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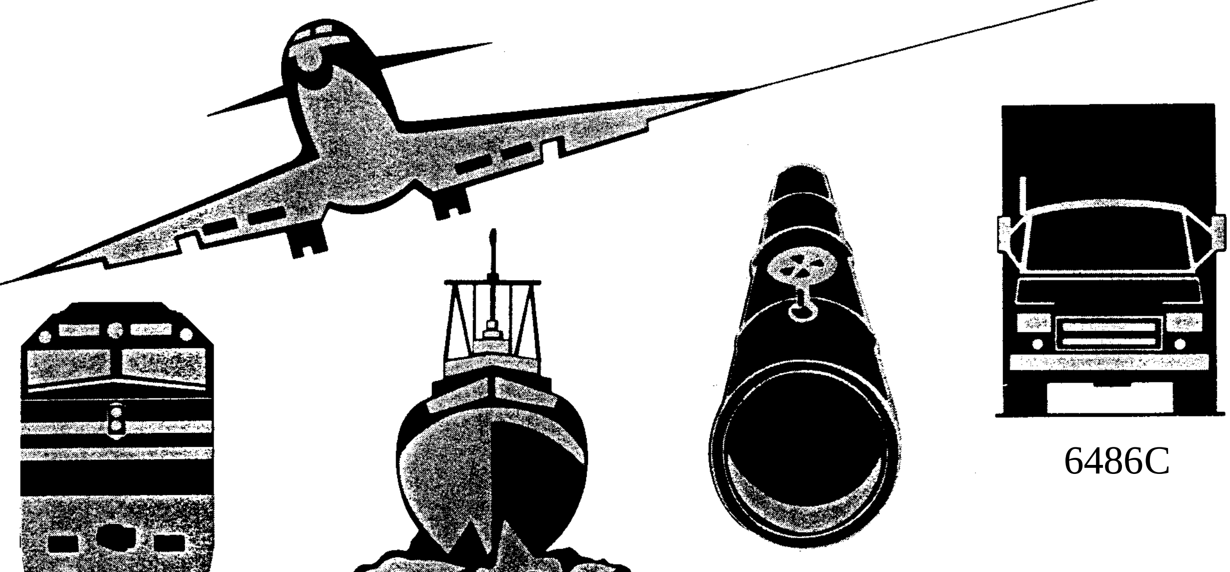
NATIONAL TRANSPORTATION SAFETY BOARD

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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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

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.

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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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.

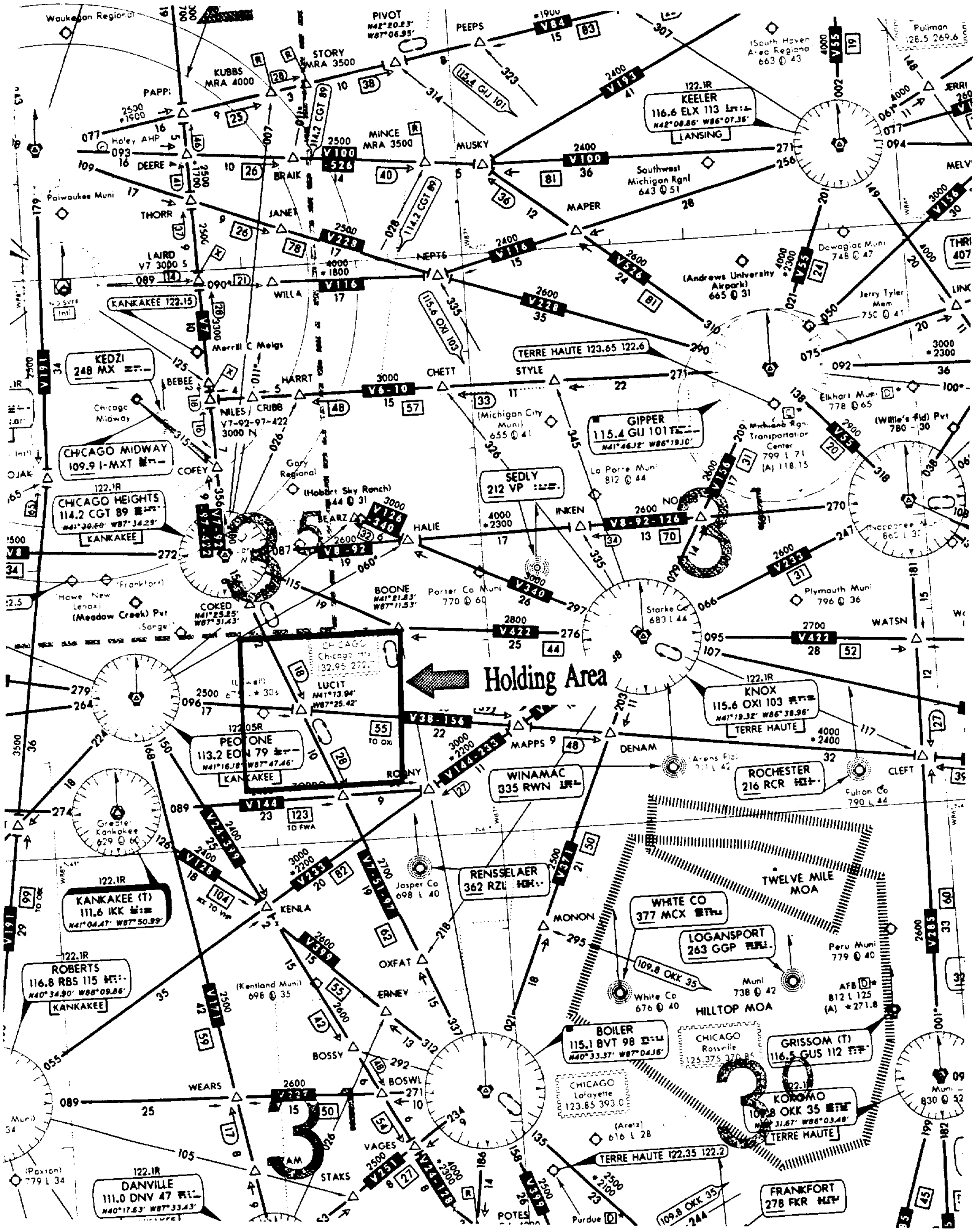

Figure 1.--Holding pattern location; box identifies LUCIT intersection.

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

[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.

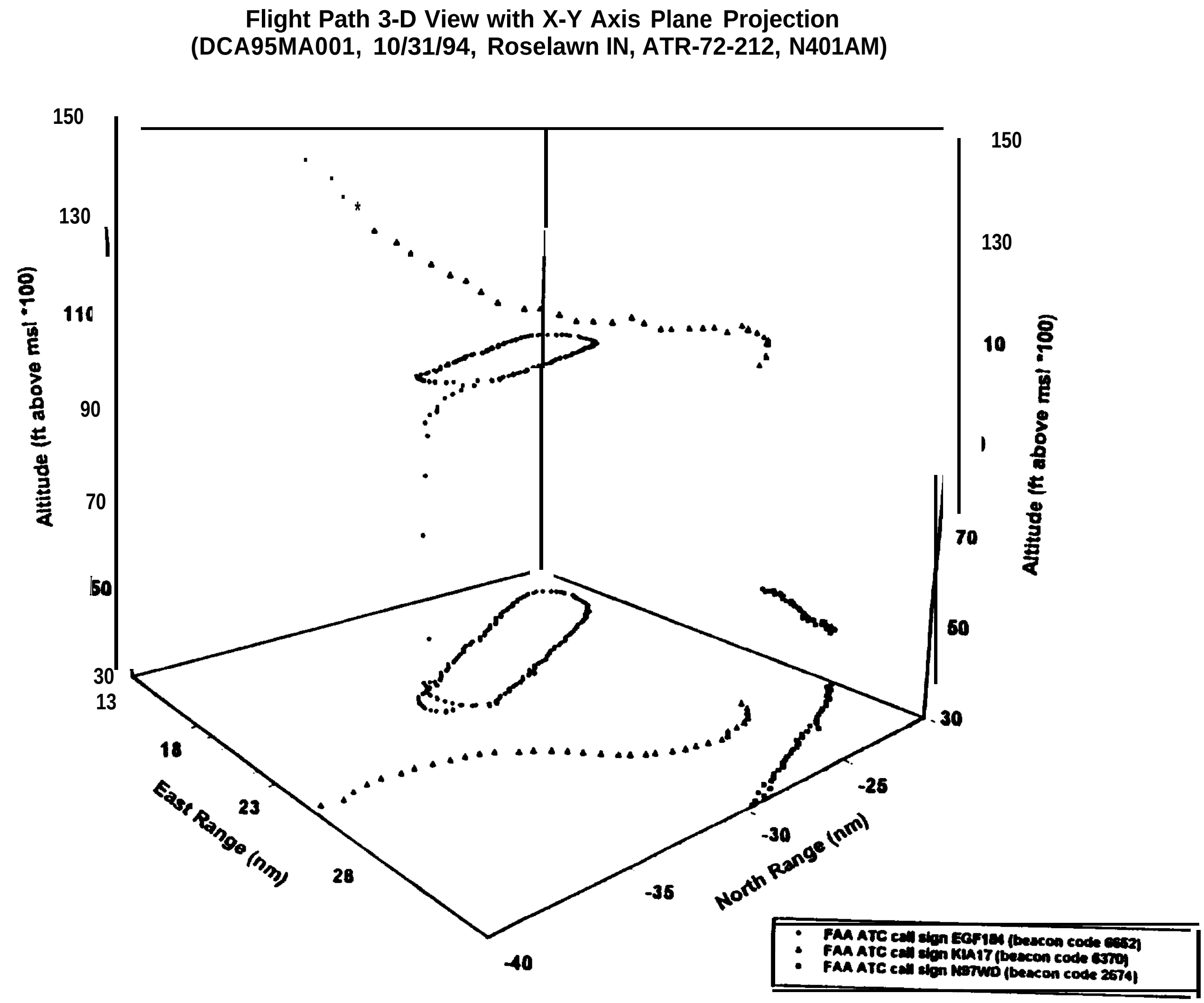

Figure 2.—Flightpath of airplane in holding pattern.

