal tracking system to ensure adequate accountability and timely resolution of reported aircraft maintenance and design problems. The FAA did not concur. Additionally, it was recommended that the TAD develop and implement standard procedures for documenting research of suspected aircraft problems. Again the FAA did not concur and stated that the current systems and procedures meet the intent of a "formal" tracking system.

1.18.7 Bilateral Airworthiness Agreement

The ATR 42/72 was type certificated in the United States under an agreement between the United States and France, enacted in 1973. The Bilateral Airworthiness Agreement (BAA) is an "enabling" document that is less formal

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[75] Office of Inspections and Evaluations, Office of the Inspector General, U.S. Department of Transportation. Report on Federal Aviation Administration, Responsiveness to Suspected Aircraft Maintenance and Design Problems, April 15, 1994. Report E5-FA-4-009.

than an international treaty, and is executed between Chiefs of State without senatorialapproval. Typically, the BAA with the United States develops when a foreign country has manufactured "civil aeronautics products" it intends to export to the United States and has a competent civil airworthiness authority. Since the agreements are technically oriented and are not trade agreements, they are intended to prevent unnecessary repetitive certification activities by facilitating cooperation and acceptance of findings between the exporting country's airworthiness authority and the FAA.

In addition to certification-related responsibilities, the agreement states:

> ...The aeronautical authorities of each Contracting Party shall keep the aeronautical authorities of the Other Contracting Party fully informed of all mandatory airworthiness modifications and special inspections which they determine are necessary in respect of imported or exported products to which this agreement applies.
>
> ...The aeronautical authorities of the exporting State shall, in respect of the products produced in that State,...assist the aeronautical authorities of the importing State in determining whether major design changes and major repairs made under the jurisdiction of the importing State comply with the laws, regulations and requirements under which the product was originally certificated and approved. They shall also assist the aeronautical authorities of the importing State in analyzing those major incidents occurring on products to which this Agreement applies and which are such as would raise technical questions regarding the airworthiness of such products....

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. Further, the FAA assesses the foreign country's laws and regulations, and the state-of-the-art design and manufacturing capability.

The FAA Team Leader for the ATR Special Certification Review testified at the Safety Board's public hearing about the certification process for the ATR 42/72. The following is a brief description of testimony provided by the team leader regarding the ATR certification process by both the FAA and DGAC:

...Under that bilateral, each of the participants have some rather well-defined roles...the DGAC has the certification authority and the FAA has the validating authority.

In addition to determining the certification basis, another major role at this stage in the process is the development of policy and guidance for the benefit of both ATR and DGAC...this was done largely by means of issue papers...There were a large number of issue papers on the ATR-42...actually 98 issue papers. Issue papers are used as a tool to transfer previous experience that we may have had on other programs...things that other manufacturers may have had some difficulty with.…

The DGAC applies our regulations...our policy...and any guidance given to them along the way...The 'flight manual,' the official document that is part of the type design of the airplane...we do not approve that document the DGAC does on our behalf. However, we review it thoroughly and make changes as necessary...and only when we're satisfied with the contents of the AFM do we then authorize the DGAC to sign it on our behalf.

...the validation of data...in general, we rely on the guidance that we have given the DGAC in specific cases...if there is an area of misunderstanding or disagreement, that's where this issue paper process comes in...flight testing is a definite part of each bilateral approval. However, the flight testing is not really an evaluation...the idea behind the FAA pilot flying the airplane is...first, it's familiarity with the airplane so he can fulfill his duties later throughout the life of the airplane. Also, it's to determine the suitability for use in airline service. The AEG also participates in this evaluation and typically it's a fairly short involvement for the flight test. Typically it's roughly ten hours of [total] flying...four flights...usually one at night to check the lighting….

[Regarding an evaluation of the aircraft in icing conditions] we do not specifically go out and seek icing conditions during the flight evaluation.…

Before the U.S. airworthiness certificate can be issued, the FAA must determine that the aircraft conforms to the applicable U.S. airworthiness requirements, which, in the case of the ATR 42 and 72, is 14 CFR Part 25. Under the BAA and by Federal regulation, a foreign-built aircraft is entitled to a U.S. type certificate if the exporting State certifies, and the FAA finds, that the aircraft does conform to the type design and appropriate certification requirements. The FAA can make a determination based in whole, or in part, on the exporting State's certification, provided a BAA exists. Also, under the bilateral agreement, the FAA does not have to conduct any flight testing of the airplane prior to the issuance of the U.S. airworthiness certificate.

On March 4, 1987, and May 8, 1987, the Safety Board conducted investigations of two Construcciones Aeronauticas, S.A. (CASA) 212 airplanes, involved in accidents at the Detroit Metropolitan Wayne County Airport, Romulus Michigan, and the Mayaguez Airport, Mayaguez, Puerto Rico, respectively.[76] The investigation of both accidents revealed that the FAA's certification of the CASA 212 under the Bilateral Airworthiness Agreement was deficient. One of the Safety Board's conclusions in both accidents stated that, "The bilateral type certification project of the CASA C-212 was not managed effectively by the FAA. The reorganizational changes, personnel changes, and the limited availability of resources in the engineering and operations departments of the FAA are contributing factors." Based on these investigations, the Safety Board issued the following recommendation to the FAA:

> A-88-100
> Complete as soon as possible and make findings available to the Safety Board the report on the in-house review of the bilateral aircraft type certification program and corrective actions taken or contemplated as a result of the review.

On January 1, 1990, the Safety Board classified recommendation A-88-100 as "Closed--Acceptable Action" after the FAA conducted a review of both the CASA 212 certification process and the BAA. The FAA subsequently produced a report entitled, <u>Review of the Construcciones Aeronauticas, S.A.</u>

[76]NTSB Aircraft Accident Report--"Fischer Bros. Aviation, Inc., dba Northwest Airlink, Flight 2268, (CASA) C-212-CC, N160FB, Detroit Metropolitan Wayne County Airport, Romulus, Michigan, March 4, 1987" (NTSB/AAR-88/08) and NTSB Aircraft Accident Report "Executive Air Charter, Inc., d.b.a. American Eagle Flight 5452, CASA C-212, N432CA, Mayaguez, Puerto Rico, May 8, 1987." (NTSB/AAR-88/07)

CASA 212 Certification Program and the U.S. Import Type Certification Process. The intent of this report was to evaluate the working relationships and the implementation of the BAA procedures, and to identify areas where improvements could be made to accomplish the objectives of the aircraft certification program regarding imported products. The FAA published the report in March 1988, and, in addition to the review of the type certification of the CASA 212, the FAA's performance regarding the BAA procedures for type certification and how airworthiness issues were resolved after certification were also examined. The FAA review team believed that the findings "...can be applied across the directorate system and should be incorporated as such." These findings/conclusions resulted in 17 recommendations to FAA management as a "start toward achieving that quality improvement." The recommendations included the subject of training of FAA personnel about product certification under BAA procedures, and the development of documentation to standardize the directorate organization, procedures, responsibilities, and functions of those organizations.

One of the issues discussed in the report pertained to the "Follow-On Type Certification" which was described in terms of the FAA questioning the foreign airworthiness authorities and manufacturer's compliance with the U.S. interpretation of FAR 25 (certification basis). The review team concluded:

> The follow-on certification issues were not performed efficiently and effectively. This can be attributed to several factors. First, there was a lack of continuity of staffing....The other major factor, which is a result of the first, was a lack of accountability. No apparent tracking or management control mechanisms were in place to assure that the issues were being handled in a manner and time period appropriate to their safety implications.

A second issue discussed in the report was the "Present Import Type Certification System - Seattle." The review team found that two mistakes can be made in a certification project: 1) certification of a product that does not meet 14 CFR Part 25 standards, and 2) disparate treatment of applicants. The team concluded:

> The organization, defined roles, and established procedures within the Transport Airplane Certification Directorate have gone a long way toward ensuring standardization of import certification programs. However, the high level of management control appears

> to be preventing timely decisions and publication of policy material. Issue papers are being used as a means of documentation and standardization. This goes beyond the original scope intended for issue papers. Certification engineers seem unfamiliar with the bilateral concept and unsure of the depth of involvement required for certification. To further complicate this, there seems to be a lack of resources to do the task at hand....The Standardization Branch seems to have reached a critical stage in coping with the increasing European workload and complexity of foreign-manufactured airplanes.

The report cited, in the discussion about the "Present Import Type Certification System - Washington," that "some concern was expressed about the many BAA's having different language and scope and, in many cases, being obsolete in dealing with today's environment of increased unilateral certification programs." The team concluded that "there is a need to review all BAA's for consistency in language and scope and for currency."

1.18.8 Federal Regulations for Flight Operations in Icing Conditions

There are several Federal Aviation Regulations that either impose limitations on the operation of aircraft in icing conditions, or provide guidance to pilots when operating conditions are conducive to icing. Both 14 CFR Part 91.527(b) and 135.227(b), state:

> Except for an airplane that has ice protection provisions that meet section 34 of Appendix A, or those for transport category airplane type certification, no pilot may fly--
>
> (1) Under IFR into known or forecast light or moderate icing conditions; or
>
> (2) Under VFR into known light or moderate icing conditions; unless the aircraft has functioning deicing or anti-icing equipment protecting each propeller, windshield, wing stabilizing or control surface....

In addition, 14 CFR Part 91.527(c) and 135.227(d) state:

> Except for an airplane that has ice protection provisions that meet section 34 of Appendix A, or those for transport category airplane type certification, no pilot may fly an aircraft into known or forecast severe icing conditions.

As for those aircraft being operated under 14 CFR Part 121, paragraph 121.629, states:

> No person may dispatch or release an aircraft, continue to operate an aircraft en route, or land an aircraft when in the opinion of the pilot in command or aircraft dispatcher (domestic and flag carriers only) icing conditions are expected or met that might adversely affect the safety of flight.

1.18.9 New Technology

1.18.9.1 Stall Protection System

Stall protection systems on transport-category airplanes typically use a fuselage mounted angle-of-attack (AOA) sensor. Such sensors cannot detect airflow separations on an airfoil, therefore their usefulness for stall protection systems is limited to airfoil configurations where aerodynamic characteristics are known. Since small amounts of contamination, such as ice on the surface of an airfoil, can significantly alter the aerodynamic characteristics of an airfoil, typical stall warning devices do not account for the presence and effect of contaminants. The Safety Board has investigated several aircraft accidents in which airframe ice and/or snow contamination was found to have been a contributing factor.

There is new technology available that can detect airflow separation on aerodynamic surfaces. One new system measures the pressure in the airflow above the upper wing surface with a probe located at about 70 percent chord (varies by airplane), inboard of the ailerons. The system has been shown to effectively detect upper wing surface turbulence associated with airflow separation, both in flight and during the takeoff roll, once the airplane has accelerated to at least 50 knots. According to a Society of Automotive Engineers (SAE) technical paper,[77] developmental testing found that:

> Conventional stall warning systems, which use a fuselage mounted AOA sensor, do not measure the actual stalling condition at the wing. The key to determining an early stall due to the presence of contamination is to measure the flow directly at the lifting surface. Local velocity changes in a region above the upper surface of the wing provide a consistent indication of an approaching aerodynamic stall even when contamination is present. This method of stall warning also offers new levels of safety during low level windshear recovery and takeoff performance monitoring.

ATR had established a test program that evaluated the effectiveness of this device before this accident. The system was tested on an ATR 72 in January 1994; and it was tested on ATR-42-500 in December 1994. In addition to ATR airplanes, tests have been conducted with the detection device mounted on a Cessna 421 (cabin-class piston twin), a NASA Sabreliner (business jet), and a Fokker 100 (passenger jet). Additionally, wind tunnel tests were conducted with various amounts of surface roughness and ice shapes on various airfoil designs.

A second new type of airflow separation detection system measures the change in sound (amplitude and frequency) of the airflow over the surface of an airfoil. This system had not been flight tested before this accident, but subsequent wind tunnel tests at the NASA Lewis Research Center showed consistent reliability in the detection of airflow separation.

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[77]SAE Technical Paper 922010, Stall Warning Using Contamination Detection Aerodynamics, by Paul Catlin, B.F. Goodrich Aerospace Avionics Systems, Presented at Aerotech '92, October 1992.

2. ANALYSIS

2.1 General

The flightcrew was properly certificated, and each crewmember had received the training and off-duty time prescribed by the Federal regulations. There was no evidence of any preexisting medical condition that might have affected the flightcrew's performance.

The air traffic controllers involved with flight 4184 were properly certificated and provided the required services to the flightcrew. The performance of the FAA's air traffic management and weather dissemination systems is discussed later in this report.

The airplane was certificated, equipped and maintained in accordance with Federal regulations and approved procedures. There was no evidence of preexisting mechanical malfunctions or other failures of the airplane structure, flight control systems, powerplants or propellers that would have contributed to the accident.

The evidence revealed that the crew of flight 4184 experienced a sudden autopilot disconnect, uncommanded aileron deflection, and rapid roll of the airplane consistent with airflow separation near the ailerons caused by a ridge of ice that formed aft of the deice boots, on the upper surface of the wing.

The accident was unsurvivable, and the catastrophic impact and destruction of the airplane precluded a complete inventory of components. However, all major structural pieces were recovered and examined. Based on the ground scars, distribution of the wreckage, damage to the horizontal stabilizer, elevators, outboard wing sections and the ailerons, FDR data and sounds recorded on the CVR, the Safety Board concludes that the outboard portion of both wings and the horizontal tail separated in flight, in close proximity to the ground. The structural separation was due to excessive aerodynamic loads.

After summarizing the accident sequence, this analysis addresses the meteorological conditions that existed in the area of the LUCIT intersection at the time of the accident, the provision of weather data to the flightcrew, icing definitions, methods of forecasting icing, ATR 72 flight characteristics with ice accretions, the FAA's certification of the ATR 42 and 72, DGAC and FAA oversight of the continuing airworthiness of ATR airplanes, the Bilateral Airworthiness Agreement between France and the United States, Air Traffic Control policy and practices, the flightcrew's actions during the flight, unusual event/attitude recovery, and the management structure of Simmons Airlines/AMR Eagle and its oversight by the FAA.

2.2 Summary of Accident Sequence

FDR data revealed that at 1517, while the airplane was descending to 10,000 feet, the flightcrew activated the anti-icing/deicing system to Level III, an action that is required whenever the airplane is accreting ice. At that time the propeller speed was set at 86 percent of maximum RPM, which is also a requirement for flight in actual or potential icing conditions (total air temperature less than +7 degrees C in the presence of visible moisture). At 1523, just prior to the airplane entering the holding pattern at LUCIT, the Level III anti-icing/deicing system was deactivated. At 1525, as the airplane was entering the holding pattern, the propeller speed was reduced to 77 percent. According to AMR Eagle procedures, this action is consistent with the reduction of anti-icing/deicing systems to Level I, which is appropriate only for flight outside of actual or potential icing conditions.

The FDR indicated that at 1540, the Level III ice protection system was activated and the propeller speed was increased to 86 percent. However, FDR data also revealed that subsequently on two occasions during the holding pattern preceding the initial upset, there was evidence of small drag increases that were probably the result of ice accretions on the airplane. The first drag increase occurred at approximately 1533 (about 24 minutes before the upset[78]) just before the flaps were extended to 15 degrees. The second increase was evident at about 1551 (6 minutes before the upset). It is likely that the airplane intermittently encountered areas of large supercooled drizzle/rain drops while it was holding which contributed to the formation of a ridge of ice on the upper surface of the wing, aft of the wing deice boots, in front of the ailerons.

The crew received a clearance to descend to 8,000 feet. At 1557:23, as they were descending at 185 KIAS, the CVR recorded the activation of the aural flap overspeed warning. The flightcrew retracted the flaps in response to the

[78]The total time from the start of the hold to the upset was about 39 minutes.

warning. The FDR data indicate that as the flaps retracted, the autopilot increased the pitch attitude to maintain a preset vertical speed for the descent.

As the airplane pitched nose up and the AOA increased through 5 degrees, the airflow in the area of the right aileron began to separate from the wing upper surface because of the ice ridge. As the AOA continued to increase, the airflow separation in the area of the right aileron also increased, causing a reversal of the right aileron hinge moment characteristics. Although the right aileron hinge moment reversal caused the ailerons to deflect rapidly to a right-wing-down (RWD) position, the AOA was not sufficient to activate the stall warning system prior to the aileron deflection. The autopilot could not control the aileron deflection rate, which exceeded that allowed by the autopilot so the autopilot disconnected.

Within 0.25 seconds of the autopilot disconnection, the ailerons fully deflected to the RWD position[79] and the airplane rolled rapidly to the right until reaching 77 degrees RWD. An immediate nose-down elevator deflection reduced the AOA; and the ailerons were deflected LWD by the flightcrew to counter the right roll. The airplane began to roll back towards a wings-level-attitude. The crew then applied 2 to 3 degrees of left rudder and nose-up elevator. The flightcrew's aileron and rudder control inputs reduced the bank angle to 55 degrees RWD. However, as the AOA increased to more than 5 degrees, the airflow over the right aileron separated again, resulting in a second aileron hinge moment reversal and rapid RWD aileron deflection.

The airplane rolled again to the right for 9 seconds, rolling approximately 1 and 1/4 times. During this roll, elevator position increased to 8 degrees nose-up, the pitch trim remained constant, the airspeed increased to more than 250 KIAS, the vertical acceleration increased to more than 2 G, the AOA remained greater than 5 degrees, and the aileron position remained RWD and oscillatory. The nose-up elevator and constant pitch trim resulted in the AOA remaining above the airflow separation AOA of 5 degrees during this 9 second period. The reduction of nose-up elevator deflection at the end of this 9 second period resulted in the AOA decreasing. As the AOA decreased through 5 degrees, the airflow over the right aileron reattached, allowing the flightcrew to regain aileron control. The ailerons momentarily deflected to 6 degrees LWD and then stabilized close to the neutral position. The airplane immediately began rolling in the LWD

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[79]Both the Safety Board and ATR analyses indicate that neither the autopilot, the roll spoiler system, nor any other airplane system were capable of generating this rapid aileron deflection.

direction, back towards a wings level attitude, with nearly neutral aileron position and 2 degrees nose-left rudder. At this point, the airplane was descending through approximately 6,000 feet, at a rate of about 400 feet per second (24,000 feet per minute).

As the airplane rolled toward wings level, the normal acceleration increased to 2 G, and the pitch attitude stopped decreasing at 73 degrees nose down. The flightcrew accelerated the pullout with a 2 to 3 degree nose-up elevator deflection. As the airplane descended through 3,700 feet, the airspeed increased through 327 KIAS, the pitch attitude increased through 60 degrees nose down, the roll angle decreased through 50 degrees RWD, the vertical acceleration increased through 2.3 G, and the captain made the statement "nice and easy." About 3 seconds later, as the airplane rolled through wings level, and the normal acceleration increased to more than 3 G, the GPWS began sounding its "TERRAIN TERRAIN" warnings. Approximately 1.7 seconds later, as the altitude decreased through 1,700 feet, the first officer made an expletive comment, the elevator position and vertical acceleration began to increase rapidly (to more than 3.7 G), and the CVR recorded a loud crunching sound. The CVR and FDR data end 0.5 second later. Analysis of the airplane wreckage indicates that the outboard 10 feet of the left and right wings, as well as the horizontal stabilizer, separated from the airframe at a very low altitude.

The first officer's expletive comment occurred when the airplane was descending through 1,700 feet, which was most likely just after the airplane descended through the base of the clouds (the clouds were broken at about 2,100 feet). The Safety Board concludes that both pilots saw the ground, realized their close proximity, nose-down attitude, and high descent rate, and made an additional nose-up elevator input. This elevator input combined with the high airspeed (about 115 KIAS over the certified maximum operating airspeed) resulted in excessive wing loading and the structural failure of the outboard sections of the wings.

2.3 Meteorological Factors

2.3.1 General

Based on the analysis of all available data, reports from pilots and evaluations by several atmospheric scientists and researchers, the Safety Board concludes that flight 4184 encountered a mixture of rime and clear airframe icing in supercooled cloud and drizzle/rain drops, while in the holding pattern at the LUCIT intersection. The supercooled drops in the area were estimated to be greater than 100 microns in diameter, with some as large as 2,000 microns. The liquid water content (LWC) was estimated to have varied from less than 0.1 to nearly 1.0 gram per cubic meter. The ambient air temperature in the area of the holding pattern (10,000 feet) was about minus 3 degrees C, with the freezing level between 7,000 and 8,000 feet, and the cloud tops between 19,000 and 30,000 feet. In addition, there were ice crystals present in the atmosphere along the flightpath traversed by flight 4184.

The LWC estimates were predicated on the maximum and minimum reflectivity values from the WSR-88D Doppler weather radar located at Romeoville, Illinois (KLOT), the upper air data for the area of the LUCIT intersection, and calculations performed using the Safety Board's ICE4A computer program and a mathematical equation developed by the U.S. Air Force.

The drop sizes in the area of the accident were estimated using the WSR-88D radar data. PIREPs support the existence of large drops in the area east of the accident site. The captain of one airplane stated that there was a mixture of rain with snow at 1610:52, when they reported to ATC, "well we're in and out of some pretty heavy rain with some sleet in it, started about fourteen thousand feet and it's continuing still." At the time of this report, as estimated from data recorded by the WSR-88D, there was a weak weather echo that included an area of precipitation with an estimated LWC of 0.1 gram per cubic meter. Based on this LWC and radar reflectivity, the drop sizes were likely as great as 2,000 microns. This is consistent with the report of "rain" by the captain.

The existence of large supercooled drops in the accident area is also supported by the distribution of radiative temperatures measured by the GOES 8 satellite, which included temperatures that were greater than minus 18 degrees C. Such temperatures are conducive to the presence of large supercooled drops. Also, the GOES 8 satellite imagery indicated the presence of rolling wave cloud features, which are indicative of windshear. The presence of windshear conditions can, and often does, result in the broadening of the drop size distributions to include large drops.

2.3.2 Provision of Weather Information to the Crew of Flight 4184

AIRMET "Zulu," Update 3, issued at 1445, by the National Aviation Weather Advisory Unit (NAWAU), Kansas City, forecast "light to moderate icing in clouds and in precipitation" for the large area covered by the AIRMET. The forecast was consistent with PIREPs for the area. However, the icing and turbulence information strip issued about 1530 by the Center Weather Service Unit (CWSU) meteorologist at the Chicago ARTCC, which was pertinent to a smaller, more defined area around northwest Indiana (including the accident site), only indicated the possibility of light rime/mixed icing in clouds at or below 18,000 feet. The CWSU meteorologist stated that he did not forecast moderate icing for this area because there were no applicable PIREPs to indicate the existence of such conditions in that particular area.

The Safety Board concludes that the forecasts produced by the National Weather Service (NWS) were substantially correct based on the available information, and the actions of the forecasters at the NAWAU and the CWSU meteorologists at the Chicago ARTCC were in accordance with NWS guidelines and procedures. Further, based on information provided by the controllers after the accident, it appears that the Chicago ARTCC controllers were only aware of the CWSU forecast of light icing, and not the NAWAU forecast of light to moderate icing, as noted in the updated AIRMET.

However, the Safety Board does have some concerns about the lack of weather information disseminated to the crew of flight 4184. Specifically, the information contained in AIRMETs "Zulu," "Sierra" and "Tango," and Update 2, was available well in advance of flight 4184's departure, and was pertinent to flight 4184's route of flight. This information was not, and typically would not be, included in the weather portion of the flight release provided by Simmons Airlines/AMR Eagle. Further, it could not be determined if the flightcrew had obtained the updated weather information via the HIWAS while en route or prior to the recorded conversations on the CVR.

14 CFR Part 121.601 (b) and (c) state, in part, respectively, "...before beginning a flight the aircraft dispatcher shall provide the pilot in command with all available weather reports and forecasts of weather phenomena that may affect the safety of flight...," and that during a flight the dispatcher shall provide "any additional available information of meteorological conditions including adverse weather phenomena." FAA Order 8400.10, paragraph 1423, requires that AIRMET

information be considered in the preflight planning process; however, Center Weather Advisories (CWAs) are not required to be included or considered. Simmons Airlines dispatchers review the AIRMETs, but they do not typically include them in the flight release package. CWAs are not included in the release packages because they are not required. The Safety Board is concerned that because Simmons Airlines dispatchers do not include AIRMETs (which include information regarding moderate icing) and CWA information, flightcrews may not be provided "...all available weather reports and forecasts of weather phenomena...." necessary to make informed decisions.

Although the Safety Board concludes that the actions of the crew of flight 4184 (see section 2.9 of this report) would not have been significantly different even if they had received the AIRMETs, the Safety Board nonetheless believes that Simmons Airlines/AMR Eagle should require its dispatchers to include in the flight release AIRMETs and CWAs that are pertinent to the route of flight so that flightcrews can consider this information in their preflight and in-flight decisions. Further, the Safety Board believes that the FAA should direct its POIs to ensure that all air carriers require their dispatchers to provide pertinent information, including AIRMETs and CWAs, to flightcrews for preflight and in-flight planning purposes.

With regard to the availability of in-flight weather information, the Safety Board notes that the HIWAS broadcast generated by the Kankakee AFSS included all of the icing information contained in AIRMET "Zulu," Update 3. Although the HIWAS broadcast generated by the Terre Haute AFSS indicated that icing was forecast above the freezing level, it did not indicate the icing levels, the intensity and type of icing, or the existence of icing conditions in clouds and precipitation included in AIRMET "Zulu," Update 3. The Safety Board understands that the HIWAS broadcasts are intended to provide hazardous weather information in a short format that will facilitate the pilot's understanding of the potentially hazardous conditions. However, the Safety Board concludes that safety would be enhanced if the information were presented more consistently among HIWAS stations and if those broadcasts included all of the information pertinent to the safety of flight, such as the altitudes of the icing conditions, the intensity and type of icing, and the location of the actual or expected icing conditions (i.e. in clouds and precipitation). The Safety Board believes that the FAA should require that HIWAS broadcasts consistently include all pertinent information contained in weather reports and forecasts, including In-Flight Weather Advisories (AIRMETs, SIGMETs, and Center Weather Advisories). The Safety Board also believes that the FAA and air carriers should reemphasize to pilots that HIWAS is a source of timely weather information and should be used whenever aircraft are operating in or near areas of potentially hazardous weather conditions.

2.3.3 Icing Definitions

The AIM sets forth the following icing definition:

1) **Trace** - Ice becomes perceptible. Rate of accumulation is slightly greater than the rate of 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);

2) **Light** - The rate of accumulation may create a problem if flight is prolonged in this environment (over 1 hour). Occasional use of deice/anti-icing equipment removes/prevents accumulation. It does not present a problem if the deicing/anti-icing equipment is used;

3) **Moderate** - The rate of accumulation is such that even short encounters become potentially hazardous and use of deicing/anti-icing equipment or flight diversion is necessary;

4) **Severe** - The rate of accumulation is such that deicing/anti-icing equipment fails to reduce or control the hazard. Immediate flight diversion is necessary.

While these icing severity definitions provide some basis for assessing ice accumulation in PIREPs, they are subjective and are of limited use to pilots of different aircraft types. For example, using these definitions, "light" icing for a Boeing 727 could be "severe" icing for an ATR 72 or a Piper Malibu. The icing report provided by the captain of the A-320 Airbus that was holding at the HALIE intersection, near Roselawn, indicated that he observed about 1 inch of ice accumulate rapidly on his aircraft's icing probe. The captain provided a PIREP to ATC and reported the icing as "light rime." He stated in an interview after the accident that the anti-ice equipment on the airplane "handled the icing adequately," and he believed the icing intensity to have been "light to moderate."

The Safety Board concludes that icing reports based on the current icing severity definitions may often be misleading to pilots, especially to pilots of aircraft that may be more vulnerable to the effects of icing conditions than other aircraft. The Safety Board believes that the FAA should develop new aircraft icing intensity reporting criteria that are not subjective and are related to specific types of aircraft.

In addition, the investigation revealed a problem with the aviation community's general understanding of the phrase "icing in precipitation," which is used by the NWS but is not defined in any aeronautical publications, including advisory circulars (ACs), Part 1 of the Federal Aviation Regulations or the Aeronautical Information Manual (AIM). This phrase is often contained in in-flight weather advisories; however, it does not typically specify types of precipitation. According to the NWS, this phrase is intended to include freezing drizzle and freezing rain. The Safety Board concludes that defining “icing in precipitation” in such publications would make pilots and dispatchers more aware of the types of precipitation and icing conditions that are implied by this phrase. Therefore, the Safety Board believes that the FAA should provide a definition of the phrase "icing in precipitation" in the appropriate aeronautical publications.

Further, the Safety Board believes that the FAA should require all principal operations inspectors (POIs) of 14 CFR Part 121 and 135 operators to ensure that training programs include information about all icing conditions, including flight into freezing drizzle/freezing rain conditions.

2.3.4 Methods of Forecasting Icing Conditions

The current methods of forecasting icing conditions are of limited value because they typically cover very large geographic areas and do not provide specific information about LWC or water drop sizes. Present forecast techniques use only relative humidity and temperature. According to the scientist from NCAR who testified at the Safety Board’s public hearing, it is not possible to infer the severity of icing using only temperature and humidity. The severity of the icing also depends on the LWC and the size of the water droplets, information which is not currently identified and forecasted.

A current state-of-the-art atmospheric model was employed by NCAR in an attempt to determine if the icing conditions that are presumed to have been present in the accident area could have been forecast accurately. The atmospheric modeling did not generate a forecast of freezing rain or freezing drizzle for the area of the LUCIT intersection. The scientist from NCAR testified that "...models aren't perfect, forecasts aren't perfect... even though it's the current state-of-the-art of atmospheric modeling."

There were no (and still are not any) reliable methods for flightcrews to differentiate, in flight, between water drop sizes that are outside the 14 CFR Part 25, Appendix C, icing envelope and those within the envelope. Further, although side window icing was recognized as an indicator of ice accretions from freezing drizzle during flight tests of an ATR 72 after the accident, the crew of flight 4184 could not have been expected to know this visual cue because its significance was unknown to the ATR pilot community at the time. Moreover, in-service ATR incidents and pilot reports have shown that side window icing does not always accompany ice accretions aft of the deice boots, which ATR has stated only occurs in freezing drizzle and/or freezing rain.

The Safety Board acknowledges the efforts of atmospheric research in the meteorological community and hopes that its important findings will eventually provide the aviation industry with a better understanding of the freezing drizzle/rain phenomenon. The Safety Board concludes that the continued development of equipment to measure and monitor the atmosphere (i.e., atmospheric profilers, use of the WSR-88D and Terminal Doppler weather radars, multispectral satellite data, aircraft-transmitted atmospheric reports, and sophisticated mesoscale models), and the development of computer algorithms, such as those contained in the FAA's Advanced Weather Products Generator (AWPG) program to provide comprehensive aviation weather warnings, could permit forecasters to refine the data sufficiently to produce more accurate icing forecasts and real-time warnings. Therefore, the Safety Board believes that the FAA should continue to sponsor the development of methods to produce weather forecasts that define very specific locations of potentially hazardous atmospheric icing conditions (including freezing drizzle and freezing rain) and to produce short-range forecasts ("nowcasts") that identify icing conditions for a specific geographic area with a valid time of 2 hours or less.

2.4 ATR Flight Characteristics in Icing Conditions

As discussed previously, the evaluation of meteorological data indicates that the range of water droplet sizes at Roselawn probably varied from cloud drops of less than 50 microns to drops as large as 2,000 microns. The 100 to 140 micron MVD drop sizes in the December 1994 ATR icing tanker tests resulted in ice ridges just aft of the active portion of the deice boots and subsequent autopilot and aileron behavior comparable to that noted in the FDR data for the accident. Control wheel force data from the icing tanker tests and the subsequent flight tests with artificial ice shapes indicated that the freezing drizzle ice shapes caused trailing edge flow separation and subsequent aileron hinge moment reversals. Therefore, the Safety Board concludes that the ATR 42 and 72 can experience ice-induced aileron hinge moment reversals, autopilot disconnects, and rapid, uncommanded rolls if they are operated in near-freezing temperatures and water droplet MVDs typical of freezing drizzle.

The freezing drizzle encounters in the December 1994 ATR icing tanker tests resulted in ice ridge accretions aft of the deice boots in both the flaps 0 and flaps 15 configurations. However, the tanker test results showed that at flaps 15, there was no pronounced ice ridge on the lower wing surface as there was when the ice accreted at flaps 0. Further, there was a much smaller drag increase when the ice accreted at flaps 15 than there was when the ice accreted at flaps 0. Based on the small drag increases apparent in the data from flight 4184, it is apparent that the ice ridge that formed during the accident flight developed and grew primarily after the flaps were extended to 15 degrees.

Also, the ridge of ice that formed in the tanker tests and in the NASA-Lewis icing tunnel tests tended to shed pieces randomly along the span of the wing, resulting in broken, jagged ridges. Although these tests only involved exposing a small portion of the outboard section (including the aileron) of one wing to freezing drizzle, it is likely that the random nature of the partial ice shedding would result in airflow asymmetry over the left and right ailerons in a natural encounter of the airplane with freezing drizzle. Such asymmetry could cause an aileron hinge moment reversal.

Because the ailerons on the ATR 72 are not hydraulically actuated, a pilot would have to overcome manually the rapid increase in force produced by a hinge moment reversal. For the accident conditions at the initiation of the aileron hinge moment reversal (185 KIAS, 1.0 G), ATR indicates that approximately 60 pounds of force on the control wheel would have been required to maintain a wings-level-attitude. This amount of force is in compliance with Federal Aviation Regulations for temporary control wheel forces. However, the Safety Board concludes that rapid, uncommanded rolls and sudden multiple onsets of even 60 pounds of control wheel force without any form of warning or pilot training for such unusual events would, and most likely did in this case, preclude the flightcrew from effecting a timely recovery.

The Safety Board recognizes that the risk of another ATR 42 or 72 accident resulting from an uncommanded aileron excursion in freezing drizzle/freezing rain has been reduced by the addition of extended deice boots, improved operational procedures, extensive crew training, and heightened awareness by pilots. Because wind tunnel and in-flight tanker tests have been performed for only a limited range of icing and flight conditions, the Safety Board remains concerned whether, even with the improvements, the airplane can be controlled under all naturally occurring combinations of conditions of liquid drop size and content, temperature, airplane configuration, load factors, speeds, and time of exposure. Moreover, the Safety Board found that ATR's post-Roselawn brochure entitled, "ATR Icing Conditions Procedures," still does not adequately address or clearly represent the exact nature of the ATR ice-induced aileron hinge moment reversal.

Additionally, as part of the investigation, the Safety Board reviewed historical accident and incident data of other similar turbopropeller aircraft. The data did not show other airplane models to have a similar incident/accident history involving uncommanded aileron excursions in the presence of freezing drizzle/freezing rain. One possible reason for this is that other model aircraft use hydraulically powered ailerons, smaller mechanical ailerons with larger hydraulically powered spoilers, or different balance/hinge moment control devices to provide adequate roll control with less propensity for aileron hinge moment reversals. The Safety Board understands that ATR is considering design changes to the lateral control system for current and future ATR airplanes that are expected to reduce the susceptibility to flow separation-induced aileron hinge moment reversals and/or uncommanded aileron deflections. The Safety Board concludes that such design changes, if effective, would reduce the need to rely on the changes to flight operations and pilot training that have already been mandated to ensure the safety of flight. Thus, the Safety Board believes that the FAA should encourage ATR to test lateral control system design changes and, if they correct the aileron hinge moment reversal/uncommanded aileron deflection problem, require these design changes on all existing and new ATR airplanes.

2.5 ATR Certification For Flight into Icing Conditions

The Safety Board has found no evidence that the ATR 42 and 72 were not properly certificated for flight into icing conditions under FAR/JAR Part 25.1419, FAR/JAR Part 25, Appendix C, and DGAC Special Condition B6. The results of a thorough review of the original airplane certification and the subsequent "Special Certification Review," including icing tanker tests, indicate that the airplane met the existing regulations. However, the investigation has raised a number of concerns relating to the process for certifying an airplane for flight into icing conditions.

Among these concerns are the regulatory authorities' acceptance of a limited number of icing test data points, most of which are not near the boundaries of the envelope; the limited range of conditions (LWC and MVD size) provided by the Appendix C icing certification envelope; the lack of standardized methods for processing LWC and MVD data; the implied authorization of flight into conditions beyond the envelope; and the certification of stall protection systems that are intended to prevent exposure to undesirable (even dangerous) characteristics of the airplane without a requirement for the manufacturer to advise the FAA, operators and pilots of such characteristics.

This investigation has revealed that the ATR 42 and 72 were not required to be tested throughout a significant portion of the icing conditions that are specified in the Appendix C icing envelope. The limited number of test points accepted by the FAA as sufficiently comprehensive were well within the boundaries of the envelope and did not include the warmer, near freezing conditions at the upper boundary of the Appendix C envelope in which run-back icing and asymmetric sliding/shedding are likely to occur. Thus, by allowing limited data well within the envelope to suffice for certification purposes, the FAA effectively precluded any chance of identifying the phenomena that led to flight 4184's ice ridge buildup, uncommanded aileron deflection and loss of control.

The Safety Board's concern about the adequacy of Appendix C criteria was heightened by the results of one December 1994 ATR icing tanker test in which ice accumulated behind the active portion of the ATR 72's deice boots during exposure to water droplet sizes of only 57 microns MVD, which is only slightly outside the Appendix C envelope. Further, data developed by NACA, the NASA predecessor, indicated in the 1950s that MVDs of 70 microns or more could be encountered in layer clouds. Flight in layer clouds is not an unusual event in this country, but flight into layer clouds can result in encounters with icing conditions beyond those set forth in 14 CFR Part 25, Appendix C. Several ATR 42 icing incidents with ice aft of the boots (Air Mauritius, Ryan Air, and Continental Express at Burlington) occurred in layer clouds, which supports the conclusion that icing encounters in high altitude layer clouds can exceed the capabilities of aircraft certified to the Appendix C envelope.

Thus, because the Appendix C envelope is limited and does not include larger water drop conditions, such as freezing drizzle or freezing rain (conditions that can be routinely encountered in winter operations throughout much of the northern United States, and were most likely encountered by flight 4184), the Safety Board concludes that the current process by which aircraft are certified using the Appendix C icing envelope is inadequate and does not require manufacturers to sufficiently demonstrate the airplane's capabilities under a sufficiently realistic range of icing conditions.

In addition, the lack of standardized methods for processing icing data to determine MVDs raises concern that certification icing tests may be conducted at actual MVDs below the calculated values. For example, during the series of icing tanker tests at Edwards AFB, it was determined that two generally accepted methods of calculating MVD and LWC provided significantly different results. One method was developed by Particle Measuring Systems, the manufacturer of the instruments used to measure the icing conditions, and the other method was developed by NCAR. It was found that when processing any given set of raw icing data collected behind the icing tanker, the two methods provided MVD and LWC results that differed by as much as a factor of 2. These differences are attributed to the different mathematical equations used by the two methods and raise concerns about the accuracy of the results. Therefore, it is possible that airplanes certificated in accordance with Appendix C criteria may not actually have been tested in the icing conditions described in the certification documentation. Thus, the Safety Board believes that the FAA should revise the icing certification requirements and advisory material to specify the numerical methods to be used in determining median volume diameter (MVD) and liquid water content (LWC) during certification tests.

Further, although no aircraft are certified for flight into freezing drizzle or freezing rain, the ATR 72 flight manual did not specify the operational limits and capabilities of the airplane in conditions such as freezing drizzle and freezing rain. Although the "Normal Procedures/Flight Conditions" section of the FAA-approved

ATR 42 flight manual (AFM), section 3-02, page 1, dated March 1992, contained the statement, "Operation in freezing rain must be avoided," the "Normal Procedures/Flight Conditions" section of the ATR 72 AFM did not contain the same statement, or any other limitation or prohibition of operation on the ATR 72 in such conditions. At the Safety Board's public hearing, the ATR Vice President, Flight Operations for North America, testified that the omission of this information from the ATR 72 manuals was "not intentional."

Currently, FAA ground deice and anti-ice programs permit operators to dispatch aircraft into freezing drizzle and light freezing rain[80] provided they use Type II anti-ice fluid and respect the specified holdover timetables. Specifically, Flight Standards Information Bulletin (FSIB) for Air Transport (FSAT), 95-29, dated October 25, 1995, states that Type II deicing fluid will be used when "operating during light freezing rain and freezing drizzle weather conditions" and that the "use of special procedures (i.e. visual inspections, remote deice capability) is required." The Safety Board recognizes that the FAA's intent of this FSAT is to provide operators with the means to dispatch airplanes that will quickly depart and climb through the freezing drizzle or light freezing rain conditions and that the FAA's permission of limited operations in freezing drizzle and light freezing rain is apparently based on the assumption that the airplane will depart within the prescribed "holdover" time of the anti-ice fluid, and transit through the freezing drizzle/light freezing rain conditions with minimal exposure. However, FSAT 95-29 does not specifically state that continued flight in such conditions is prohibited. The Safety Board is concerned that in some situations it may be necessary to operate in such conditions for an extended period of time. One such situation is the failure of an engine shortly after takeoff, which could require maneuvering for an indeterminate period of time while returning to the departure airport where freezing drizzle or light freezing rain conditions are known to exist.

Further, although it is known by many in the aviation community that flight into freezing drizzle or freezing rain is not safe, the Safety Board is unaware of an explicit provision in the Federal Aviation Regulations that prohibits flight into freezing drizzle and freezing rain. Additionally, as was noted in the Safety Board's 1981 study on aircraft icing, airplanes certificated for flight into known icing are

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[80]The National Center for Atmospheric Research (NCAR) definition for light freezing rain is: "measured intensity up to 0.10 in/hr (2.5 mm or 25 $gr/dm^2/hr$); Maximum 0.01 inch in 6 minutes from scattered drops that, regardless of duration, do not completely wet an exposed surface up to a condition where individual drops are easily seen."

authorized to fly into weather conditions that produce "severe" icing under 14 CFR Parts 91, 135 and 121. However, by definition, severe icing conditions result in a rate of ice accumulation that exceeds the capabilities of the airplane deice/anti-icing system or that require immediate diversion from the planned route of flight.

The Safety Board is concerned that these unclear and inconsistent messages to pilots about the operation of aircraft that are certified for flight in icing conditions may create the misconception that flight in freezing drizzle and/or freezing rain is acceptable when it is not. Such confusing and apparently contradictory information could have contributed to the belief by Simmons Airlines/AMR Eagle management that it was permissible for ATR 42 and 72 airplanes to be dispatched and flown into conditions of freezing drizzle and light freezing rain when it disseminated a memorandum to its pilots in 1991 setting forth the conditions for such flights.

The Safety Board concludes that no airplane should be authorized or certified for flight into icing conditions more severe than those to which the airplane was subjected in certification testing unless the manufacturer can otherwise demonstrate the safety of flight in such conditions. Thus, the Safety Board believes that the FAA should revise its certification regulations 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 operation 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.

Many of the concerns raised about icing certification criteria in this investigation were previously identified by the Safety Board and were the basis for safety recommendations issued in 1981 to the FAA and NOAA as a result of the Safety Board's study on icing avoidance and protection. The study raised concerns about the adequacy of the Appendix C envelope and icing certification, the inability to properly measure icing and atmospheric parameters forecast, the inadequacy of the icing severity definitions, and the inconsistency of being legally permitted to operate in conditions that are more severe than those to which the airplane is subjected during the certification process.

As a result of the study, the Safety Board recommended that the FAA evaluate individual aircraft performance in icing conditions and establish operational limits in terms of LWC and MVD for pilot use; review icing criteria in 14 CFR Part 25 and expand the certification envelope to include freezing rain as necessary; establish standardized procedures for icing certification; and resolve the incompatibility between the regulations and the definition of severe icing provided in the AIM.

However, the FAA has not acted positively on these recommendations. For example, in its June 7, 1982, response to Safety Recommendation A-81-115, which requested the evaluation of individual aircraft performance in icing conditions and establishing operational limits, the FAA stated, in part:

> ...Forecasts issued or icing conditions described in terms of intensity levels...should not affect the capabilities of icing certified aircraft to operate safely in icing conditions regardless of the size of aircraft. This is because icing-certified aircraft are evaluated to the full icing envelope expected in nature **as** defined in 14 CFR 25, Appendix C.

Safety Recommendation A-81-115 was classified "Closed—Unacceptable Action" on April 11, 1990.

In a subsequent response, dated August 28, 1995, to other Safety Board 1981 recommendations, which were still being held as "Open," the FAA again stated that it did not intend to initiate any action because:

> the FAA has put in place major programs in recent years which have addressed various anti-ice and deice 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 as requested by these safety recommendations. The FAA considers its actions to be complete.

The FAA has continually indicated in its responses to the 1981 safety recommendations during the past 14 years that sufficient research and data collection had been accomplished and that icing was not a significant problem for airplanes certified under 14 CFR Part 25, Appendix C. Despite the funding of research and occasionally providing positive written responses to some of the safety recommendations, the Safety Board found that the FAA's actions were not adequate to satisfy the intent of these recommendations; and in a November 20, 1995, letter it classified A-81-116 and -118 as "Open--Unacceptable Response." The Safety Board concludes that if the FAA had acted more positively upon the safety recommendations issued in 1981, this accident may not have occurred.

Additionally, the Safety Board understands that the FAA, as a result of this accident, is currently planning a review of its icing certification and operational regulations, including the icing severity definitions issue. The Board supports and encourages this action. However, the Safety Board believes that the FAA should revise 14 CFR Parts 91.527 and 135.227 in a timely manner to ensure that the regulations are compatible with the published definition of severe icing, and to eliminate the implied authorization of flight into severe icing conditions for aircraft certified for flight in such conditions.

Finally, the Safety Board notes that Special Condition B6, developed by the French DGAC in the 1980's and initially applied during the ATR 72 certification, includes a "zero G" flight test maneuver (pushover) designed to identify ice-induced elevator hinge moment reversals. The Safety Board understands that at least some manufacturers in the world aviation community (including the United States) are concerned that Special Condition B6 is too demanding, particularly the tailplane icing pushover test. However, the Safety Board concludes that the addition of a test procedure to determine the susceptibility to aileron hinge moment reversals in both the clean and iced-wing conditions could help to prevent accidents such as that involving flight 4184. Thus, the Safety Board believes that the FAA should develop a test procedure similar to the tailplane icing pushover test to determine the susceptibility of airplanes to aileron hinge moment reversals in the clean and iced-wing conditions.

2.5.1 Stall Protection Systems

The Safety Board is concerned that the FAA and other airworthiness authorities still permit airplane manufacturers to use stall protection systems (SPS) to prevent flightcrews from experiencing known undesirable flight characteristics unique to their particular aircraft design without requiring the manufacturers to reveal these characteristics to the airworthiness authorities, operators, and pilots. According to ATR, its use of an SPS to prevent, among other things, aileron hinge moment reversals in the clean and iced configurations was not explained to the airworthiness authorities or the operators because ATR was not required to do so. The Safety Board concludes that the failure of the DGAC and the FAA to require that they be provided with documentation of known undesirable post-SPS flight characteristics contributed to their failure to identify and correct, or otherwise properly address, the abnormal aileron behavior early in the history of the ATR icing incidents. Therefore, the Safety Board believes that the FAA should require aircraft manufacturers to provide, as part of the certification criteria, information to the FAA and operators about any known undesirable flight characteristics beyond the SPS and related shaker/pusher flight regime.

2.6 Continuing Airworthiness

2.6.1 Adequacy of Actions Taken by ATR After Previous ATR Incidents

ATR's analysis of the 1988 ATR 42 incident at Mosinee, Wisconsin, concluded that ice had formed on the upper surface of the wings, aft of the deice boots, because the airplane had been operated in conditions that were outside the certification envelope. ATR's analysis also concluded that the ice accretion changed the aileron hinge moments, resulting in an autopilot disconnect, uncommanded aileron deflection, and subsequent roll excursions. ATR stated that "…the ailerons tended to adopt the zero hinge moment position in absence of pilot reaction…." The zero hinge moment position referred to by ATR was 12.5 degrees. ATR further stated that, "…the control surfaces remained effective and, owing to their reaction alone, enabled the aircraft to recover a normal attitude, although control stability was affected, owing to the changes in hinge moment according to angle of attack, which was probably due to the presence of ice on the airfoil beyond the deicers, as is the case on all aircraft in freezing rain conditions."

Further, ATR had experienced aileron hinge moment reversals during the development of both the ATR 42 and 72. For example, the aileron hinge moment reversals that resulted during early flight tests of the ATR 72 occurred at low AOAs on a "clean" wing. The occurrence of hinge moment reversals prompted ATR in the late 1980s to develop and install vortex generators that were intended to raise the AOA at which the ailerons would become unstable and a hinge moment reversal would occur. In addition, during development of the ATR 72-210 series airplanes, ATR added additional vortex generators to further increase the AOA at which the aileron hinge moment reversals occurred. ATR also specifically designed the stall protection system to activate at AOAs lower than the AOA at which the ailerons would become unstable. The knowledge gained from flight testing about hinge moment reversals, the findings from the previous incidents, and ATR's active participation in the study of tailplane icing hinge moment reversals, leads the Safety Board to conclude that ATR recognized the reason for the aileron behavior in the previous incidents and determined that ice accumulation behind the deice boots, at an AOA sufficient to cause an airflow separation, would cause the ailerons to become unstable. ATR had sufficient basis to modify the airplane and/or provide airworthiness authorities, operators, and pilots with adequate, detailed information regarding this phenomenon.

Following the Mosinee incident, ATR issued an “Operators Information Message” (OIM), added the Anti-Icing Advisory System (AAS) and vortex generators in front of the ailerons to all ATR airplanes, proposed airplane flight manual (AFM) and flightcrew operating manual (FCOM) changes and developed an icing package for the ATR simulators. The 1989 OIM characterized the Mosinee incident in a manner that could have been interpreted by operators and pilots to indicate only that the ailerons became “stiff” or hard to move because of an accretion of ice, and that the autopilot was unable to move the ailerons and correct the increasing roll attitude. The OIM did not indicate that an ice accretion behind the deice boots in front of the ailerons, could cause them to overpower the autopilot, move uncommanded in an abrupt manner to their full travel limits, cause rapid rolls and create unusual lateral control behavior.

The 1989 icing simulation package provided to simulator manufacturers and aircraft operators by ATR for use in their ATR 42 training programs did not adequately present the effects of the icing event experienced by the Mosinee flightcrew or the crew of flight 4184. The modification did not model abrupt, full aileron and control wheel deflections with high control wheel forces that would typically be necessary to recover from an aileron hinge moment reversal. Further, AMR Eagle stated that in its simulator program, the pilots were taught to initiate recovery from a stall at the first indication of stick shaker, stall aural warning, airframe buffet or stick pusher, and that any training in an incorrect configuration, such as further increasing the AOA beyond stall warning to cause the airplane to roll off, would be classified as "negative" training.

In 1996, after the Roselawn accident, ATR provided simulator operators with another, more accurate icing simulation package. This simulator package would have provided the crew of flight 4184 with a higher awareness of the potential effects of icing conditions on ATR airplanes and the ability to recognize and probably recover from an uncommanded, unstable aileron movement. The Safety Board concludes that the 1989 icing simulation package developed by ATR for the training simulators did not provide training for pilots to recognize the onset of an aileron hinge moment reversal or to execute the appropriate recovery techniques.

The Safety Board notes that when ATR developed the AAS and the vortex generators following Mosinee, it also proposed changes to the ATR 42 AFM and FCOM. These changes were adopted in part by the German and Canadian airworthiness authorities; however, the DGAC and the FAA did not require these changes. In its 1992 Airworthiness Directive (AD) requiring the installation of the vortex generators, the FAA indicated that the vortex generator modification would "remove" the source of the abnormal aileron behavior; thus, it did not require the inclusion of ATR's proposed AFM or FCOM changes. The DGAC did not require the AFM or FCOM changes because they addressed a condition outside the certification envelope of the airplanes.

Although the AFM/FCOM changes proposed by ATR did enhance the existing icing information in the manuals, these changes did not warn pilots of unexpected autopilot disconnects or rapid and uncommanded aileron deflections to near their full travel limits with high, unstable control wheel forces. Thus, the Safety Board concludes that ATR's proposed AFM/FCOM changes, even if adopted by the DGAC and the FAA, would not have provided flightcrews with sufficient information to identify or recover from the type of event that occurred at Roselawn, and the actions taken by ATR following the incident at Mosinee were insufficient.

In 1990, ATR conducted flight tests with run-back ice shapes developed from the 1989 British blower tunnel tests and found that the ice shapes, although located aft of the boot on the under surface of the wing, did not adversely affect the stability and control of the airplanes. However, the height of the shapes was 1/4 inch, which ATR indicates was not sufficient to initiate an aileron hinge moment reversal prior to SPS activation.

Following the two ATR 42 incidents in 1991 (involving Ryan Air and Air Mauritius), which ATR also attributed to operation in icing conditions outside of the certification envelope, ATR published its 1992 All Weather Operations brochure.[81] The brochure, which was sent to all ATR operators, provided

[81]The All Weather Operations brochure, in which ATR consolidated general aircraft operating information for flight in all types of weather conditions (including freezing drizzle and freezing rain), was not provided by Simmons Airlines/AMR Eagle to its pilots. Simmons Airlines/AMR Eagle management stated that the brochure was not disseminated because some information was contrary to Federal regulations and because most of the information already existed in the various approved flight and operating manuals.

information about freezing rain, including temperature ranges that could produce such conditions. It stated "Aileron forces are somewhat increased when ice accretion develops, but remain otherwise in the conventional sense," which is inconsistent with the actual rapid and uncommanded aileron and control wheel deflections to near their full travel limits with unusually high, unstable control wheel forces. The brochure also stated "Freezing rain is capable of rapidly covering an aircraft with a sizable layer of clear ice, well beyond the usual accretion areas around the stagnation point." However, the statement does not specifically indicate that ice may accumulate a significant distance beyond the deice boots, although the wing leading edges and windscreen may be free of ice. Finally, the brochure stated that "Should the aircraft enter a freezing rain zone, the following procedures should be applied: Autopilot engaged, monitor retrim roll left/right wing down messages. In case of roll axis anomaly, disconnect autopilot holding the control stick firmly." However, this does not indicate that a roll trim message may not occur, or could occur coincident with the autopilot disconnecting (as it did with flight 4184), thus precluding sufficient time for the flightcrew to perform the recommended procedures, nor does it advise flightcrews to expect sudden autopilot disconnects, rapid and uncommanded aileron and control wheel deflections to near their full travel limits with unusually high, unstable control wheel forces. Therefore, the Safety Board concludes that the ATR All Weather Operations brochure was misleading and minimized the known catastrophic potential of ATR operations in freezing rain.

Following the 1993 incident at Newark, New Jersey, which ATR attributed to turbulence and freezing rain, and the incident about 1 year later at Burlington, Massachusetts (both of which involved aileron-hinge moment reversals in icing conditions), ATR had sufficient knowledge to conclude that the ATR 42 had a significant, recurring airworthiness problem in icing conditions outside the Appendix C icing certification envelope. Although ATR knew that the icing conditions encountered in these incidents were outside the icing certification envelope, ATR also knew that the airplanes were being flown more than occasionally into such conditions and that neither the vortex generators nor the operational information it had disseminated had corrected the problem or prevented recurrence. Therefore, the Safety Board concludes that ATR's failure to disseminate adequate warnings and guidance to operators about the adverse characteristics of, and techniques to recover from, ice-induced aileron hinge moment reversal events, and ATR's failure to develop additional airplane modifications, led directly to this accident.

2.6.2 Continuing Airworthiness Oversight by DGAC

ATR provided the DGAC (but not the FAA) with copies of all its incident analyses, including the incident at Mosinee, Wisconsin. Thus, the DGAC should have been fully aware that ATR had concluded that the Mosinee and other incident flightcrews had flown their airplanes into icing conditions that were beyond the Appendix C icing certification envelope. The DGAC should have recognized from the ATR analyses that such incidents resulted in unexpected autopilot disconnects, and rapid, uncommanded aileron and control wheel deflections.

As discussed in Section 2.6.1, following the 1991 Ryan Air and Air Mauritius incidents, ATR developed its 1992 All Weather Operations brochure in which the aileron behavior was vaguely discussed without directly alerting operators or pilots to the specifics of the prior incidents or providing explicit guidance on how to cope with aileron hinge moment reversals. The DGAC did not require ATR to provide more specific information to operators and pilots, nor did it require ATR to do further research and testing in icing conditions. Nonetheless, because ATR had indicated that the airplanes in these incidents were inappropriately flown in icing conditions beyond the certification envelope, and that in most cases the pilots had not increased the propeller speed to 86 percent (as required by the aircraft flight manual procedure for flight in icing conditions), it was reasonable for the DGAC to accept ATR's commitment to educate flightcrews with the All Weather Operations brochure as an adequate response at that time. However, the Safety Board concludes that the DGAC did not require ATR to include adequate information about sudden autopilot disconnects, and rapid, uncommanded aileron and control wheel deflections in its All Weather Operation brochure, nor did the DGAC require that ATR flightcrews receive mandatory training on this subject.

During its investigation of the 1993 Continental Express incident at Newark, New Jersey, ATR concluded that turbulence was a primary factor in the upset of the airplane. Excessive ice accumulation on the wings was also identified but attributed to freezing rain and the flightcrew's failure to increase the propeller speed from 77 percent to 86 percent as required by the flight manual. However, the DGAC should have known that the amount of turbulence in that incident (+/-0.3 G) was too low a turbulence level to cause aileron hinge moment reversals in a transport category aircraft, and therefore should have recognized that the freezing rain encounter was the reason for the unstable aileron behavior. Further, the 1994 investigation of the Continental Express incident at Burlington, Massachusetts, provided data that led to the conclusion that an ice-induced aileron hinge moment reversal occurred after "severe" ice had caused the airplane to decelerate and pitch up despite proper use of all ice protection procedures.

Based on the long history of ATR incidents in icing conditions, especially those that occurred after 1992, the DGAC should have recognized that the vortex generators, the AAS, and the All Weather Operations brochure were not sufficient to correct or prevent the recurrence of the ice-induced aileron hinge moment reversal problem. Further, it should have been clear that the ATR airplanes were still being flown into icing conditions that were beyond the Appendix C envelope or were otherwise conducive to aileron hinge moment reversals.

The Safety Board concludes that following the 1994 Burlington incident, the DGAC should have required ATR to take further action to correct the ice-induced aileron instability and to ensure that all operators and regulators were aware of ATR's analyses of the incidents and the characteristics of the phenomenon. Further, the Safety Board concludes that the DGAC's failure to require ATR to take additional corrective actions, such as performing additional icing tests, issuing more specific warnings regarding the aileron hinge moment reversal phenomenon, developing additional airplane modifications, and providing specific guidance on the recovery from a hinge moment reversal, led directly to this accident.

2.6.3 Continuing Airworthiness Oversight by FAA

As early as 1981, the Safety Board had recommended that freezing rain be included in the Appendix C envelope because aircraft operate in such conditions.[82] In 1983, Dr. Richard Jeck, now one of the FAA's experts in aircraft icing, raised similar concerns within the FAA. Following the 1988 Mosinee incident, the FAA became aware that the ATR 42 was susceptible to aileron hinge moment reversals in freezing drizzle/light freezing rain conditions. In a 1989 letter to the FAA, the Air Line Pilots Association (ALPA) stated that the AAS and vortex generator modifications to the ATR airplanes were a positive step forward in taking corrective action. However, ALPA questioned whether they were adequate to solve

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[82] See discussion in section 1.18.3.

the problem, and also stated its concern that pilots still had no definitive way of identifying when they encounter icing conditions that are outside the certification envelope. The FAA, which had indicated that the vortex generators would correct the aileron anomaly, did not respond to ALPA's concerns except to state that freezing rain is a "...rare, low altitude phenomena, that is generally easy to forecast and therefore avoid[able]."

The Safety Board is concerned that the FAA apparently misunderstood the function of the vortex generators when it approved their installation on the ATR 42 and rescinded the previously imposed flight restrictions. The language used in the airworthiness directive (AD) indicated that the FAA believed that the installation of vortex generators would eliminate the aileron hinge moment reversal problem, rather than only delaying the onset of the hinge moment reversal to a greater AOA. The Board is also concerned that apparently neither ATR nor DGAC corrected the FAA's misunderstanding.

In 1989, the manager of the FAA's airworthiness evaluation group (AEG) stated in a briefing paper that there had been 10 ATR icing incidents that warranted further study and that "...in the context of problem solving we would like to see flight tests on the ATR series aircraft with irregular shapes emulating "run-back" [ice]...." Despite the Safety Board’s request for information, the FAA was unable to provide the Safety Board with a copy of any FAA response to the concerns raised in this paper.

Further, in 1991, the FAA led an industry/government team in developing a more detailed understanding of the icing accidents attributed to tailplane icing. Freezing drizzle and freezing rain were a primary topic of discussion.

Following the 1991 Ryan Air and Air Mauritius incidents, neither ATR nor DGAC provided the FAA with copies of ATR's analyses of these incidents. Although some FAA staff may have been aware of these incidents and the 1992 ATR All Weather Operations brochure, the FAA may still not have had sufficient information to recognize that the ATR 42's susceptibility to aileron hinge moment reversal required further action by ATR.

Following the 1993 Newark, New Jersey, and the 1994 Burlington, Massachusetts, incidents, ATR and DGAC again did not provide the FAA with copies of ATR's analyses. Important information regarding these incidents was not provided to the FAA following the 1994 incident at Burlington. However, the FAA should have had sufficient information regarding specific events and general concerns to recognize the significance of the ATR problems in icing conditions and to recognize that the actions taken by ATR were insufficient to correct the aileron hinge moment reversal problems. The Safety Board concludes that the FAA's failure, following the 1994 Continental Express incident at Burlington, to require that 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. The determination by the Safety Board that the FAA's role in the causation of this accident was contributory and not directly causal stems from the failures of ATR and DGAC to provide important information to the FAA, and from the FAA's more secondary role than the State of manufacture in the chain of assuring continued airworthiness of the ATR airplanes.

The Safety Board evaluated the role of the FAA’s AEG to determine why it did not act to correct the problem with the ATR. FAA Order 8430.6C states that an AEG inspector will, "Provide expert information on aircraft in support of accident/incident investigations and assist in the development of corrective actions." In testimony at the Safety Board's public hearing, the AEG operations unit supervisor stated that:

> ...all three boards, the Maintenance Review Board, Flight Standardization Board and the Flight Operations Evaluation Board ha[d] only just [consolidated to form the AEG]. So we had to bridge the gap...and use some of that pre-existing material [for guidance] for a period of time because the new material has been in draft until just a short time ago and it was somewhat incomplete....

The supervisor testified further that "...the AEG does not maintain a data base of incident/accident information...." Also, it was found that the AEG did not regularly use other data bases within the FAA and outside the FAA from which incident/accident data may be derived to formally monitor trends that could compromise the continued airworthiness of aircraft that it had been assigned to oversee. However, the supervisor stated that the AEG office "does keep records" and obtains incident and accident information through a line of communication with the FAA's other Flight Standards organizations or through information gathered from ADs. The information that had been gathered by the AEG regarding the previous

ATR incidents and the foreign accidents was general and had been difficult to obtain, particularly with regard to the BAA. The supervisor also testified that under the BAA, the lines of communication need to be "defined."

This deficiency in communication resulted in the AEG's failure to receive pertinent documentation regarding the ATR icing incidents (such as the ATR analyses) 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 the FAA's monitoring of airworthiness issues relating to that aircraft was inadequate. Specifically, that investigation revealed that the FAA delayed for more than 3 years taking actions to correct known issues of noncompliance with 14 CFR Part 25, and that there "was an apparent lack of standardization and coordination" among various offices within the FAA.[83]

The Safety Board concludes that the lack of defined lines of communication and adequate means to retrieve pertinent airworthiness information prevented the AEG from effectively monitoring the continuing airworthiness of aircraft. Therefore, the Safety Board believes that the FAA should develop an organizational structure and communications system that will enable the 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 the effective AEG monitoring of the continued airworthiness of aircraft.

2.7 ATR Certification and Continuing Airworthiness Monitoring Under the Bilateral Airworthiness Agreement

The Bilateral Airworthiness Agreement between the U.S. and France[84] eliminates a significant amount of duplication in the overall certification of an aircraft. This method of certification relies significantly upon the airworthiness authority of the exporting country to review manufacturer data and ensure adherence

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[83]NTSB Accident Report AAR-88-08, 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, p.44.

[84]Described in section 1.18.7.

to the U.S. type certification procedures and requirements. It is generally an appropriate process if the FAA is adequately involved in monitoring the certification by a foreign airworthiness authority. However, it appears that the FAA has implemented the process with extremely limited "hands-on" involvement in the development, construction and flight testing of the aircraft.

The FAA team leader for the ATR certification testified about the original ATR certification process:

> ...[the original certification process] takes generally five years....The major way that we try to stay in the loop during this is with meetings at the facility....In a perfect world, we would schedule four meetings during this period to go over there with a team...and review what has been done to date....But the budget realities being what they are, the last several projects that we have been working on, the best we've been able to do is generally two meetings.
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> The team leader also stated:
>
> ...Generally half way through the process, ...we review all that's been done to date, we see if there are any problem areas....If we can do it, we will bring the team back over again just before the airplane begins to go into flight testing. That's usually a good time to catch any little things before they start a lot of expensive flight testing....And if possible, we like to get the team back over for the final type board. Although on the last several programs that I'm familiar with, we've sent the project manager alone just to make sure that everything has been done satisfactorily....

The Safety Board is concerned about the FAA's limited involvement during the initial certification of the ATR 42 and 72. For example, there were several meetings in which only one person from the FAA reviewed vast amounts of certification documentation and had to resolve problems from many technical disciplines. Further, because FAA personnel were either unavailable, or budget constraints restricted travel, issues involving noncompliance or other concerns were resolved only through "issue papers." An issue paper, of which there were more than 90 for the ATR 42 and 17 for the ATR 72, describes the FAA position regarding a certification issue and the method(s) necessary to achieve compliance.

For the ATR, the FAA delegated the compliance oversight for the issue papers to the DGAC.

Included in the certification process is the FAA review of test data, including data acquired from flight tests. According to testimony provided by the FAA ATR certification team leader, the FAA does not flight test the aircraft; rather, it conducts "evaluation" flights for the purpose of "familiarity with airplane...and [to] determine suitability for use in airline service...." The FAA conducted about 10 hours of evaluation flights on the ATR; however, none of these flights duplicated any tests required for certification, and none were conducted in icing conditions.

The Safety Board concludes that the FAA's limited involvement in the ATR 42 certification does not appear to have resulted in an improperly certificated airplane (ATR 42/72). However, such excessive reliance on a foreign airworthiness authority could result in improper certification of an aircraft. Therefore, the Safety Board believes that the FAA should review and revise, as necessary, the manner in which it monitors a foreign airworthiness authority's compliance with U.S. type certification requirements under the Bilateral Airworthiness Agreement (BAA).

The Safety Board is also concerned about the process by which the FAA ensures the continuing airworthiness of airplanes certificated under the BAA. The FAA did not receive pertinent information about the airworthiness of the ATR 42 and 72 series airplanes, including ATR’s analyses of the icing-induced aileron hinge moment reversal incidents in 1991, and those in 1993 and 1994. The FAA could have been more aggressive in requesting data from the DGAC following these incidents. However, the DGAC should have, on its own accord, taken actions to make sure that the FAA was provided with all information about the ATR incidents to ensure FAA involvement in the continuing airworthiness of the airplane.

Unfortunately, this is not the only foreign manufactured airplane for which the United States has failed to receive information that was critical to the monitoring of the continued airworthiness of the airplane. In 1995, the Safety Board investigation of an incident in which a Northwest Airlines Airbus A320 had experienced severe roll oscillations while on final approach to runway 18 at Washington National Airport, Washington, D.C., revealed a lack of communication between the airworthiness authorities and Airbus. Prior to the Northwest A320 incident, the DGAC had determined that a temporary Airbus revision to a procedure in its flightcrew operating manual, addressing flight conditions conducive to such oscillations, did not require regulatory action. However, the FAA was unable to determine if regulatory action was required because the pertinent information had not been provided by either the DGAC or Airbus. In a letter to the FAA dated November 14, 1995, the Safety Board concluded that information regarding undesirable flight characteristics in the A320 had not been "effectively disseminated from the manufacturer to the different airworthiness authorities, operators and flightcrews." Further, the Safety Board expressed its concern that, "...other useful and perhaps critical information of a similar nature is not being effectively communicated," and in Safety Recommendation A-95-109, asked that the FAA "in conjunction with the French [DGAC] establish policy and procedures to assure effective dissemination of all essential information regarding airworthiness problems and corrective actions in accordance with ICAO Annex 8, Part II, paragraph 4."

The FAA’s first response (dated January 29, 1996) to this recommendation addressed only communication of airworthiness information related to Airbus Industries, and its subsequent response (dated May 7, 1996) went further. (See section 1.16.3, Communication of Airworthiness Information Between FAA, DGAC and ATR.)

As stated previously, on May 15, 1996, the Safety Board classified Safety Recommendation A-95-109 “Open--Acceptable Response,” pending implementation and review of the agreement regarding the Promotion of Aviation Safety.

The Safety Board concludes that the FAA's ability to monitor the continued airworthiness of the ATR airplanes has been hampered by an insufficient flow of critical airworthiness information. The DGAC’s apparent belief that such information was not required to be provided under the terms of the BAA raises concerns about the scope and effectiveness of the BAA. Thus, the Safety Board believes that the FAA should establish policies and procedures to ensure that all pertinent information is received, including the manufacturer's analysis of incidents, accidents or other airworthiness issues, from the exporting country's airworthiness authority so that it can monitor and ensure the continued airworthiness of airplanes certified under the BAA.

2.8 Air Traffic Control

The primary air traffic control issues examined by the Safety Board were the ground delay and airborne holding of flight 4184, the traffic flow into

Chicago's O'Hare International Airport, and the dissemination of significant weather information to the flightcrew.

At 0800, on the day of the accident, the Chicago Air Route Traffic Control Center (ARTCC) Traffic Management Coordinator (TMC) requested that a ground delay program be implemented for aircraft scheduled to land at O'Hare International Airport between the hours of 1200 and 1800 because of the forecast of unfavorable weather conditions. Flight 4184 was released from IND into an area of forecast icing conditions after a 42-minute ground hold with the anticipation that the flight would probably hold en route. The area supervisor at the Chicago ARTCC testified that it is considered an acceptable practice to issue a holding clearance for turbopropeller aircraft operating in "light" or "moderate" icing conditions. Icing conditions often do not exist even though such conditions are forecast. The supervisor stated that the controllers would be "very responsive" if a pilot indicated that they were holding in icing conditions and "wanted to get out," or rejected a holding pattern because of icing conditions. The supervisor also stated that on the day of the accident, he was not aware of any flightcrews rejecting holding instructions because of icing conditions. Because forecasts of hazardous weather may not be precise, and because airplanes can encounter a variety of icing conditions including those considered to be "severe," and exit the conditions safely, efficient use of airports is typically achieved by dispatching aircraft at rates that may require holding if the weather deteriorates. Therefore, the Safety Board concludes that although the controlling facilities were aware that light icing conditions were forecast for the area of the LUCIT intersection, flight 4184 was properly released from Indianapolis because there were viable options for pilots who chose to avoid holding in icing conditions.

Periodically, throughout the day of the accident, all sector controllers responsible for aircraft inbound to ORD were advised that the holding of aircraft was possible, and that if the majority of traffic was inbound from the east, the west sectors would hold aircraft, and vice versa. At 1452, when the Chicago Center Flow Control (CFC) advised the Indianapolis Clearance Delivery (CD) that flight 4184 was released, the CD was also told "...that fix is in the hold so he might do some holding when he gets up here...." At 1517, approximately 22 minutes after flight 4184 departed, the sectors responsible for inbound flights from the east [which included flight 4184] were instructed to implement holding because a "rush" of inbound aircraft were arriving from the west sector. FAA Order 7110.65 states that air traffic services will be provided to aircraft on a "...first come first served basis as circumstances permit." However, this is not always feasible during periods of high traffic volume or adverse weather conditions. During these periods, the primary responsibility of traffic management is to ensure the safe and orderly flow of air traffic, which may require the holding of aircraft in some sectors while allowing other aircraft to continue inbound to their destination. The Safety Board concludes that under the circumstances on the day of the accident, the controllers acted appropriately in the management of traffic flow into ORD, which necessitated the holding of flight 4184 in the BOONE sector.

At 1524:40, flight 4184 entered the holding pattern, and, according to ATC procedures, the flight became an "arrival delay" when it was still holding after 15 minutes. FAA Order 7210.3, Facility Operation and Administration, Chapter 4, paragraph 4-73, requires that air traffic personnel report delays of 15 minutes or more that occur in facilities or airspace under the control of the Air Traffic Control System Command Center (ATCSCC). ATCSCC personnel use these reports as a guide to determine the success of a particular traffic management program. Typically, controllers advise their supervisor(s) or the TMC of the specific delay(s). The supervisor or TMC in turn advises the ATCSCC specialist so that a course of action can be planned and implemented to alleviate the en route holding. However, the Safety Board found that on the afternoon of the accident, because the supervisor did not advise the ARTCC TMC that flight 4184 was an arrival delay, as required by the FAA Order, the TMC was not aware that the BOONE sector was holding aircraft. However, the Safety Board concludes that the supervisor's failure to report flight 4184 as an arrival delay did not affect the operation of the flight because, according to the ATCSCC, it would not have amended the flow control program based on one delayed aircraft. Nevertheless, testimony and statements from the controllers indicate that any flight would have been rerouted to accommodate a pilot who expressed concern about holding in icing conditions. Therefore, the Safety Board concludes that the supervisor's failure to alert the ATCSCC that flight 4184 had been holding for more than 15 minutes did not contribute to the accident.

Controllers are required by FAA Order 7110.65 to solicit a pilot report when certain weather conditions that are specified in the order are either forecast or reported for the area of jurisdiction. "Lighter or greater..." icing conditions, which include freezing rain, are one of the five conditions specified by the Order for which a controller will solicit a PIREP. When the BOONE sector controller assumed control of the position and received a briefing by the departing controller, he was told, "...no one was complaining about the weather." This included flight 4184 which had been on the radio frequency for approximately 3 minutes when the BOONE controller assumed control. Because there were no PIREPs provided to the previous controller and the crew of flight 4184 did not provide a PIREP of icing conditions at the LUCIT intersection, it was reasonable for the controller to assume that there were no significant weather events in that area, and that the crew of flight 4184 was not experiencing any problems that would have required the controller to take alternative actions. Nonetheless, the Safety Board believes the FAA should revise FAA Order 7110.65, “Air Traffic Control,” Chapter 2, “General Control,” Section 6, “Weather Information,” paragraph 2-6-3, “PIREP” Information, to include freezing drizzle and freezing rain. These conditions should also be clearly defined in the Pilot/Controller Glossary.

2.9 Flightcrew Actions

As noted in section 2.2, flight 4184 entered the holding pattern at 77 percent propeller RPM, which is consistent with the use of Level I ice protection and would have been appropriate only if the flight were operating outside of all clouds and precipitation. However, the drag increase noted at approximately 1533 was evidence of flight in at least intermittent icing conditions in clouds or precipitation. Further, on two occasions while flight 4184 was holding, the CVR recorded a single tone chime identified as a caution alert. The caution alert can be activated by one of several different aircraft systems, including the ice detection system. The flightcrew did not increase the propeller RPM to 86 percent and activate the ice protection system when the first caution alert chime sounded at 1533:56, but following the second caution alert at 1541:07, the FDR indicated that the flightcrew did activate the Level III ice protection system and increased the propeller RPM to 86 percent. Because there was no discussion between the crewmembers regarding the 1533:56 caution alert, it is possible that it was activated by one of the other aircraft systems. Assuming the chime at 1533:56 was activated by the ice detection system, consistent with the drag increase noted at that time on the FDR, the Safety Board concludes that the flightcrew’s failure to increase the propeller RPM to 86 percent and activate the Level III ice protection system was not a factor in the accident because: 1) according to ATR, the increased propeller RPM is necessary to increase the ice shedding capabilities of the propeller blades; 2) the increased propeller RPM will prevent the formation of ice aft of the deice boots in the area of the propeller slipstream, but will not prevent the formation of ice on the wing in the areas behind the deice boots, in front of the ailerons, or the airflow over the ailerons.