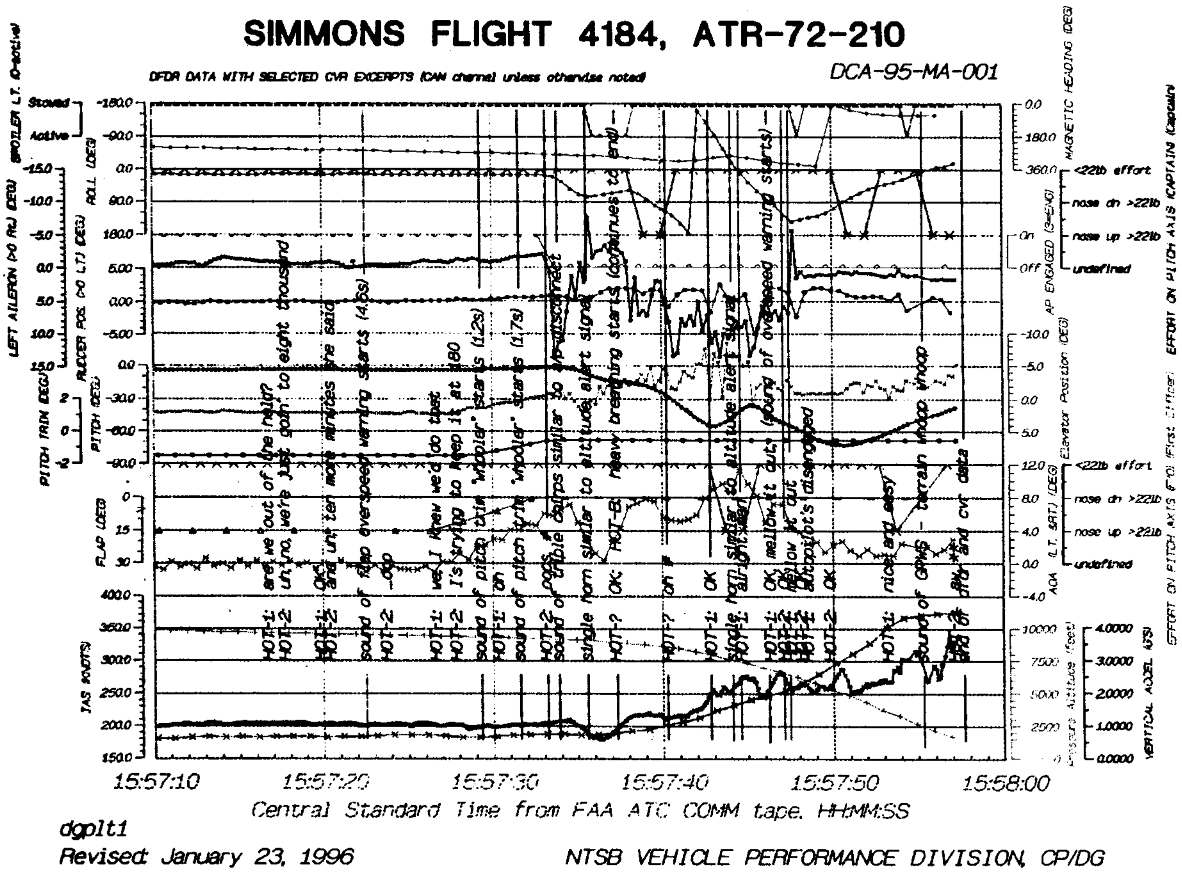

Figure 3.--FDR/CVR data correlation.

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

[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^{o} 5' 40" north latitude and 87^{o} 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.

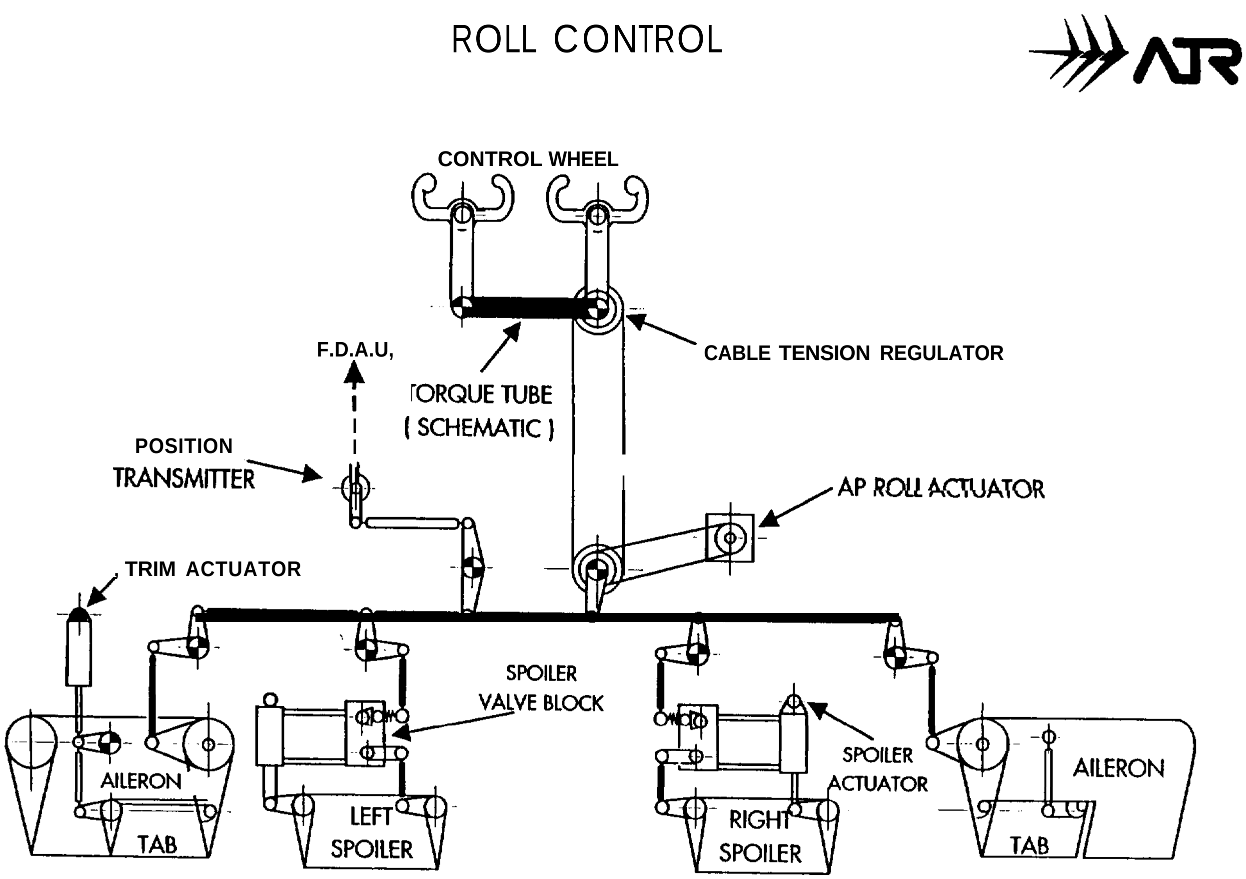

Figure 4.—Roll control diagram.

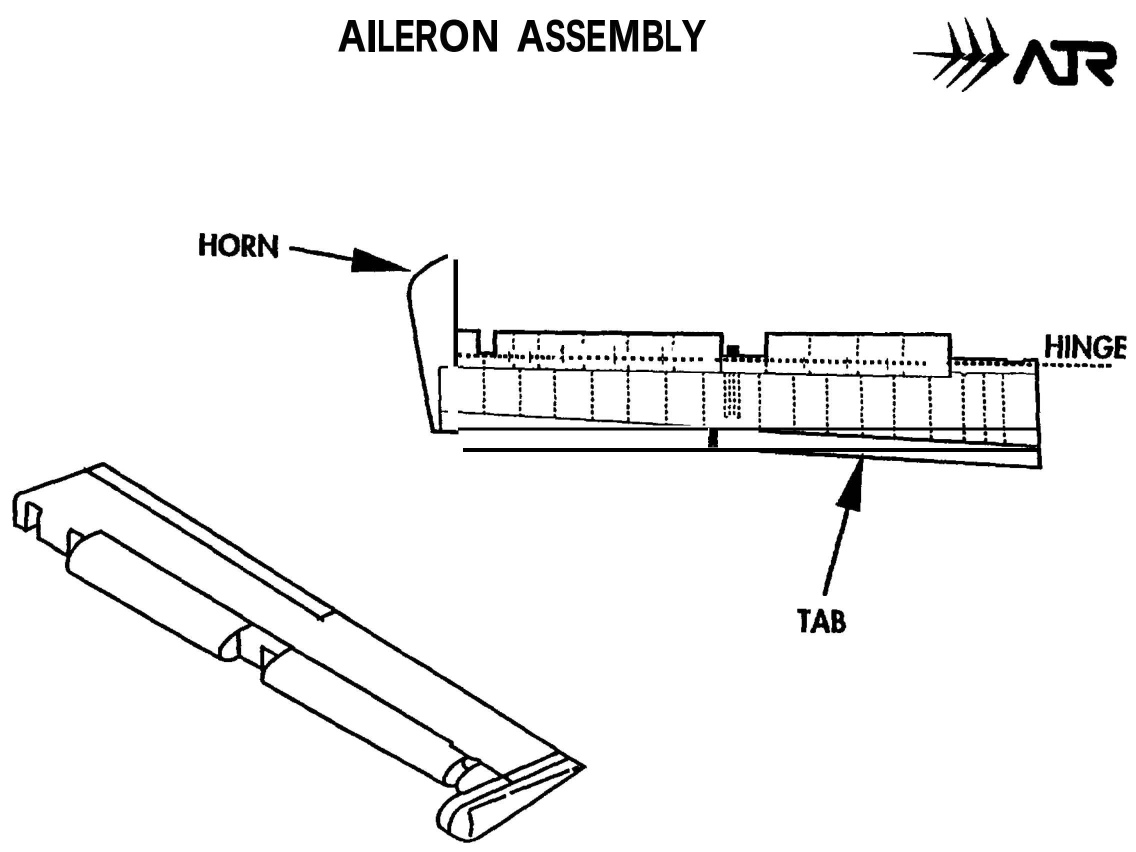

Figure 5.--Aileron assembly.

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

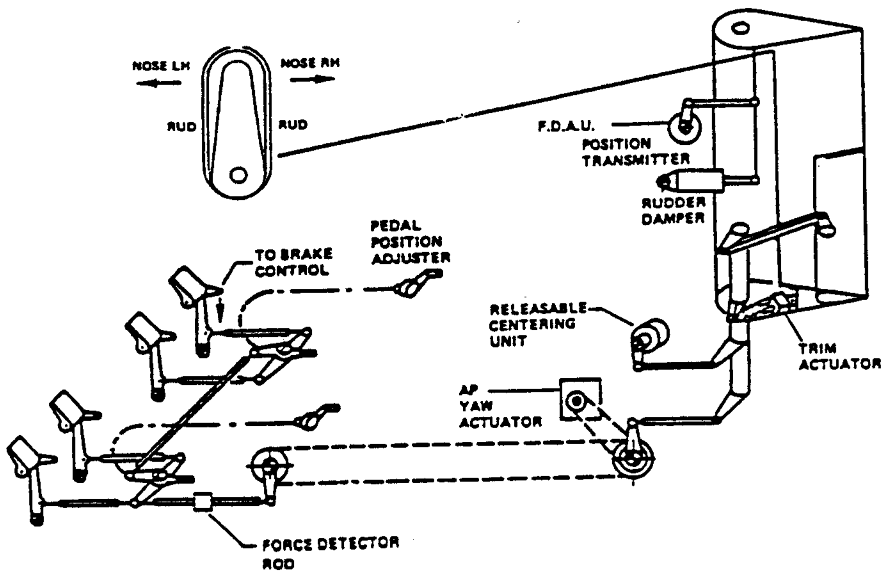

Figure PPLT-3

Rudder Control System

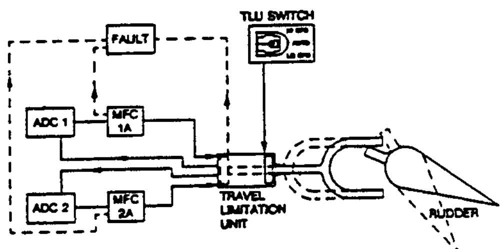

Figure FLT CTL-23

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

[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).

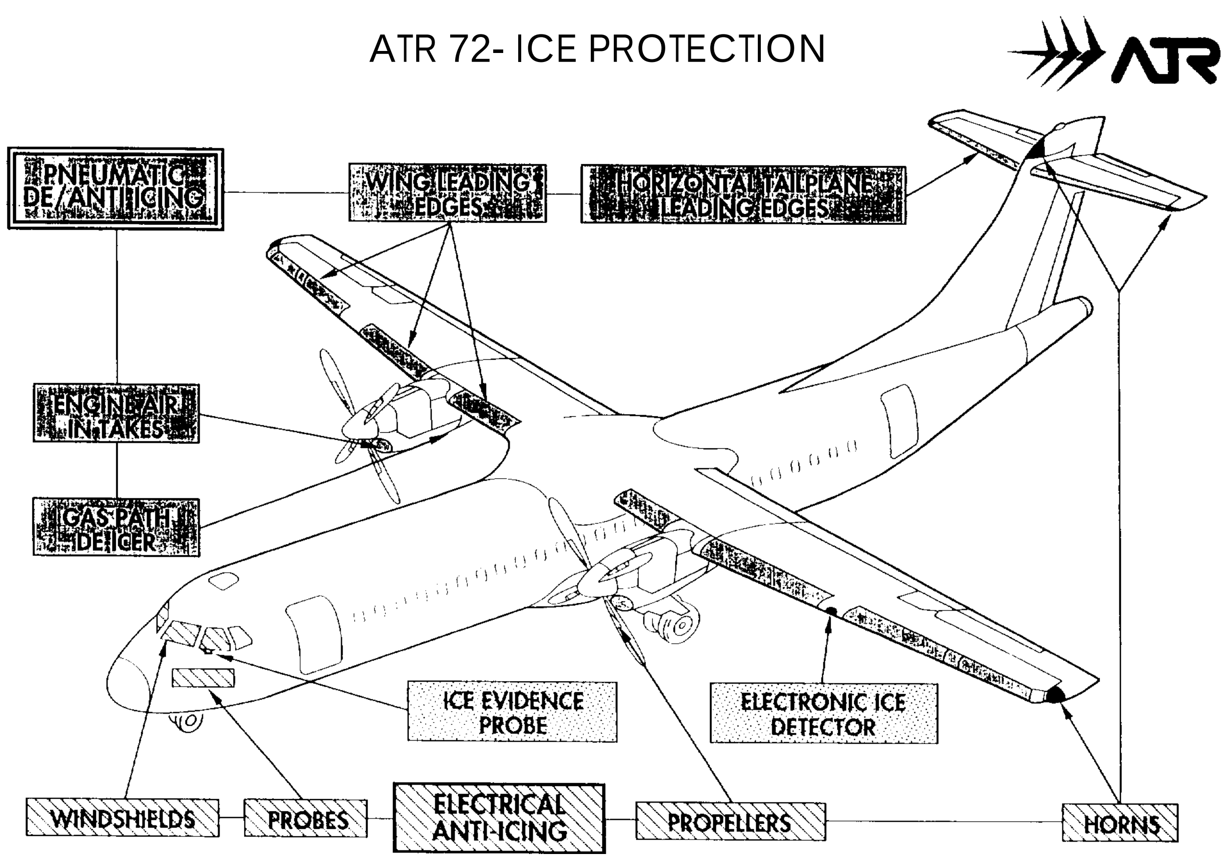

Figure 7.--Ice protection system.

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.

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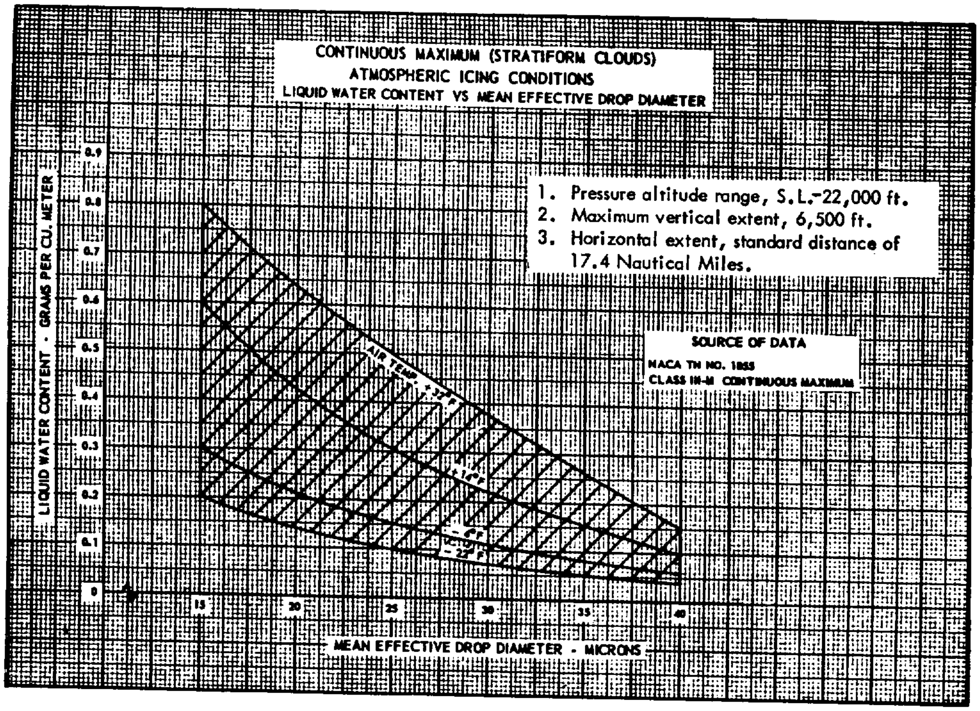
[30]Refer to Section 1.18.7 for further information regarding the ATR 42 and 72 certification process under the Bilateral Airworthiness Agreement.

[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.



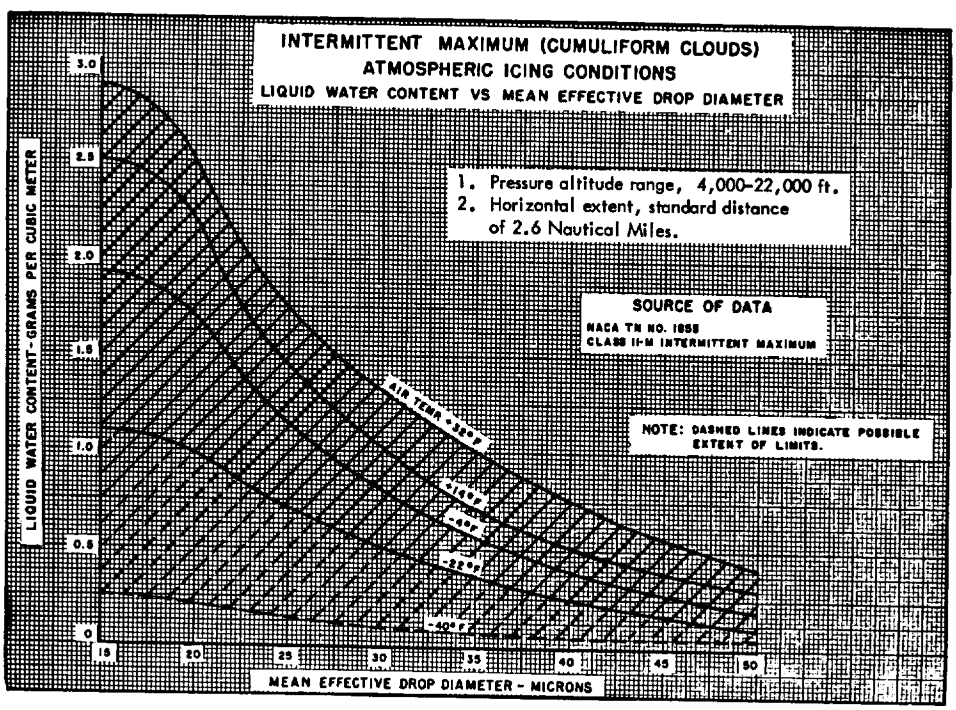


Figure 8.—14 CFR Part 25 Appendix C Icing Envelope.