There was no discussion recorded on the CVR to suggest that the flight crewmembers had a safety concern about the icing conditions in which they were holding. Two comments by the crewmembers recorded on the CVR indicated they were aware that ice was accreting on the airframe. The first comment, "I'm showing some ice," occurred about 9 minutes before the initial upset of the airplane, and the second comment, "we still got ice" occurred about 2 minutes before the upset. Neither comment indicated the type or amount of ice, nor did the comments suggest that the crew was aware the ice accretions were related to an encounter with freezing drizzle or freezing rain. The comments only indicate that the flightcrew was aware that they were operating in an icing environment. Further, the flightcrew responded appropriately to the caution alert at 1541:07 by increasing the propeller RPM to 86 percent and activating the deice boots 5 seconds later, or about 16 minutes before the upset.

Although AMR Eagle cautioned pilots in its 1989 memorandum about flight in freezing rain, the information and training provided by Simmons Airlines/AMR Eagle to its flightcrews did not prohibit holding in icing conditions that were perceived to be within the capabilities of the airplane. In addition, the crew did not have specific training or information necessary to determine that the airplane was operating in conditions (freezing rain) beyond those for which it had been certificated.

It is generally understood that flight in icing conditions in any aircraft at low airspeeds with the flaps and/or the landing gear extended for a long period of time is not a good operating practice because such exposure increases the likelihood of a significant accumulation of ice on the flaps and/or landing gear, which could result in increases in weight and drag, and a decrease in aircraft performance. However, at the time of the accident, the AFM issued by ATR and approved by the both the DGAC and FAA did not prohibit (either implicitly or explicitly), holding with flaps 15 in icing conditions nor did it address the use of flaps in icing conditions. According to AMR Eagle, the flaps 0 holding data provided by ATR for use in the AOM is advisory in nature and does not prohibit holding with flaps 15. Additionally, the basis upon which ATR recommends holding with the flaps up is, according to AMR Eagle, predicated on "…the most economical holding configuration with respect to fuel consumption…this configuration provides for the lowest dispatch fuel requirement and consequently the highest available payload."

Based on the information provided by ATR at the time of the accident, holding with flaps 15 extended at 175 KIAS provides a more desirable operating margin for stall protection than the flaps 0 configuration. Further, ATR's 1992 All Weather Operations brochure advised flightcrews that if they recognized that they were in freezing rain, they should, "extend flaps as close to V_{fe} as possible." This position was reiterated at the Safety Board's public hearing by ATR's chief test pilot, who stated, in part:

> …as I told you not only nobody knew the pattern associated with the large droplets but even more, nobody knew that it would have [been] aggravated in the flaps 15 [configuration]. Flaps 15 on its own right, selection of flaps 15, is [not] wrong and never was made illegal…. You know, it [is a] means to reduce [the] angle of attack….

Because there was no prohibition against flap extension in icing conditions, and no published information explaining the potential consequences of extending the flaps in icing conditions, the crew of flight 4184 would not have had reason to believe that the extension of the flaps would result in an adverse ice accumulation in front of the ailerons. In addition, the flightcrew's training was such that the only performance degradation they would expect from ice accumulation would have been a continuous loss of airspeed and subsequent stall condition with stick shaker activation, rather than an aileron hinge moment reversal at an airspeed well above stall speed, that would suddenly overpower and disconnect the autopilot and cause the ailerons and control wheel to move uncommanded to near their full travel limits with no stick shaker activation.

The flightcrew's apparent lack of concern regarding the prolonged operations in icing conditions may have been influenced by their extensive experience of safely flying commuter aircraft in winter weather conditions, especially in icing conditions that are prevalent in the Great Lakes region. In addiction, they were probably confident in the ability of the airplane deicing system to adequately shed the ice that had been accumulating on the wings and in their ability to perform safely under the existing circumstances. The flightcrew was operating in icing conditions that exceeded the limits set forth in 14 CFR Part 25, Appendix C, resulting in a complete loss of aircraft control. However, the insidious nature of these icing conditions was such that the ice accumulation on the observable portions of the wings, windshield and other airframe parts was most likely perceived by the flightcrew as nonthreatening throughout the holding period. Moreover, the flightcrew was undoubtedly unaware that the icing conditions exceeded the Appendix C limits and most likely had operated in similar conditions many times prior to the accident, since such conditions occur frequently in the winter throughout the Great Lakes and northeastern parts of the United States.

Further, the flightcrew entered the holding pattern with the belief that the holding would be of a short duration, unaware that it would be continually extended in short increments for a total of 39 minutes. Therefore, the Safety Board concludes that if a significant amount of ice had accumulated on the wing leading edges so as to burden the ice protection system, or if the crew had been able to observe the ridge of ice building behind the deice boots or otherwise been provided a means of determining that an unsafe condition could result from holding in those icing conditions, it is probable that they would have exited the conditions.

The Safety Board is aware that ATR provided information to the operators of its airplanes that indicated that encounters with certain freezing precipitation conditions could result in “roll axis anomalies.” However, this information was vague and did not indicate to flightcrews how to determine that they were in freezing rain, nor did it specifically alert them that encounters with freezing rain could result in sudden autopilot disconnects, uncommanded aileron movements and rapid roll excursions. Therefore, the crew of flight 4184 had no reason to expect that the icing conditions in which they were operating could cause the autopilot to disconnect unexpectedly because of the onset of an aileron hinge moment reversal and cause a loss of normal, stable aileron control. In addition, ATR did not provide, nor did the regulatory authorities require, training or guidance to pilots about the roll axis “anomalies” or the recovery techniques if such an event should occur. Thus, the Safety Board concludes that the crew of flight 4184 was not provided with adequate information by the manufacturer or the regulatory authorities to recognize and cope with the problems they experienced during an encounter with freezing rain.

Although the flightcrew did not indicate that it was concerned about holding in icing conditions, the Safety Board notes that there were some potentially distracting events that occurred during the hold. About 15 minutes of personal conversation took place between a flight attendant and the captain that was recorded on the CVR from 1528:00 to 1542:38. The CVR also recorded a music station playing on the ADF frequency for about 18 minutes, as well as the sounds of the captain's departure from the cockpit for about 5 minutes to use the rest room.

According to 14 CFR Part 121.542 (the “sterile cockpit” rule) and FAA staff testimony at the public hearing, holding at 10,000 feet or above is not considered to be a “critical” phase of flight. Thus, the presence of the flight attendant in the cockpit and the ensuing conversation were not in violation of AMR Eagle policy or Federal regulations.

Although the presence of the flight attendant and the music could have been a distraction to the flightcrew, both pilots appeared to be attentive to flight-related duties both immediately before, as well as during the roll upset. Thus, the Safety Board also concludes that neither the flight attendant's presence in the cockpit nor the flightcrew's conversations with her contributed to the accident.

The Safety Board did note, however, that the AMR Eagle ATR 72 flight manual provides the captain with the authority to declare "...any other phase of a particular flight...." a critical phase depending on the circumstances and thus to invoke the sterile cockpit rule at the captain's discretion. The Safety Board concludes that a sterile cockpit environment would have reduced flightcrew distractions and could have heightened the flightcrew’s awareness to the potentially hazardous environmental conditions in which the airplane was being operated. However, the sterile cockpit environment would not have increased the flightcrew’s understanding of the events that eventually transpired when the autopilot disconnected and the ailerons and control wheels suddenly and rapidly moved uncommanded to their full travel limits.

Had ATR provided the flightcrew with the detailed information about these characteristics that were previously known, and have been made available since this accident, there would have been a basis to question the flightcrew’s situational awareness and action. However, without the appropriate information about the aileron hardover induced by an aerodynamically unstable aileron system (as a result of flight in freezing precipitation/large droplets), the Safety Board concludes that the flightcrew’s actions were consistent with their training and knowledge.

Nonetheless, the Safety Board does believe that Simmons Airlines/AMR Eagle should encourage its captains to observe a sterile cockpit environment when an airplane is holding, regardless of altitude, in meteorological conditions, such as convective areas and icing conditions that have the potential to demand significant attention by a flightcrew. The Safety Board also believes that the FAA should evaluate the need to require a sterile cockpit environment for airplanes holding in such weather conditions as icing and convective activity, regardless of altitude.

Finally, regarding the captain's decision to take a restroom break while in the extended holding period, the Safety Board notes that the break occurred during a period of relatively low workload, with the first officer performing the "flying pilot" duties and the autopilot engaged. Because the workload would have increased substantially once the flight was cleared out of the hold and the approach was commenced, it was appropriate for the captain to choose that time to take such a break. Therefore, the Safety Board concludes that the captain's departure from the cockpit to use the rest room during this period of time was neither prohibited by Federal regulations nor inconsistent with Simmons Airlines/AMR Eagle policies and procedures, and did not contribute to the accident.

14 CFR Part 121.561 states that a pilot should provide a PIREP "whenever he encounters a meteorological condition...inflight, the knowledge of which he considers essential to the safety of other flights." Simmons Airlines/AMR Eagle policies are more specific in that they require the flightcrew to provide a PIREP to ATC "...when encountering, among other conditions, inflight icing conditions...." Further, the AIM "urges" pilots to "...cooperate and promptly volunteer reports...." of hazardous weather conditions, including "...icing of light degree or greater...." Flight 4184 had been operating in icing conditions for more than 24 minutes; however, no PIREP was provided. The evidence suggests that the flightcrew was not concerned about the icing conditions and did not consider this environment to be a threat to either their safety or that of other flights. Therefore, although the Simmons Airlines/AMR Eagle policy did require the reporting of such conditions, and it would have been prudent for the flightcrew to report the icing conditions as suggested in the AIM, the Safety Board concludes that this did not contribute to the accident.

In addition, the crew received an aural TCAS alert of "traffic traffic" shortly before the roll excursion. This particular type of alert is advisory in nature and did not require a verbal acknowledgment or response by either crewmember, nor did it require a pilot to make radio contact with the ATC controller unless a conflict was perceived. Radar and FDR data indicate that the traffic which triggered the alert was several miles away from flight 4184 and was not a factor in the accident. The Safety Board concludes that although flight 4184 was close enough to a second aircraft to activate the TCAS alert, the proximity of the two airplanes to one another did not contribute to the accident.

2.9.1 Unusual Event Recovery

The Safety Board attempted to determine why the crew of flight 4184 was unable to successfully recover the airplane and prevent the accident when the flightcrews of the airplanes involved in the prior incidents were able to do so. At the time of the roll upset, flight 4184 was most likely operating in instrument meteorological conditions (IMC), which precluded the flightcrew's use of visual cues outside the airplane for attitude reference. According to the FDR data, the airplane initially rolled to the right, reversed direction momentarily and subsequently rolled again to the right.

The Safety Board notes that the ATR aileron hinge moment incidents prior to this accident occurred with the flaps retracted and involved large, long-term speed losses from ice-induced drag that are normally recognizable by pilots. Flight 4184 did not experience large or long-term drag increases while holding.

Analysis of the data collected during the icing tanker test and the data from the previous ATR ice-induced aileron hinge moment reversal incidents suggest that the successful recoveries may have been attributable, in part, to rapid pilot corrective action. Also, because in the prior incidents the flaps had not been extended and therefore were not retracted after ice was accreted, the airplanes were not trimmed for flight at AOAs that were significantly higher than the aileron hinge moment reversal AOA, as was the case with flight 4184 when the flaps were retracted. Thus, in the previous incidents, a small speed increase would permit the airplanes to maintain level flight at an AOA below the aileron hinge moment reversal AOA. However, once the flaps were retracted by the crew of flight 4184, there was a need to significantly increase the airplane's speed and trim nose down to keep the AOA below that at which the aileron hinge moment would reverse. Because the crew had not been alerted to or trained to recognize this situation, they were confronted with a more difficult task than that which confronted the flightcrews of the airplanes involved in the prior incidents. Additionally, the crew of flight 4184 could not redeploy the flaps to reduce the AOA because of the flaps 15 V_{fe} lockout.

The second roll event was not terminated before the airplane rolled 1 and 1/4 times, and pitched down to a nearly vertical attitude. Further, throughout the second roll event, the elevators were deflected in a primarily nose-up position by both crewmembers, and the rudder was deflected most of the time from 2 to 3 degrees nose left. Although the crew was applying corrective rudder during the roll excursion, the aileron inputs by the flightcrew were not sufficient to effect recovery. Aileron control during this time was most likely very difficult and confusing as a result of the multiple encounters with high control wheel forces and unusual oscillatory aileron behavior associated with the aileron hinge moment reversal.

When the crew relaxed the back pressure on the control column, thereby reducing the nose-up elevator, the AOA decreased below the hinge moment reversal threshold, and the crew regained control of the ailerons and initiated recovery at 6,000 feet. At this point, the airplane was in a very steep, high speed descent, in a near-inverted attitude that would most likely have been unfamiliar to the crew, considering their lack of unusual attitude recovery training in this airplane. The FDR, CVR, and wreckage distribution data show that in the next 9 seconds, the crew had leveled the wings and was bringing the nose up towards a level attitude. However, the airplane was moving at 375 KIAS with a load factor rapidly increasing through 3.7 G when the outboard sections of the wings and the horizontal tail separated from the airplane.

At the time of the accident, the AMR Eagle pilot training program did not include an "unusual attitude" or "advanced maneuvers" segment (nor was such training required). During simulator training, AMR Eagle pilots were not exposed to aircraft attitudes that were typically beyond those used for normal operations or considered unusual, and they only experienced an abnormal pitch attitude when they practiced emergency descents. Although both crewmembers of flight 4184 were certified flight instructors,[85] it is likely that this was the first time they had experienced such unexpected and excessive roll and pitch attitudes in the ATR 72. Shortly after the upset, when the airplane rolled to an inverted position and progressed into a steep nose-low attitude, the captain told the first officer to "mellow it out." However, there was no evidence on the CVR to indicate that the captain was conveying information to the first officer about the airplane's attitude, airspeed or altitude.

The lack of unusual attitude training may have significantly hampered the immediate recovery of the airplane once the upset occurred. However, because the flightcrew was not aware that icing conditions could cause a sudden autopilot disconnect, rapid and uncommanded aileron and control wheel deflections to near their full travel limits with unusually high, unstable control wheel forces, the crew was confronted with a situation that could have been perceived as having been induced by the autopilot, a structural failure, or a mechanical malfunction. Because the upset occurred suddenly and without forewarning, the crew did not have time to assess the situation and determine the appropriate corrective actions before the roll attitude exceeded 90 degrees. The Safety Board concludes that unusual attitude

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[85] A requisite for a flight instructor certificate, set forth by the FAA, is the demonstration of an entry and recovery from a spin.

training would have assisted the flightcrew in its recovery efforts and might have prompted the captain to provide useful information to the first officer to facilitate a timely recovery of the airplane. However, the Safety Board also concludes that without the knowledge of the ice-induced aileron hinge moment reversal problem, the flightcrew’s execution of conventional unusual attitude recovery techniques may have been ineffective.

In four separate safety recommendations over the past 27 years, the Safety Board has addressed the issue of unusual attitude training. The FAA's unfavorable responses and failure to require such training have resulted in the Safety Board classifying the FAA's past actions as "Unacceptable" in three of the four cases. In the fourth case, Safety Recommendation A-93-72, the FAA's actions to promulgate rules to bring most 14 CFR Part 135 scheduled passenger operators under 14 CFR 121 training requirements (which include the use of simulators) was classified "Closed—Acceptable Action" on August 29, 1995. However, the Safety Board remains concerned that this does not necessitate a requirement to provide unusual event/attitude training.

Based on the circumstances of this accident, the historical data of similar accidents, and safety recommendations previously issued by the Safety Board, the FAA, in August 1995, in joint cooperation with the aviation industry, issued an FAA Inspector Handbook Bulletin detailing a program that encourages air carriers to implement advanced maneuver/unusual attitude training in their pilot training programs. AMR Eagle implemented an unusual attitude training curriculum into its pilot training syllabus, action that the Safety Board supports. Additionally, the Safety Board is encouraged by the FAA's latest position regarding unusual attitude/events training; however, there remains a concern that the lack of a required program might result in some carriers not providing unusual attitude training, and that their respective training programs might be insufficient to demonstrate the cause for and the recovery from aircraft attitudes that are not considered to be "normal." Therefore, the Safety Board believes that the FAA should amend the Federal Aviation Regulations to require air carriers to provide standardized training that adequately addresses the recovery from unusual events and attitudes, including extreme flight attitudes, in large, transport category airplanes.

2.10 AMR Eagle/Simmons Airlines Management Structure and FAA Oversight

As noted in section 1.17, Simmons Airlines is one of four regional air carriers owned by AMR Eagle. AMR Eagle does not hold an FAA-issued Air Carrier certificate, but it serves as a coordinator among the four individual air carriers, providing centralized crew scheduling, flight dispatch, and pilot training facilities, which are staffed by employees of the individual carriers. In addition, AMR Eagle centrally coordinates pilot recruitment and hiring, pilot training and checking, aircraft acquisition, and airline planning and marketing. AMR Eagle also develops and publishes standardized company manuals, such as aircraft operating manuals and flight manuals, which are applicable to each of the four carriers.

Although major management decisions affecting Simmons Airlines operations are often made by AMR Eagle management personnel who are not directly involved with Simmons Airlines or its operations, the Safety Board found no evidence that the Simmons Airlines/AMR Eagle management structure adversely affected safety, or that it was a factor in this accident.

The FAA oversight of Simmons Airlines and the other air carriers operating under AMR Eagle is accomplished by FAA principal operations inspectors (POIs) assigned to each of the carriers. In addition, another FAA employee, known as the Focal Point Coordinator (FPC), serves as a liaison between AMR Eagle management and each of the individual POIs. When addressing matters of compliance within their assigned airline, each POI interacts directly with the appropriate management individual(s) from that airline. However, when addressing matters that require coordination with AMR Eagle management, such as a modification to the flight manuals, the POIs can only interact indirectly with AMR Eagle through the FPC. Changes to published procedures or operating specifications are proposed by AMR Eagle management and reviewed independently by each of the four POIs. Once agreed upon by the POIs, the changes are then issued by AMR Eagle.

Because the FAA's method of exercising oversight of Simmons Airlines and the other AMR Eagle carriers relies on the FPC to coordinate the flow of information communicated between the POIs and AMR Eagle, this structure effectively insulates the POIs from direct contact with key decision-making personnel at AMR Eagle. In a recent accident investigation involving Flagship Airlines, another one of the four AMR Eagle carriers, the Safety Board examined these same organizational and surveillance issues and concluded that the structure of the FAA and its oversight of AMR Eagle did not provide for adequate interaction between the POIs and AMR Eagle management personnel.[86] While the Safety Board found no evidence that this method of oversight contributed in any way to the Flagship accident or this accident, the Safety Board remains concerned about the lack of direct communication between the POIs of the individual air carriers and AMR Eagle management. In its previous recommendation in conjunction with the Flagship accident, the Safety Board urged the FAA to:

> A-95-99
> Review the organizational structure of the FAA surveillance of AMR Eagle and its carriers with particular emphasis on the positions and responsibilities of the Focal Point Coordinator and principal inspectors, as they relate to the respective carriers.

In a letter to the Safety Board dated February 13, 1996, the FAA responded to recommendation A-95-99 as follows:

> There are four American Eagle air carriers located in the FAA's Southern, Western-Pacific, and Southwest regional offices. Each air carrier is owned by American Eagle and has an individual air carrier certificate issued by the FAA. In July 1990, the flight standards division managers of the affected regions, in coordination with FAA headquarters, designated a focal point to coordinate the FAA approval/acceptance process among the principal inspectors of each carrier. A Memorandum of Understanding was signed by the respective regional division managers formalizing the process. Recently, an action plan was developed to review the organizational structure and effectiveness of the American Eagle oversight process. The review should be completed by February 29, 1996, and a final report issued by March 15, 1996. I will apprise the Board of the findings of the review as soon as it is completed.

In its subsequent letter, dated May 31, 1996, concerning Safety Recommendation A-95-99, the FAA stated, in part:

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[86] NTSB/AAR-95/07, "Uncontrolled Collision with Terrain, Flagship Airlines, Inc., d.b.a. American Eagle Flight 3379, BAe Jetstream 3201, N918AE, Morrisville, North Carolina, December 13, 1994."

In February 1996, the FAA conducted an evaluation of the organizational structure and effectiveness of the American Eagle oversight process, including the focal point process. There are four American Eagle air carriers located in the FAA's Southern, Western-Pacific, and Southwest regional offices. Each FAA region having FAA air carrier certificate oversight for American Eagle assigned a management representative to the evaluation team. The team reviewed the effectiveness of the 1990 Memorandum of Understanding (MOU) and interviewed FAA principal inspectors from the respective certificate holders, flight standards district office management, and American Eagle management. The FAA and American Eagle focal points were also interviewed during the evaluation. The evaluation included a visit to American Eagle headquarters, the crewmember training center, and the dispatch facility located in Fort Worth, Texas. On March 1, 1996, the FAA issued its final report resulting from its evaluation. The major findings of the evaluation are as follows:

- Overall surveillance of the four air carriers meets and/or exceeds the requirements of 14 CFR Part 121 and FAA orders.

- The focal point process provides a quality review yet is slow at times.

- The 1990 MOU needed to be revised to reduce coordination time between the FAA and American Eagle for items requiring FAA approval or acceptance.

As a result of this evaluation, the FAA revised the MOU on March 1, 1996, to reflect the concerns revealed during the evaluation. I have enclosed a copy of the final report and a copy of the revised MOU for the Board's information.

I believe that the FAA has met the full intent of this safety recommendation, and I consider the FAA's action to be completed.

The FAA's action adequately addresses the issues raised by the Safety Board. Therefore, the Safety Board classifies Safety Recommendation A-95-99 "Closed—Acceptable Action."

3. CONCLUSIONS

3.1 Findings

1. The flightcrew was properly certified and qualified in accordance with applicable regulations to conduct the flight.

2. The Chicago air route traffic control center (ARTCC) sector controllers were properly certified and trained to perform their duties.

3. The ATR 72 was certificated, equipped, and maintained in accordance with Federal regulations and approved procedures.

4. There was no evidence of an aircraft structural or system failure that would have either been causal or contributing to the accident.

5. Flight 4184 encountered a mixture of rime and clear airframe icing in supercooled cloud and drizzle/rain drops. Some drops were estimated to be greater than 100 microns in diameter, and some were as large as 2,000 microns.

6. The forecasts produced by the National Weather Service (NWS) were substantially correct, and the actions of the forecasters at the National Aviation Weather Advisory Unit (NAWAU) and the meteorologists at the Chicago ARTCC's Center Weather Service Unit (CWSU) were in accordance with NWS guidelines and procedures.

7. Safety would be enhanced if the hazardous in-flight weather advisory service (HIWAS) information were presented more consistently and had included all of the information pertinent to the safety of flight, such as the altitudes of the icing conditions, the intensity and type of icing, and the location of the actual or expected icing conditions (e.g. in clouds and precipitation).

8. The flightcrew's actions would not have been significantly different even if they had received the available AIRMETs.

9. The flightcrew’s actions were consistent with their training and knowledge.

10. PIREPs [pilot reports] of icing conditions, based on the current icing severity definitions, may often be misleading to pilots, especially to pilots in aircraft that may be more vulnerable to the effects of icing than other aircraft.

11. The aviation community's general understanding of the phrase "icing in precipitation," which is used by the NWS and is often contained in in-flight weather advisories, does not typically specify types of precipitation. The provision of a definition in aviation publications, such as the Aeronautical Information Manual (AIM) or Part 1 of the Federal Aviation Regulations, would make pilots and dispatchers more aware of the types of precipitation and icing conditions that are implied by this phrase.

12. Continued development of equipment and computer programs to measure and monitor the atmosphere could permit forecasters to produce real-time warnings that define specific locations of potentially hazardous atmospheric icing conditions (including freezing drizzle and freezing rain) and short range forecasts ("nowcasts") that identify icing conditions for a specific geographic area with a valid time of 2 hours or less.

13. The 14 Code of Federal Regulations (CFR) Part 25, Appendix C, envelope is limited and does not include conditions of freezing drizzle or freezing rain; thus, the current process by which aircraft are certified using the Appendix C icing envelope is inadequate and does not require manufacturers to sufficiently demonstrate the airplane's capabilities in all the possible icing conditions that can, and do, occur in nature.

14. No airplane should be authorized or certified for flight into icing conditions more severe than those to which the airplane was subjected in certification testing, unless the manufacturer can otherwise demonstrate the safety of flight in such conditions.

15. If the FAA had acted more positively upon the Safety Board's aircraft icing recommendations issued in 1981, this accident may not have occurred.

16. ATR 42 and 72 ice-induced aileron hinge moment reversals, autopilot disconnects, and rapid, uncommanded rolls could occur if the airplanes are operated in near freezing temperatures and water droplet median volume diameter (MVDs) typical of freezing drizzle.

17. At the initiation of the aileron hinge moment reversal affecting flight 4184, the 60 pounds of force on the control wheel required to maintain a wings-level-attitude were within the standards set forth by the Federal Aviation Regulations. However, rapid, uncommanded rolls and the sudden onset of 60 pounds of control wheel force without any warning to the pilot, or training for such unusual events, would most likely preclude a flightcrew from making a timely recovery.

18. ATR is considering design changes to the lateral control system for current and future ATR airplanes that will reduce the susceptibility to flow separation-induced aileron hinge moment reversals. Such design changes could minimize the reliance on the changes to flight operations and pilot training that have already been mandated.

19. The French Directorate General for Civil Aviation (DGAC) and the Federal Aviation Administration (FAA) failed to require the manufacturer to provide documentation of known undesirable post-SPS [stall protection system] flight characteristics, which contributed to their failure to identify and correct, or otherwise properly address, the abnormal aileron behavior early in the history of the ATR icing incidents.

20. The addition of a test procedure, similar to the "zero G" flight test maneuver (pushover) designed to identify ice-induced elevator hinge moment reversals, could determine the susceptibility of an aircraft to aileron hinge moment reversals in both the clean and iced-wing conditions and could help prevent accidents such as the one involving flight 4184.

21. Prior to the Roselawn accident, ATR recognized the reason for the aileron behavior in the previous incidents and determined that ice accumulation behind the deice boots, at an AOA sufficient to cause an airflow separation, would cause the ailerons to become unstable. Therefore, ATR had sufficient basis to modify the airplane and/or

provide operators and pilots with adequate, detailed information regarding this phenomenon.

22. The 1989 icing simulation package developed by ATR for the training simulators did not provide training for pilots to recognize the onset of an aileron hinge moment reversal or to execute the appropriate recovery techniques.

23. ATR’s proposed post-Mosinee AFM/FCOM changes, even if adopted by the DGAC and the FAA, would not have provided flightcrews with sufficient information to identify or recover from the type of event that occurred at Roselawn, and the actions taken by ATR following the Mosinee incident were insufficient.

24. The 1992 ATR All Weather Operations brochure was misleading and minimized the known catastrophic potential of ATR operations in freezing rain.

25. ATR failed to disseminate adequate warnings and guidance to operators about the adverse characteristics of, and techniques to recover from, ice-induced aileron hinge moment reversal events; and ATR failed to develop additional airplane modifications, which led directly to this accident.

26. The DGAC failed to require ATR to take additional corrective actions, such as performing additional icing tests, issuing more specific warnings regarding the aileron hinge moment reversal phenomenon, developing additional airplane modifications, and providing specific guidance on the recovery from a hinge moment reversal, which led directly to this accident.

27. The FAA's failure, following the 1994 Continental Express incident at Burlington, Massachusetts, to require that 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.

28. The FAA Aircraft Evaluation Group (AEG) did not receive in a timely manner, from all sources, pertinent documentation (such as the ATR analyses) regarding the previous ATR icing incidents/accidents that could have been used to monitor the continued airworthiness of the airplane.

29. The ability of the FAA's AEG to monitor, on a real-time basis, the continued airworthiness of the ATR airplanes was hampered by the inadequately defined lines of communication, the inadequate means for the AEG to retrieve pertinent airworthiness information, and the DGAC's failure to provide the FAA with critical airworthiness information, because of the DGAC's apparent belief that the information was not required to be provided under the terms of the Bilateral Airworthiness Agreement (BAA). These deficiencies also raise concerns about the scope and effectiveness of the BAA.

30. The FAA's limited involvement in the ATR 42 certification does not appear to have resulted in an improperly certificated airplane (ATR 42/72). However, the FAA's excessive reliance on a foreign airworthiness authority may result in tacit approval of the certification of a foreign-manufactured airplane without sufficient oversight and is not in the best interest of safety.

31. The nearby air traffic control facilities were aware that light icing conditions were forecast for the area of the LUCIT intersection. Nonetheless, the release of flight 4184 from Indianapolis was proper because there were viable options for pilots who chose to avoid holding in icing conditions.

32. Under the circumstances on the day of accident, the controllers acted appropriately in the management of traffic flow into O’Hare International Airport (ORD), which necessitated the holding of flight 4184 in the BOONE sector.

33. The air traffic control (ATC) traffic management coordinator failed to report flight 4184 to the air traffic control system command center (ATCSCC) as an arrival delay, and he failed to alert the ATCSCC that flight 4184 had been holding for more than 15 minutes. However, this

lack of information did not affect the operation of the flight and did not contribute to the accident.

34. Because there were no PIREPs [pilot reports] provided to the Boone sector controller by other pilots, and because the crew of flight 4184 did not provide a PIREP of icing conditions at the LUCIT intersection, it was reasonable for the controller to conclude that there were no significant weather events in that area and that the crew of flight 4184 was not experiencing any problems that would have warranted precautionary action by the controller.

35. Because the DGAC did not require ATR, and ATR did not provide to the operators of its airplanes, information that specifically alerted flightcrews to the fact that encounters with freezing rain could result in sudden autopilot disconnects, aileron hinge moment reversals, and rapid roll excursions, or guidance on how to cope with these events, the crew of flight 4184 had no reason to expect that the icing conditions they were encountering would cause the sudden onset of an aileron hinge moment reversal, autopilot disconnect, and loss of aileron control.

36. Neither the flight attendant's presence in the cockpit nor the flightcrew's conversations with her contributed to the accident. However, a sterile cockpit environment would probably have reduced flightcrew distractions and could have promoted an appropriate level of flightcrew awareness for the conditions in which the airplane was being operated.

37. The flightcrew’s failure to increase the propeller RPM to 86 percent and activate the Level III ice protection system in response to the 1533:56 caution alert chime was not a factor in the accident.

38. Had ice accumulated on the wing leading edges so as to burden the ice protection system, or if the crew had been able to observe the ridge of ice building behind the deice boots or otherwise been provided a means of determining that an unsafe condition was developing from holding in those icing conditions, it is probable that the crew would have exited the conditions.

39. The captain's departure from the cockpit to use the rest room while the airplane was in the holding pattern was neither prohibited by Federal regulations nor inconsistent with Simmons Airlines/AMR Eagle policies and procedures and did not contribute to the accident.

40. Although the Simmons Airlines/AMR Eagle policy does require flightcrews to provide a PIREP of icing conditions, and it would have been prudent for the crew of flight 4184 to provide such a report, their failure to do so did not contribute to the accident.

41. Although the crew of flight 4184 received an aural traffic alert and collision avoidance system (TCAS) alert shortly before the roll excursion, this alert was not perceived by the crew as a conflict, and the proximity of the two airplanes to one another did not contribute to the accident.

42. Both pilots saw the ground, realized their close proximity and high descent rate, and made a nose-up elevator input that, combined with the high airspeed (about 115 KIAS over the certified maximum operating airspeed) resulted in excessive wing loading and structural failure of the outboard sections of the wings.

43. Although both crew members of flight 4184 were certified flight instructors, this was probably the first time they had experienced such unexpected and excessive roll and pitch attitudes in the ATR 72. If the operators had been required to conduct unusual attitude training, the knowledge from this training might have assisted the flightcrew in its recovery efforts and might have prompted the captain to provide useful information to the first officer to facilitate a timely recovery of the airplane.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of this accident were the loss of control, attributed to a sudden and unexpected aileron hinge moment reversal that occurred after a ridge of ice accreted beyond the deice boots because: 1) ATR failed to completely disclose to operators, and incorporate in the ATR 72 airplane flight manual, flightcrew operating manual and flightcrew training programs, adequate information concerning previously known effects of freezing precipitation on the stability and control characteristics, autopilot and related operational procedures when the ATR 72 was operated in such conditions; 2) the French Directorate General for Civil Aviation's (DGAC's) inadequate oversight of the ATR 42 and 72, and its failure to take the necessary corrective action to ensure continued airworthiness in icing conditions; and 3) the DGAC's failure to provide the FAA with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions, as specified under the Bilateral Airworthiness Agreement and Annex 8 of the International Civil Aviation Organization.

Contributing to the accident were: 1) the Federal Aviation Administration's (FAA's) failure to ensure that aircraft icing certification requirements, operational requirements for flight into icing conditions, and FAA published aircraft icing information adequately accounted for the hazards that can result from flight in freezing rain and other icing conditions not specified in 14 Code of Federal Regulations (CFR) Part 25, Appendix C; and 2) the FAA's inadequate oversight of the ATR 42 and 72 to ensure continued airworthiness 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:

Direct principal operations inspectors (POIs) to ensure that all 14 Code of Federal Regulations (CFR) Part 121 air carriers require their dispatchers to provide all pertinent information, including airman's meteorological information (AIRMETs) and Center Weather Advisories (CWAs), to flightcrews for preflight and in-flight planning purposes. (Class II, Priority Action) (A-96-48)

Require that Hazardous In-flight Weather Advisory Service (HIWAS) broadcasts consistently include all pertinent information contained in weather reports and forecasts, including in-flight weather advisories, airman' s meteorological information (AIRMETs), significant meteorological information (SIGMETs), and Center Weather Advisories (CWA's). (Class II, Priority Action) (A-96-49)

Encourage principal operations inspectors (POIs) and operators to reemphasize to pilots that Hazardous In-flight Weather Advisory Service (HIWAS) is a source of timely weather information and should be used whenever they are operating in or near areas of potentially hazardous weather conditions. (Class II, Priority Action) (A-96-50)

Revise the existing aircraft icing intensity reporting criteria (as defined in the Aeronautical Information Manual (AIM) and other Federal Aviation Administration (FAA) literature) by including nomenclature that is related to specific types of aircraft, and that is in logical agreement with existing Federal Aviation Regulations (FARs). (Class II, Priority Action) (A-96-51)

Publish the definition of the phrase "icing in precipitation" in the appropriate aeronautical publications, emphasizing that the condition may exist both near the ground and at altitude. (Class II, Priority Action) (A-96-52)

Continue to sponsor the development of methods to produce weather forecasts that both define specific locations of atmospheric icing conditions (including freezing drizzle and freezing rain) and produce short-range forecasts ("nowcasts") that identify icing conditions for a specific geographic area with a valid time of 2 hours or less. (Class II, Priority Action) (A-96-53)

Revise the icing criteria published in 14 Code of Federal Regulations (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. (Class II, Priority Action)) (A-96-54) (Supersedes A-81-116 and-118)

Revise the Federal Aviation Regulations (FAILs) icing certification requirements and advisory material to specify the numerical methods to be used in determiningg median volumetric diameter (MVD) and liquid water content (LWC) during certification tests. (Class II, Priority Action) (A-96-55)

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. (Class II, Priority Action) (A-96-56)

Require all aircraft manufacturers to provide, as part of the certification criteria, information to the FAA and operators about any known undesirable characteristics of flight beyond the protected (stall system and related shaker/pusher) flight regime. (Class II, Priority Action) (A-96-57)

Develop an icing certification test procedure similar to the tailplane icing pushover test to determine the susceptibility of airplanes to aileron hinge moment reversals in the clean and iced-wing conditions. Revise 14 CFR Parts 23 and 25 icing certification requirements to include such a test. (Class II, Priority Action) (A-96-58)

Encourage ATR to test the newly developed lateral control system design changes and upon verification of the improved or corrected hinge moment reversal/uncommanded aileron deflection problem, require these design changes on all new and existing ATR airplanes. (Class-II, Priority Action) (A-96-59)

Revise 14 CFR Parts 91.527 and 135.227 to ensure that the regulations are compatible with the published definition of severe icing, and to eliminate the implied authorization of flight into severe icing conditions for aircraft certified for flight in such conditions. (Class II, Priority Action) (A-96-60)

Require all principal operations inspectors (POIs) of 14 CFR Part 121 and 135 operators to ensure that training programs include information about all icing conditions, including flight into freezing drizzle/freezing rain conditions. (Class II, Priority Action) (A-96-61)

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 AEG monitoring of the continued airworthiness of aircraft. (Class II, Priority Action) (A-96-62)

Review and revise, as necessary, the manner in which the FAA monitors a foreign airworthiness authority's compliance with U.S.

type certification requirements under the Bilateral Airworthiness Agreement (BAA). (Class II, Priority Action) (A-96-63)

Establish policies and procedures to ensure that all pertinent information is received, including the manufacturer's analysis of incidents, accidents or other airworthiness issues, from the exporting country's airworthiness authority so that the FAA can monitor and ensure the continued airworthiness of airplanes certified under the Bilateral Airworthiness Agreement (BAA). (Class II, Priority Action) (A-96-64)

Evaluate the need to require a sterile cockpit environment for airplanes holding in such weather conditions as icing and convective activity, regardless of altitude. (Class II, Priority Action) (A-96-65)

Amend the Federal Aviation Regulations to require operators to provide standardized training that adequately addresses the recovery from unusual events, including extreme flight attitudes in large, transport category airplanes. (Class II, Priority Action) (A-96-66)

Revise FAA Order 8400.10, Chapter 7, Section 2, paragraph 1423 (Operational Requirements - Flightcrews) to specify that Center Weather Advisories (CWAs) be included and considered in the flightcrew's preflight planning process. (Class II, Priority Action) (A-96-67)

Revise FAA Order 7110.65, "Air Traffic Control," Chapter 2, "General Control," Section 6, "Weather Information," paragraph 2-6-3, "PIREP" Information, to include freezing drizzle and freezing rain. Additionally, these conditions should be clearly defined in the Pilot/Controller Glossary. (Class II, Priority Action) (A-96-68)

Conduct or sponsor research and development of on-board aircraft ice protection and detection systems that will detect and alert flightcrews when the airplane is encountering freezing drizzle and freezing rain and accreting resultant ice. (Class II, Priority Action) (A-96-69)

--to the National Oceanic and Atmospheric Administration:

Develop methods to produce weather forecasts that both define specific locations of atmospheric icing conditions (including freezing drizzle and freezing rain), and that produce short range forecasts ("nowcasts") that identify icing conditions for a specific geographic area with a valid time of 2 hours or less. Ensure the timely dissemination of all significant findings to the aviation community in an appropriate manner. (Class II, Priority Action) (A-96-70)

--to AMR Eagle:

Require dispatchers to include in the flight release airman's meteorological information (AIRMETs) and center weather advisories (CWAs) that are pertinent to the route of flight so that flightcrews can consider this information in their preflight and in-flight decisions. (Class II, Priority Action) (A-96-71)

Encourage captains to observe a "sterile cockpit" environment when an airplane is holding, regardless of altitude, in meteorological conditions such as convective areas or icing conditions, that have the potential to demand significant attention of a flightcrew. (Class II, Priority Action) (A-96-72)

Conduct a procedural audit to eliminate existing conflicts in guidance and procedures between the Aircraft Flight Manuals, Flight Operations Manuals, and other published material. (Class II, Priority Action) (A-96-73)

Also as a result of this accident, the Safety Board issued the following safety recommendations to the FAA on November 7, 1994:

Conduct a special certification review of the ATR 42 and ATR 72 airplanes, including flight tests and/or wind tunnel tests, to determine the aileron hinge moment characteristics of the airplanes operating with different airspeeds and configurations during ice accumulation and with varying angles of attack following ice accretion. As a result of the review, require modifications as necessary to assure satisfactory flying qualities and control system stability in icing conditions. (Class II, Priority Action) (A-94-181)

Prohibit the intentional operation of ATR 42 and ATR 72 airplane in known or reported icing conditions until the effect of upper wing surface ice on the flying qualities and aileron hinge moment characteristics are examined further as recommended in A-94-181 and it is determined that the airplane exhibits satisfactory flight characteristics. (Class I, Urgent Action) (A-94-182)

Issue a general notice to ATC personnel to provide expedited service to ATR 42 and ATR 72 pilots who request route, altitude, or airspeed deviations to avoid icing conditions. Waive the 175 knot holding speed restriction for ATR 42 and ATR 72 airplanes pending acceptable outcome of the special certification effort. (Class I, Urgent Action) (A-94-183)

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. (Class I, Urgent Action) (A-94-184)

Caution pilots of ATR 42 and ATR 72 airplanes that rapid descents at low altitude or during landing approaches or other deviations from prescribed operating procedures are not an acceptable means of minimizing exposure to icing conditions. (Class I, Urgent Action) (A-94-185)

In addition, the Safety Board issued the following safety recommendations to the FAA on November 6, 1995:

Require the Air Traffic Control System Command Center to retain all flow control-related facility documents for 15 days, regardless of title, name. or form number, for reconstruction purposes. (Class II, Priority Action) (A-95-103)

Develop a list of documents to be completed by the Air Traffic Control System Command Center personnel in the event of an incident or accident. (Class II, Priority Action) (A-95-104)

Revise Order 8020.11, "Aircraft Accident and Incident Notification, Investigation and Reporting," to include the Air Traffic Control System Command Center (DCC) facility. Ensure that the DCC facility is assigned specific requirements to be included in an accident/incident package. (Class II, Priority Action) (A-95-105)

Revise FAA Order 7210.3, "Facility Operation and Administration," Chapter 3, "Facility Equipment," Section 4, "Recorders," paragraph 3-41, "Assignment of Recorder Channels," to include the Air Traffic Control System Command Center facility, listing the recorded positions and their priority. (Class II, Priority Action) (A-95-106)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

James E. Hall
Chairman

John Hammerschmidt
Member

John J. Goglia
Member

George W. Black
Member

Vice Chairman Robert T. Francis did not participate.