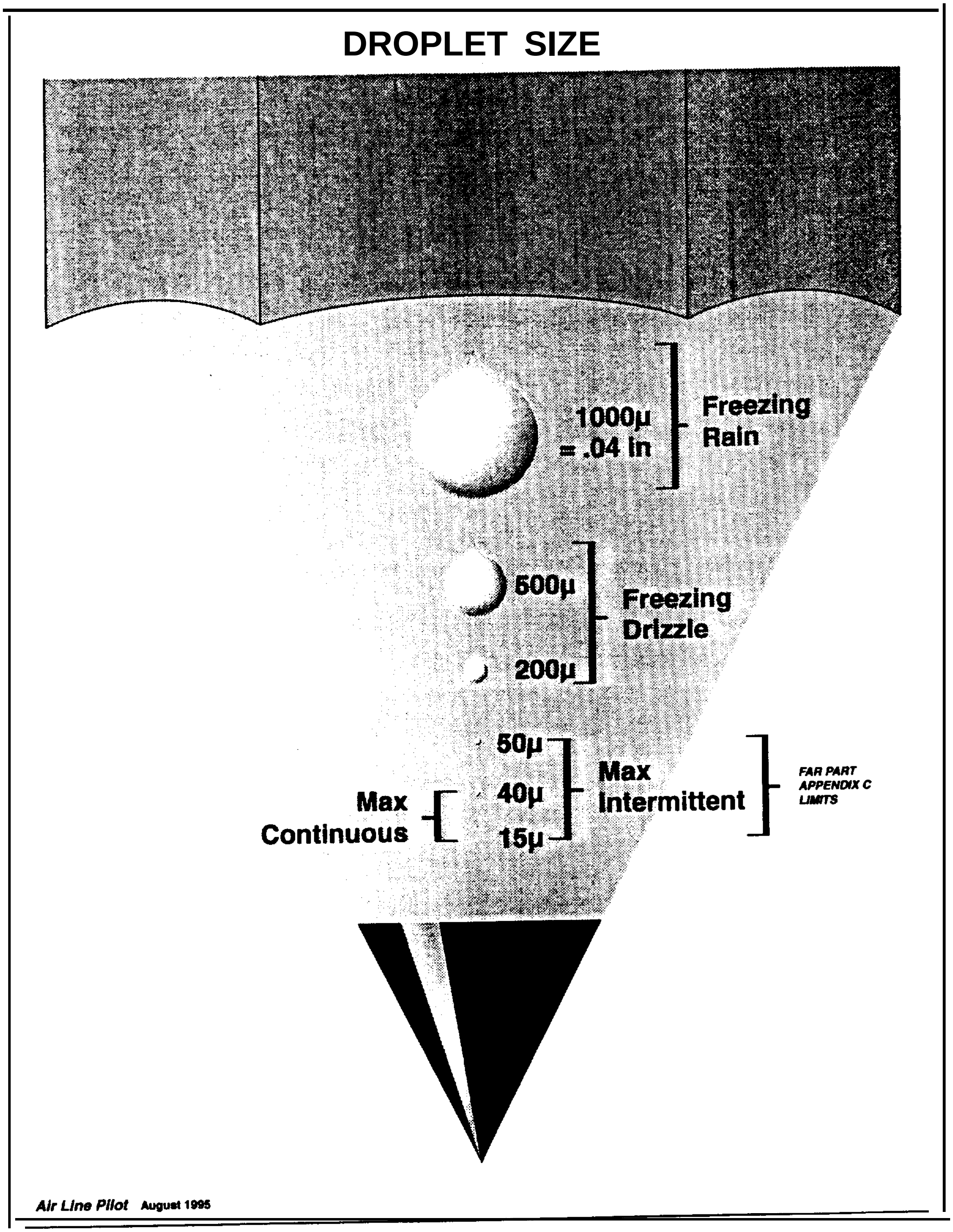


Figure 9.—Drop size diagram.

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.

[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^{o} 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

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[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:

Height (Feet)	SAT (Degrees C)

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.

[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

[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

[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

[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

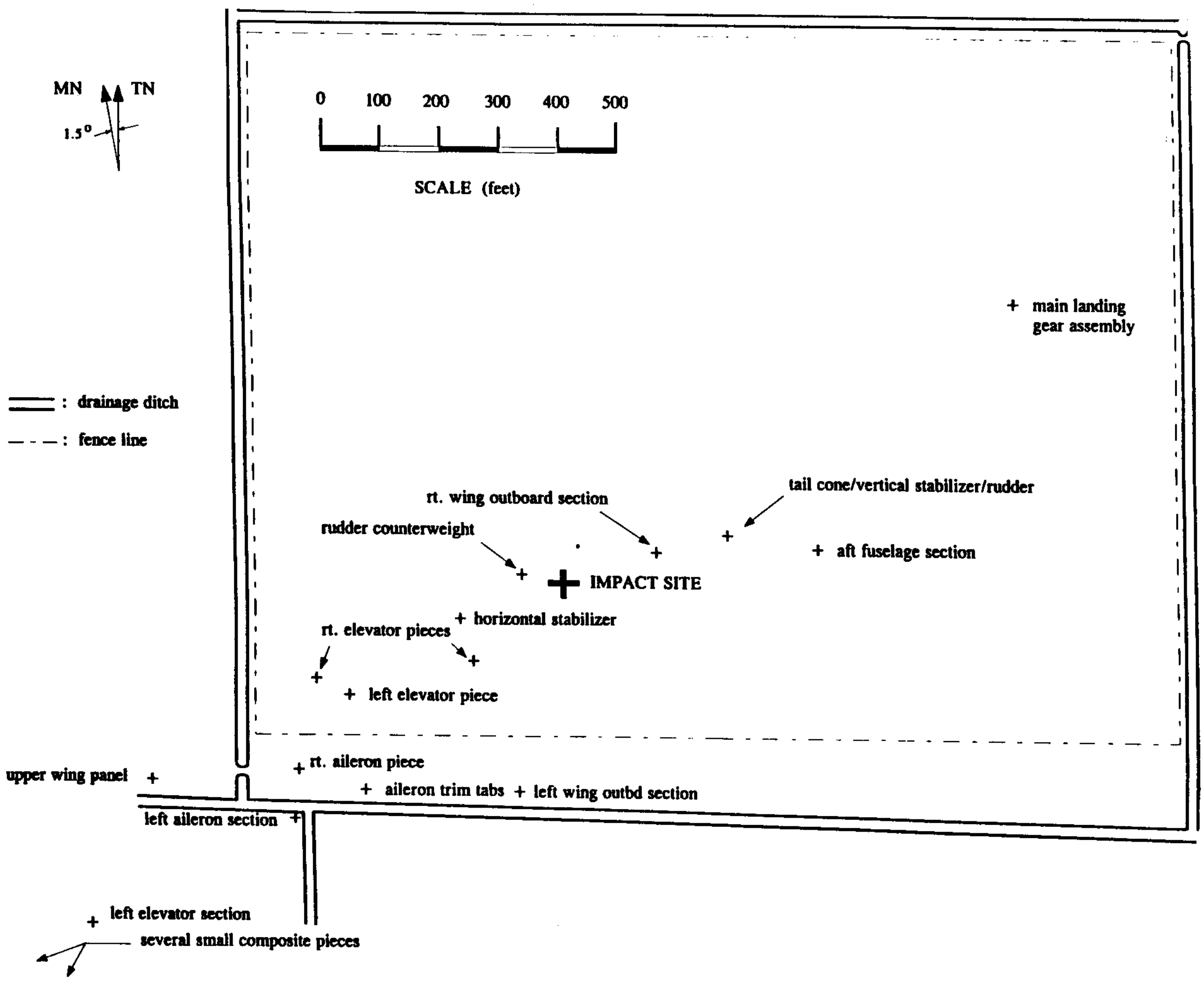

Figure 10a.--Wreckage distribution diagram.

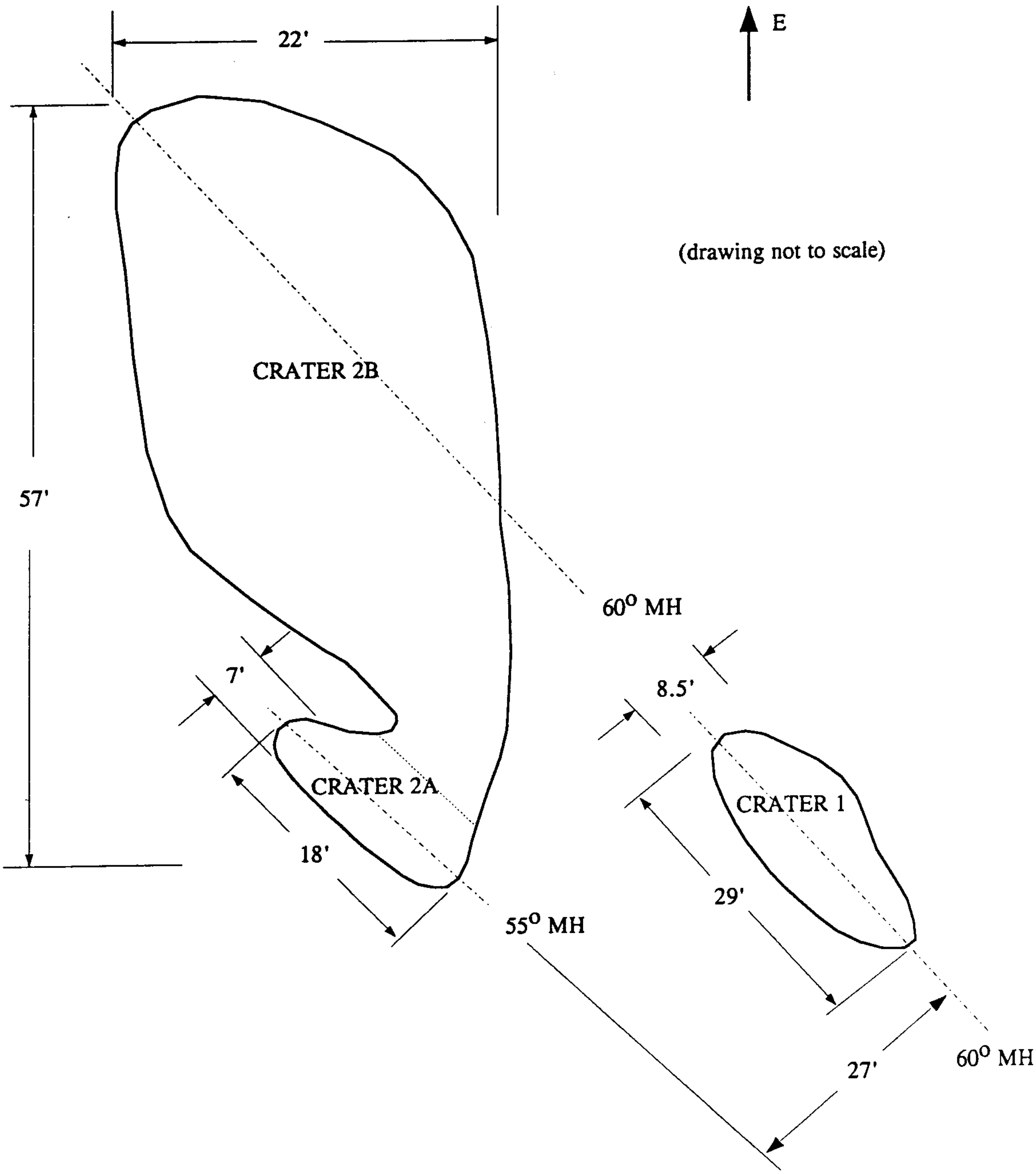

Figure 10b.--Impact craters.

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

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[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

[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.

[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 All Weather Operations 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

[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 Aviation Weather Services 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

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[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:

A-95-103
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-95-104
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-95-105
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)

A-95-106
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 Federal Aviation Administration, Responsiveness to Suspected Aircraft Maintenance and Design Problems. 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, Review of the Construcciones Aeronauticas, S.A.

[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

[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.
>
> 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:

> <u>A-95-99</u>
> 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

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 acknowledge 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 thousand.
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 contin-ues 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 actualIy 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 loss 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 also 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

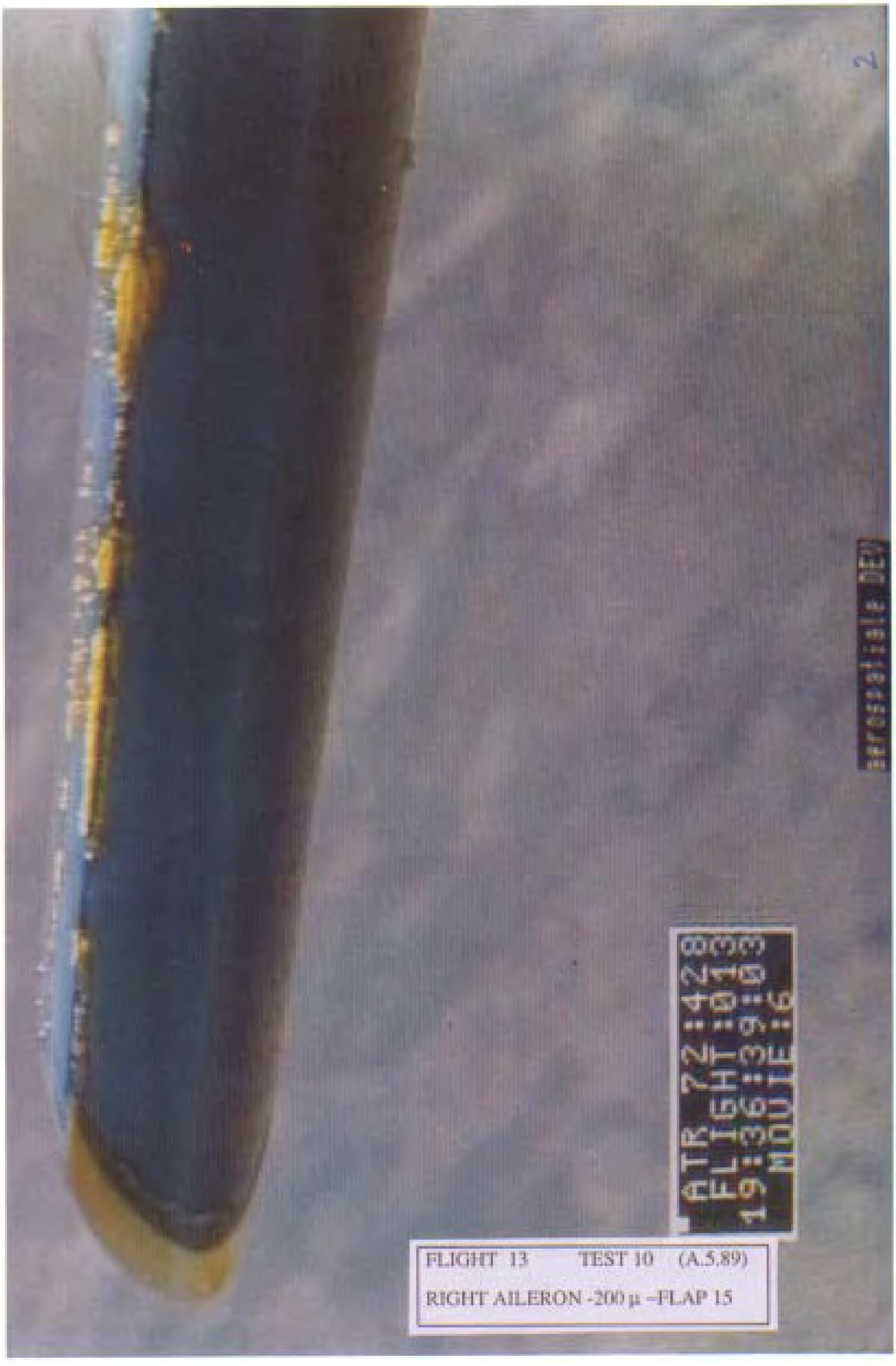
Methods to accurately forecast SLD conditions, and mechanisms to disseminate that information to flight crews in a timely manner should be improved.

APPENDIX D

PHOTOGRAPHS OF ICE ACCRETIONS ON THE ATR 72 DURING THE ICING TANKER TESTS

A.0.1


A.0.2

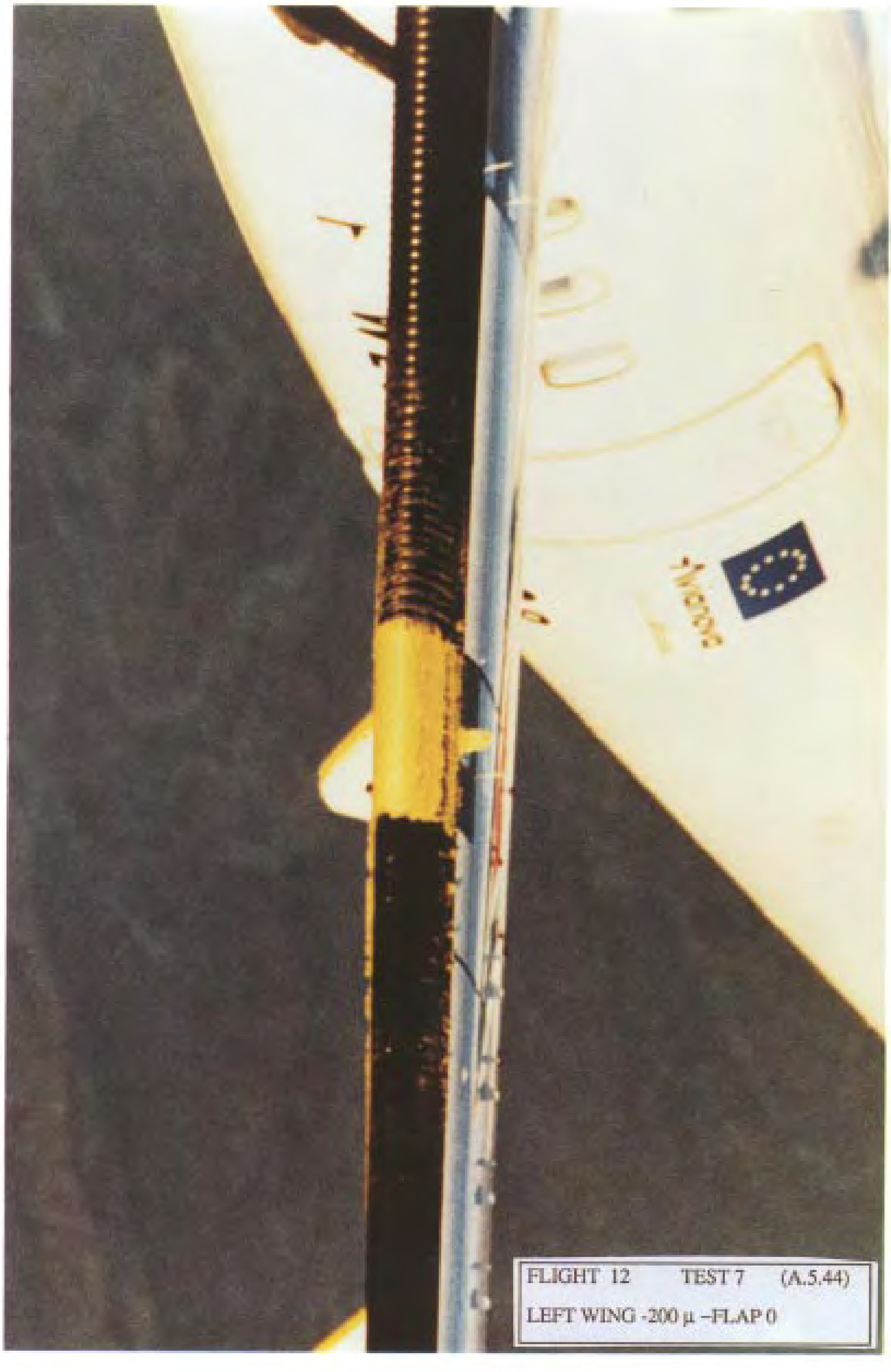


FLIGHT 13 TEST 10 (A.5.89)