July 9, 1996

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APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The Safety Board was notified of the accident by the FAA Communications Center, Washington, D. C., at approximately 1700 eastern standard time on October 31, 1994. A full Go-Team was dispatched to Roselawn, Indiana, at approximately 2100 that evening via the FAA's Gulfstream IV aircraft. The Investigator-in-Charge (IIC) was Mr. Gregory A. Feith, and Chairman James Hall was the Board Member who accompanied the team to the site. The on-scene investigation was conducted over a period of 9 days. The follow-up investigative activities were conducted at various locations, including Toulouse, France, and Edwards Air Force Base, California, and involved extensive operational, engineering, airworthiness, air traffic control, and aircraft performance issues.

Investigative groups were convened at the Safety Board's Headquarters in Washington, D. C., to read out the cockpit voice recorder (CVR) and flight data recorder (FDR) after they were recovered from the accident airplane and transported to the Safety Board.

The following were designated as parties to the investigation:

1. The Federal Aviation Administration (FAA)
2. Simmons Airlines, Inc./AMR Eagle
3. Air Line Pilots Association (ALPA)
4. Avions de Transport Regional (ATR)
5. National Air Traffic Controllers Association (NATCA)
6. National Weather Service (NWS)
7. National Aeronautics and Space Administration (NASA)
8. Honeywell, Inc.

An accredited representative from the Bureau Enquetes-Accidents (BEA) and the Direction General a l'Aviation Civile (DGAC) participated in all investigative activities.

2. Public Hearing

A public hearing, chaired by Member John Hammerschmidt, was held in Indianapolis, Indiana, from February 27 through March 3, 1995.

APPENDIX B

COCKPIT VOICE RECORDER TRANSCRIPT

Transcript of a Fairchild A-100A cockpit voice recorder (CVR), s/n 60753, installed on an American Eagle ATR 72, N401AM, which was involved in a collision with terrain near Roselawn, Indiana, on October 31, 1994.

LEGEND

HOT	Crewmember hot microphone voice or sound source
RDO	Radio transmission from accident aircraft
CAM	Cockpit area microphone voice or sound source
INT	Transmissions over aircraft interphone system
CTR	Radio transmission from Chicago Center
ADF	Transmission received over aircraft's ADF radio
PA	Transmission made over aircraft Public Address system
AEC	Radio transmission from American Eagle Chicago Operations Control
KW17	Radio transmission from KIWI flight seventeen.
-B	Sounds heard only through both pilots' hot microphone systems
-1	Voice identified as Pilot-in-Command (PIC)
-2	Voice identified as Co-Pilot
-3	Voice identified as 1st female Flight Attendant
-4	Voice identified as 2nd female Flight Attendant
-?	Voice unidentified
*****	Unintelligible word
@	Non pertinent word
#	Expletive
%	Break in continuity
( )	Questionable insertion
[ ]	Editorial insertion
....	Pause

Note 1: Times are expressed in central standard time (CST).

Note 2: Non pertinent conversation where noted refers to conversation that does not directly concern the operation, control, or condition of the aircraft, the effect of which will be considered along with other facts during the analysis of flight crew performance.

NATIONAL TRANSPORTATION SAFETY BOARD
Engineering and Computer Services Division
Washington, D.C. 20594

ADDENDUM

SPECIALIST'S FACTUAL REPORT OF INVESTIGATION
Cockpit Voice Recorder
DCA 95 MA 001

October 16, 1995

The following corrections on page #8 of the original transcript have been approved by the CVR Group:

1. **Modify editorial comment at time 1542:40;**

   CAM [sound of several clicks similar to cockpit door being opened and closed]

   Modify editorial comment at time 1542:46;

   CAM [low frequency sound decreases slightly in volume]

Albert G. Reitan
Transportation Safety Specialist

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
START of RECORDING			
START of TRANSCRIPT			
		1527:59 **ADF-2**	[sound of music]
1528:00 **CAM-1**	did that transmit?		
1528:02 **CAM-2**	looks like it did.		
1528:06 **CAM-3**	***.		
1528:07 **CAM-2**	I didn't see the transmit thing go off because I was distracted.		
1528:11 **CAM-3**	wow, ***.		
1528:18 **CAM-?**	** see what's going on up here.		
1528:21 **CAM**	[sound of loud music]		
1528:26 **CAM-3**	is that like stereo, radio. ... you don't have a hard job at all. ... we're back there slugging with these people. *****.		
1528:38 **HOT-1**	yeah you are.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1528:40 **CAM-3**	**.		
1528:44 **HOT-1**	we do have it pretty easy. I was telling Jeff I don't think I'd ever want to do anything else but this .		
1528:51 **CAM-3**	*****.		
1528:53 **CAM-2**	no, ****.		
1528:54 **CAM-3**	***.		
1528:55 **CAM-2**	just wanted to see your reaction. I, I like dealing people in a way it's kinda' neat to be able to talk to them.		
1529:03 **CAM**	[miscellaneous non-pertinent conversation between captain and flight attendant continues]		
1530:00 **CAM-3**	I know.		
1530:00 **CAM-3**	and how late are we going to be?		
1530:01 **CAM-1**	well.		
1530:02 **CAM-3**	we already got two people that have already missed their flight.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1530:05 **CAM-1**	oh really.		
1530:06 **CAM-3**	three fifteen is one of them.		
1530:08 **CAM-1**	three fifteen, three fifteen?		
1530:10 **CAM-3**	it's all your fault.		
1530:11 **CAM-3**	uh huh. we weren't due into Chicago until three fifteen. ***.		
1530:15 **CAM-3**	***.		
1530:20 **CAM-1**	she's lying then.		
1530:23 **CAM-3**	you know what we deal with out here?		
1530:26 **CAM-2**	** four fifteen.		
1530:28 **CAM-1**	ya, you should hit her.		
1530:29 **CAM-3**	yeah.		
1530:30 **CAM-1**	three fifteen eastern time.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1530:34 - 1531:11 **CAM**	[miscellaneous non-pertinent conversation between pilot and flight attendant continues]		
1531:11 **CAM-3**	what do you all do up here when *** when auto-piloting? just hang out?		
1531:17 **CAM-2**	you still gotta tell it what to do.		
1531:20 **CAM-1**	if the auto-pilot didn't work, he'd be one busy little bee right now.		
1531:23 **CAM-2**	[sound of laughter}		
1531:25 **CAM-3**	so does the FO's do a lot more work than you do?		
1531:28 **CAM-1**	yep.		
1531:29 **CAM-3**	[sound of laughter]		
1531:30 **CAM-2**	not really.		
1531:31 - 1533:10 **CAM**	[non-pertinent pilot and flight attendant conversation continues]		
1533:13 **HOT-1**	man this thing gets a high deck angle in these turns.		
1533:15 **HOT-2**	yeah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
1533:17 **HOT-1**	we're just wallowing in the air right now.		
1533:19 **HOT-2**	you want flaps fifteen?		
1533:21 **HOT-1**	I'll be ready for that stall procedure here pretty soon.		
1533:22 **HOT-2**	[sound of chuckle]		
1533:24 **HOT-1**	do you want kick 'em in (it'll) bring the nose down.		
1533:25 **HOT-2**	sure.		
1533:26 **CAM**	[sound of several clicks similar to flap handle being moved]		
1533:29 **HOT-1**	guess Sandy's going "ooo".		
1533:34 **CAM**	[wailing sound of "whooler" similar to pitch movement]		
1533:36 **HOT-1**	so anyway ..		
1533:37 **CAM-3**	aah.		
1533:39 **HOT-1**	.. the trim, automatic trim.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1533:41 **CAM-3**	what were they telling me about, what if, ***** something about rain. they always trick the hiring people. * about rain, ** some little person that talks.		
1533:56 **CAM**	[single tone similar to caution alert chime]		
1533:57 **HOT-1**	rain?		
1533:58 **HOT-2**	no, this one maybe?		
1533:59 **HOT-3**	sounds like it said something about the rain, or.		
1534:01 **CAM-5**	glide slope, whoop whoop, pull-up, whoop whoop pull-up.		
1534:05 **HOT-1**	that one?		
1534:07 **CAM-3**	ya, but there's something else.		
1534:09 **HOT-2**	no, like I said. it's a rain cloud they say, well how you know? because this thing tells us. it'll tell you, terrain, terrain.		
1534:18 **CAM-3**	that's what it says, terrain ***.		
1534:19 **HOT-1**	I think it's this thing here.		
1534:20 **CAM-3**	ya.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1534:21 **HOT-1**	I don't know ..		
1534:23 **CAM-5**	too-low, terrain, too-low terrain.		
1534:25 - 1538:47 **CAM**	[non-pertinent pilot and flight attendant conversation continues]		
1537:40 **CAM**	[wailing sound for 1.0 seconds similar to "whooler" pitch trim movement]		
		1538:43 **CTR**	Eagle flight one eight four, expect further clearance two two zero zero.
		1538:47 **RDO-1**	OK, we'll expect further two two zero zero. Eagle flight uh, one eight four.
1538:55 - 1542:34 **CAM**	[non-pertinent pilot and flight attendant conversation continues]		
		1538:55 **ADF-2**	[sound of music similar to standard broadcast radio station continues]
1541:07 **CAM**	[single tone similar to caution alert chime]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1541:12 **CAM**	[low frequency sound starts and increases slightly in frequency similar to increase in propeller RPM]		
1542:15 **CAM**	[wailing sound for 0.5 seconds similar to "whooler" pitch trim movement]		
1542:20 **CAM**	[sound of eight clicks]		
1542:38 **CAM-3**	see you all.		
1542:39 **CAM-1**	alright.		
1542:40 **CAM**	[sound of several click similar to cockpit door being opened and closed]		
1542:41	[Hereafter, all cockpit conversation and radio transmissions relating to flight 4184 have been transcribed in their entirety.]		
1542:46 **CAM**	[low frequency sound decreases slightly in similar to decrease is propeller RPM]		
1543:16 **HOT-2**	let's see, we got about uh, thirty six hundred pounds of fuel?		
1543:19 **HOT-1**	uh huh.		
1543:27			

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
HOT-2	they sent us a message see that dispatch?		
1543:30 **HOT-1**	does it work?		
1543:32 **HOT-2**	so they must have got that message that we were in a hold there.		
1543:35 **HOT-1**	why, what happened?		
1543:37 **HOT-2**	um,		
1543:40 **HOT-1**	oh, you got this?		
1543:42 **HOT-2**	yeah. it just came up on its own.		
1543:51 **HOT-1**	so did you send 'em uh, the new updated uh, EFC?		
1543:56 **HOT-2**	yeah. I just threatened to send it. it says acknowledge it. how do you acknowledge it? this is the only way I know how.		
1544:03 **HOT-1**	yeah, you just uh, send 'em something.		
1544:06 **HOT-2**	should I tell 'em how much fuel we got?		
1544:07 **HOT-1**	sure.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1544:09 **HOT-2**	**.		
1544:14 **HOT-?**	*.		
		1544:19 **ADF-2**	[sound of music similar to standard broadcast radio station continues]
1544:25 **HOT-2**	space, f-u-e-l is that?		
1544:36 **HOT-1**	**** thirty six hundred pounds **.		
1545:10 **HOT-2**	crews receive dummy messages but I don't what that ***.		
1545:14 **HOT-1**	acknowledge message one two one one? they sending you another message?		
1545:18 **HOT-2**	see that was in there before.		
1545:20 **HOT-1**	oh OK, that's an old one?		
1545:21 **HOT-2**	yeah, I think ...		
1545:27 **HOT-1**	did you send 'em something?		
1545:29 **HOT-2**	I think that's if you send them that uh, acknowledged it's called **.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1545:34 **HOT-1**	essential data *** .		
1545:36 **HOT-2**	yeah.		
		1545:48 **ADF-2**	[sound of music similar to standard broadcast radio station stops]
1545:48 **PA-1**	well folks once again, this is the captain. you're uh, do regret to inform that, air traffic control has put us into a holding pattern up here, we're holding for approximately twenty minutes out of Chicago at this time but uh, I guess the congestion an' traffic's continued on uh, they need us to hold out here for some spacing. they're saying at this point uh, on the hour before we depart the hold though that may not hold uh, we may not be here the full thirteen minutes. we'll be sure to keep you updated. once we leave the hold we'll let you know more if they tell us the hold is going to be a little bit longer. I do apologize for all these delays. chances are that all the flights in and out of Chicago here this afternoon are going to be delayed as well. this is not just aircraft in the air right now but this is also uh, for aircraft that were in the air earlier, aircraft on the ground and aircraft that are going to be departing. so uh, once again chances are that your flight would be delayed also and you'll still have a real good chance of making your connection. if not, they'll uh, automatically re-book you on the next flight in Chicago.		
1546:51 **HOT-1**	did you get another note?		
1546:55 **HOT-2**	no. I'm just trying to figure this out. this uh, ... messages. there isn't any company messages. but I think that's the number you put in there you just hit this number. and, after		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
	you write a message, you know with the free text, you do this and see to make sure if they acknowledge **.		
1547:21 **HOT-1**	why did they do that?		
1547:23 **HOT-2**	this a free text one to send your own stuff. that's what I say.		
1547:28 **HOT-1**	did you tell them the new, the new delay times er the EFC is zero zero?		
1547:31 **HOT-2**	yeah. but I didn't do it on that line, I did it on uh, uh, uh, the delays.		
1547:39 **HOT-1**	OK they know so they know OK. what if you went like this? messages, message received, acknowledged thirty nine twenty, so ...		
1547:52 **HOT-2**	I, I just typed that one in myself and I, I hit enter.		
1547:56 **HOT-1**	oh, OK.		
1547:57 **HOT-2**	and uh, I don't know if that means they sent me that I'm supposed to acknowledge that and hit it or if I'm sup.. or if that's us sending them a message for them to acknowl-edge us.		
1548:05 **HOT-1**	oh, I don't know.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1548:05 **HOT-?**	**.		
1548:06 **HOT-?**	.. confused on that.		
1548:09 **HOT-1**	yeah, I'll get my little uh, ACARS book and read it.		
1548:13 **HOT-2**	one guy told me that system you, send another message and you type that number in to see if they got it. if they uh, if write in there "acknowledged", message thirty nine twenty from you.		
1548:24 **HOT-1**	huh.		
1548:26 **HOT-2**	I guess.		
1548:33 **CAM**	[sound of click]		
1548:34 **HOT-2**	that's much nicer, flaps fifteen.		
1548:36 **HOT-1**	yeah.		
1548:43 **HOT-?**	I'm showing some ice now.		
1548:45 **HOT-?**	**.		
1548:46			

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
HOT-1	I'm sure that once they let us out of the hold and forget they're down we'll get the overspeed.		
1548:48 **HOT-2**	[sound of chuckle]		
1548:57 **HOT-1**	good, I can't hold any more man, that big (cup) needs out right now.		
1548:59 **HOT-2**	[sound of chuckle] they're gonna be giving you dirty looks, man.		
1549:02 **HOT-1**	oh man, oh yeah, I know they are. people do. it's either that or pee on 'em.		
1549:05 **CAM**	[sound of ding dong similar to flight attendant call bell]		
1549:05 **HOT-1**	[sound of clink similar to seat belt being unfastened]		
1549:06 **HOT-2**	yeah, I'll talk to her.		
1549:06 **CAM**	[sound of ding dong similar to flight attendant call bell]		
1549:07 **CAM**	[sound of clunk]		
1549:08 **INT-1**	what's up?		
1549:08 **INT-4**	it's just me.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1549:09 **INT-1**	huh?		
1549:10 **INT-4**	I'm uh, it was just me.		
1549:11 **INT-1**	oh.		
1549:12 **INT-4**	I'm just wondering how much gas do we got.		
1549:14 **INT-1**	how much gas we have?		
1549:15 **INT-4**	yeah.		
1549:16 **INT-1**	we got more than plenty of gas. we can be out here for a long time.		
1549:19 **INT-4**	cool, OK. just, was worried. maybe you'd have to divert somewhere, and really make these people ...		
1549:25 **INT-2**	sixty miles from Chicago.		
1549:26 **INT-1**	oh, yeah.		
1549:26 **INT-4**	six, sixty miles?		
1549:27 **INT-2**	yeah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1549:28 **INT-4**	yeah, but they're still gonna hold us, huh?		
1549:30 **INT-1**	'til, about another ten minutes.		
1549:32 **INT-4**	and that's not a for sure thing, is it?		
1549:34 **INT-1**	eehh ya, pretty for sure as of right now unless they decide to make it different. how's that, for an answer?		
1549:40 **INT-4**	[chuckle] same like the other one.		
1549:42 **INT-1**	yeah, I know.		
1549:43 **CAM**	[sound of clunk]		
1549:44 **CAM-1**	talk to her bro.		
1549:45 **INT-2**	OK.		
1549:49 **INT-4**	bye.		
1549:50 **INT-2**	hey. you there?		
1550:41 **CAM**	[sound of ding dong similar to flight attendant call bell]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1550:43 **INT-2**	hello.		
1550:43 **INT-4**	*, are you sure you can handle it up there?		
1550:46 **INT-2**	I'll try.		
1550:47 **INT-4**	'K uh,		
1550:48 **INT-2**	why do you ...		
1550:49 **INT-4**	turn it down. it needs to be cooler back here. it's hot.		
1550:51 **INT-2**	I'm uh, it's all the way down now.		
1550:53 **INT-4**	OK thanks.		
1550:53 **INT-2**	it's been,		
1550:54 **INT-4**	it's been down?		
1550:55 **INT-2**	yeah, well, I'll, I'll chill it up up with * too.		
1550:59 **INT-4**	really, well we're sweatin' [sound of panting]		
1551:01 **INT-2**	you know why?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1551:02 **INT-4**	you wanta hear us breathe heavy? [sound of chuckle]		
1551:03 **INT-2**	it's it's, one of the bleeds are off.		
1551:06 **INT-4**	OK.		
1551:07 **INT-2**	one of the for the air conditioning.		
1551:08 **INT-4**	yeah.		
1551:09 **INT-2**	and it's, your side.		
1551:10 **INT-4**	oh *.		
1551:11 **INT-2**	it's the one that gives you most of the air back there.		
1551:13 **INT-4**	figures.		
1551:14 **INT-2**	so now you got y-y-you got less than uh, half, not only that it's your your half. [sound of chuckle]		
1551:20 **INT-4**	OK.		
1551:22 **INT-2**	I'll try.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1551:22 **INT-4**	OK, well here. Orlando wants to talk to you.		
1551:24 **INT-2**	Orlando does?		
1551:35 **INT-2**	hello.		
1551:39 **INT-1**	hey bro.		
1551:39 **INT-2**	yeah.		
1551:40 **INT-1**	gettin' busy with the ladies back here.		
1551:41 **INT-2**	oh.		
1551:43 **INT-4**	[sound of snicker]		
1551:45 **INT-1**	yeah, so if so if I don't make it up there within the next say, fifteen or twenty minutes you know why.		
1551:49 **INT-2**	OK.		
1551:50 **INT-1**	OK.		
1551:51 **INT-2**	I'll uh, when we get close to touchdown I'll give you a ring.		
1551:53			

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
INT-1	there you go.		
1551:54 **INT-2**	*.		
1551:55 **INT-1**	no, I'll I'll be up right now. there's somebody in the bathroom so ****.		
1551:55 **CAM**	[wailing sound similar to "whooler" pitch trim movement for two seconds]		
1551:59 **INT-1**	talk to you later.		
1552:00 **INT-2**	OK.		
		1553:36 **KW17**	good afternoon Chicago, Kiwi Air seventeen out of twenty for eleven.
		1553:42 **CTR**	Kiwi Air seventeen Chicago center roger. Midway altimeter two niner seven niner.
1553:48 **CAM**	[sound of two clicks]		
1554:13 **CAM**	[sound of several clicks similar to cockpit smoke door being operated]		
1554:16 **CAM-1**	we have a brand new hombre.		
1554:20			

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
CAM	[sound of two clicks similar to captain's seat moving laterally and forward]		
1554:25 **HOT-2**	oh yeah.		
1554:30 **CAM**	[sound of click similar to lap belt being fastened]		
1554:24 **HOT-1**	[sound similar to captain's hot microphone bumping against object]		
		1553:47 **KW17**	two niner seven niner, roger.
1554:38 **HOT-2**	hello.		
		1553:39 **CTR**	Kiwi Air seventeen, expedite your descent all the way down to eleven, please.
		1553:42 **KW17**	expedite to eleven, Kiwi Air seventeen.
1554:47 **HOT-1**	did you get any more messages from the cabbage patch?		
1554:49 **HOT-2**	no. I sent them another message saying did you get our twenty two hundred uh, out of the hold thing through.		
1554:52 **CAM**	[sound of click similar to shoulder harness being fastened]		
1554:55 **HOT-1**	*.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1554:56 **HOT-2**	you know the other mode about delays and just asked them if they got that.		
1555:04 **HOT-1**	[sound of sigh] **.		
1555:04 **HOT-2**	enough playing with that.		
1555:05 **HOT-1**	where's the uh, where's the connecting gates? did we throw those away?		
1555:09 **HOT-2**	uh, I didn't throw 'em away.		
1555:12 **HOT-1**	how do you how do you get connecting gates?		
1555:14 **HOT-2**	i- in-range one.		
1555:23 **HOT-1**	and you haven't heard any more from this chick in, this controller chick huh?		
1555:26 **HOT-2**	no, not a word. where'd it go anyway?.		
1555:30 **HOT-1**	I don't know. I must have thrown it away.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1555:32 **CTR**	Kiwi Air seventeen, fly a heading zero seven zero. this is radar vectors for your descent.
		1555:37 **KW17**	* Air seventeen * zero five zero.
1555:42 **HOT-2**	we still got ice.		
1555:46 **CAM**	[sound similar to paper being torn from ACARS printer]		
1555:47 **HOT-1**	here.		
1555:58 **HOT-2**	get a message?		
1555:59 **HOT-1**	you did.		
1556:01 **HOT-2**	understand a definite maybe on twenty two, release time. [sound of "ha, ha"]		
1556:08 **HOT-B**	[sound of beep similar to frequency change on VHF comm]		
1556:11 **HOT-1**	I'll be right back. 'K, I'm a talk to the company.		
		1556:14.7 **CTR**	Eagle flight one eighty four, descend descend and maintain eight thousand?
		1556:15.8 **RDO-1**	Chicago, do you copy forty, one eighty four?

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
		1556:20.1 **AEC**	forty one eighty four, go ahead.
		1556:21.7 - 1556:47.0 **RDO-1**	yeah, we've already been talking to dispatch uh, on the ACARS but so they are aware of our delay I don't know if you guys got the word on that. we're on a hold out here uh, we got three, thirty two hundred pounds, thirty three hundred pounds of fuel. they're saying zero zero, for uh, EFC so in about another four or five minutes we'll find what the new word is. but what can you tell me about um, there's this guy concerned about his Frankfurt connection uh, do you know anything about that?
1556:24 **CAM-5**	traffic, traffic.		
		1556:27.8 **CTR**	Eagle flight one eighty four, descend and maintain eight thousand.
		1556:31.6 **RDO-2**	down to eight thousand. Eagle flight one eighty four.
1556:38.3 **CAM**	[wailing sound similar to "whooler" pitch trim movement]		
		1556:44.9 **CTR**	Eagle flight one eighty four uh, should be about ten minutes uh, till you're cleared in.
		1556:48.3 **AEC**	uh, I can double check on that uh, yeah. just sent a message to dispatch to see if you were in a hold. copy thirty on the fuel and estimated out time on the hour.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
			and, did you have that uh, Frankfurt flight number by any chance?
		1556:50.1 **RDO-2**	thank you.
1556:53.1 **HOT-2**	they say ten more minutes.		
		1557:01.5 **CTR**	Kiwi Air seventeen, fly a heading of three six zero.
		1557:02.0 **RDO-1**	um, no I sure don't but I pulled up connecting gates out of the ACARS and is says it's going out of K five if that helps you any at all.
		1557:05.0 **KW17**	Kiwi Air seventeen, heading three six zero.
1557:07	**[**sound of light tapping heard on first officer channel**]**		
		1557:08.8 **AEC**	let me check.
1557:16.3 **HOT-1**	are we out of the hold?		
1557:17.3 **HOT-2**	uh, no, we're just goin' to eight thousand.		
1557:19.4 **HOT-1**	OK.		
1557:20.0 **HOT-2**	and uh, ten more minutes she said		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1557:22.1 **CAM**	[sound of repeating beeps similar to overspeed warning starts and continues for 4.6 seconds]		
1557:23.3 **HOT-2**	... oop.		
		1557:24.7 **CTR**	Kiwi Air seventeen, descend and maintain six thou-sand.
1557:26.2 **HOT-1**	we, I knew we'd do that.		
1557:27.4 **HOT-2**	I's trying to keep it at one eighty.		
		1557:28.2 **KW17**	Kiwi Air seventeen, eleven point five for six.
1557:29.2 **HOT-2**	[ramping repetitive thud sound]		
1557:28.9 **HOT-B**	[wailing sound for 1.2 seconds similar to "whooler" pitch trim movement]		
1557:29.9 **HOT-1**	oh.		
1557:31.2 **HOT-B**	[wailing sound for 1.7 seconds similar to "whooler" pitch trim movement]		
1557:32.8 **HOT-2**	oops, #.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1557:33.0 **CAM**	[sound of three thumps followed by rattling]		
1557:33.5 **CAM**	[sound of three sets of repetitive rapid triple chirps similar to auto-pilot disconnect warning lasting 1.09 seconds]		
1557:33.8 **HOT-2**	#.		
1557:35.2 **CAM**	[single horn similar to altitude alert signal]		
		1557:35.6 **CTR**	Kiwi Air seventeen, direct Chicago Heights, direct Midway.
1557:36.9 **HOT-?**	OK		
1557:37.0 **HOT-B**	[intermittent heavy irregular breathing starts and continues to end of recording]		
		1557:39.0 **KW17**	direct the Heights direct Midway, Kiwi Air seventeen.
1557:38.8	[repetitive thumping sound heard on first officers channel]		
1557:39.9 **HOT-?**	oh #.		
1557:42.4 **HOT-1**	OK.		
1557:43.7 **CAM**	[single horn similar to altitude alert signal]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
1557:44.0 **CAM**	[sound of “growl” starts and continues to impact]		
1557:44.2 **HOT-1**	alright man, ...		
1557:45.8 **HOT-1**	OK, mellow it out.		
1557:45.8 **CAM**	[sound of repeating beeps similar to overspeed warning starts and continues to impact]		
1557:46.7 **HOT-2**	OK.		
1557:47.1 **HOT-1**	mellow it out.		
1557:47.7 **HOT-2**	OK.		
1557:48.1 **HOT-1**	auto-pilot’s disengaged.		
1557:49.4 **HOT-2**	OK.		
1557:52.8 **HOT-1**	nice and easy.		
1557: 54.9 **CAM-5**	terrain, whoop whoop.		
1557:56.6 **HOT-2**	aw **.		
1557:56.7			

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
CAM	[loud crunching sound]		

1557:57.1
END of RECORDING

END of TRANSCRIPT

APPENDIX C

EXCERPTS FROM THE FAA SPECIAL CERTIFICATION

REVIEW OF THE ATR

Executive Summary

On October 31, 1994, an accident involving an Aerospatiale Model ATR-72 series airplane occurred when the airplane was enroute from Indianapolis to Chicago. Although the official cause of the accident has not been determined, preliminary information from the accident investigation indicates that, following exposure to a complex and severe icing environment including droplets much larger than those specified in certification criteria for the airplane, and during a descending turn immediately after the flaps were raised, the ailerons abruptly deflected in the right-wing-down direction, the autopilot disconnected, and the airplane entered an abrupt roll to the right, which was not fully corrected before the airplane impacted the ground.

As a result of this accident, the National Transportation Safety Board (NTSB) recommended that the Federal Aviation Administration (FAA) conduct a Special Certification Review (SCR) of Model ATR-42 and -72 series airplanes. The NTSB also recommended that flight test and/or wind tunnel tests be conducted as part of that review. These tests would be performed to determine the aileron hinge moment characteristics of the airplanes while operating at different airspeeds and in different configurations during ice accumulation, and with varying angles of attack following ice accretion.

A ten-person team was formed, including six certification specialists from the FAA, and four specialists from the Direction Générale de l'Aviation Civile (DGAC), which is the airworthiness authority for France. Hundreds of hours were spent investigating the certification and performance of ATR-42 and ATR-72 series airplanes over a six-month period, at eight venues both in the United States and in France.

During its investigation, the SCR team participated in the creation of two telegraphic airworthiness directives (AD). Telegraphic AD T94-25-51, which was issued on December 9, 1994, while the special review team was in France, prohibited flight into known or forecast icing conditions for the ATR fleet. The second telegraphic AD, T95-02-51, restored flight in icing conditions upon incorporation of certain flight and dispatch restrictions and procedures. That telegraphic AD was signed on January 11, 1995--only 72 days after the accident, including three major year-end holidays.

In accordance with its charter, the SCR team focused its attention on the following major categories during its investigation:

CERTIFICATION BASIS

The basic Model ATR-42 was approved by the FAA on October 25, 1985 [Type Certificate (TC) A53EU]. The certification basis for the airplane is 14 CFR Part 25, as amended by Amendment 25-1 through Amendment 25-54, with certain special conditions not related to icing. The basic Model ATR-72 was approved by the FAA on November 15, 1989, as an amendment to TC A53EU. The ATR-72-2 11/2 12 model (the accident airplane) was approved by the FAA on December 15, 1992.

REVIEW OF CERTIFICATION PRACTICES AND RESULTS

The icing certification program conducted for the ATR-42 and -72 demonstrated the adequacy of the anti-ice and de-icing systems to protect the airplane against adverse effects of ice accretion in compliance with the requirements of FAR/JAR 25.1419. The wing deicing system has demonstrated acceptable performance in the meteorological conditions defined in the FAR/JAR 25 Appendix C envelope. Additionally, during the icing tanker testing conducted at Edwards Air Force Base (AFB), California, the proper functioning of the wing deicing boots was observed to correlate with Aerospatiale (ATR) test data within the Appendix C envelope. The certification program for the ATR-72-201/202 and ATR-72-21 1/212 icing systems was documented thoroughly using sound procedures and was processed and conducted in a manner consistent with other FAA icing certification programs. All data reviewed shows compliance with FAR 25/JAR 25.1419. The SCR team concluded that results show a good correlation with Special Condition B6 stall requirements and also with FAR/JAR 25.203 (handling qualities). Model ATR-42 and ATR-72 series airplanes were certificated properly in accordance with DGAC and FAA regulations practices, and procedures.

AUTOPILOT CERTIFICATION PROCEDURES AND CHARACTERISTICS

The Honeywell Automatic Flight Control System (AFCS) was approved by the DGAC in accordance with the FAA certification basis that existed for each successive ATR series airplane. System design parameters for performance and servo authority meet those specified by FAR 25.1329 and AC 25. 1329-1A. The system installation and monitor design is supported by the Aerospatiale Safety Assessment Automatic Pilot System and Honeywell DFZ-6000 Safety Analysis for critical and adverse failure cases. The equipment qualification and subsequent performance and malfunction flight tests that were performed are consistent with acceptable industry practices and procedures and are similarly consistent with practices and procedures accepted by the FAA in the past for other aircraft. The SCR team concluded that the Honeywell AFCS installed in the successive ATR series airplanes was certificated properly to the requirements of the FAR's.

REVIEW OF PERTINENT SERVICE DIFFICULTY INFORMATION

While all icing-related accident and incident information was not examined to the full extent of the Roselawn accident due to time and resource limitations, certain important aspects of the event history were studied and some conclusions were possible. Events of unacceptable control anomalies were associated with severe icing conditions such as freezing rain/freezing drizzle and, in a few cases, the icing was accompanied by turbulence. These other roll anomaly events provided no evidence that the ATR-72 had any problems with any icing conditions for which it was certificated. Appendix 8 contains a tabulation of events that were known to the SCR team.

ENVIRONMENTAL CONDITIONS OUTSIDE THE APPENDIX C ENVELOPE

Weather observed in the area of the accident appears to have included supercooled water droplets in the size range of about 40 to 400 microns. This weather phenomenon is defined by the SCR team as Supercooled Drizzle Drops (SCDD).

Freezing drizzle and SCDD can be considered to present the same icing threat in terms of adverse effects. While the physics of formation are not the same, the difference between them is that freezing drizzle is found at the surface, while SCDD is found aloft with air at temperatures above freezing underneath. Freezing rain contains droplets in the range of 1,000 to 6,000 microns. Collectively, all these large drops are referred to as supercooled large droplets (SLD). When used herein, the aerodynamic effects of SCDD and freezing drizzle are synonymous. While the effects of ice accreted in SLD may be severe, the clouds that produce them tend to be localized in horizontal and/or vertical extent.

The scientific investigation of SCDD and the body of knowledge on this subject is relatively new. SCDD is not universally understood in the aviation community. SCDD may be considered to icing as the microburst is to wind shear. Both have been unrecognized until recent times. Since they may be very severe, but are localized in extent and difficult to detect until the airplane has encountered the condition, for now, pilot awareness and prompt action to exit the condition are relied upon. Some researchers have observed that the effects of ice accreted in SCDD are far more severe than those of freezing rain.

Considering all available data, the SCR team has determined that the icing conditions of the accident environment were well outside the Appendix C icing envelope. This report contains a detailed description of this phenomenon, several short and long term recommendations are made.

ANALYSIS OF AILERON HINGE MOMENT CHARACTERISTICS

The flight test data and qualitative assessments made by the DGAC during basic certification of the ATR-42 and -72, and the ATR-72-2 11/212, did not indicate that any unsafe or atypical lateral control wheel force characteristics exist. This conclusion also was based on the comprehensive assessment of the airplane in icing conditions conducted in accordance with Special Condition B6. The original certification test program did lack an evaluation of airplane characteristics with asymmetrical ice shapes; however, such an evaluation is not considered standard practice. Ice asymmetry was considered unlikely due to system design and Airplane Flight Manual (AFM) procedures.