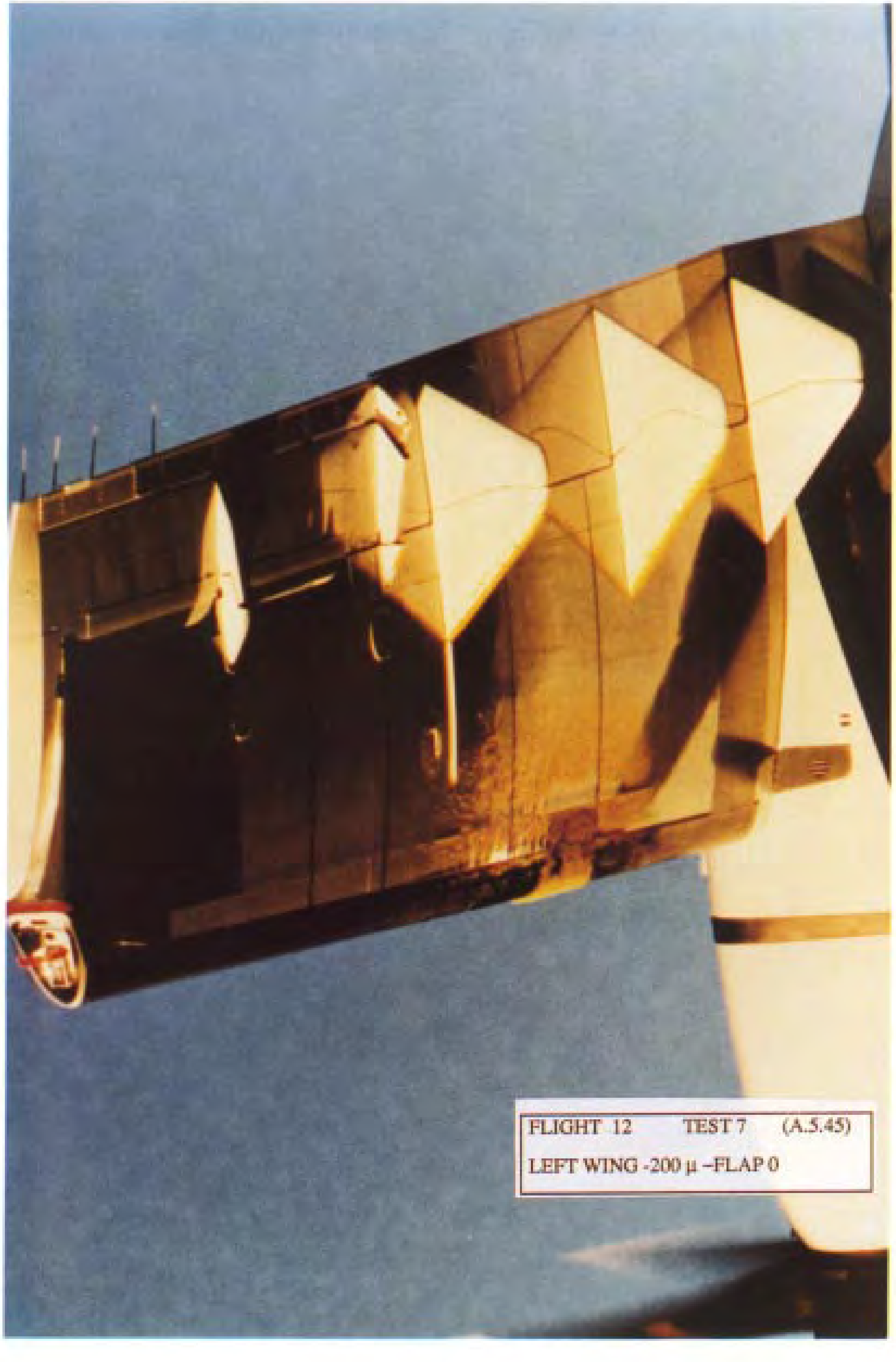
RIGHT AILERON -200 µ -FLAP 15

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

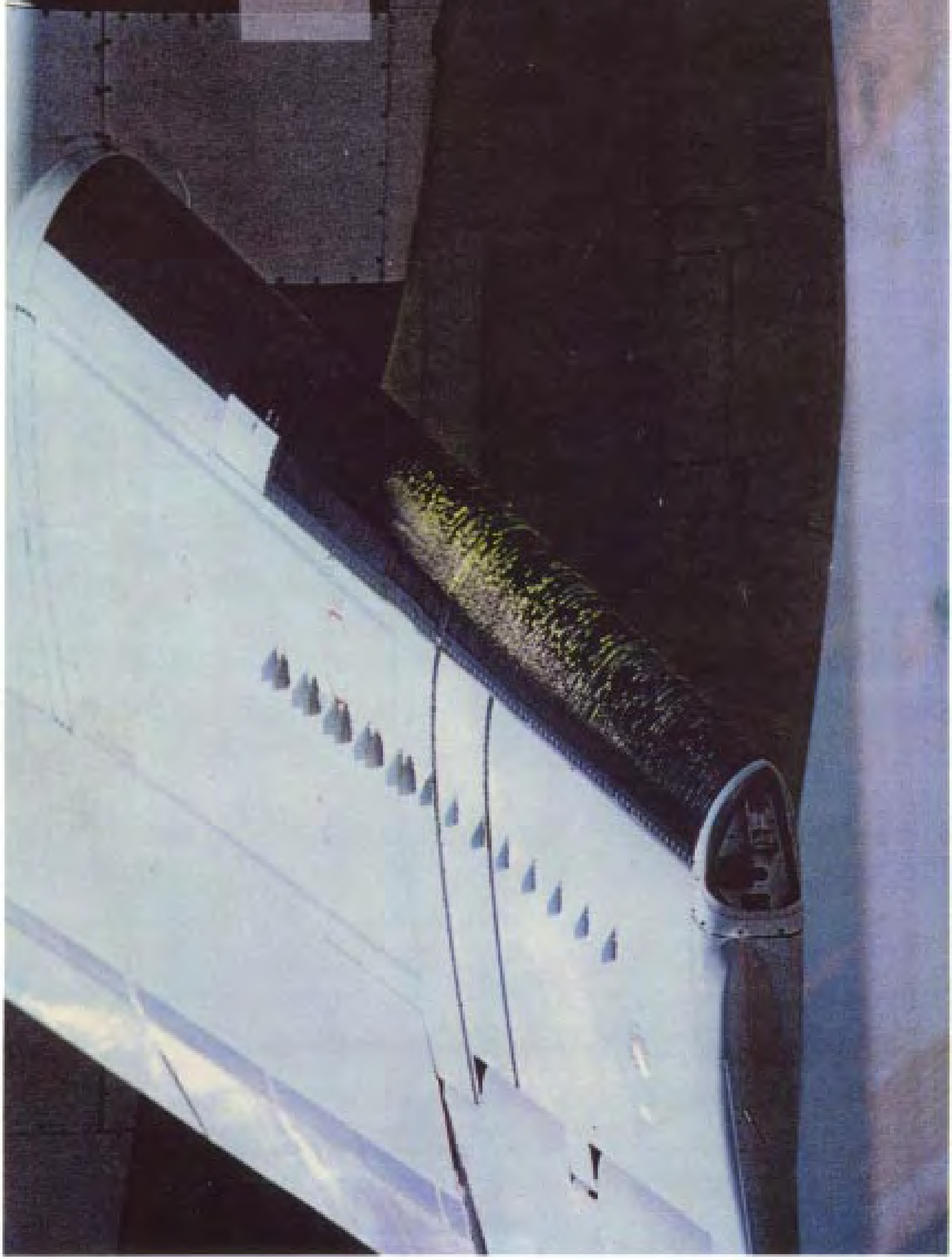


FLIGHT 12 TEST 7 (A.5.45)