Wind tunnel data and analysis have shown that a sharp-edge ridge on the wing upper surface in front of one aileron only can cause uncommanded aileron deflection. By using a very conservative analysis, these data show that keeping the wings level at 175 knots indicated airspeed (KIAS) takes approximately 56 pounds of control wheel force. These force levels were not seen during any of the icing tanker tests. However, during the first series of tests in the icing cloud behind the tanker (see below), a ridge of ice did buildup behind the deicing boots in a similar location to the wind tunnel model, but it was not sharp-edged and only extended spanwise approximately 40 percent in front of the ailerons due to the dimension of the icing cloud. However, these tests indicated that a mechanism existed that could actuaIly produce such a ridge in actual icing conditions. Even though high lateral wheel forces were not seen during the tanker tests, icing specialists indicated that under sIightly different conditions of the icing environment, other shapes could develop. Since the ice ridge sheds in a random manner, and in light of the airflow difference over the wings during maneuvering and turbulence or due to aerodynamic effects, an assumption was made that there could be a significant difference in ice accretion between the left and right wings. Additional flight tests were conducted by Aerospatiale with artificial ice shapes, duplicating the ice that accreted during the tanker tests in freezing drizzle conditions. Initially, these shapes were applied in front of the aileron in a random pattern to duplicate the shedding that was observed during the tanker tests. Additionally, a series of flight tests were conducted with ice shapes covering full and partial spans of the wing. The results of these tests coincided with the results obtained from the tanker tests. Further testing by Aerospatiale with more asymmetry and with sharper edge shapes indicated higher lateral control forces, however, not as high as those derived from the initial wind tunnel studies.

FAA/AIR FORCE ICING TANKER TESTING

Two series of icing tanker tests were performed at Edwards AFB, California in support of the investigation of the October 31, 1994, accident. A United States Air Force jet airplane (similar to a Boeing Model 707) specially modified to produce an icing cloud was used to simulate the conditions believed to have existed at the time of the accident. Direct. results of the icing tanker tests were used to determine possible (1) immediate and long term changes to the aircraft, (2) changes to flight crew operations procedures, (3) changes to the Master Minimum Equipment List (MMEL), and (4) changes to flight crew training.

The first tanker test took place December 13-22, 1994; the second test program took place March 4-7, 1995. Both test programs were conducted as similarly as possible so that the results of the two tests could be compared directly.

APPROVAL OF MODIFIED DEICING BOOTS

Aerospatiale developed a modification that consists of an increase in coverage of the active portion of the upper surface of the outer wing deicing boots from 5 percent chord on the ATR 42 and 7 percent chord on the ATR-72 to 12.5 percent chord for both airplane models. These enlarged wing deicing boots were certificated by extensive dry air and icing wind tunnel tests, and by dry air and natural icing flight tests conducted by Aerospatiale and FAA flight test pilots. In addition, an ATR-72 fitted with the modified boots was flown behind the icing tanker at Edwards AFB. The results of all these tests revealed that the modified boots perform their intended fiction within the icing requirements contained in Appendix C of Part 25 of the Federal Aviation Regulations. All U. S.-registered Model ATR-42 and ATR-72 series airplanes were modified with the new boots prior to June 1, 1995.

Aerospatiale developed the deicing boot modification to provide an increased margin of safety in the event of an inadvertent encounter with freezing rain or freezing drizzle (SLD). With the ability to recognize that an inadvertent encounter had occurred, flight crews would be afforded an increased opportunity to safely exit those conditions. However, even with improved boots installed, Model ATR-42 and -72 airplanes, along with all other airplanes, are not certificated for flight into known freezing drizzle or freezing rain conditions.

OPERATIONAL CONSIDERATIONS THAT MAY REQUIRE CHANGES

Several recommendations regarding operational considerations for the turboprop transport fleet were made. These recommendations include changes to flight crew and dispatcher training, expanded pilot reports, Air Traffic Control and pilot cooperation regarding reporting of adverse weather conditions, flight crew training in unusual attitude recovery techniques, aircraft systems design and human factors, and MMEL relief.

CHANGES TO THE CERTIFICATION REQUIREMENTS (APPENDIX C)

The FAA recognizes that the icing conditions experienced by the accident airplane, as well as other airplanes involved in earlier accidents and incidents (see Appendix 8), may not be addressed adequately in the certification requirements. Therefore, the FAA has initiated the process to create a rulemaking project under the auspices of the Aviation Rulemaking Advisory Committee (ARAC). The ARAC will form a working group, made up of interested persons from the U.S. aviation industry, industry advocacy groups, and foreign manufacturers and authorities. The ARAC working group will formulate policy and suggested wording for any proposed rulemaking in the area of icing certification.

REPORT RECOMMENDATIONS

This report contains 14 specific recommendations in the areas of airplane certification testing and operational considerations.

SCR Team Conclusions

- € ATR-42 and ATR-72 series airplanes were certificated properly in accordance with the FAA and DGAC certification bases, as defined in 14 CFR parts 21 and 25 and JAR 25, including the icing requirements contained in Appendix C of FAR/JAR 25, under the provisions of the BAA between the United States and France.

- € The Roselawn accident conditions included SCDD outside the requirements of 14 CFR part 25 and JAR 25. Investigations prompted by this accident suggest that these conditions may not be as infrequently as commonly believed and that accurate forecasts of SCDD conditions does not have as high a level of certitude as other precipitation. Further, there are limited means for the pilot to determine when the airplane has entered conditions more severe than those specified in the present certification requirements.

SCR Team Recommendations

The 14 recommendations made by the ATR-42 and ATR-72 Airplane Special Certification Review Team are listed below:

RECOMMENDATION 1

The current fleet of transport airplanes with unboosted flight control surfaces should be examined to ascertain that an inadvertent encounter with SLD will not result in a catastrophic loss of control due to uncommanded control surface movement. The following two options should be considered:

1. The airplane must be shown to be free from any hazard due to an encounter of any duration with the SLD environment or

2. The following must be verified for each airplane, and procedures or restrictions must be contained in the AFM:

a The airplane must be shown to operate safely in the SLD environment long enough to identify and safely exit the condition.

b. The flight crew must have a positive means to identify when the airplane has entered the SLD environment.

c. Safe exit procedures, including any operational restrictions or limitations, must be provided to the flight crew.

d. Means must be provided to the flight crew to indicate when all icing due to the SLD environment has been shed/melted/sublimated from critical areas of the airplane.

RECOMMENDATION 2

FAR 25.1419, Appendix C, should be reviewed to determine if weather phenomena which are known to exist where commuter aircraft are operated most often should be included. The following steps should be taken:

1. Scientifically define the SLD environment using the appropriate parameters (LWC, droplet diameter, temperature, horizontal extent).

2. Foster development and validation of analytical tools, computer codes, and test methods to reliably predict and test impingement limits, shape, texture, location, and aerodynamic effects of ice accretions in SLD conditions.

3. Evaluate current certification policy and procedures to determine whether new information regarding the SLD environment should be included.

4. Develop Advisory Circulars or other guidance materials to aid in future aircraft certification programs.

RECOMMENDATION 3

Rulemaking and associated advisory material should be developed for airplanes with unpowered flight control systems to address uncommanded control surface movement characteristics that are potentially catastrophic during an inadvertent encounter with the SLD environment. Discussions about these new criteria should consider the criteria already contained in the certification requirements, as summarized below:

When the aircraft is flying manually:

- FAR 25.143 (c)-Controllability and Maneuverability (Prior to Amendment 25-84)

. . . the "strength of pilots" limits may not exceed:

-60 lbs. for temporary application for roll control

-5 lbs. for prolonged application for roll control

[These forces have been changed to harmonize with JAR 25.143(c) per Amendment 25.84, effective July 10, 1995, as shown below.]

€ JAR 25.143 (c)-Controllability and Maneuverability

. . . the "strength of pilots limits" for conventional wheel type controls may not exceed:

-50 lbs. for temporary application for roll control - two hands available for control

-25 lbs. for temporary application for roll control - one hand available for control

-5 lbs. for prolonged application for roll control

When the autopilot is engaged:

€ ACJ 25.1379 **(Interpretative material and acceptable means of compliance, contained in JAR 25).** pertinent excerpts of ACJ 25.1329 include the following:

- A load on any part of the structure greater than its limit load.

- Bank angles of more than 60° enroute or more than 30° below a height of 1,000 ft.

- Hazardous degradation of the flying qualities of the airplane.

- Hazardous height 1oss in relation to minimum permitted height for autopilot use.

- Engagement or disengagement of a mode leading to hazardous consequences.

• FAR 25.1329 and AC 25.1329-1A

- Roll force to overpower greater than 30 pounds.

- A load in excess of structural limits or beyond 2g.

. Climb, Cruise, Descent, and Holding: Recovery action should not be initiated until three seconds after the recognition point.

RECOMMENDATION 4

The SCR team recommends that existing criteria used for evaluation of autopilot failures be used to evaluate the acceptability of the dynamic response of the airplane to an uncommanded aileron deflection. Moreover, since both of these events (failure/hardover, aileron deflection) can occur without the pilots being directly in the loop, the three-second recognition criteria used for the cruise conditions aIso should be adopted.

RECOMMENDATION 5

Policy should be developed to assure that on-board computers do not inhibit a flight crew from using any and all systems deemed necessary to remove an airplane from danger.

RECOMMENDATION 6

Airplane Flight Manuals should be revised to clearly describe applicable icing limitations.

RECOMMENDATION 7

The FAA/JAA harmonization process for consideration of handling qualities and performance of airplanes while flying in icing conditions should be accelerated. The following specific points should be included:

1. SC B6 does not specify that ice be accreted in one configuration e.g., flaps up, and then demonstrated in subsequent configurations that maybe more adverse. This condition should be considered as a possible revision for future regulatory change.

2. SC B6, Section 4.3.1, states in part:

> "Flight tests in measured natural icing conditions should include observations of actual ice shapes to allow correlation to be made with the predicted shapes in identical conditions, in terms of location, general shape and, where possible, thickness."

The regulation is unclear as to how artificial ice shapes used in flight testing must be correlated with natural ice accretions. This point should be considered for future regulatory change.

RECOMMENDATION 8

Evaluate state-of-the-art ice detector technology to determine whether the certification regulations should be changed to require these devices on newly developed airplanes.

RECOMMENDATION 9

Flight crew and dispatcher training related to operations in adverse weather should be re-eva.lusted for content and adequacy.

RECOMMENDATION 10

Flight crews should be exposed to training related to extreme unusual attitude recognition and recovery.

RECOMMENDATION 11

Pilots should be encouraged to provide timely, precise, and realistic reports of adverse flight conditions to ATC. The tendency to minimize or understate hazardous conditions should be discouraged.

RECOMMENDATION 12

An informational article should be placed in the ***Winter Operations Guidance for Air Carriers,*** or airline equivalent which explains the phenomenon of uncommanded control surface movements and the hazards associated with flight into SLD conditions.

RECOMMENDATION 13

MMEL relief for all aircraft, particularly items in Chapter 30 (Ice and Rain Protection), should be reviewed for excessive repair intervals.

RECOMMENDATION 14

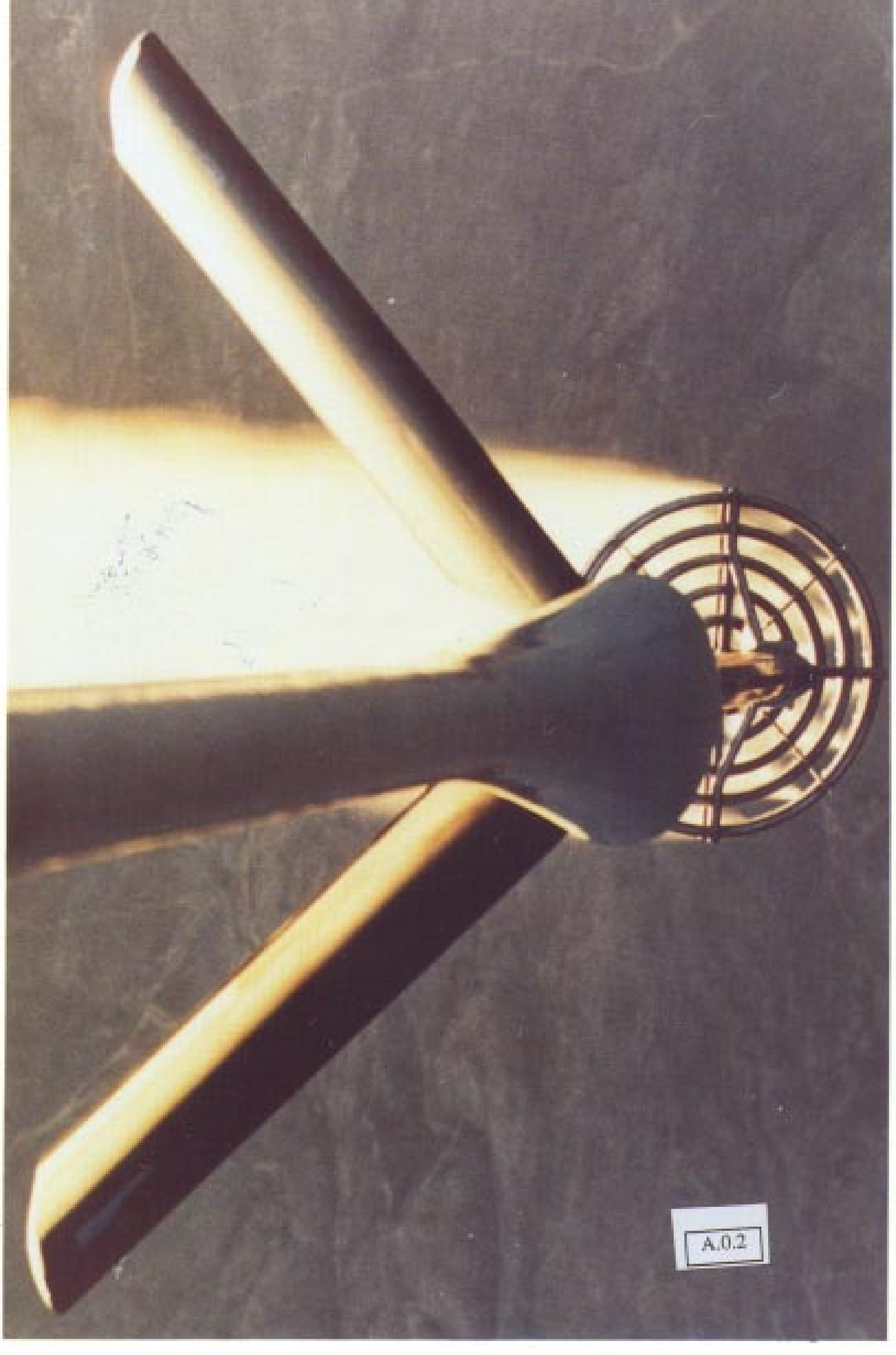
Methods to accurately forecast SLD conditions, and mechanisms to disseminate that information to flight crews in a timely manner should be improved.

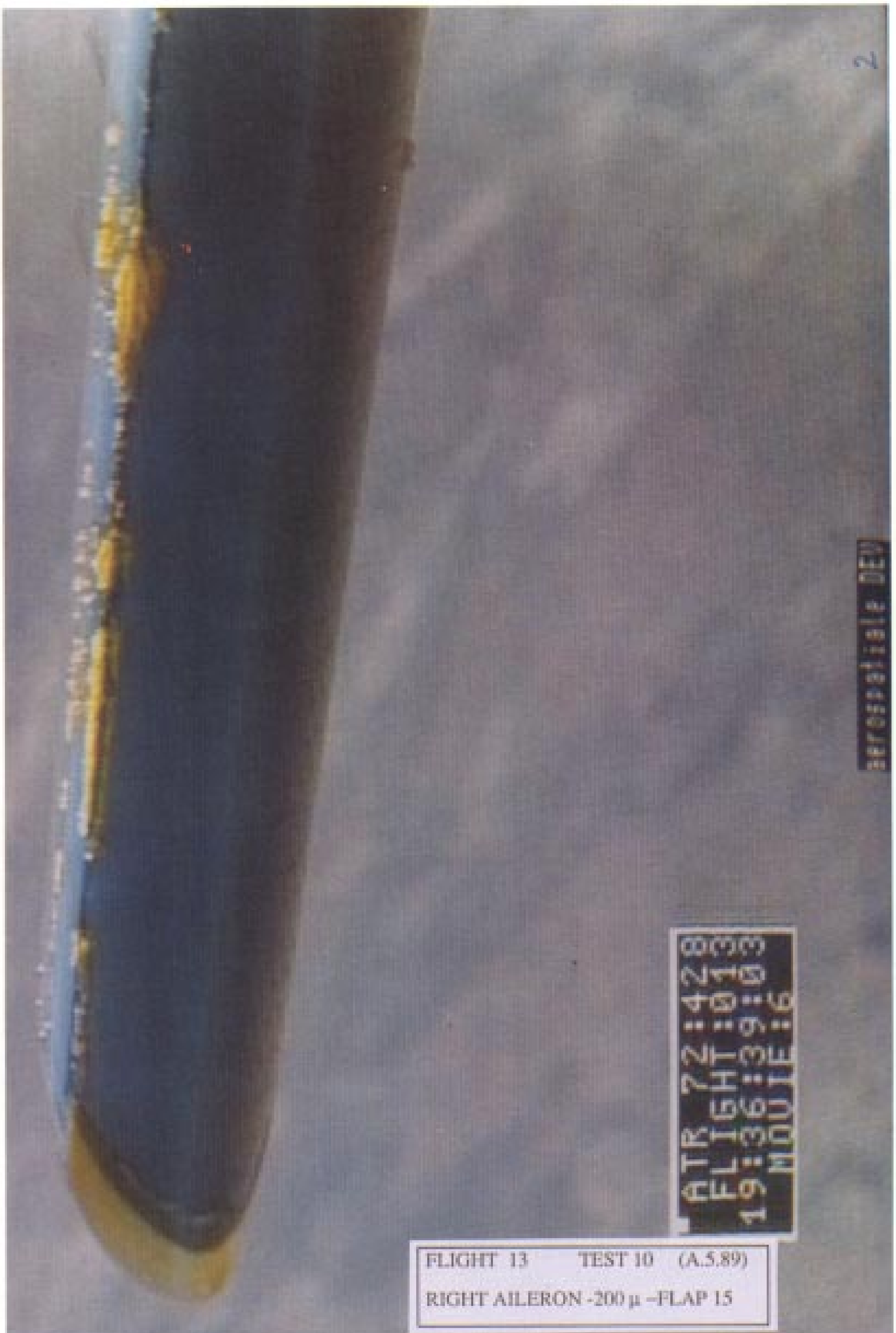
APPENDIX D

PHOTOGRAPHS OF ICE ACCRETIONS ON THE ATR 72

DURING THE ICING TANKER TESTS

A.0.1


A.0.2



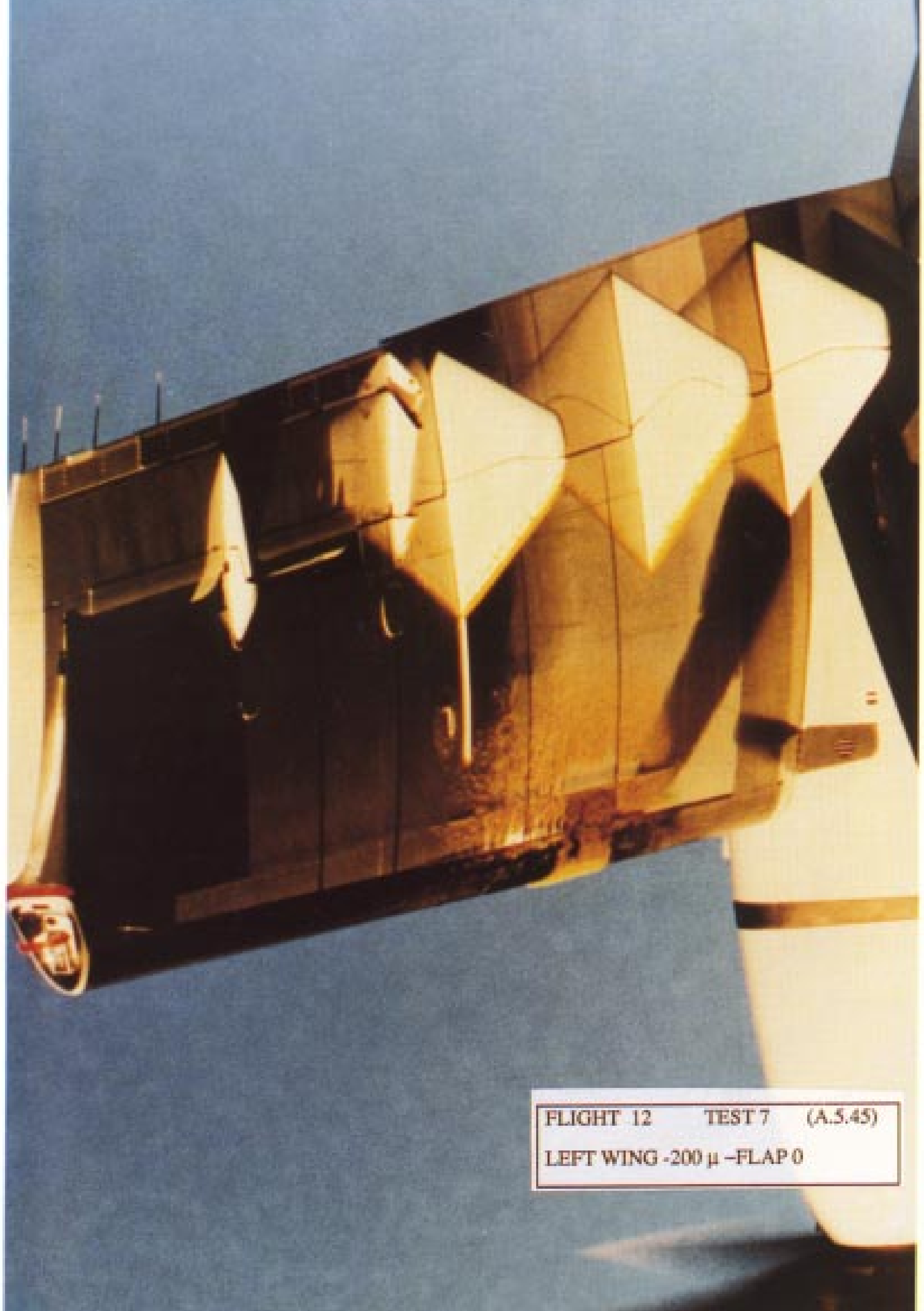
FLIGHT 13 TEST 10 (A.5.89)

RIGHT AILERON -200 µ -FLAP 15

FLIGHT 13 TEST 8 (A.5.63)
RIGHT AILERON -200 µ –FLAP 0

FLIGHT 12 TEST 7 (A.5.44)

LEFT WING -200 μ –FLAP 0

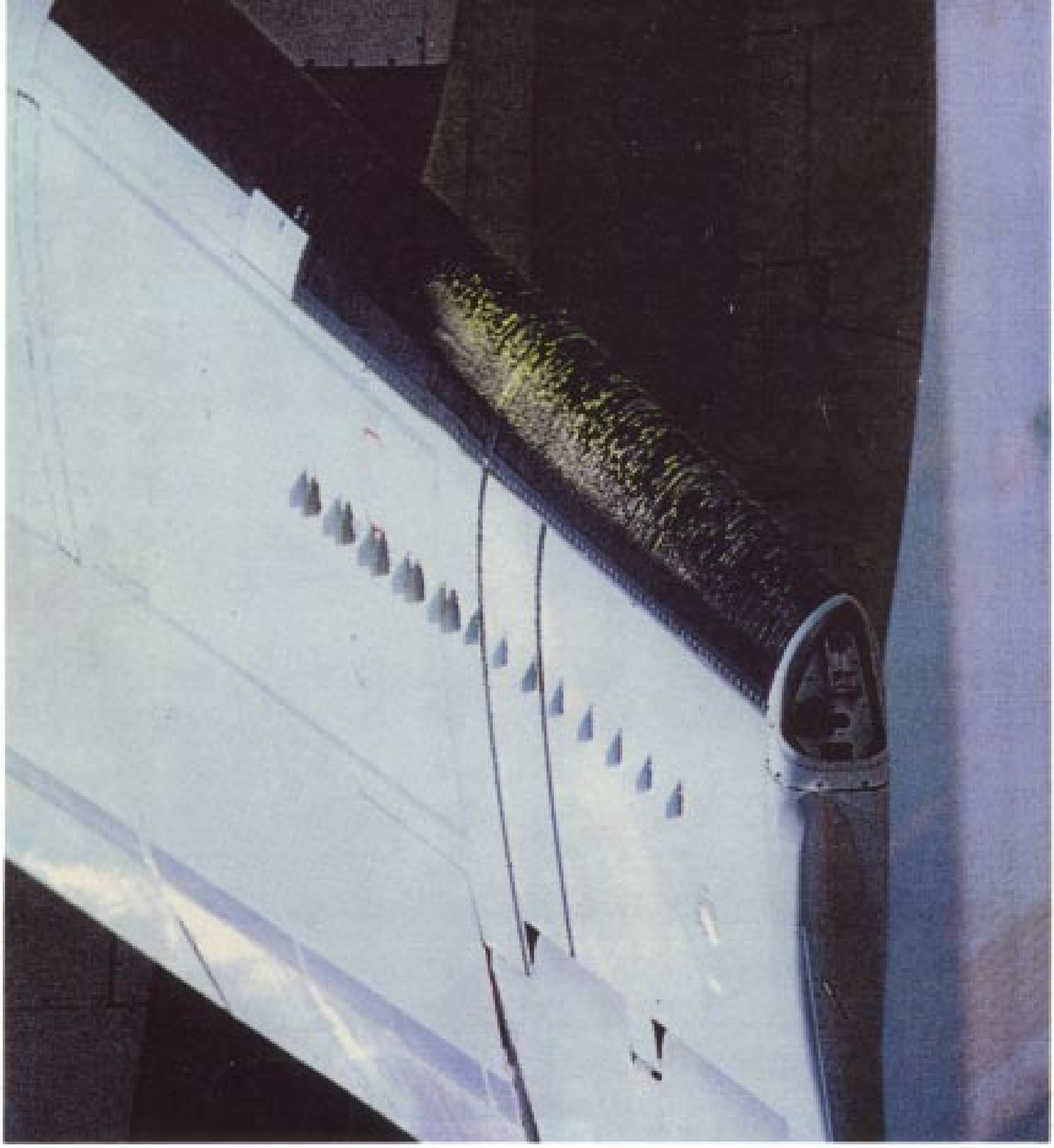


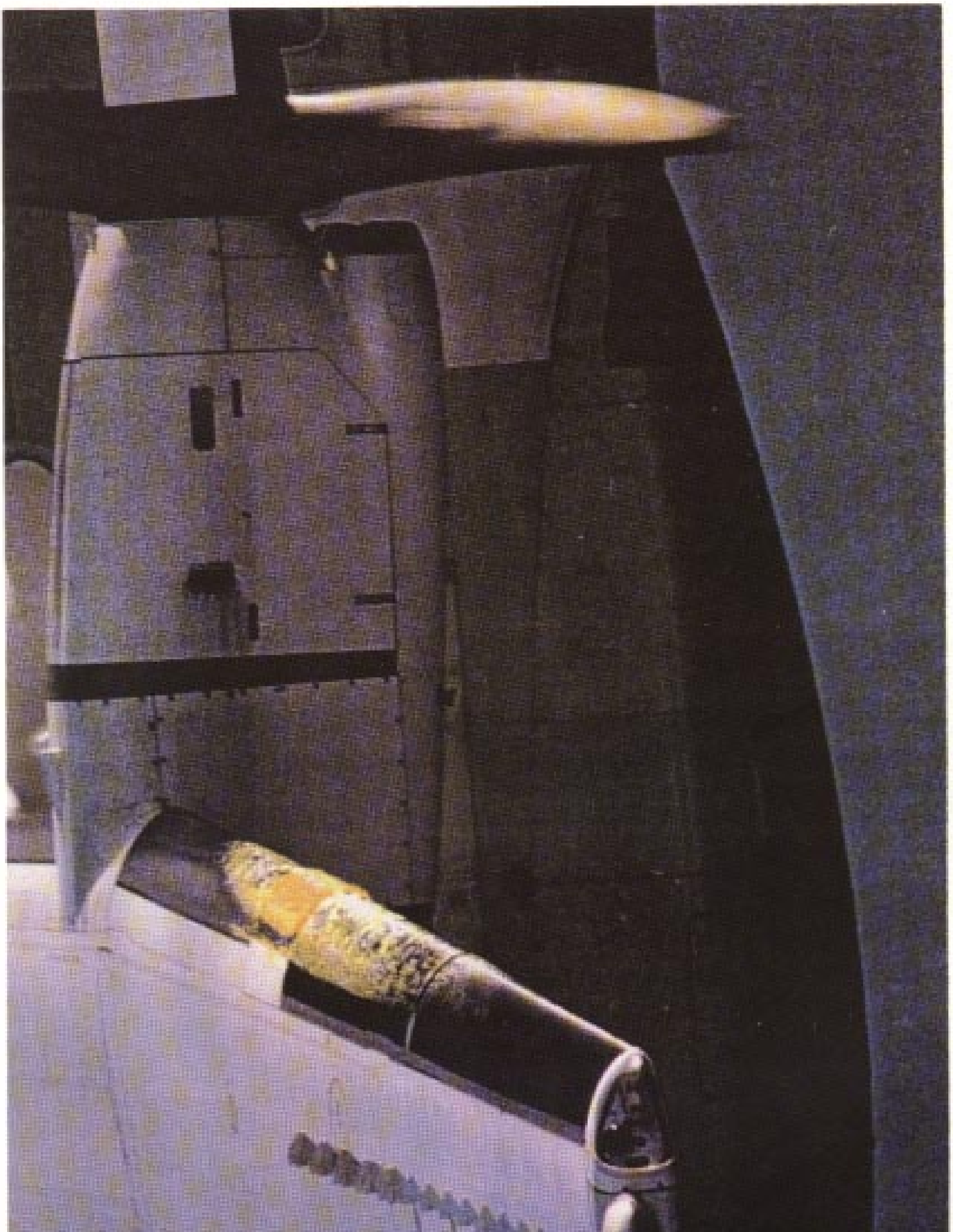
FLIGHT 12 TEST 7 (A.5.45)

LEFT WING -200 μ –FLAP 0

FLIGHT 13 TEST 10 (A.5.88)

RIGHT AILERON -200 μ –FLAP 15





APPENDIX E

DOPPLER WEATHER RADAR

WIND AND WINDSHEAR CALCULATIONS

Winds from the WSR-88D Doppler Weather Radar at KLOT and Wind Shear Calculations

Upper winds were obtained from the WSR-88D doppler weather radar VAD Vertical Wind Profile (VWP) product for 1611. The following winds were estimated from the 1548 data. The doppler weather radar is located at Romeoville, Illinois (KLOT) about 46 nautical miles northwest of the accident site. The VAD VWP product samples the volume of atmosphere at about a 22 nautical mile radius of KLOT. Wind speed is in knots and wind direction is in degrees true.

Height feet AGL	Wind Direction	Wind Speed
1,000	360	15
2,000	027	40
3,000	030	40
4,000	030	40
5,000	050	40
6,000	052	40
7,000	063	35
8,000	090	25
9,000	122	15
10,000	163	20
11,000	180	25

Wind Shear values based on the above wind profile are as follows:

Altitude Interval (Feet)	Wind Shear (sec^{-1})
7,000 to 8,000	.029
8,000 to 9,000	.025
9,000 to 10,000	.022
10,000 to 11,000	.014

APPENDIX F

DOPPLER WEATHER RADAR IMAGES

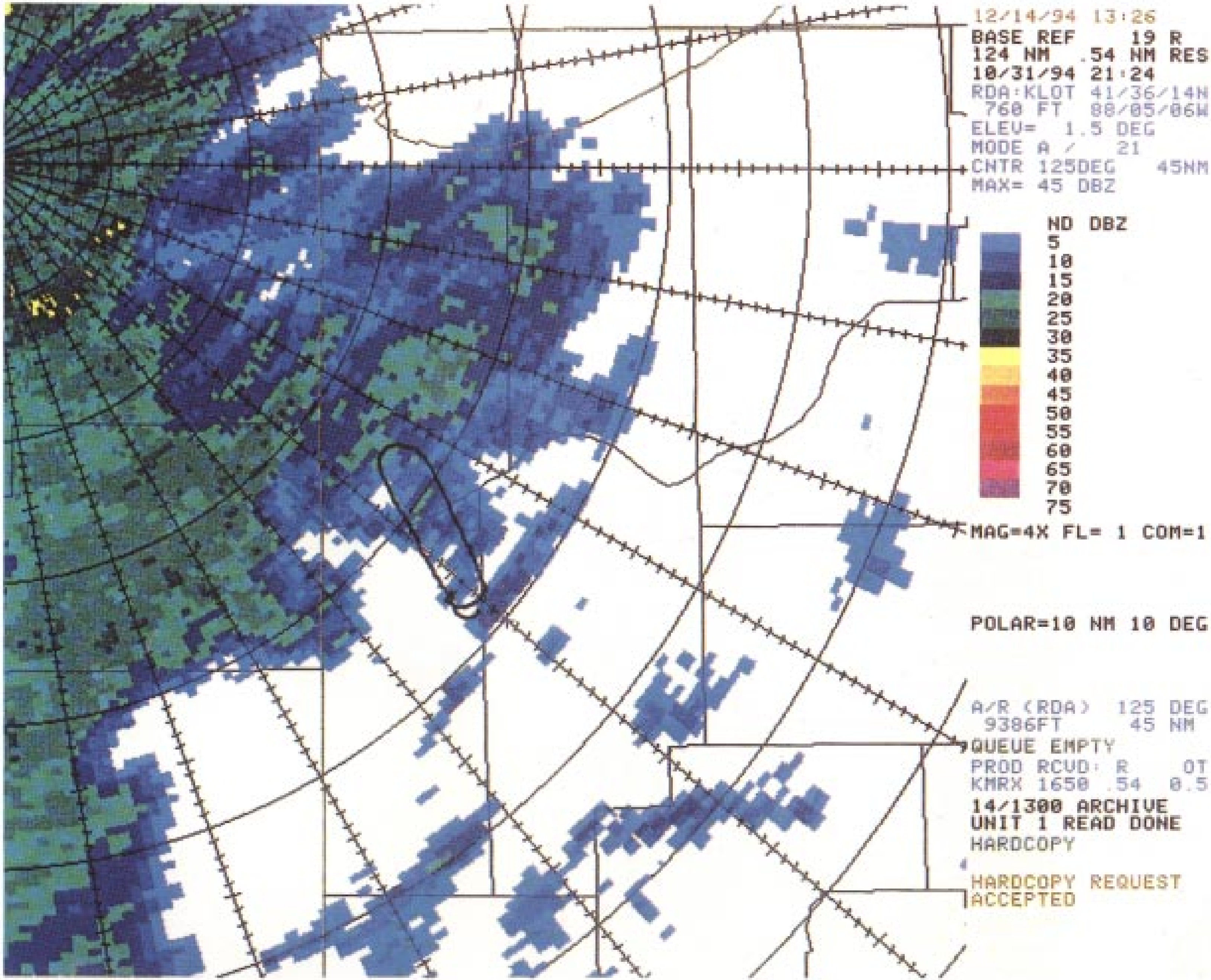
WITH TRACK OF FLIGHT 4184 SUPERIMPOSED

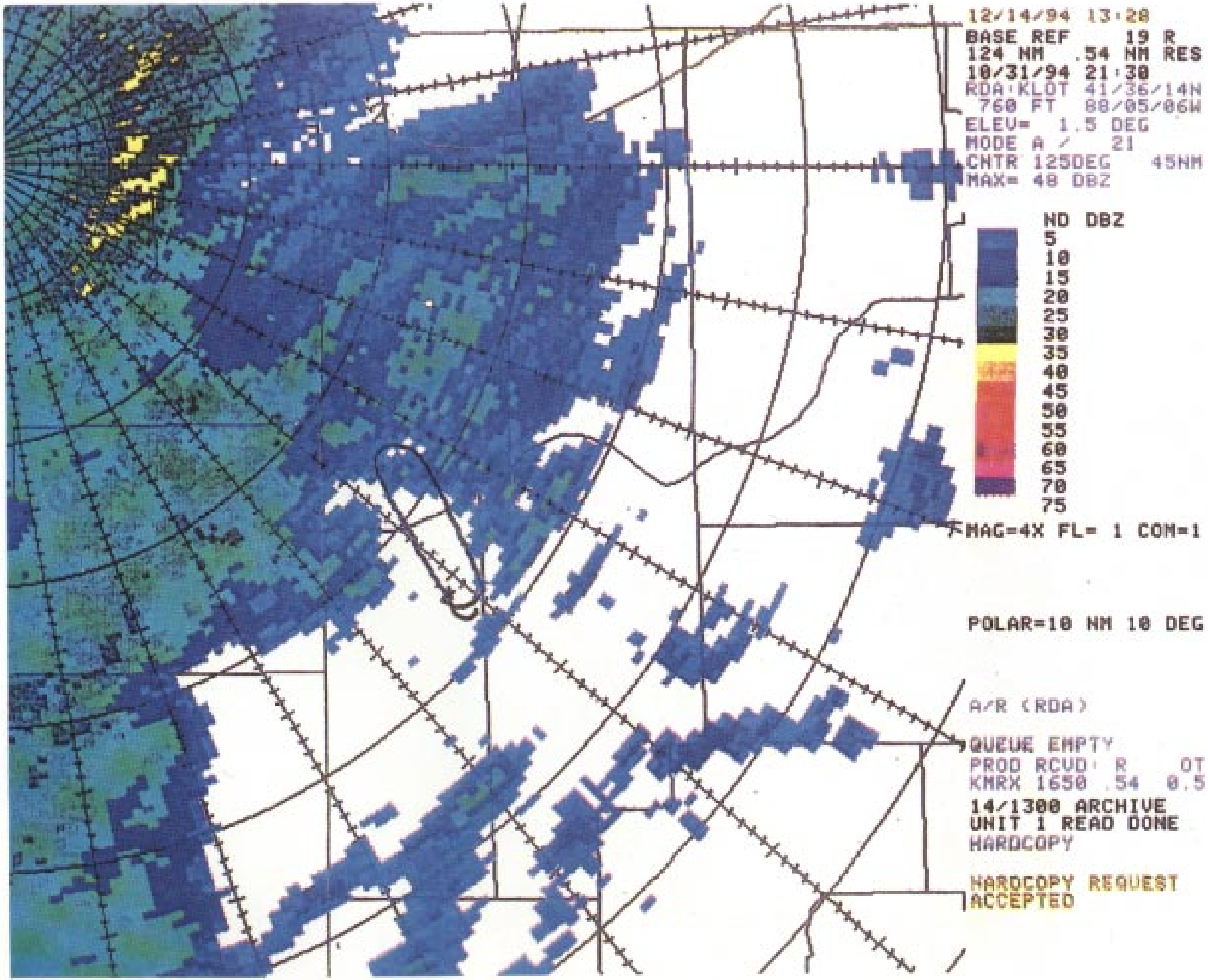
KLOT WSR-88D Doppler Weather Radar Images with the Track of Flight 4184 Superimposed

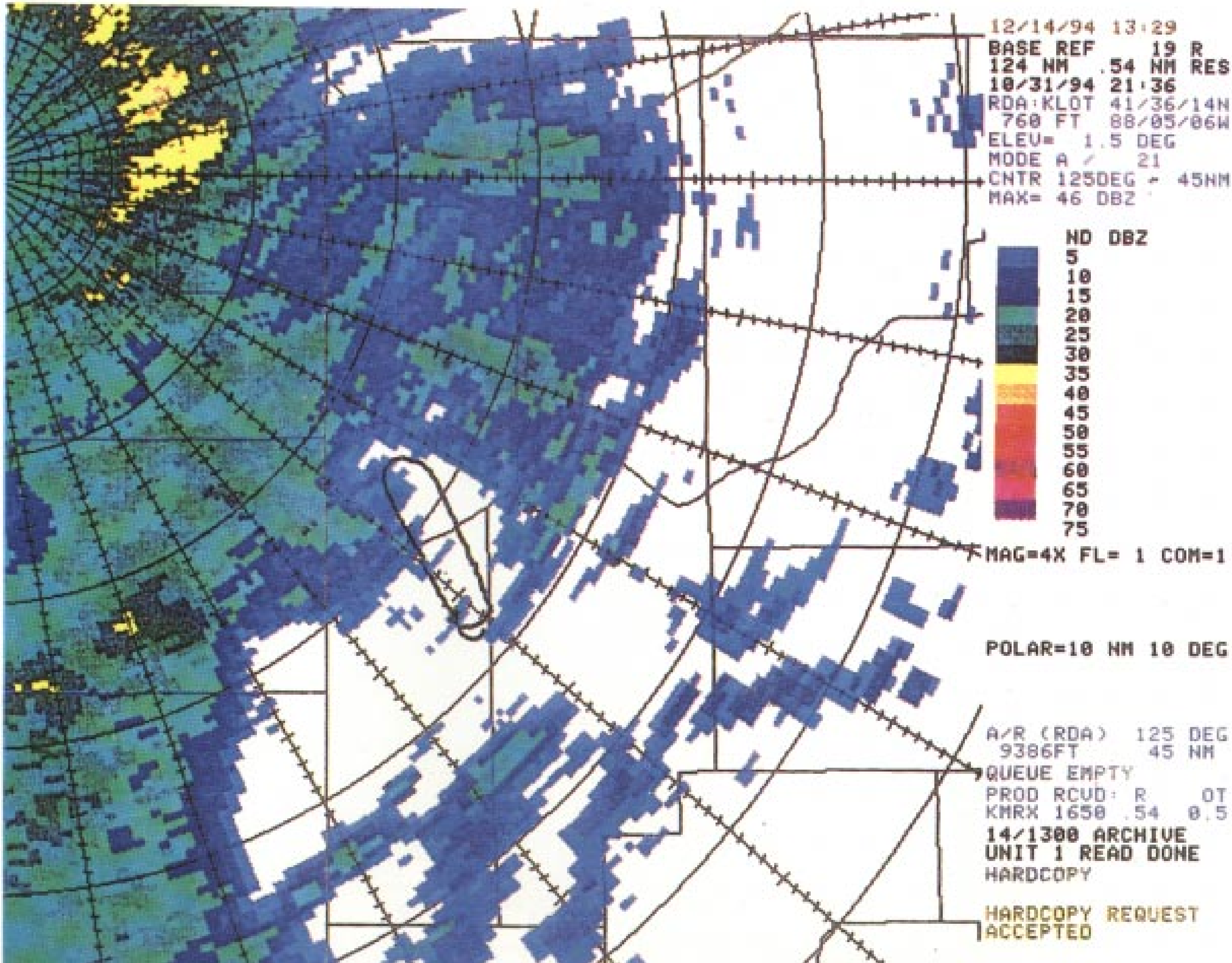
This Appendix contains WSR-88D Doppler Weather Radar Images from KLOT. The radar ground track of the last circuit of Flight 4184 in the hold at the LUCIT intersection is superimposed on the images. In the images colors correspond to weather radar echo intensities [see the vertical color baron the right side of the images]. The intensities are measured in dBZ [see Table A Below]. The times of the images are 21242, 21302, 2136Z, 2142Z, 2148Z, 2154Z, and 2200Z. The elevation angle is set to 1.5 degrees. The accident site is located about 132 degrees at 46 nautical miles from KLOT. At an elevation angle of 1.5 degrees the radar beam center in the area of the accident was at about 9,500 feet. The width of the beam was about 4,600 feet.

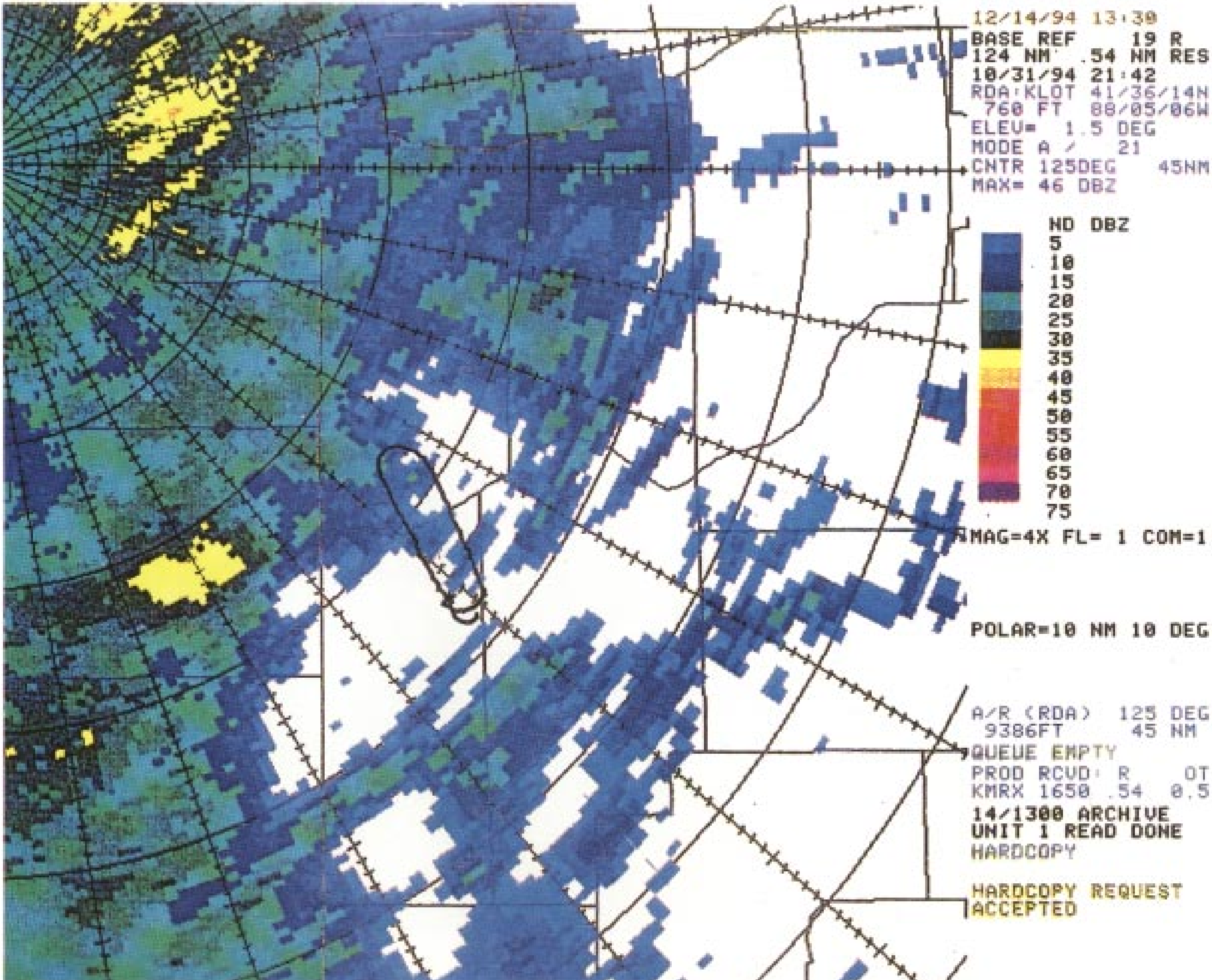
Table A

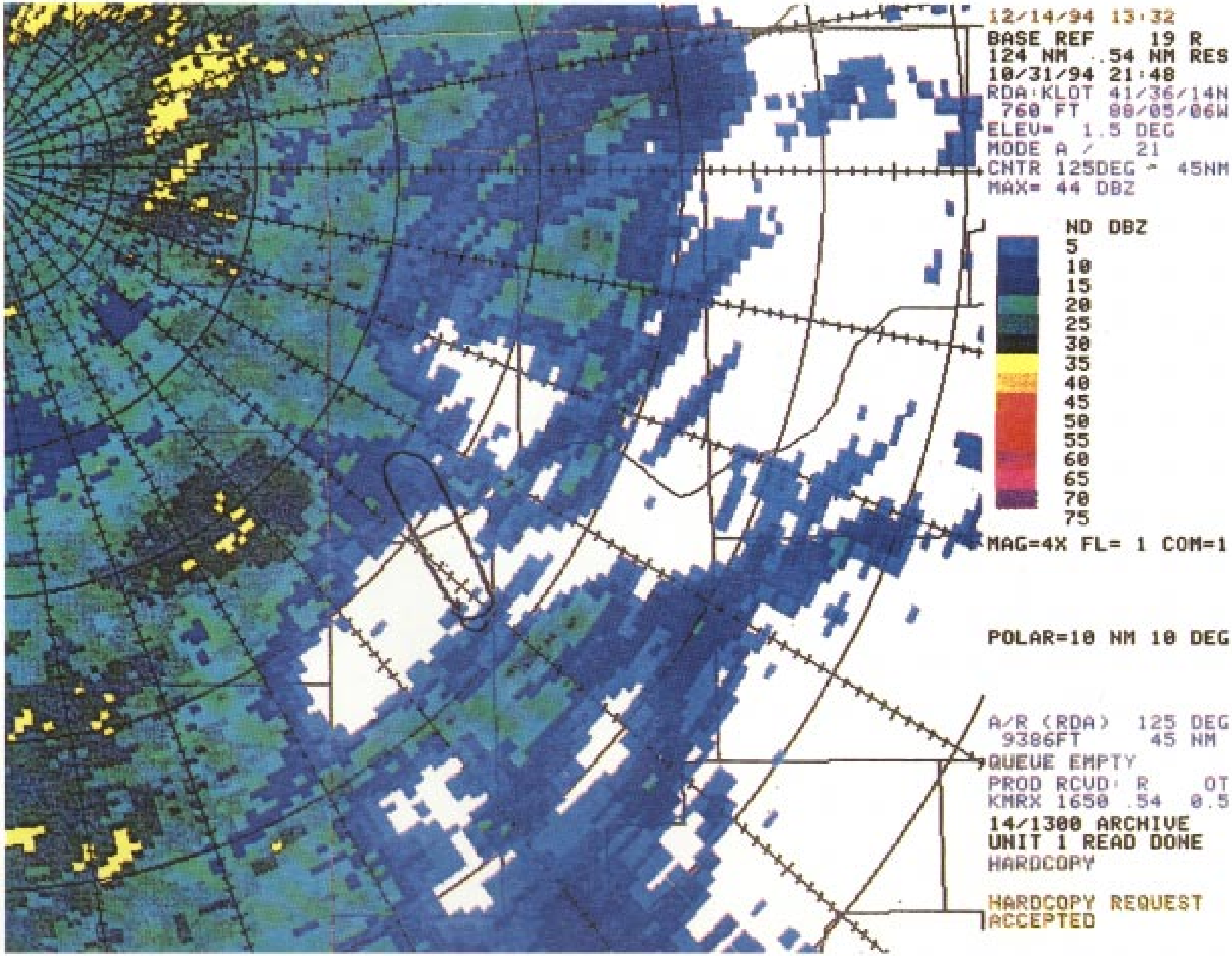
dBZ	Intensity
0t029	Weak
30 to 39	Moderate
40 to 44	Strong
45 to 49	Very Strong
50 to 54	Intense
55 or greater	Extreme

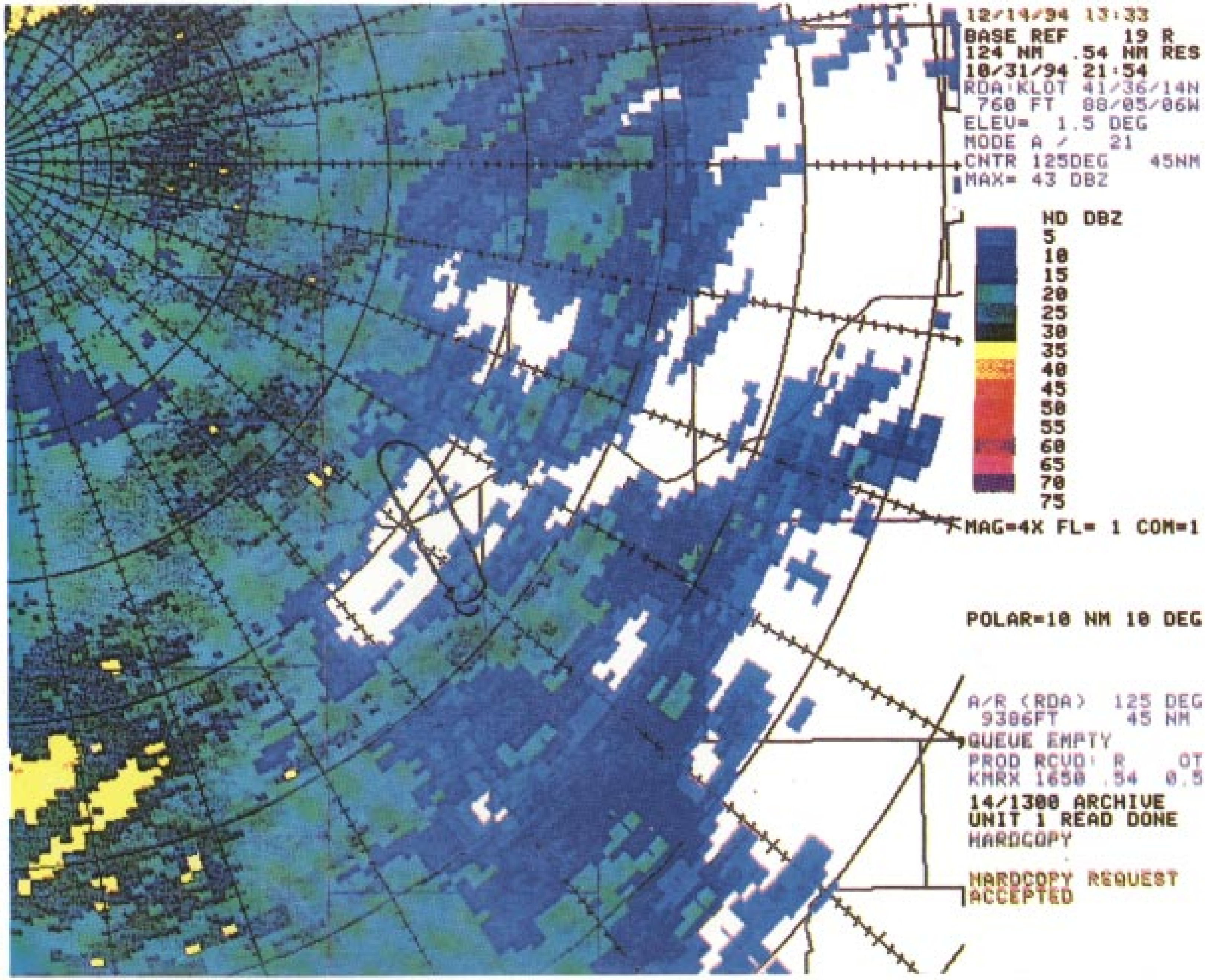

12/14/94 13:26
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:24
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 45 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

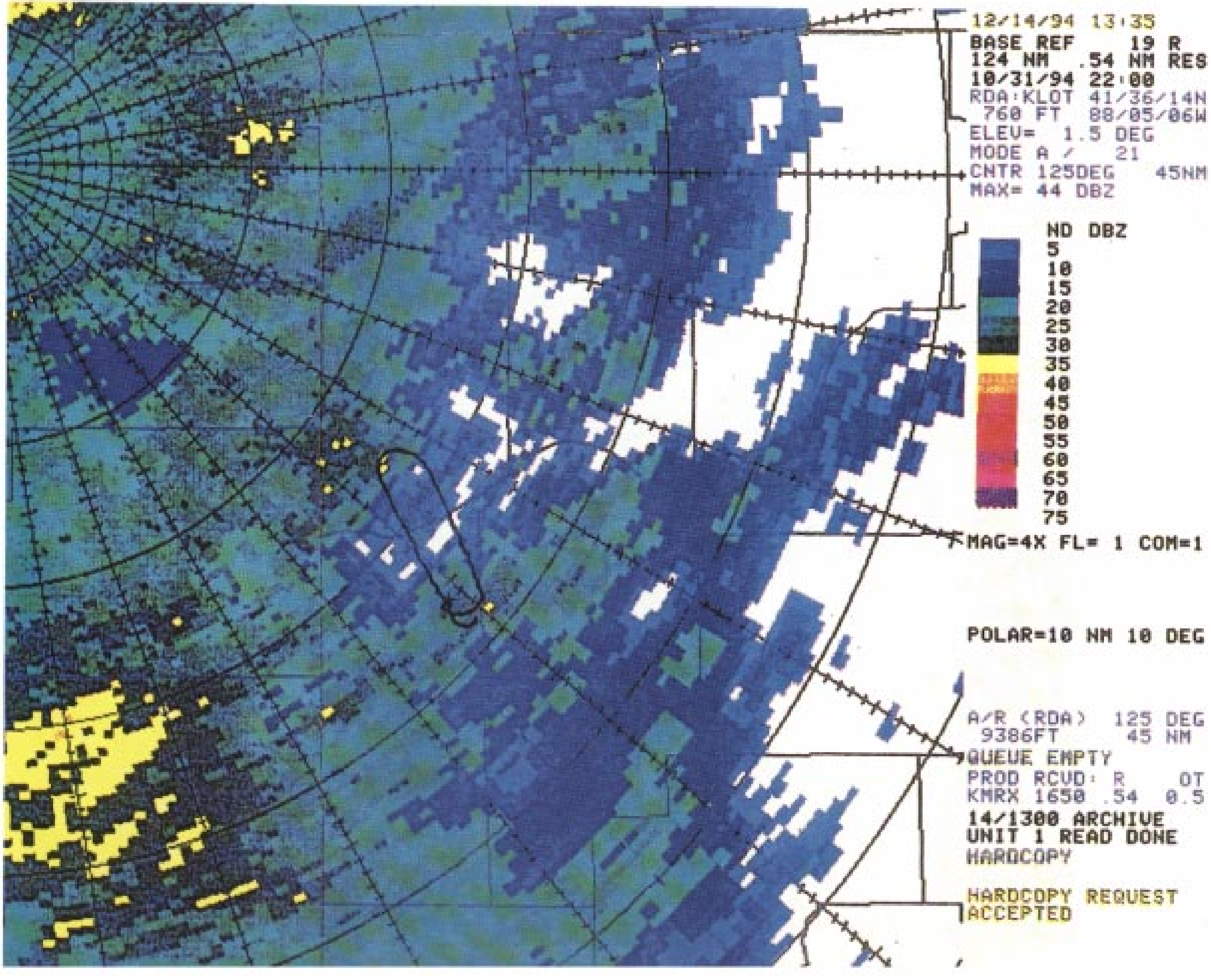

12/14/94 13:28
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:30
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 48 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA)
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED


12/14/94 13:29
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:36
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG - 45NM
MAX= 46 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED


12/14/94 13:30
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:42
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 46 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED


12/14/94 13:32
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:48
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG - 45NM
MAX= 44 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED


12/14/94 13:33
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:54
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 43 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9306FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED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124 NM .54 NM RES
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760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 44 DBZ
ND DBZ
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POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

APPENDIX G

DISCUSSION OF LIQUID WATER CONTENT

AND LIQUID WATER DROP SIZE

I

Drop Diameters

Precipitation Intensity millimeters per hour.
Drop Diameter millimeters.
1 millimeter = 1,000 microns.

Popular Name	Precipitation Intensity	Drop Diameter
Fog	Trace	.01
Mist	.05	.1
Drizzle	.25	.2
Light Rain	1.00	.45
Moderate Rain	4.00	1.0
Heavy Rain	15.0	1.5

From Physics of the Air, Humphreys, Third Edition, 1940.

The following cloud droplet size scale is from: Forecasters' Guide on Aircraft Icing, March 1980, Air Weather Service.

Category	Droplet Diameter
Small	< 10 microns
Medium	10 to 30 microns
Large	30 to 100 microns
Freezing rain or drizzle	100 to 1,000 microns

According to a research professor from the University of Wyoming the diameter of drizzle drops are from 50 to 300 to 400 microns. The diameter of cloud drops are less than these values and the diameter of rain drops are greater than these values. According to a scientist from NCAR drizzle drops have a diameter of 50 to 500 microns and rain drops have a diameter greater than 500 microns.

French meteorologists define rain as having a drop diameter of greater than 500 microns. Drizzle is defined as having a drop diameter of less than 500 microns.

Liquid Water Content Calculation

Liquid Water Content (LWC) in grams per cubic meter, Icing

II

Intensity based on the definition of *icing intensities established by the National Committee for Aviation Meteorology on February 25, 1964, and Rate of Ice Accumulation in inches per minute were obtained from the NTSB Computer Program ICE4A.

* Icing Intensities
Heavy (Severe) . ..Accumulation of 1/2 inch of ice on a small probe per 10 miles.
Moderate. . .Accumulation of 1/2 inch per 20 miles.
Light. . .Accumulation of 1/2 inch per 40 miles.

The following is output from ICE4A. . .

Assumptions. . .
Cloud Base 959 millibars (about 1,500 feet), temperature 4 degrees C, moist adiabatic ascent in cloud, LWC = .25 times the adiabatic LWC.

TAS = Aircraft True Airspeed meters per second.

Altitude 9,700 feet // TAS = 75

LWC = .72 Rate of Ice Accumulation = . 120 // Icing Intensity Severe.

Altitude 10,600 feet // TAS = 75

LWC = .76 Rate of Ice Accumulation = . 134 // Icing Intensity Severe.

Altitude 9,700 feet // TAS 100

LWC = .72 Rate of Ice Accumulation = .170 // Icing Intensity Severe.

Altitude 10,600 feet // TAS 100

LWC = .76 Rate of Ice Accumulation = .179 // Icing Intensity Severe.

Altitude 9,700 feet // TAS 125

LWC = .72 Rate of Ice Accumulation = .212 // Icing Intensity Severe.

Altitude 10,600 feet // TAS 125

LWC = .76 Rate of Ice Accumulation = .223 // Icing Intensity Severe.

I I I

Note: The above values should only be viewed as possible estimates.

The following was obtained from the <u>Forecasters' Guide On Aircraft Icing;</u> Air Weather Service; Scott AFB, Illinois; March 1980:

$LWC = .348 (W_0 - W_1) P/T$

As noted in the report, this represents a practical upper limit of the LWC in cumuliform clouds at flight level. The LWC in stratiform clouds averages about 1/2 the value computed for cumuliform clouds.

W_0 = saturation mixing ratio at cloud base (grams per kilogram) .
WI = saturation mixing ratio at flight level (grams per kilogram) .
P = pressure at flight level (millibars) .
T = cloud temperature at flight level (degrees Kelvin) .

Given: cloud base = 2,000 feet; temperature = 4 degrees C at cloud base; P at cloud base = 937 millibars // W_0 = 5.46 grams per kilogram.

At 10,000 feet; P = 692 millibars; T =-4 degrees C (269.16 degrees Kelvin) // W_1 = 4.14 grams per kilogram.

Therefore, LWC = .59 grams per cubic meter for stratiform conditions and 1.18 grams per cubic meter for cumuliform conditions for an altitude of 10,000 feet.

The following relationship from a paper by *Greene and Clark relates LWC to weather radar reflectivity:

$M = 3.44X10^{-3}Z^{4/7}$ where M = LWC in grams per cubic meter and Z = weather radar reflectivity in millimeters to the sixth power per cubic meter (mm^6/m^3) . The following Table relates M to weather radar reflectivity in dBZ:

$dBZ = 10 \times Log(Z)$
$Z = 10^{dbZ/10}$

Reflectivity (dBZ)	LWC (grams per cubic meter)
<5	<.01
10	.01

15	.02
20	.05
25	.09
30	.18
35	.34
40	.66
45	1.28

An exponential drop-size distribution proposed by Marshall and Palmer (1948) is assumed.

According to a Research Professor from the University of Wyoming at a weather radar reflectivity of 20 to 25 dBZ " you're getting well up into the millimeter sizes and the Marshall Palmer is probably much more appropriate [than a monodisperse drop size distribution] then." [Public Hearing February 27, 1995].

* Vertically Integrated Liquid Water - A New Analysis Tool; Monthly Weather Review; Vol. 100 No. 7; July 1972.

Weather Radar Echo Intensities (maximum and minimum) for the approximate area enclosed by the track [last circuit in the hold at the LUCIT intersection] of Flight 4184; elevation angle = 1.5 degrees.

From KLOT WSR-88D Data:

Time	Weather Echo Intensity
1524 . . .	Maximum dBZ 20 to <25 Minimum <5 dBZ
1530 . . .	Maximum dBZ 20 to <25 Minimum <5 dBZ
1536 . . .	Maximum dBZ 25 to <30 Minimum <5 dBZ
1542 . . .	Maximum dBZ 20 to <25 Minimum <5 dBZ
1548 . . .	Maximum dBZ 15 to <20 Minimum <5 dBZ
1554 . . .	Maximum dBZ 20 to <25 Minimum <5 dBZ
1600 . . .	Maximum dBZ 35 to <40 Minimum <5 dBZ

Figure A [from Penn State University] relates the number of drops per cubic centimeter and the radar reflectivity factor for various droplet radii. Given the number of drops per cubic centimeter and the diameter of the drops a Liquid Water Content (LWC) can be calculated: $LWC = (.52) * N * D^3 / 10^6$ LWC in grams per cubic meter; N number of drops per cubic centimeter; and D drop diameter in microns. A monodisperse droplet distribution is assumed (better representation for a drizzle situation as opposed to a convective situation) . Although, review of the chart shows that the same value for reflectivity factor can result from a few large drops per cubic centimeter or many smaller drops per cubic centimeter LWC values need to be checked for reasonableness. For v

example, one 200 micron diameter drop per cubic centimeter would result in a reflectivity factor of 20 dBZ as would about ten thousand 50 micron drops per cubic centimeter. However, the LWC in the first case is estimated as 4.2 and in the second case 650; both values not realistic given the conditions. A concentration of .04 per cubic centimeter of droplets with a 200 micron diameter results in a reflectivity factor of about 5 dBZ and a LWC of about .17. A concentration of .1 per cubic centimeter of droplets with a 200 micron diameter results in a reflectivity factor of about 10 dBZ and a LWC of about .42. A concentration of .00003 per cubic centimeter of droplets of a 1000 micron diameter results in a reflectivity factor of about 15 dBZ and a LWC of about .02.

If a monodisperse distribution is assumed (all drops the same size) approximate drop sizes can be calculated from the WSR-88D data. A monodisperse distribution is a better representation of a drizzle situation than a Marshall - Palmer size distribution. If a maximum SLW content of 1 gram per cubic meter is assumed and given the maximum and minimum reflectivity values for the area outlined by the track of Flight 4184 (see dBZ values above) drop diameters ranging from 100 to some as large as 2,000 microns are possible.

Estimates of drop diameters using Figure A:

40 dBz // .0003 drops per cubic centimeter // drop diameter 2,000 microns // LWC = 1.3 grams per cubic meter.

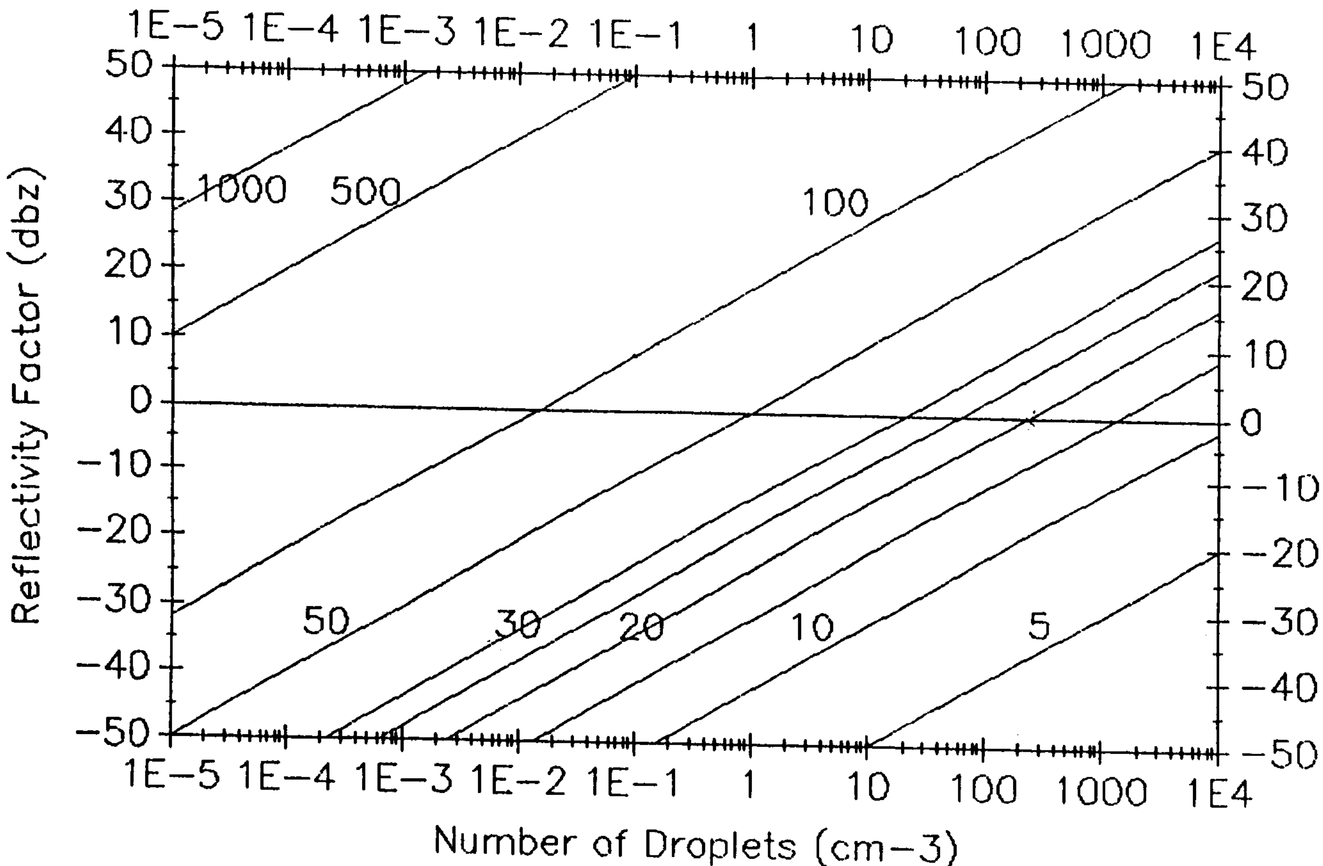
25 dBZ // .00001 drops per cubic centimeter // drop diameter 2,000 microns // LWC = .042 gram per cubic meter.

25 dBZ // .01 drops per cubic centimeter // drop diameter 600 microns // LWC = 1.1 grams per cubic meter.

5 dBZ // .00001 drops per cubic centimeter // drop diameter 800 microns // LWC = .003 gram per cubic meter.

5 dBZ // 2 drops per cubic centimeter // diameter 100 microns // LWC = 1.0 gram per cubic meter.

Reflectivity Factor(dbz) vs. Number of Droplets (cm−3)
for various droplet radii (microns)



$LWC = \frac{\pi}{6} N D^3 / 10^6$

$LWC = g\,m^{-3}$ $N = cm^{-3}$
D @ μm

Penn State Univ.

for monodisperse droplet distribution

APPENDIX H

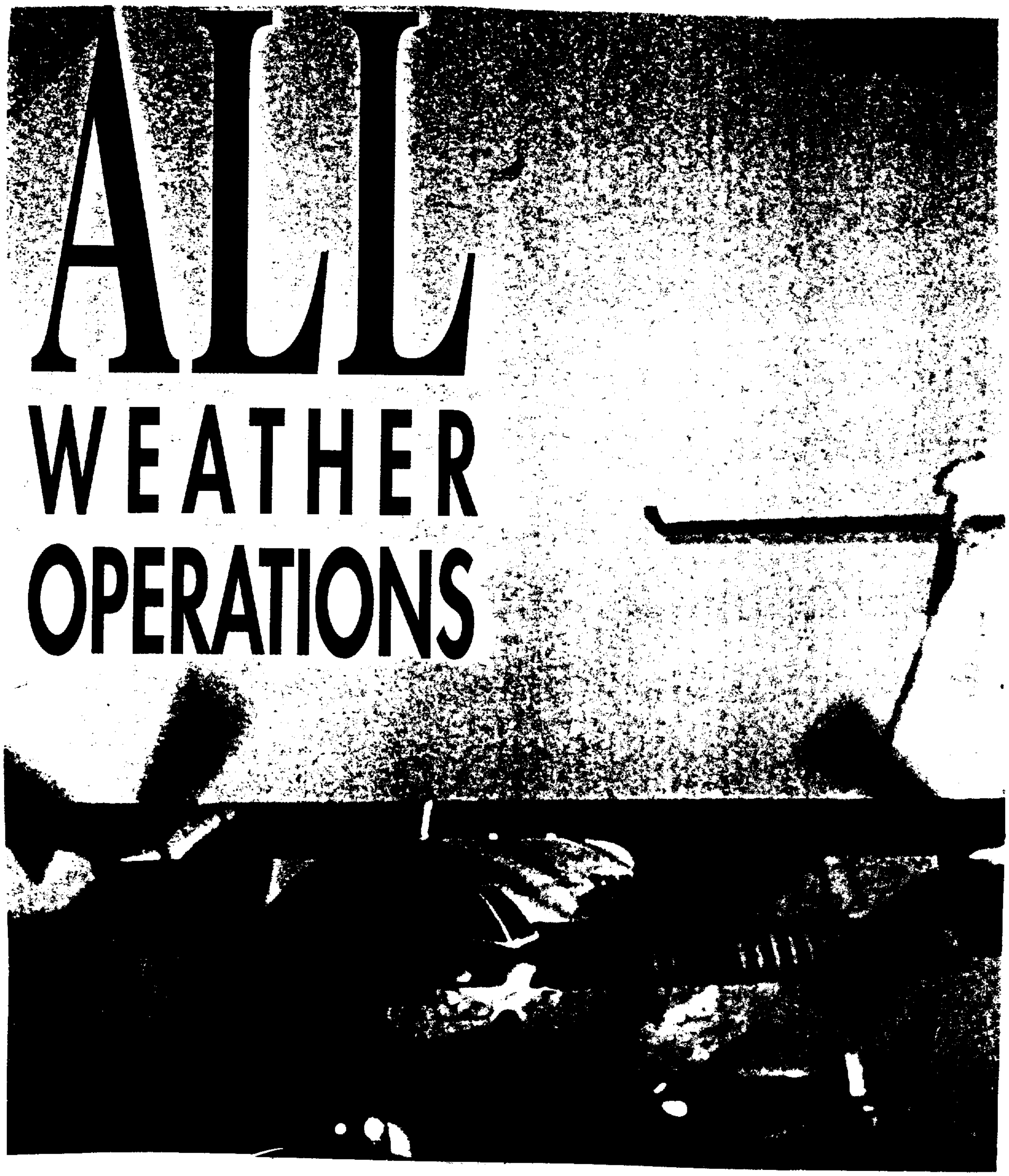
LISTING OF PREVIOUS INCIDENT AND ACCIDENT HISTORY FOR THE ATR 42/72 AIRCRAFT

No	Date	Type/MSN	Airline/Location	Available (Fax/Reports/From-To)	Icing	Mechan-ical	DFDR	Related Event
1	18 Dec 86	42/MSN 028	Simmons/Detroit	ALPA, NTSB, ATR Prod. Supp. Report	X		X	X
2	18 Dec 86	42/MSN 030	Simmons/Detroit	ALPA, NTSB	X			X
3	15 Oct 87	42/MSN 046	ATI/Crezzo Italy	ALPA, ATR	X		X	X
4	15 Oct 87	42/MSN 020	ATI/Crezzo Italy	ALPA, ATR	X			X
5	20 Oct 87	42/MSN 037	Simmons/N426MQ /Traverse City	FAA Service Difficulty Report (SDR)	?	?		?
6	22 Dec 88	42/MSN 091	Simmons/Wisconsin	BEA Report	X		X	X
7	10 Jan 89	42/MSN 028	Simmons/Marquette	FAA SDR		X		
8	15 May 89	42/MSN 086	PanAm/JFK	FAA SDR		X		
9	14 Jun 90	42/MSN ???	Simmons/ORD	FAA SDR, ALPA		?		
10	6 Nov 90	42/MSN 023	Express Air/San Juan	BEA Report		X	X	
11	17 Nov 90	42/MSN 159	Britt/Houston	NTSB	?	?		
12	17 Apr 91	42/MSN 208	Air Maurtius/Indian Ocean	BEA Report	X		X	X
13	22 Jul 91	42/MSN ???	Command Air/ N141DD/ JFK	FAA SDR		?		
14	8 Aug 91	42/MSN 091	Simmons/Chicago	FAA SDR		X		
15	11 Aug 91	42/MSN 161	Ryan Air/UK	BEA Report	X		X	X
16	06 Sep 91	42/MSN ???	Simmons/N429MQ/ Marquette, MI	FAA SDR		X		
17	21 Apr 92	42/MSN 136	Simmons/Lousiville	FAA SDR		X		
18	04 Mar 93	42/MSN 259	CAL/Newark	NTSB, BEA	X		X	X
19	14 Sep 93	42/MSN	Trans States/Quincy, IL	ALPA	X	?		X
20	26 Sep 93	42/MSN 259	NVEA/N275BC/JFK	FAA SDR		X		
21	28 Jan 94	42/MSN 153	Cont./Burlington	FAA SDR, BEA Report	X		X	X
22	15 Sep 94	42/MSN 124	RAIA/MDW	FAA SDR		X		
23	31 Oct 94	72/MSN 401	Simmons/Roselawn, IN	NTSB, ATR	X		X	X
24	31 Oct 94	72/MSN 407	Am. Eagle/South Bend	NTSB	X			X

APPENDIX I

ATR ALL WEATHER OPERATIONS BROCHURE

AND ATR ICING CONDITIONS PROCEDURES - VERSION 2.0



Icing conditions

There are a great number of occasions, referred to as "icing conditions", where an aircraft is subject to accretion of frozen water under various forms.