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

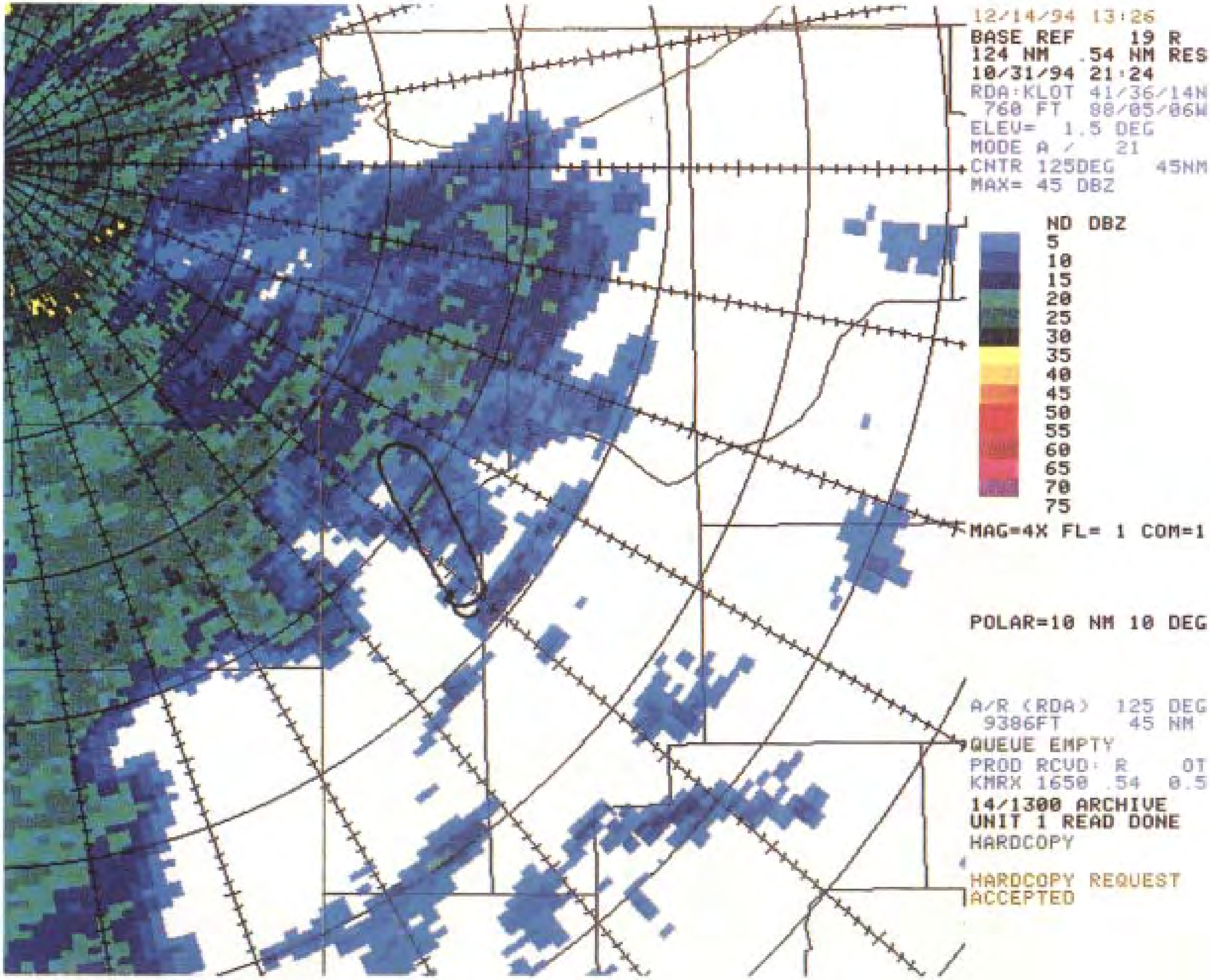
WITH TRACK OF FLIGHT 4184 SUPERIMPOSED

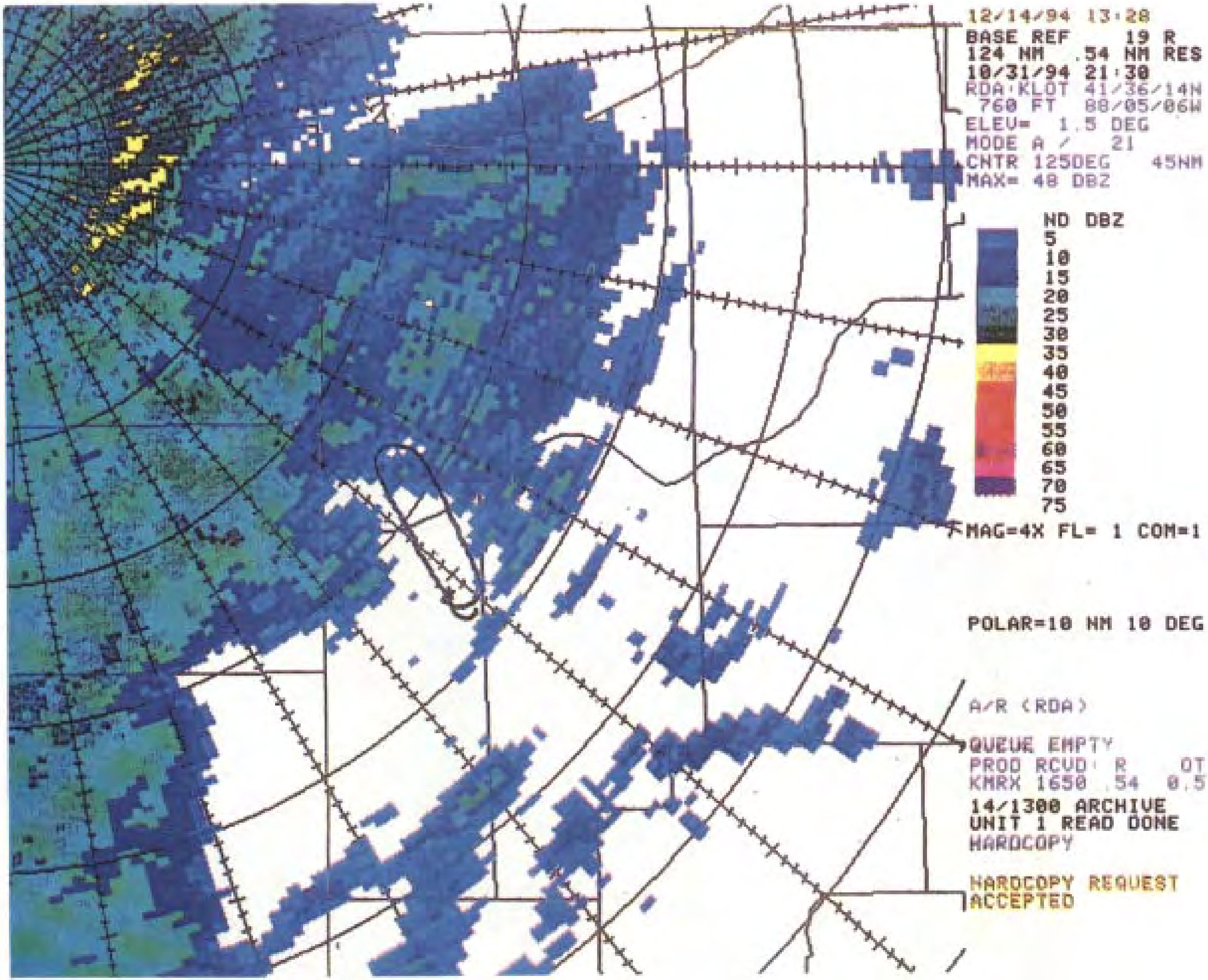
KLOT WSR-88D Doppler Weather Radar Images with the Track of Flight 4184 Superimposed

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.