In order to illustrate its variability, an essential feature of aircraft icing, the main occurrences of this phenomenon will be recalled hereafter.

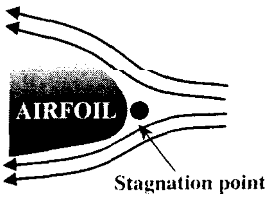
EXPOSURE TO PRECIPITATION in cold weather of a still or taxying aircraft can lead to various types of accretion ranging from dry snow to clear ice, with all possible intermediates such as coarse frost or mixtures of these elements, depending upon the conditions.
A characteristic of these accretions is the wide coverage of aircraft surfaces, changing airfoil shapes and consequently their aerodynamic properties, and possible local accumulations that may affect the normal functioning of systems or the clearance of moving parts.

GROUND ICING CONDITIONS exist when the temperature is at or below 5° C (410 F), when operating on ramps, taxiways and runways where surface snow, standing water or slush is present. In such conditions, limited aircraft surfaces can be contaminated during aircraft operations on ground (tests have shown that such ground contaminants cannot impact airfoils).

ATMOSPHERIC ICING can occur when the Outside Air Temperature (OAT) on the ground and for take-off is at or below 5° C (41"F) or when TAT in flight is at or below 7° C (45° F), and visible moisture in any form is present (such as clouds, fog with visibility of less than one mile, rain, snow, sleet and ice crystals).

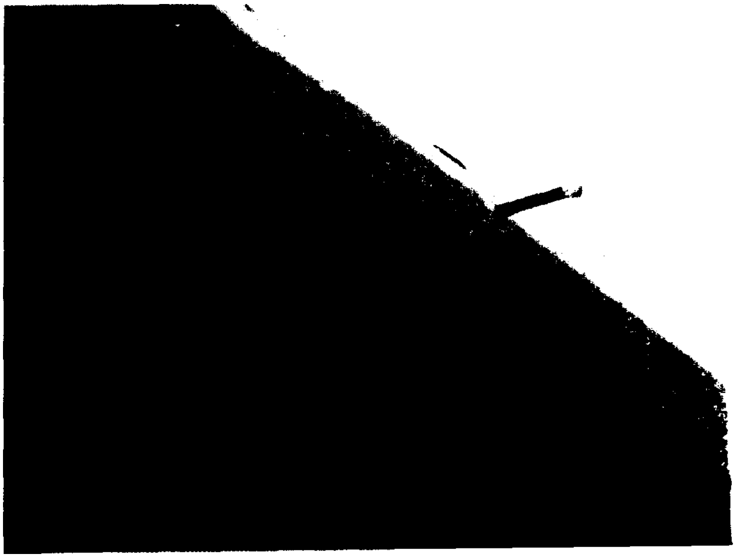
Whether ice accretion will really occur or not depends upon many factors that are not available to the pilots, therefore only visual evidence will tell the crew that accretion does exist.

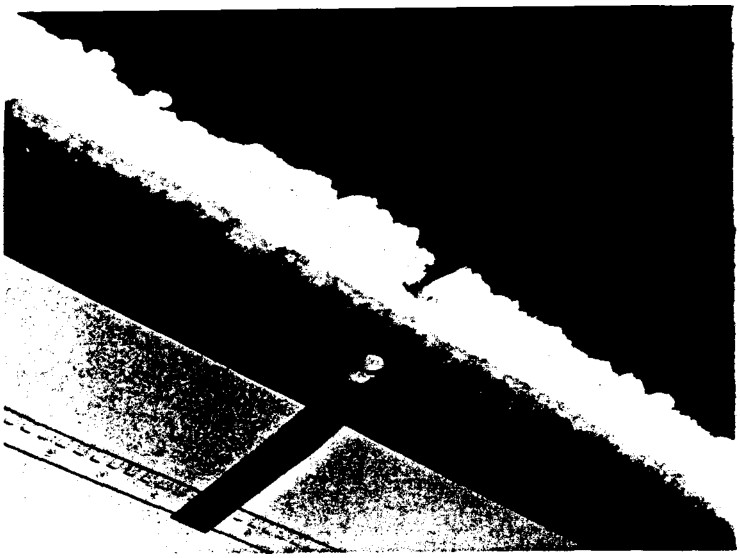
In flight, the accretion will normally be limited to areas around the aerodynamic stagnation point, that is the leading edges of airfoils (including propellers), aircraft nose, spinners...



The accretion however can have a large variety of shapes and textures, ranging from clear, thin ice difficult to detect to coarse rime with single or double horn form (fig. 1 and 2).

FREEZING RAIN is a fairly rare phenomenon where supercooled raindrops freeze when impacting the aircraft or arty obstacle. Generally associated with abnormal atmospheric parameters such as inverted temperature gradients with altitude, freezing rain is capable of rapidly covering an aircraft with a sizeable layer of clear ice, well beyond the usual accretion areas around stagnation points. ■





Theory and tests

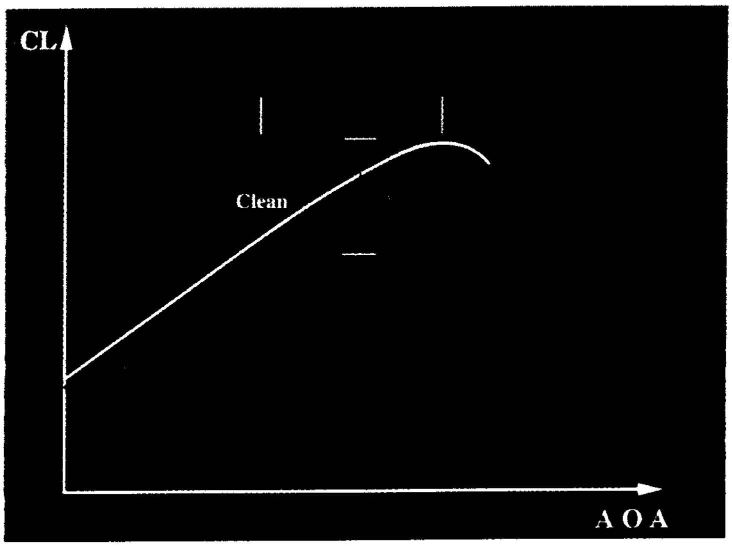


Fig. 3- Effect of certified ice shapes on lift curve - Flaps 30°, gear down standard de-icers

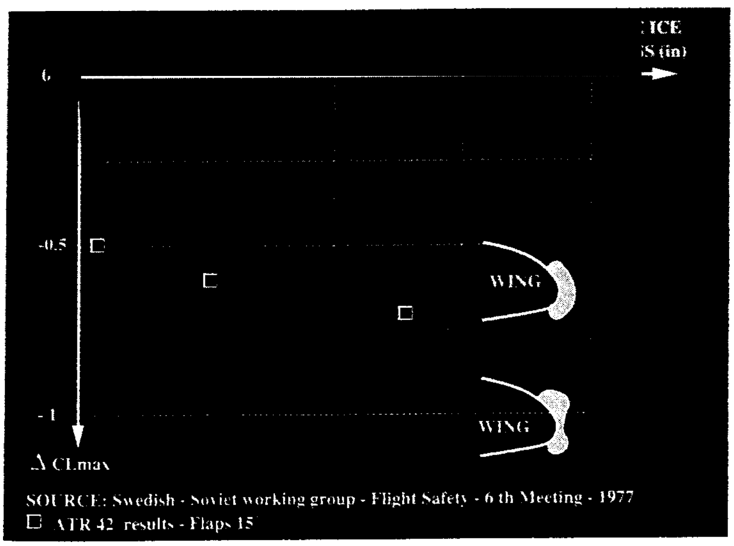


Fig. 4- Effect of ice shape on CLmax - Wind tunnel tests - Flaps 15°

As the aircraft external shapes are carefully optimized from an aerodynamic point of view, it is no wonder that any deviation from the original lines due to ice accretion leads to an overall degradation of performance and handling, whatever the type. The real surprise comes from the amount of degradation actually involved and its lack of "logical" relationship with the type of accretion. Systematical wind tunnel tests have been carried out by various institutes and manufacturers during the last decades, providing a wealth of results that have been largely confirmed by flight tests on different types of jets and turboprops.
The main effects of ice accretion can be summarized as follows.

LIFT

The lift curves are substantially modified compared to clean aircraft (fig. 3):
€ reduction of lift at a given angle of attack,
€ reduction of maximum lift,
€ reduction of maximum lift angle of attack.
When the maximum lift capability of the wing decreases by 25%, the actual stall speed is 12% higher then the basic stall speed (aircraft clean).
So an iced aircraft (fig. 3) flying at a given speed (and thus at a given CL) will have stall margin reduced either looking at angle of attack (6°5 less margin) or looking at stall speed (12% less margin).
More surprising is the fact evidenced by fig. 4: the bulk of the maximum lift degradation is already there for accretions as small as a few millimeters.
A Clmax decrease of 0.5 typically means a stall speed increase of 10 kt for an ATR 42 with

flaps 15°. The ATR 42 wind tunnel test results with single or double horn shapes are consistent with the curves derived from extensive tests carried on conventional airfoils by the Swedish - Soviet working group on flight safety.

DRAG

The drag polar is also heavily affected (fig. 5)
€ superior drag at a given angle of attack,
€ superior drag at a given lift,
€ best lift/ drag ratio at a lower lift coefficient.

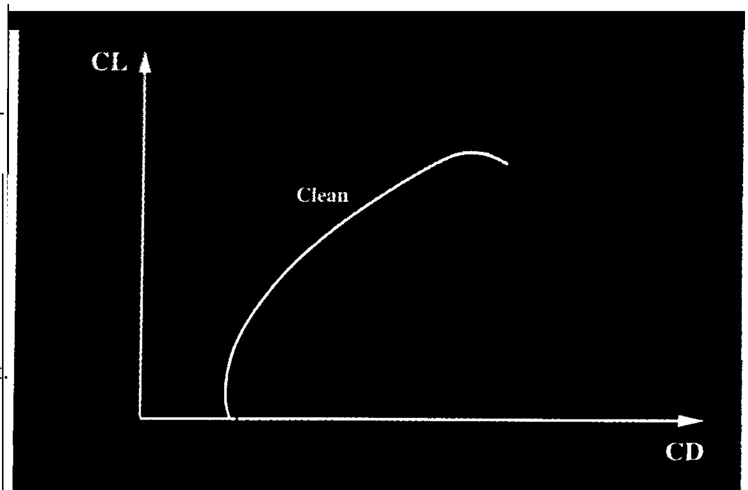


Fig. 5- ATR 72- Effect of certified ice shapes on drag polar. Flaps 0° . Standard de-icers

PERFORMANCE

The drag and lift penalties described in the paragraphs above give a good idea of the performance impacts that could be expected from ice accretion.
Beyond those main phenomenon, other effects should not be underestimated: as an example ice accretion on prop blades will reduce the efficiency and the available thrust of propeller driven aircraft.

On the other hand, ice weight effect will remain marginal when compared to other penalties.

HANDLING

In order to ensure a satisfactorybehaviour, aircraft are carefully designed so that stall will occur initially in the inner part of the wings and spread out towards the tips as angle of attack increases. Roll moments and abruptness of lift drop are then minimized.
This stall behaviour can be completely jeopardized by ice accretions that have no particular reason to be symmetrical or regular along the entire span of the wing.
Other potentially hazardous effects are linked to tail surface icing : reduced maximum lift and stall angle of attack may result in tail surface stall under conditions where, if clean, it would properly do its job.
These conditions are those of high negative angle of attack and downloads on the tail surfaces, found for extreme maneuvers at flap settings higher then 35°.
Separated airflow on the tail surface can also seriously affect elevator behaviour when manually actuated, as aerodynamic compensation of control surfaces is a fine tuned and delicate technique.
Similar anomalies can affect other unpowered controls (such as ailerons) when ice accretion exists. ■

Certification

Airworthiness Authorities in the certification process had several important factors to consider :

- the broad spectrum of icing conditions which exist in an operating environment ;
- how to apply icing models to all aircraft.

Furthermore current regulations for large aircraft have mainly been jet oriented until the early eighties, when scores of new turboprop projects were launched.

For a number of reasons, jets are less affected in flight than turboprops in icing conditions :

- shorter flight times in the lower altitudes where icing conditions mostly exist,
- higher speeds increasing impact temperature above freezing in the most frequent cases of severe icing (0 to -10° C, 32 to 14° F OAT),
- anti-iced airframe versus de-iced airframes on most turboprops,
- powered controls,
- given icing conditions have relatively less detrimental effect on bigger aircraft.

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

CONSOLIDATED REPRINT
This consolidated reprint incorporates Change 1

Subject : HAZARDS FOLLOWING GROUND DEICING AND GROUND OPERATIONS IN CONDITIONS CONDUCIVE TO AIRCRAFT ICING

Date : 12/17/82 *
Initiated by : AWS-100

AC No : 20-117
Change :

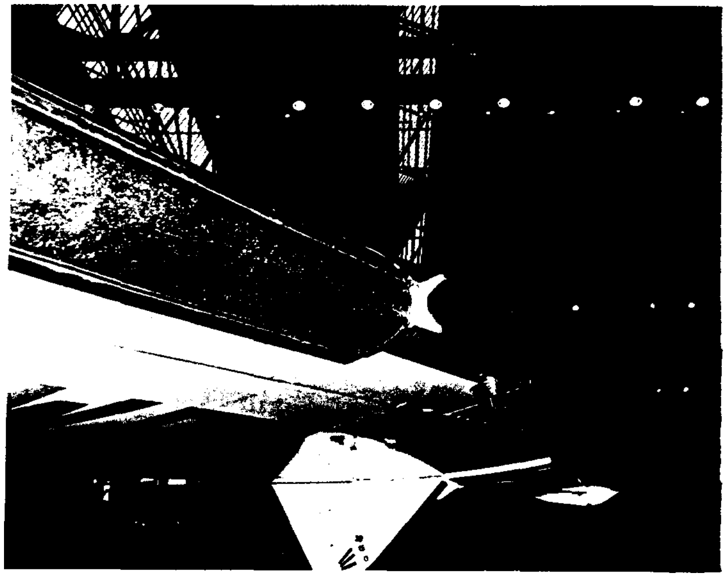
1. PURPOSE. To emphasize the "Clean Aircraft Concept" following ground operations in conditions conducive to aircraft icing and to provide information to assist in compliance.
2. RELATED FEDERAL AVIATION REGULATIONS (FAR) SECTIONS. Sections 121.629, 91.209, and 135.227.

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

§ 91.209 Operating in icing conditions
(a) No pilot may take off an airplane that has —
(1) Frost, snow or ice adhering to any propeller, windshield, or powerplant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;
(2) Snow or ice adhering to the wings, or stabilizing or control surfaces; or
(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth.

§ 135-227 Icing conditions; Operating limitations
(a) No pilot may take off an aircraft that has —
(1) Frost, snow or ice adhering toany rotor blade, propeller, windshield or powerplant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;
(2) Snow or ice adhering to the wings, or stabilizing or control surfaces; or
(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth

Text of FAA Advisory circular AC 20-117
** 12/17/82 issue updated on 4/15/83 and on 3/29/88.*



Nevertheless, all aircraft are equal when ground icing is concerned, and from this point of view, the "clean aircraft concept" at take-off is strictly enforced by Airworthiness Authorities through FAR regulations (sections 121.629, 91.209 and 135.227), and recalled through FAA Advisory Circular AC 20-117 issued in 1982, and updated in April 83 and in March 1988. Recent accidents of improperly de-iced jets at take-off unfortunately confirm the necessity to comply with these requirements.

Furthermore, wind tunnel tests have demonstrated the disastrous effects of a complete wing upper surface coverage with frost.

Degradations up to 40% in CLmax and 5° in stall angle of attack were evidenced in a take-off configuration, likely to prevent any take-off at all.

As far as flight is concerned, current regulations (FAR and JAR) are very explicit on icing conditions definition and on related system tests but remain rather vague on aircraft handling and performance requirements applicable to aircraft with ice accretion.

Generally, it is only stated that the aircraft must be able to operate safely in the maximum defined icing conditions and that acceptable handling characteristics with real ice accretion and with simulated ice shapes (fig. 6) must be demonstrated.

It therefore appears very desirable to provide specific interpretative material, and in this respect the two Airworthiness Manual Advisories 525/2-X (Jan 88) and 525/5-X (Feb 88) from DOT Canada constitute the first achievement of this kind, addressing specifically handling and performance requirements for flight in icing conditions.

Years before, during ATR 42 certification process and flight tests, requirements beyond existing regulations were agreed with French DGAC, and these requirements have been formalized later in the form of a Special Condition B6 for ATR 72 certification. Performance and handling requirements are comprehensively addressed by this document, with special emphasis on polluted aircraft stall characteristics and tail surface behaviour (pushover demonstration at high flaps settings).

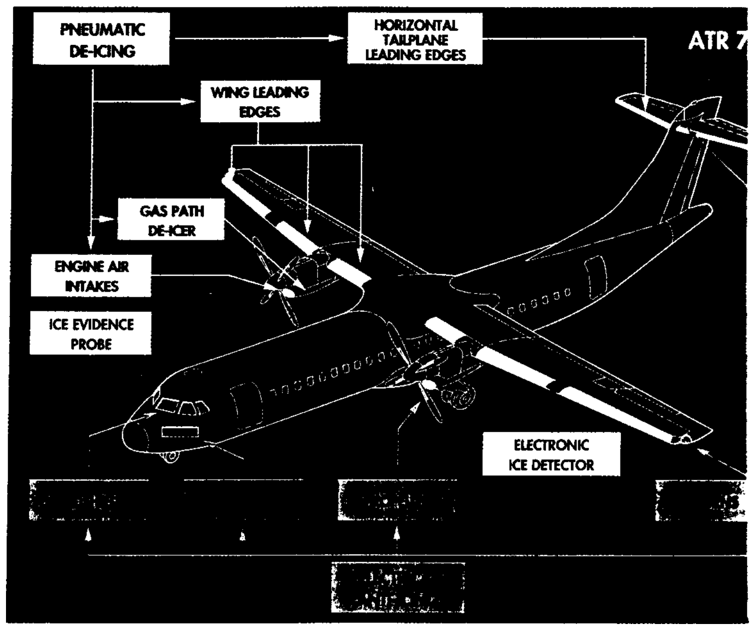
The main purpose of this special condition is to ensure that the safety level and margins in icing conditions as defined by regulations remain equivalent to what exist without ice. JAR Authorities and FAA have been approached in order to promote this Special Condition as a basis for future requirements applicable to all new propeller driven aircraft. ■

Highlights of special condition B6 (basis for ATR 72 certification in icing)

- All phases of flight considered, including take off.
- Ice shapes determined by proven theoretical methods, leading to horn forms.
- Minimum roughness is specified.
- Depending on deicers used, residual ice on protected ports must be simulated.
- Failure cases of de-icers must be demonstrated to determine handling and performance penalties; and procedures to continue safely the flight when needed.
- Handling and performance tests must be conducted in all flight phases with appropriate simulated ice shapes. Adequate behaviour must be demonstrated in terms of controllability, manoeuverability, stability, ability to trim, vibrations, buffeting. Particular attention must be paid to stall characteristics, stall speeds, and stall warning (artificial or natural) must ensure the same margin as for a clean aircraft.
  Push over manoeuvers down to 0 g with full flaps must be demonstrated with no abnormality in the most critical cases.
- Minimum operational speeds must be defined so as to provide the same manoeuverability margin as those required on the clean aircraft.
- Aircraft Flight Manual must provide all necessary data applicable to the aircraft with ice accretion.
- Real icing tests must be conducted in various conditions to confirm the validity of theoretical shapes, and ensure that performance and handling degradations have been established on a conservative basis, with special attention to stall warning.

System description

On a turboprop the ancillary power available (bleed air and electrical power) being less than on a jet, a permanent thermal protection is unpracticable in particular for the airframe.
A solution consists in installing a pneumatic de-icing system on the critical exposed parts (i.e. air-frame) complemented by an electrical anti-icing protection for the parts on which a pneumatic de icing device is not applicable (i.e rotating components like the propellers, windshields, probes).
This philosophy is applied on all new generation turboprop airplanes.



On all ATR aircraft the ice protection system can be summarized as follows (fig. 7):

€ **A PNEUMATIC SYSTEM** supplying the de icing for the critical areas of the airframe:

€ wing and horizontal leading edges,

€ engine air intakes and ducts to engines[1]. The engines supply bleed air through the HP ports.

€ **ELECTRICAL HEATING** (anti icing) of:

€ probes and windshields (always selected ON),

€ inner leading edge of propeller blades (outer part is de-iced by centrifugation),

€ flight control horns.

The power is supplied primarily by AC wild frequency current.

To operate efficiently, a sequential operation of de-icing system must be performed in fast or low mode depending on external temperatures.

***1: some countries, these protections must be used as soon as anti-icing system is selected** ON.*

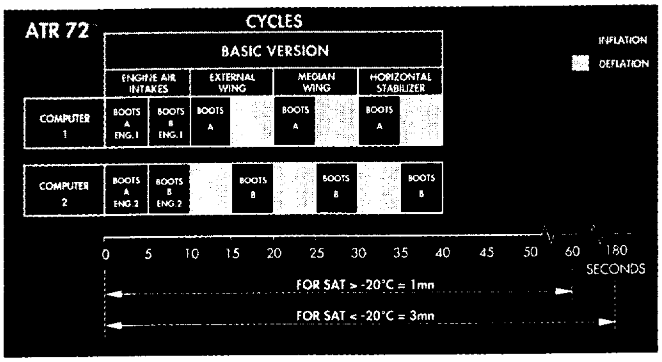


Fig. 8- Pneumatic de icing **system**

PNEUMATIC SYSTEM (AIRFRAME)

The switching temperatures have been determined during flight tests. Thanks to the two cycles system efficiency the boots life can be optimized.

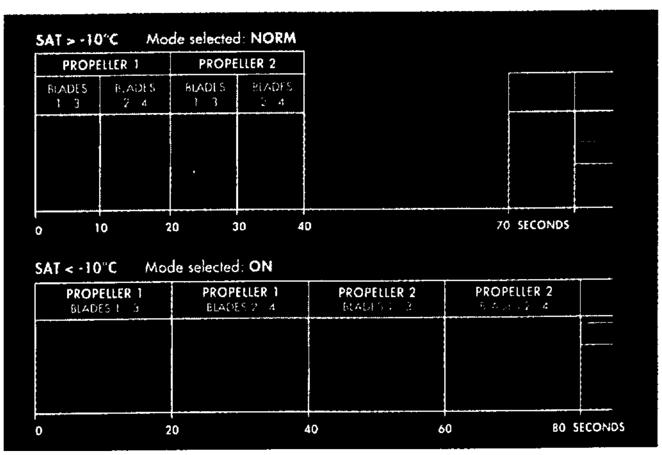


Fig. 9- Electrical ice protection lime sequence diagrum

ELECTRICAL SYSTEM (PROPELLER)

The temperature reference prevents the possibility of "run back" on the propeller, a phenomenon where melted ice freezes again aft of the de icers, with heavy performance losses.

MONITORING ICE ACCRETION

The ice accretion is primarily detected by observing the natural stagnation points : windshield, airframe leading edge, wipers, side windows and propeller spinners.

At night wing lights are used to assist in ice accretion detection.

Since the ATR 72 fuselage is longer than the ATR 42's one, the propeller spinners are not visible from the cockpit. For this reason, an Ice Evidence Probe (IEP), visible by both pilots, has been installed on the ATR 72.

The FEP indicates ice accretion and is shaped to retain ice until all other parts of airframe are free of ice. On the ATR 42, this function is performed by the propeller spinner.

In addition to the previous primary ice accretion recognition means, an Anti icing Advisory System (AAS) is installed on the ATR (fig. 10).

It includes :

€ an electronic ice detector

€ three lights in the cockpit on the central panel between the two pilots : ICING (amber), ICING AOA (green), DE ICING (blue).

This system is not a primary system but has been designed to alert the crew on the correct procedures when flying in icing conditions as detailed later in the document.

The electronic ice detector is located under the left wing and alerts the crew as soon as and as long as ice accretion develops on the probe. Aural and visual alerts are generated (amber ICING light on the central panel and single chime).

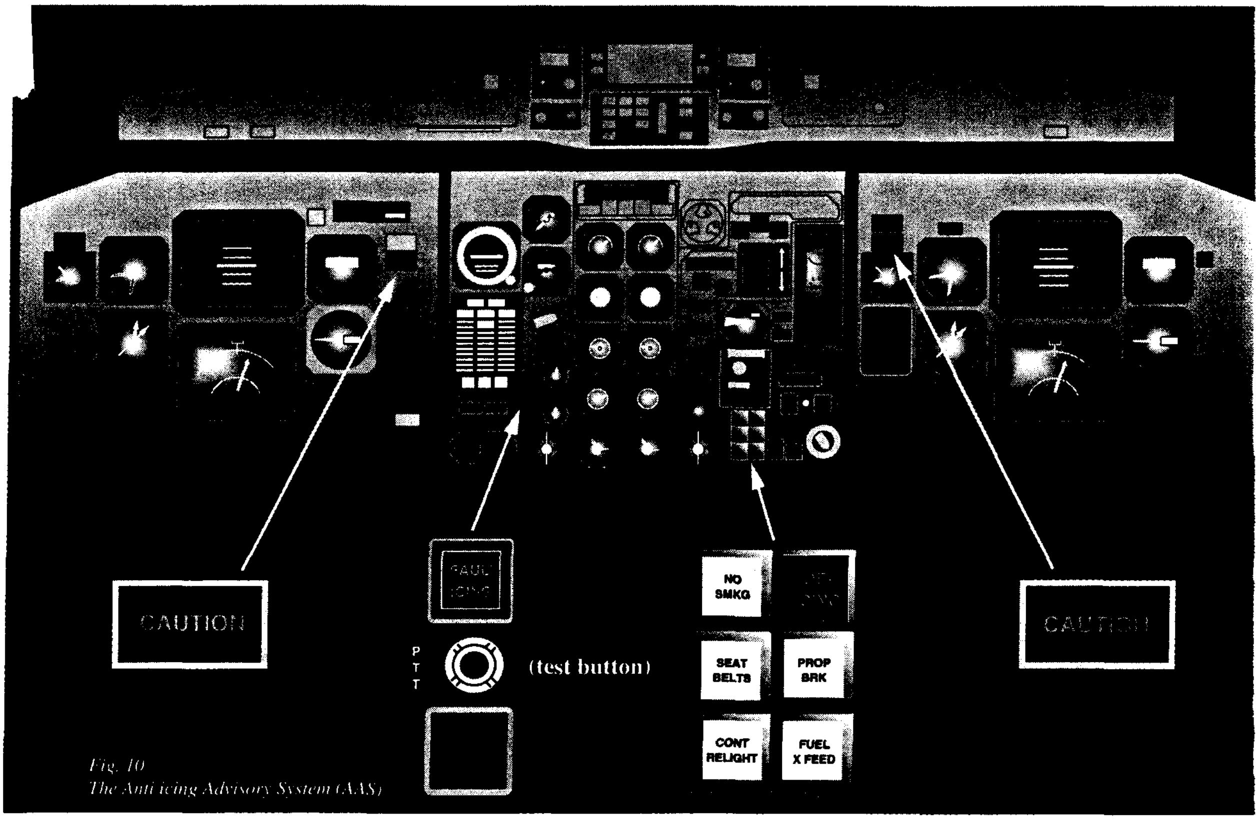


Fig. 10
The Anti icing Advisory System (AAS)

AAS PRINCIPLE

■ ICING (amber - ice detector light)

Illuminates ICING (amber flashing) when ice accretion is detected and the horns anti-icing is not selected ON. The crew has forgotten to select any ice protection system.
Illuminates ICING (amber steady) when ice accretion develops on the probe and horns anti-icing is selected ON. The crew knows he is in icing conditions since he has selected the anti-icing protection system. This indication informs the crew about ice accretion.

■ ICING AOA (green - push button)

Illuminates green as soon as one horn anticing push button is selected on, reminding the crew of stall alarm threshold being lower in icing conditions. The lower stall warning threshold defined for icing is active. ICING AOA green light can only be extinguished manually by depressing it, provided both horns anti icing are selected OFF. This should be done after the pilots have checked that aircraft is clear of ice. In this case the stall alarm threshold recovers the values defined for flight in normal conditions.

■ DE ICING (blue)

Illuminates blue when airframe de icing system is selected ON.
Flashes when the airframe de icing system is selected ON five minutes after last ice accretion detection. The electronic ice detector correct operation can be checked by using the ICE DETECTOR TEST push button.

Advantages and limitations

The associated performance penalties are the price of safety

The technology adopted by all the new tech nology turboprop manufacturers is the pneumatic system for the following reasons:

• The pneumatic system induces a very small penalty on the bleed air supplied by the engines Consequently the performance of tbe engine! and of the aircraft are only slightly reduced. The average air flow picked-up is about 100 times lower than what would be necessary with hot air anti-icing.

• The weight of such a system complies with the turboprop design objectives in terms of weight savings, It is not the case with an electrical ice protection system which requires large

First the life duration of such a system is directly related to the number of inflation/deflation cycles. Consequently, use it when needed and only when needed.

Secondly it does not completely prevent icing of leading edges. The system limits the amount of ice adhering to airfoil but cannot eliminate all the ice accretion because of continuous accretion between two consecutive boots cycles. Remains of ice may also exist after a de-icing cycle (fig. 11).

These limitations are known by all the manufacturers but are differently accounted for by each of them. ■

ATR philosophy

In line with the Special Condition previously presented, ATR philosophy is to propose a global solution maintaining equivalent safety levels and margins in icing conditions as defined by certification and in normal cases, taking into account system performance and limitations.

After extensive testing with real and simulated ce shapes, this philosophy translates into :

SPECIFIC PROCEDURES

These procedures (recalled hereafter) essentially maintain safety margin through increases in minimum speed for each phase of the flight.

INFORMATION

All effects on handling are clearly described, and performance penalties quantified in the manuals. ■

Before take-off

Flight dispatch must take into account severe icing conditions for both routing and cruise flight level selection. Preparation and operation of the ATR following cold soak in very low temperature require particular precautions. Following recommendations which complement normal operating instructions should be observed when applicable.

EXTERIOR SAFETY INSPECTION

As stated in the operational requirements AC 20-117, no person may take-off an aircraft when frost snow or ice is adhering to the wing, control surfaces or propeller of the aircraft.
Perform normal exterior inspection.
Check that the following items are free of frost, ice or snow.
Deice as necessary:

- engine inlets, cowling and drains, propellers,
- pack inlets,
- landing gear assemblies, landing gear doors,
- drains, pitot and static vents, angle of attack sensors,
- fuel tank vents,
- all external surfaces (fuselage, wings, tail surfaces, vertical and horizontal stabilizers, control surfaces) **including gaps** between fixed and movable control surfaces.

What are the ground de-icing and anti-icing procedures ?

- **Ground de-icing** is the cold weather procedure by which snow, ice, rimeand/or slush are removed from the surfaces and all openings and hinge points of the aircraft.

- Ground **anti-icing** is a precautionary measure which uses anti-icing fluids to **prevent rime,**

Tail should be given a particular attention. Make sure it is clear of ice, specially upper surface.

An aircraft de-iced before take-off is in no case an anti-iced aircraft.

ice or snow forming or accumulating on the surfaces of a clean aircraft.

Two types of fluids can respectively be used:

Type I fluids (low viscosity), used for the de-icing, consist of a minimum of 80% of inhibited glycol and phosphates. They are designed according to AEA, AMS or MIL specifications.

Type 11 fluids (high viscosity), used for the de and anti-icing, are composed of aminimum of 50% of glycol and polymer. These fluids are said to possess non-Newtonian characteristic (change in state as a result of surface tension).

NOTE

Only KILFROST ABC 3, HOECHST 1704 LTV 88 and SPCA AD 104 fluids meet the AEA type II fluid specification, including holdover requirements.

The holdover time of the type 11 advanced fluid are considerably increased in comparison wit] the type I fluids.
It should be carefully noted than strict adherence to adequate procedures by both qualified ground servicing crews (application of fluids) and pilots (holdover times) is essential.
De-icing / anti-icing maybe performed in Hotel mode provided bleed 2 is selected OFF.

ONLY EXCEPTION TO CLEAN AIRCRAFT CONCEPT AT TAKE-OFF

Limited frost accretion on lower wing surfaces due to cold fuel remaining and high ambient humidity.
Frost is a light, powdery, crystalline ice which forms on the exposed surfaces of a parked aircraft when the temperature of the exposed surfaces is below freezing (while the free air temperature may be above freezing).
Frost degrades the airfoil aerodynamic characteristics. However, performance decrement at take-off due to 2 mm of frost located on lower surface of the wing only is covered by performance decrement taken into account preventively for take-off in atmospheric icing conditions.

Take-off may be performed with frost on the wings provided:

The frost is located on the lower surface of the wing only.

Frost thickness is limited to 2 mm.

A visual check of the leading edge, upper surface of the wing, tailplane, control surfaces and propellers is performed to make certain that those surfaces are totally cleared of ice.

Performance decrement and procedures defined for take-off in atmospheric icing conditions are applied.

ENGINE STARTING

Perform normal cockpit preparation with the following procedures modifications:

OVDB VALVE override control sw ______ FULL CLOSE

Provided ENG 2 air intake and both pack inlets are free of snow, frost, ice:

ENG 2 IN HOTEL MODE ______ START

TAXIING

The standard single engine taxi procedure may still be used provided the friction coefficient remains at or above 0.3 (braking action medium, snowtam code 3) and nose wheel steering is not used with too large deflections. If the OAT is very low, it may be necessary anyway to start up engine 1 early enough to get the necessary oil warm up time (refer to notes 2 and 3 under).
On icy taxiways or in the presence of slush (low friction coefficients), it is recommended to use both engines and differential power for taxi. ■

NOTES

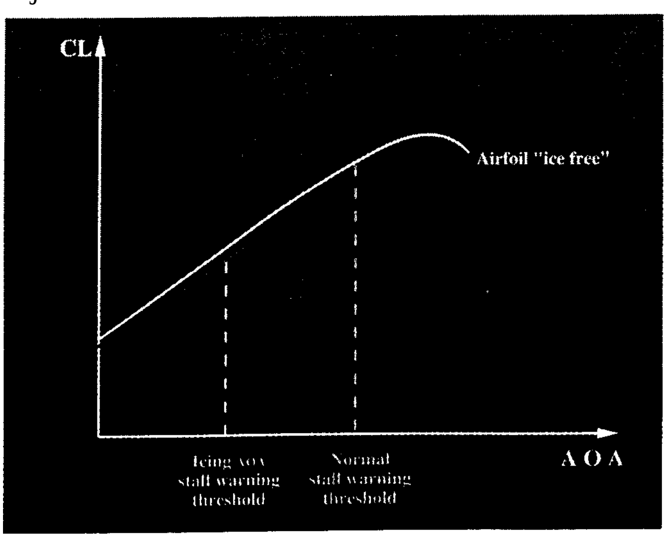
1. Starting on aircraft batteries is possible without special precautions down to -15° C (5° F).
2. When starting the engine in extremely cold conditions:
   - start up time is slightly increased;
   - oil pressure raising time is considerably increased: OIL LO PRESS red warning, may be activated for 60 seconds;
   - after the initial increased raising time, OIL PRESS will be higher than usual (up to 70 PSI) for several minutes.
3. PL motion above FI is only allowed when oil temperature is at or above 0° C (32° F): this warm up time may take up to 4 minutes when OAT is -35° C (- 30° F).
4. During cockpit preparation, both packs should be used to warmup cabin and cockpit while running engine 2 in Hotel mode. Using gust lock stop power with HI FLOW selected (together with all doors, particularly cargo, closed) is recommended for warm up with OAT below -15° C (5° F).
5. Below -15° C (5° F'), several equipment items (e.g. fuel flow, pressurization ind., ADU, AFCS control box) may be not working initially but will automatically recover as cabin and cockpit warm up takes place and compartment temperature rises.

Operations in atmospheric icing conditions

As explained in the previous chapters, and to take into account the system limitations, ATR brings a global solution to maintain equivalent safety levels and margins in icing conditions as provided in normal operations.

Anti-icing procedures and speed limitations have been developed and must be complied with as soon as and as long as icing conditions are met which may occur even before ice accretion actually takes places. The procedures and speed limitations do apply until the aircraft is clear of ice.

Fig. 12



Why should we apply relevant icing procedures, and above all observe relevant speed limitations as soon as we fly into icing conditions and even before ice accretion actually takes place ?

Answer should be obvious to all pilots and based on two main factors:

- Even small ice accretion is enough to destroy lift significantly (refer to fig, 4 page 4).
- Small ice accretions are most often difficult to observe and may even be missed by the ice detector,

The conclusion is straight forward : as soon as there is a possibility of icing, play the game as if icing were really there !

Stall occurs at higher speeds (fig. 12) when ice accretion spoils the airfoil, therefore the stall warning threshold must be reset to a lower value of angle of attack.

Thanks to the computing power of MFC on ATR 72, stick pusher threshold activation is also lowered accordingly.

The minimum manoeuver/operating speeds defined for normal (no icing) conditions must be increased. These new minimum operating speeds are called MINIMUM ICING SPEEDS. They arc given in the approved AFM (chap. 6) in the FCOM (2.02) and in the check list booklet.

Ice accretion may also affect forces required to manoeuver flight controls.

On the ATR:

- rudder forces are not affected;
- aileron forces are somewhat increased when ice accretion develops, but remain otherwise in the conventional sense;
- pitch forces arc not affected in flaps 0°, 15° and 30° (see further: take-off after type II fluid use).

PERFORMANCE WITH ICE ACCRETION

When flying in icing conditions, remain "**performance minded".** Make sure your planned cruise level is coherent with the ceiling computed in icing conditions.

Example:

ATR 72- TWIN engine Weight 20 T, ISA +20°C		
	Normal cond.	**Icing cond.**
Service ceiling*	FL 180	FL 200

***** *The service ceiling is computed with a 300 ft/mn residual rate of climb in normal conditions and 100 ft/mn in icing conditions.***

NOTE

Do not attempt, in icing conditions, to fly above the service ceiling computed in normal conditions (refer FCOM 3.04), as your residual rate of climb is reduced.

As far as the single engine ceiling is concerned, it is clear that loss of performance are minimized by selecting flaps 15°.

Example:

ATR 72- One engine out Weight 20 T, ISA -10°C			
	Flaps	**Normal cond.**	**ICING cond.**
Gross ceiling*	0	FL 160	FL 130
	15	--	FL 140

***** *The gross ceiling is computed in drift down* conditions.

This is the reason why, if obstacle limitations exist whenever minimum icing speeds are imposed (icing AOA light illuminated), single engine critical phases (final take-off climb, en route drift down procedure) must be performed with flaps 15° configuration.

If no obstacle limitation exists, flaps 0 may be used for single engine cruise in order to benefit from a higher cruise speed but a lower cruising altitude.

Never climb below minimum icing speed

The minimum icing speed is always close to the best climb gradient speed. Any attempt to climb at a speed lower than the minimum icing speed is **hazardous** and can only lead to reduced climbing performance.

When flying close to top of icing clouds (even a few hundred feet below) never try to exchange speed for height when already flying minimum icing speeds!

As mentioned here above no benefit can be taken by reducing the prescribed minimum icing speed **even for the last hundred feet!**

Never try to fly above your practical ceiling: BE PERFORMANCE MINDED. Minimum icing speed must NEVER be deliberately transgressed.

CRUISE IN ICING CONDITION

When flying in icing conditions, do not forget to:

- **set NP at/or above 86% :**

NP = 86% corresponds to the **minimum** rotating speed required to provide effective propeller de-icing (centrifugal effect is predominant to physically eliminate ice on the blades).

Sticking to NP 77% may lead to blade contamination resulting in drastic thrust reduction and drag increase, which could, in extreme cases, push the aircraft down to stall in level flight.

- **Compare predicted data (FCOM 3.05) to observed performance.**

For example: ATR 72, 20 T, ISA, FL 220, NP 86%. Speed is reduced from 197 kt in clear conditions to 188 kt IAS in icing conditions.

- Set the internal bug to the speed given in the manuals and **never accept any** SLOW **indication.**

€ **If necessary, push the throttle** to Max climb or even Max cont., and change your flight level and/or your route.

USE OF AFCS IN ICING CONDITIONS

When climbing with A/P selected ON (V/S mode), be sure the required vertical speed is compatible with the minimum icing speed. Otherwise the speed may regress down to the stall speed. Flying a 5° pitch basic mode is always safe but it is more consistent to use the IAS mode set at a speed equal to or greater than the minimum speed (VmLB or VmHB in accordance with the required selection of LB or HB on auto pilot). ■

Particular attention should be paid to aileron mistrim message (flashing on ADU and EADI): if this message appears, apply Aileron mistrim procedure.

Procedures

Before presenting the procedures, it is necessary to recall the properties of the ground anti-icing fluids.

The type II fluids are used for their anti-icing qualities. Under the effect of the speed they spread out on the control surfaces, especially the lower surface of the elevator through the elevator gap during rotation while taking-off.
Tests have been performed on ATR development aircraft.
Results and relevant information are gathered together in service information letters referenced SIL ATR 42.30.5007 and SIL ATR 72.30.6001.
This phenomenon temporarily changes the trim characteristics of the elevator and can lead to an increase in control forces necessary to rotate, these forces become more noticeable when the center of gravity is forward with temperatures around 0° C (32° F).
Depending upon the fluid type, this effect can double temporarily the pilot force necessary to move the elevator and achieve the required rotation rate.
This problem is legitimate and not associated to any other control or performance problem. This phenomenon can be perfectly controlled by the pilots and the take-off path remains unaffected.

NOTES

1. These procedures are applicable to all flight phases including take-off.
2. Ice accretion may he primarily detected by observing the Icing Evidence Probe (IEP). At night, this IEP is automatically illuminated when NAV lights are turned ON. Ice accretion may be detected on propeller spinner, windshield, airframe (leading edges), wipers and side windows on the ATR 42.
3. Clear ice accretion may be difficult to detect. If clear ice is suspected, temporary selection of airframe boots is recommended as the action of the boots will shatter the ice and make its observation much more obvious.
4. With very cold **OAT,** delay start of take-off roll until oil temperature is at least 45° C (113° F); this is necessary to guarantee inlet splitter de icing capability.
5. When ice accretion is visually observed de-icers must he selected and maintained **ON** as long as ice continues to accumulate.
6. Ice detector may also help the crew to determine continuous periods of ice accretion. Nevertheless it may not detect certain ice accretion forms.

The following procedures must be applied for take-off and for flight in icing conditions.

NOTE

Permanent heating (probes/windshield) is always selected ON.

TAKE-OFF IN GROUND ICING CONDITIONS WITHOUT ATMOSPHERIC ICING CONDITIONS

When taking off from a contained runway (slush, snow, supercooled water, . ..). without atmospheric icing condition (no air contaminants such as fog), wing leading edge pollution is not anticipated during the take-off run and consequently operational speed increase needs not to be considered.
Horns anti-icing should therefore not be selected ON in order to avoid lowering the stall warning threshold. Icing AOA light should not be illuminated. It is better to maintain low VI (and V2) on this type of runway, in case an aborted take-off would have to be performed.
Note that propellers and brakes however may be affected by these contaminants. Propeller anti-icing should therefore be selected and it is recommended to cycle after take-off the landing gear in order to avoid wheel brake freezing.

Before take-off

ENG START ROTARY SEL	CONT RELIGHT
PROPELLERS ANTI ICING ONLY	ON

After take-off

LANDING GEAR (if possible)	CYCLE
PROP ANTI ICING	AS RQD
ENG START ROTARY sel	AS RQD

NOTES

1. ***Take-off may be scheduled using normal minimum V2.***

2. ***Horns anti icing must not be selected ON to avoid lowering the stall warning threshold.***

TAKE-OFF IN ATMOSPHERIC ICING CONDITIONS

Operational speeds must be increased whenever possible wing leading edge pollution during take-off due to air contaminants is anticipated.

Standard take-off procedure must be used with the following addition : for take-off with atmospheric icing conditions, refer to appropriate speeds and performance penalties to take into account possible ice accretion during take-off run.

▲ ***RUNWAY IS CONTAMINATED*** (water, ice, snow, slush) use the relevant performance penalties defined in the performance section (FCOM 3.03). At very low speeds using reverse on contaminated runways should be limited to avoid contaminant projections at the level of cockpit windshield which may reduce visibility to zero (snow, slush).

Using increased speeds in icing conditions is the only guarantee of a safe margin.

ENTERING ICING CONDITIONS

ANTI ICING (PROP - HORNS - SIDEWINDOWS)	ON
ICING AOA light	check ILLUMINATED
MINIMUM ICING SPEED	Bugged and OBSERVED
PROP mode sel	according to SAT
CL	set FOR NP ≥ 86%
ICE ACCRETION and/or speed deceleration	MONITOR

AT FIRST VISUAL INDICATION OF ICE ACCRETION, AND AS LONG AS ICE ACCRETION DEVELOPS ON AIRFRAME

ENTERING ICING CONDITIONS procedure	CONFIRM COMPLIED WITH
MINIMUM ICING SPEED	CONFIRM BUGGED AND OBSERVED
ENG START ROTARY sel	CONT RELIGHT
DEICING (ENG then airframe)	ON
ENG and AIRFRAME mode sel	ACCORDING TO SAT
SPEED DECELERATION	Monitored against relevant FCOM predicted values

LEAVING ICING CONDITIONS

De-icing, continuous relight and anti-icing may be switched OFF, but ICING AOA caption must not be cancelled until it is visually confirmed that the aircraft is cleared of any residual ice. Experience has shown that, when the aircraft is flown in warmer temperature, the last part to clear on the ATR 72 is the Icing Evidence Probe (IEP) : when there is no more ice visible on the IEP, the whole aircraft is cleared of residual ice. On the ATR 42, end of ice accretion can be checked on the propeller spinner.

As long as ICING AOA green caption is illumnated,

MINIMUM ICING SPEED	confirm bugged and observed

Maintening de icing equipment in operation unnecessarily is very detrimental to boots life. [n order to remind the crew to check if ice accretion has ceased and, when ascertained, to switch the de-icing boats OFF, the de-icing blue light on memo panel will blink if de-icers are still ON more than 5 minutes after the ice detector has stopped to signal ice accretion (icing amber light OFF).

When no more residual ice,

ICING AOA	PUSH TO CANCEL

DESCENT

Normal or icing approach conditions	CONFIRM
Relevant approach speeds	BUGGED
Relevant performance restrictions up to landing	APPLY

The procedure to follow in case of landing with a defective airframe de-icing system is given in the FCOM 2.05 and in the check-list.

LANDING ON SLIPPERY RUNWAYS

Under these circumstances, the recommended procedure is :

- Use the longest runway compatible with crosswind limits. Avoid tailwind landings.
- Avoid a long landing and put the aircraft down in the touch-down zone.
- After touch-down, lower the nose. Select ground idle then reverse (use of reverse at high power down to very low speeds may reduce visibility as contaminant are blown up by reversed air flow) and apply the brakes symmetrically.
- If no deceleration is felt, do not use alternate brakes, do not pump the brakes as the anti-skid system will always stop the aircraft in a shorter distance than the pilot can by modulating the brakes.
- In an emergency, reverse may he used until standstill.
- Reduce to taxi speed prior to turning off the runway.

SLIPPERY RUNWAYS AND CROSSWINDS (LANDING)

The wind component at right angles to the landing direction tends to push the aircraft to the down-wind side of the runway. The aircraft additionally tends to behave like a weather vane and yaws into the wind. This creates a side component of reverse thrust which also pushes the aircraft downwind.
The counter-acting side force required to keep the aircraft on the centerline is provided by tire traction. However on wet and/or slippery surfaces, tire traction is considerably reduced. So when directional control becomes doubtful, release the brakes and reduce reverse to ground idle. Use rudder to re-align the aircraft with the runway, reapply reverse and use the brakes as required to stop the aircraft.

PARKING

When OAT is below -5° C (23° F), particularly in wet conditions, avoid leaving the aircraft with parking brake engaged and use chocks instead whenever possible,
When severe cold soak is expected (temperature below -20° C (- 4° F) for a prolonged time) avoid immobilisation of the aircraft with propeller brake engaged. It is recommended to remove the batteries and keep them in heated storage. ■

Freezing rain

Freezing rain is a precipitation of large supercooled water drops. These drops (negative temperature) may be transformed into clear ice when impacting the aircraft's skin in slightly negative temperature condition.

Although freezing rain is not part of certification cases, it must be taken into account for operations in icing conditions.
Freezing rain normally occurs as a result of weather conditions where temperature increases with altitude (temperature inversion, ref. fig. 13), Warm rain falls from or passes through this warm layer into a region of subfreezing temperature and typically becomes supercooled. These supercooled large rain drops will then freeze upon impact with an object.
Impact of these large drops on the leading edge of an aircraft wing or other aerodynamic surfaces, under certain conditions, can cause the entire surface to become incrusted with ice.
To protect an aircraft from freezing rain of this type would require that the entire aircraft rather than only the leading edges, be equipped with de-icing and anti-icing systems. This is obviously impracticable.
Ice accretion due to freezing rain may result in asymmetrical wing lift and associated increased aileron forces necessary to maintain coordinated flight before aerodynamic stall.

FREEZING RAIN LOCALIZATION

Freezing rain seldom occurs and is seldom encountered at high altitudes unless associated with large storm systems such as thunderstorms. It is normally a low altitude weather phenomena and is mainly linked to the presence of a front (temperature ranging from -5° to 0° C — 23° to 32° F).

AVOIDANCE

Freezing rain conditions are usually predictable, recognizable and avoidable.

These conditions are predictable:
- **on ground,** by
  - consulting weather chart
  - reading AIREP and AIRMET message
- **in flight,** by
  - listening to SIGMET message
  - monitoring outside air temperature for the presence of temperature inversion condition.

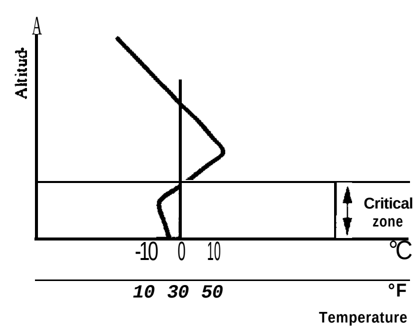


Fig. 13- Temperature inversion is a zone where temperature increases with altitude.

Freezing rain and certification

Advisory circular 20.117 states

" It is emphasized that aircraft ice protection systems are designed basically to cope with supercooled cloud water environment (not freezing rain). Supercooled cloud water droplets have a median volumetric diameter (MVD) of 5 to 50 microns. Freezing rain MVD is as great as 1300 microns. Large drops of freezing rain impact much larger areas of aircraft componements and will, in time, exceed the capability of most ice protection equipments. Flight in freezing rain should be avoided where practical. "

As soon as possible, leave freezing rain conditions. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course.

These conditions are recognizable :
If heavy rain occurs whenever the flight crew have identified conditions propitious to freezing rain formation, it is highly probable that freezing rain is involved. Heavy rain is visually detectable (at night by use of the landing lights) and can be heard striking the fuselage,
If all above conditions are met, this heavy rain will lead to clear ice building on aircraft.

This accretion :

- € is transparent and consequently more difficult to detect but gives an unusual shiny aspect to the covered surfaces ;
- € adheres to most of the surfaces of the aircraft, whereas the de-ice system is only designed for de-icing the leading edges, and limits the efficiency of the de-icing boots,

Should the aircraft enter in a freezing rain zone, he following procedure should be applied,

AP engaged,
RETRIM ROLL L/R WING DOWN " messages
MONITOR

In case of roll axis anomaly, disconnect AP holding the control stick firmly. Possible abnormal roll will be felt better when piloting manually.

SPEED **INCREASE**

Increase the speed as much as performance and weather conditions (turbulences) will allow.
Extend flaps as close as possible to respective VFE. ■

Maintenance recommendations

Beyond the previous procedures, a particular care must be taken for the maintenance when operations in icing conditions are performed. Some maintenance recommendations are presented hereafter.

LANDING GEAR CLEANING

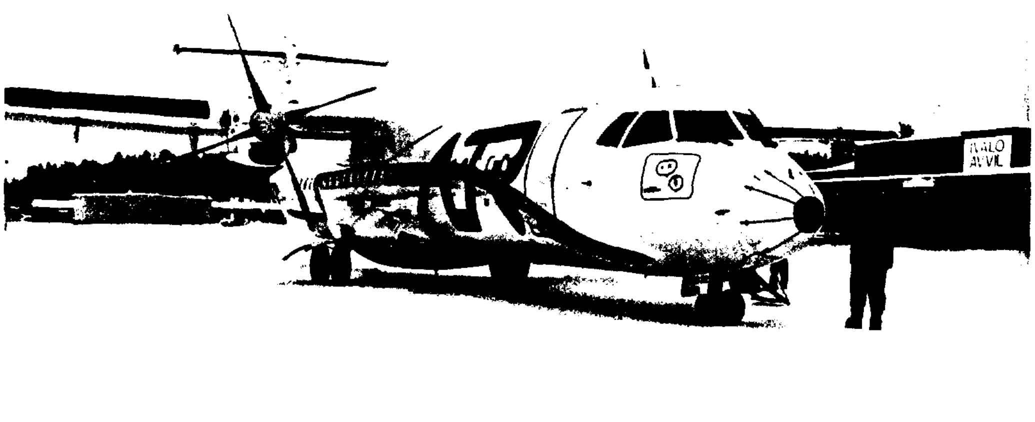
whatever external conditions exist, the landing gears should not be cleaned with high pressure water which can cause grease to be washed away and electrical plugs possibly damaged or contaminated.
Plain water should not be used in cold weather conditions since it could re-freeze on the landing gears components and cause latches, locks, sliding parts to jam or electrical continuities to he lost. It is therefore preferable to clean the landing gears with low pressure water mixed with glycol.
Hot air may also be used to remove snow, slush or ice accumulations on the landing gears. This method should be considered for brake units as the spraying of de-icing fluid between stator and rotor discs can affect the brakes performance.

TIRES

Tires can become frozen to the ground under ground icing condition. In such a case hot air may be used to warm and free the tires. Do not use hot air temperatures above 80° C (176° F).

LANDING GEAR SERVICING

When charging the landing gears shock asborbers in a hangar, the difference in inside / outside temperatures should be taken into consideration as it affects the struts height.



FLIGHT CONTROLS

Flight surfaces are controlled by cables and rods through pulleys and bellcranks. De-icing fluids have a detrimental effect on bearing lubrications. The direct spraying of fluid on these mechanisms, particularly in the wing rear spar area should be avoided when possible,
Inspections of the roll control mechanism are planned in the aircraft maintenance program for generai condition corrosion or excessive play at a C interval. Additional checks may be advi - sable for airplanes subject to frequent de-icing operations.

PNEUMATIC DE-ICING SYSTEM

To prevent water accumulation in the pneumatic de-icing system, it is recommended to periodically blow the air distribution circuit and to "dry" the system. This can be achieved by blowing compressed air into the circuit through the regulator/shut-off valve port.

DE-ICERS (BOOTS)

De-icing boots should be seasonally checked for debonding, presence of pin holes and blisters and repaired or replaced whenever necessary, to ensure their efficient operation (ref. CMM AERAZUR 30-11 ; 30-21).

FUEL SYSTEM

The fuel tanks and surge tanks should be drained at each line check, whatever conditions exist.
When the airplane is parked or operated for a long time in negative temperatures, the water in the fuel can freeze and could cause engine supply difficulties or plugging of the fuel tank venting duct.
If the airplane was parked for a long time at subzero temperatures and the drainage is made in these conditions, water may not be evacuated as it has become frozen. The drainage should therefore be performed when possible after the airplane has remained again some time in a positive ambient atmosphere (hangar, airfield). This can also be achieved after a refueling operation with warm incoming fuel.

DOORS

During on ground aircraft handling operations, precipitations can cause water to enter into the doors mechanisms, If the aircraft is then cold soaked at very low temperatures, the door operating mechanism may become jammed or hard to open. In that case hot air only should be used to dry and free the system. Again de-icing fluids should not be used to avoid wash out of the grease. ■

Despite continuous emphasis. on icing hazards, accidents and incidents linked to icing continue to occur in air transport.

ATR certification process and philosophy is on the safe side, and covers all predictable cases of icing occurrences, provided some basic rules are respected:

- *If you have any doubt about the proper ground de-icing of your aircraft, DO NOT TAKE OFF.*

- *As soon as you enter icing conditions, do not wait for actual ice accretion to play the game: turn Icing AOA green light ON and observe minimum icing speed right away. Cancel Icing AOA only when you are sure there is no more ice on the aircraft.*

- *AAS is designed to help you but remember You are in charge. No system can replace PILOT JUDGMENT and GOOD AIRMANSHIP.*

ATR Icing Conditions Procedures

Version 2.0

Background

An extensive icing tanker test program of the ATR 72 has been completed at Edwards Air Force Base. The program was conducted as part of the Special Certification Review being conducted by the FAA and the DGAC and the continuing investigation into the loss of American Eagle Flight 4184. This document has been created to provide flight crews with a briefing on that program and to explain the operating procedures being implemented as a result of those tests. Within the next 60 days, flight crews will also be furnished a video that provides additional detail on the subject of icing, and the test results.

The Edwards Air Force Base Testing

The temperatures and droplet sizes selected for these tests were based upon the meteorologic analysis of conditions at the time of the October 31 accident of Flight 4184.

SPECIFIC PROCEDURES

The tests conducted at Edwards Air Force Base had two objectives:

1) To confirm that the ATR meets certification standards for icing conditions; and
2) To observe the ice accretion characteristics at marginal freezing temperatures of large water droplet sizes that are outside certification standards.

Tire temperatures and droplet sizes selected for these tests were based upon the meteorologic analysis of conditions at the time of the October 31 accident of Flight 4184.

The target exposure time of 17.5 minutes was selected to match the time interval in the accident between ice detector activation and the roll upset.

IMPORTANT NOTICE:
This choice of 17.5 minutes does not imply that such is the minimum time to reach a critical level of ice buildup in real flight conditions.

EQUIPMENT USED

The testing involved the following aircraft:

- USAF KC-135 – This aircraft has a special water spray array on the end of the refueling boom. The diameter of the "cloud" produced by the array was approximately 8 feet, The size of the water droplets and the liquid water content of the cloud was adjusted by varying air pressure in the spray system and changing nozzles on the spray array.
- LearJet 36A - This aircraft was equipped with sensors to measure the characteristics of the cloud. This aircraft also functioned as a chase plane.
- ATR 72-212- A stock production aircraft was used. The normal crew escape hatch was replaced with a special hatch equipped with two video cameras, Tire cameras were pointed to the outboard sections of the wings and were equipped with zoom lenses. They were controlled by one of the two crew members.

DEFINITIONS OF TERMS USED

MVD - **Mean Volumetric Diameter**

In simple terms, this is the water droplet size. In nature, the droplets that make up clouds and precipitation are a variety of sizes. Some air masses may contain a greater proportion of large diameter droplets, while others are composed primarily of small droplets. The data collected by the LearJet calibration aircraft was prncessed through a variety of mathematical analysis programs to produce an MVD value that might be thought of as an average drop size.

WC- Liquid **Water Content**

This is the number of grams of water that are contained in one cubic meter of the cloud (g/m^3). It might be thought of as describing the density 1 of the cloud.

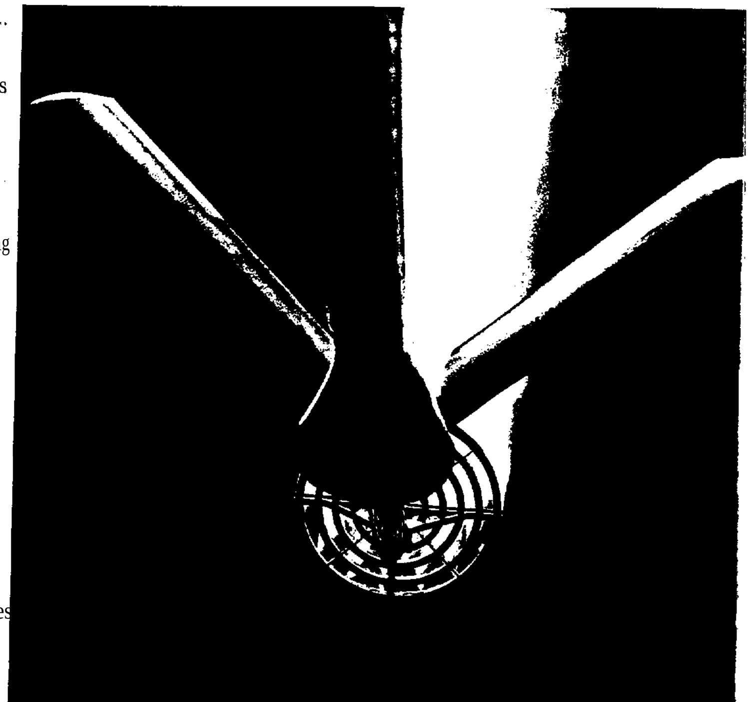
Purpose of the Tests

The tests were designed to examine both the upper limits of the certification envelope at marginal freezing temperatures and the icing characteristics of very large droplets not covered by certification.

Marginal freezing temperature tests were conducted at a SAT of approximately -2C (TAT of approximately +3C). Altitude was varied as necessary to achieve and maintain the desired temperature, and most testing was conducted between 11,000 and 13,000 feet. Air speed used during accretion was between 175 KIAS and 180 KIAS and was selected to replicate the Flight 4184 accident scenario.

Certification standards call for a droplet size for the test temperature range of 40 microns in diameter, but most of the tanker test program flights occurred at an MVD in excess of 70 microns — or almost double the regulatory requirement. The LWC by regulation is. 15 g/m^3. The tests were actually conducted with a LWC of approximately .45 g/m^3 — or approximately 3 times the regulatory requirement. For the purposes of this document, these tests will be referred to as the "70 micron tests",

The tests to explore very large water droplet sizes were conducted at an MVD of approximately 180 microns and the LWC was approximately .35 g/m^3. These tests will be referred to as "the 180 micron tests." ***The U.S. Air Force had never before applied droplets of this size to any aircraft, either military or civilian.***



The U.S. Air Force had never before applied droplets of this size to any aircraft, either military or civilian.

Summary of findings

The following is a brief summary of the findings. The video, now in production, will cover the tests in more detail and provide specific values when all data reduction is complete. In all ice accretion conditions tested, the aircraft was flown down to stick pusher. The target application time of 17.5 minutes was achieved with no difficulty for all tests.

70 Micron Tests

FLAPS 0° AND 15°

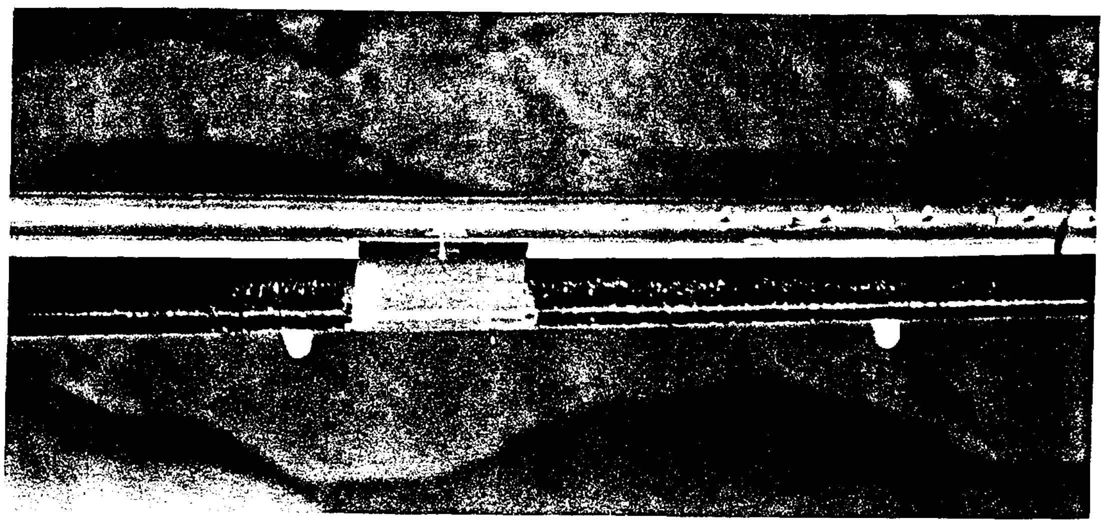
Ice Accretion Pattern

- The deice boots provided full protection.
- The windshield heating unit provided a clear area both on the forward window and on the side window. The only ice accretion noted on the side windows was some small random droplets or "globs." Coverage on the forward side window was less than 10 percent with no discernible pattern. There was no accretion on the aft side window.
- The ice detector actuated within 1.5 minutes of entering the icing "cloud."
- The ice evidence probe accreted ice very quickly and, during the course of the test. created a "double horn" shape of approximately 4 to 5 inches in height and approximately 1-inch thick.

Handling Characteristics

- At no time were there any changes in handling characteristics other than a small lateral imbalance that would be expected with ice accretion occurring on only one wing tip.

70 Micron exposure

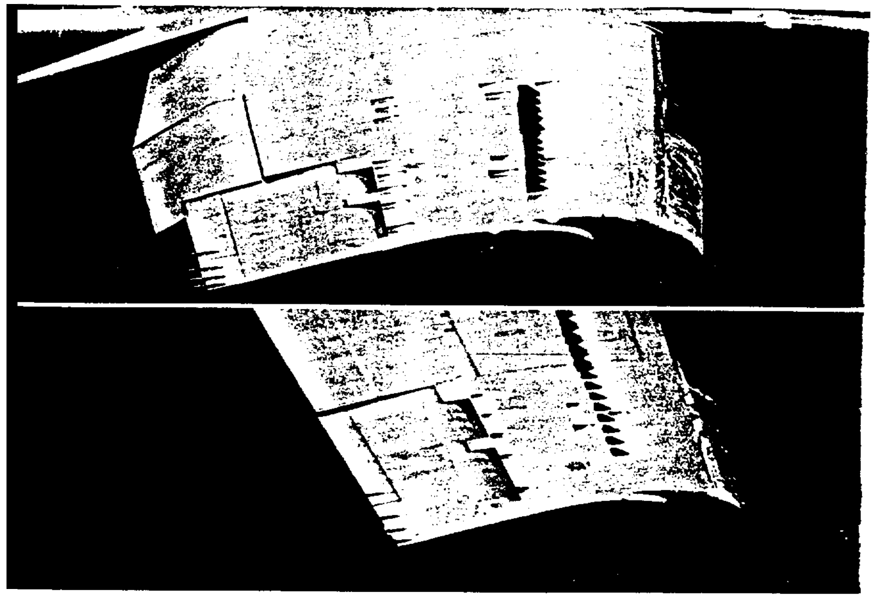


180 Micron Tests
(Outside Certification Envelope)

180 *Micron Test:*

Accretion 15°

Accretion 0°



FLAPS 0°

Ice Accretion Pattern

- Ice accretion occurred at the top edge of the boot in the form of a "saw tooth" ridge. This ridge would build to a height of between 3/4 inch and 1 inch and then break away in the airstream. It is estimated that at any point in time this buildup may have covered approximately 60 percent of the leading edge area. Some accretion appeared on the lower surface of the wing back as far as approximately 50 percent chord.
- Minor ice accretion recurred on the lower aft surface of the aileron control horn. The aileron gap remained clear at all times.
- Vortex generators remained clear with only occasional minor accretion at the tips, which cleared itself periodically.

Handling Characteristics

- Handling characteristics remained essentially normal, with only a "wing heavy" tendency that would be expected under asymmetric accretion,

FLAPS 15°

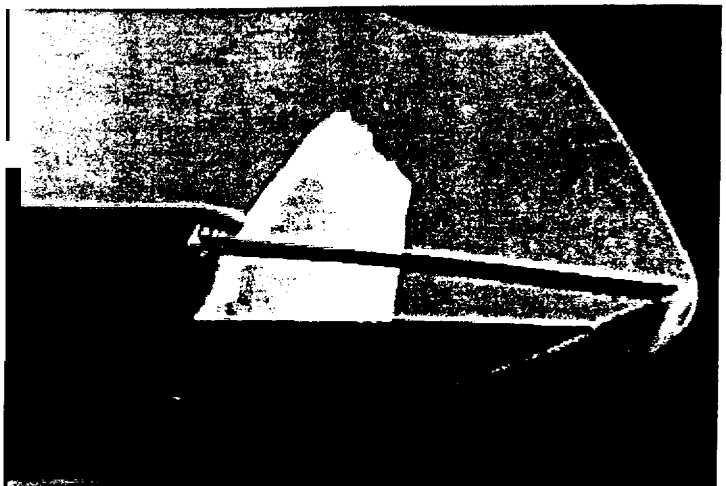
Ice Accretion Pattern

- While the boots kept the leading edge area clear, ice accretion did recur behind the boots to about 16 percent chord. This accretion consisted of a major ridge, at about 10 percent chord, and a second minor ridge at about 14 percent chord. This second ridge reached a height of only about 1/4 inch. However, the forward ridge was able to reach a height of approximately 3/4 inch during the 17.5-minute exposure time. The lower surface of the wing remained clean.
- The vortex generators remained clear with only occasional minor accretion at the tips, which cleared itself periodically.

FLAPS 15°

Handing Characteristic

- In checking the handling characteristics in this test, the autopilot was used to simulate the accident scenario. The autopilot was engaged at 175 KIAS and was capable of holding the lateral forces. The aircraft was then accelerated to 185 KIAS and the flaps retracted to copy the accident scenario. No abnormalities were noted.



Ice Evidence Probe

AFTER FLAPS RETRACTION

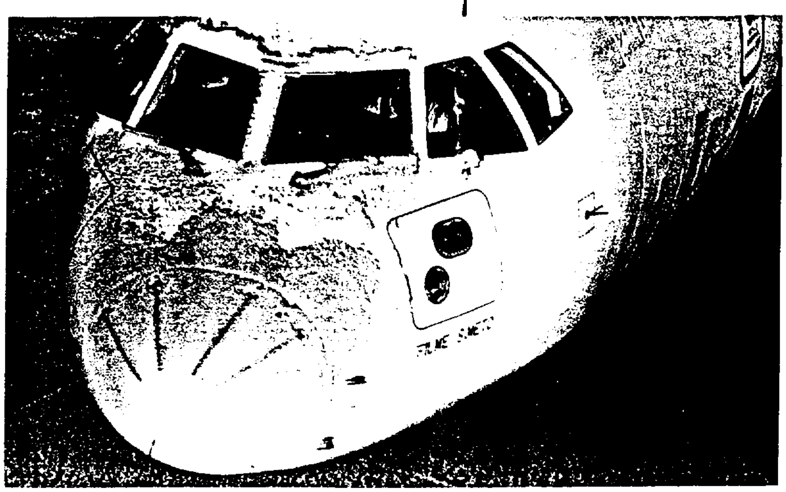
Handling Characteristics (Flaps 0°)

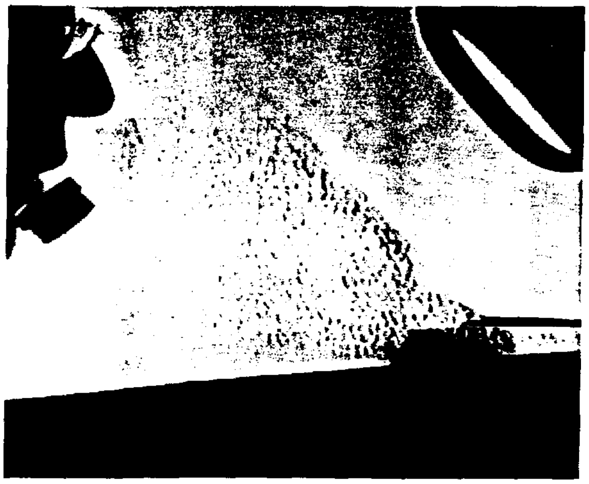
- The aircraft then began a deceleration with autopilot engaged.
- Aileron mistrim messages appeared on the ADU prior to autopilot disconnect at approximately 125 KIAS. The aircraft was then hand flown down to stick pusher. As stick pusher was approached, the aircraft exhibited a tendency for the ailerons to deflect in the direction of the contaminated wing. The maximum lateral forces noted, even with the asymmetric ice accretion, were approximately 35-to-40 pounds.

In addition to the tests described above, a number of other tests were conducted, including failure modes of outboard boots and aileron horn heat as well as operation at 77 percent Np. Details of these tests will be covered in the video.

The maximum lateral forces noted, even with the asymmetric ice accretion, were approximately 35-to-40 pounds.

180 Micron Exposure



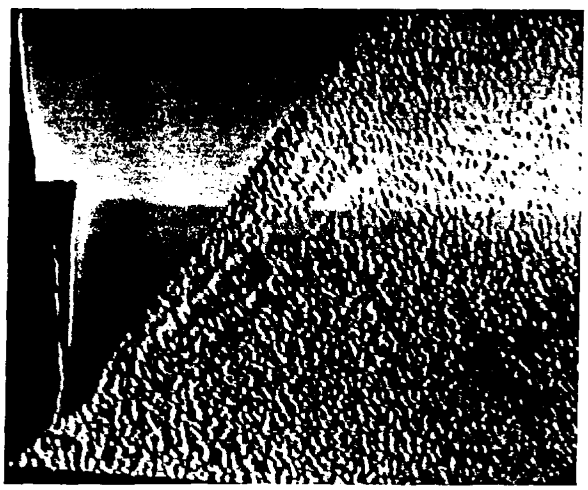


After 30 seconds of exposure.

After one minute of exposure.

Visual cues identified with freezing min or freezing drizzle are characterized as a dispersed granular ice pattern, spanning the entire height of either side window, covering all or part of the window from front to back.

After five minutes of exposure. (Right window)



After ten minutes of exposure.