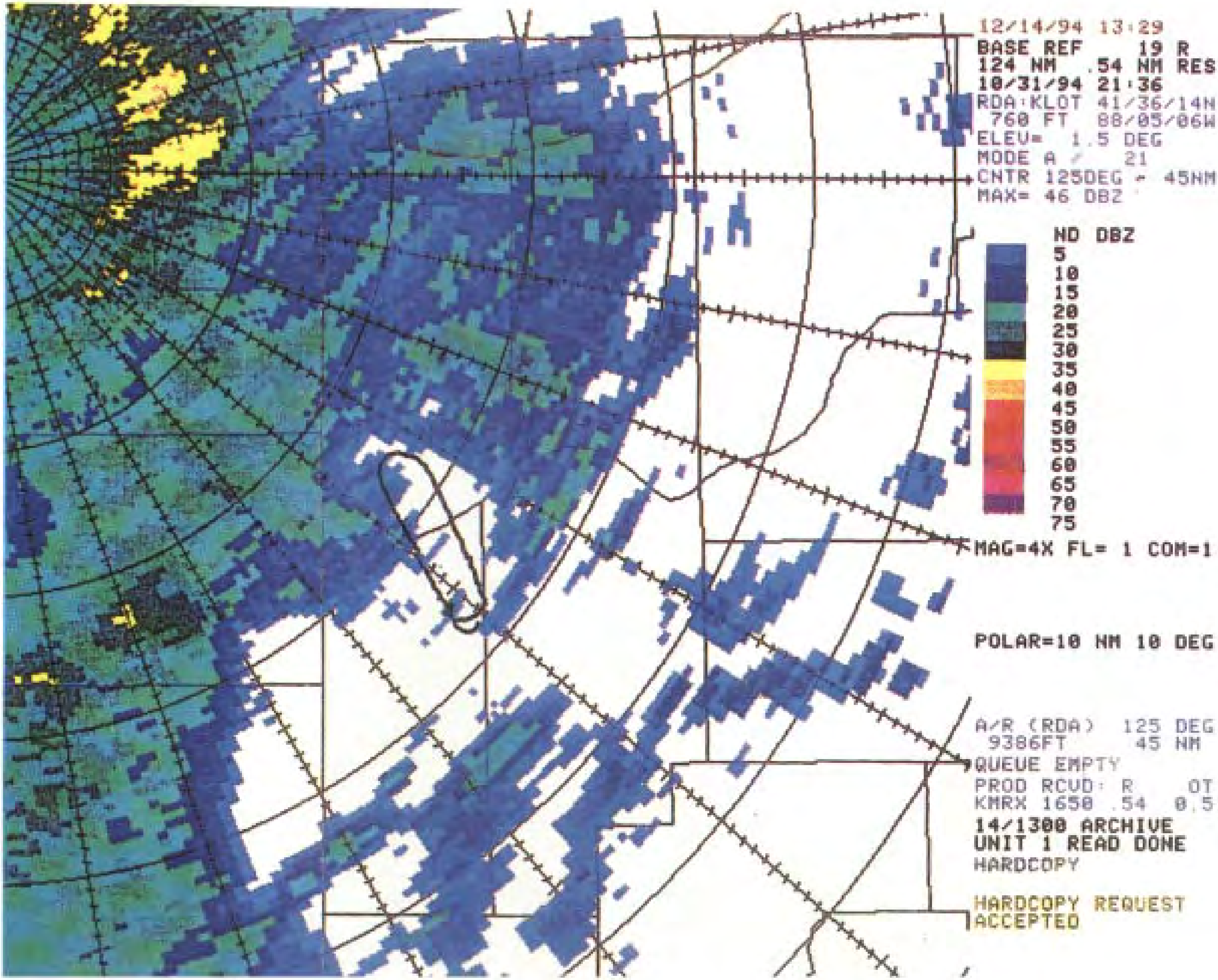
Table A

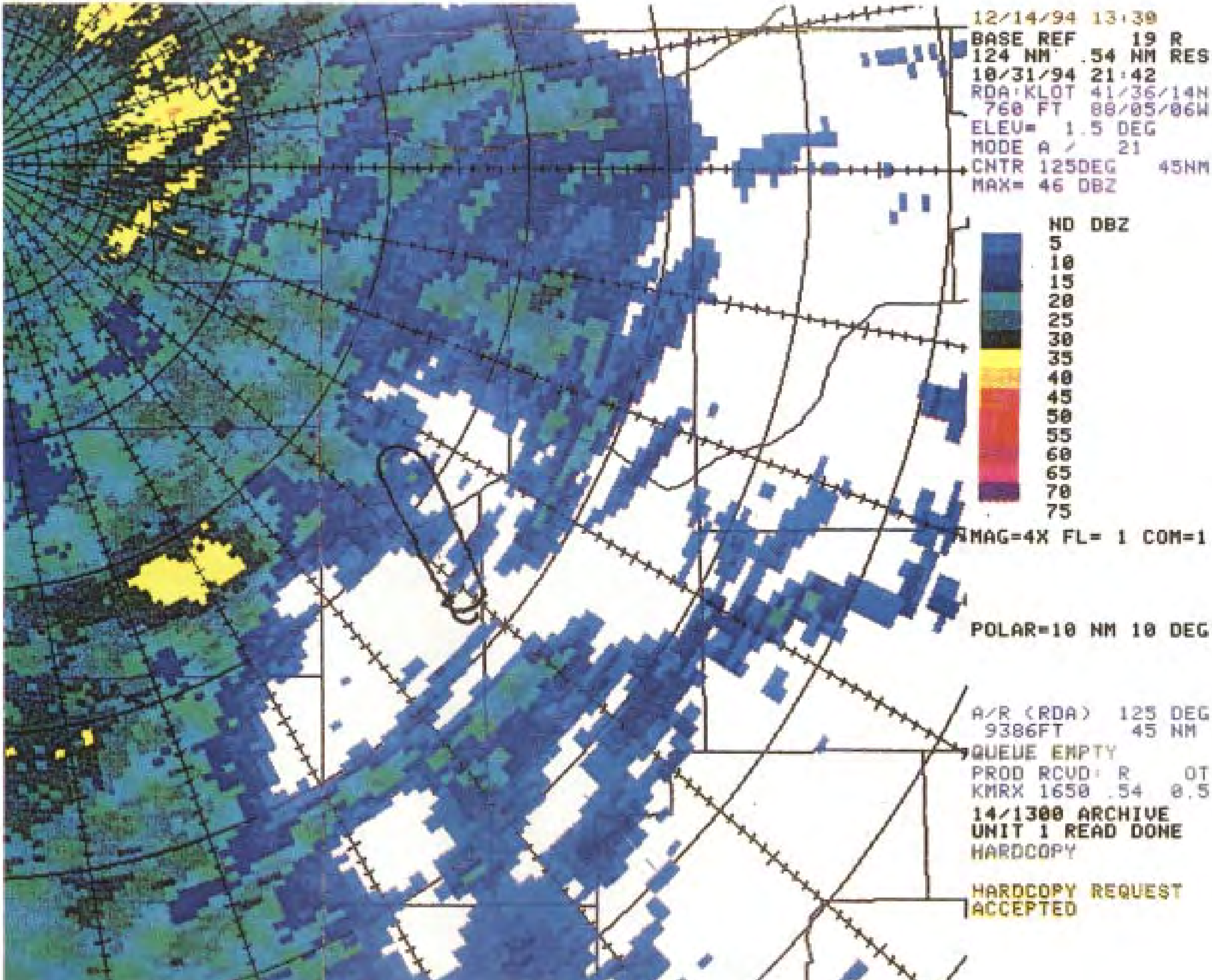
dBZ	Intensity
0t029	Weak
30 to 39	Moderate
40 to 44	Strong
45 to 49	Very Strong
50 to 54	Intense
55 or greater	Extreme


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

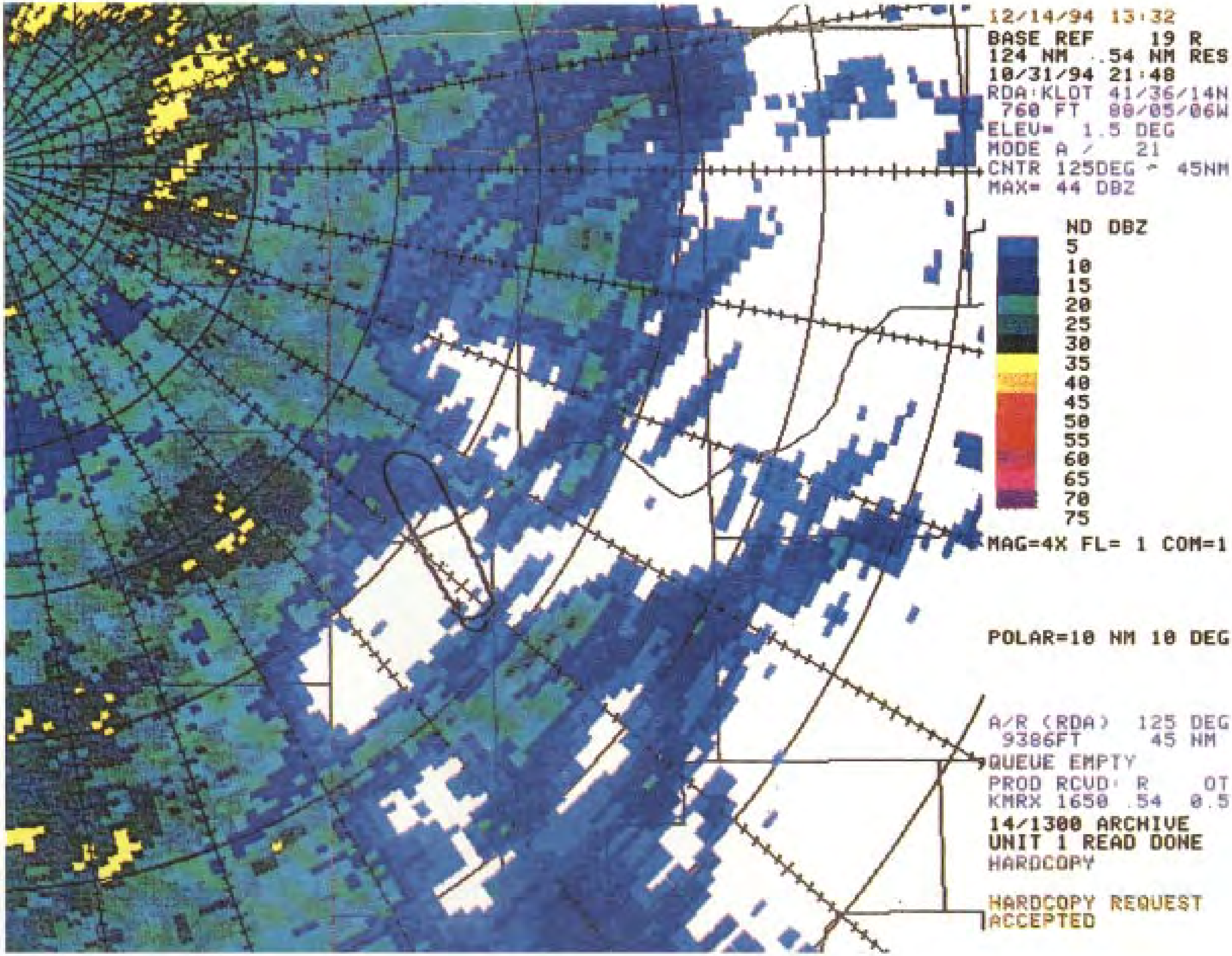


12/14/94 13:28
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:30
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 48 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA)
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 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 13:39
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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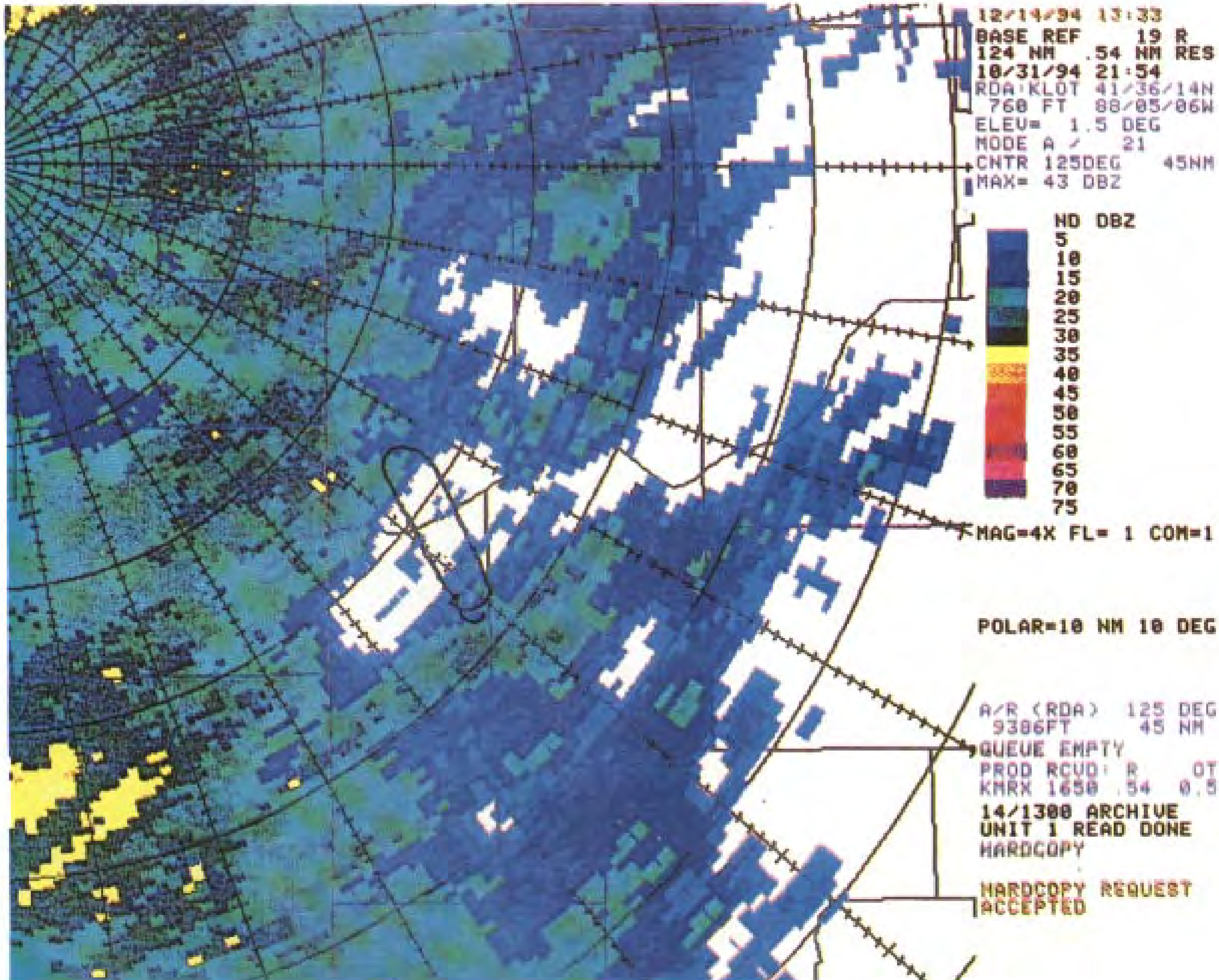
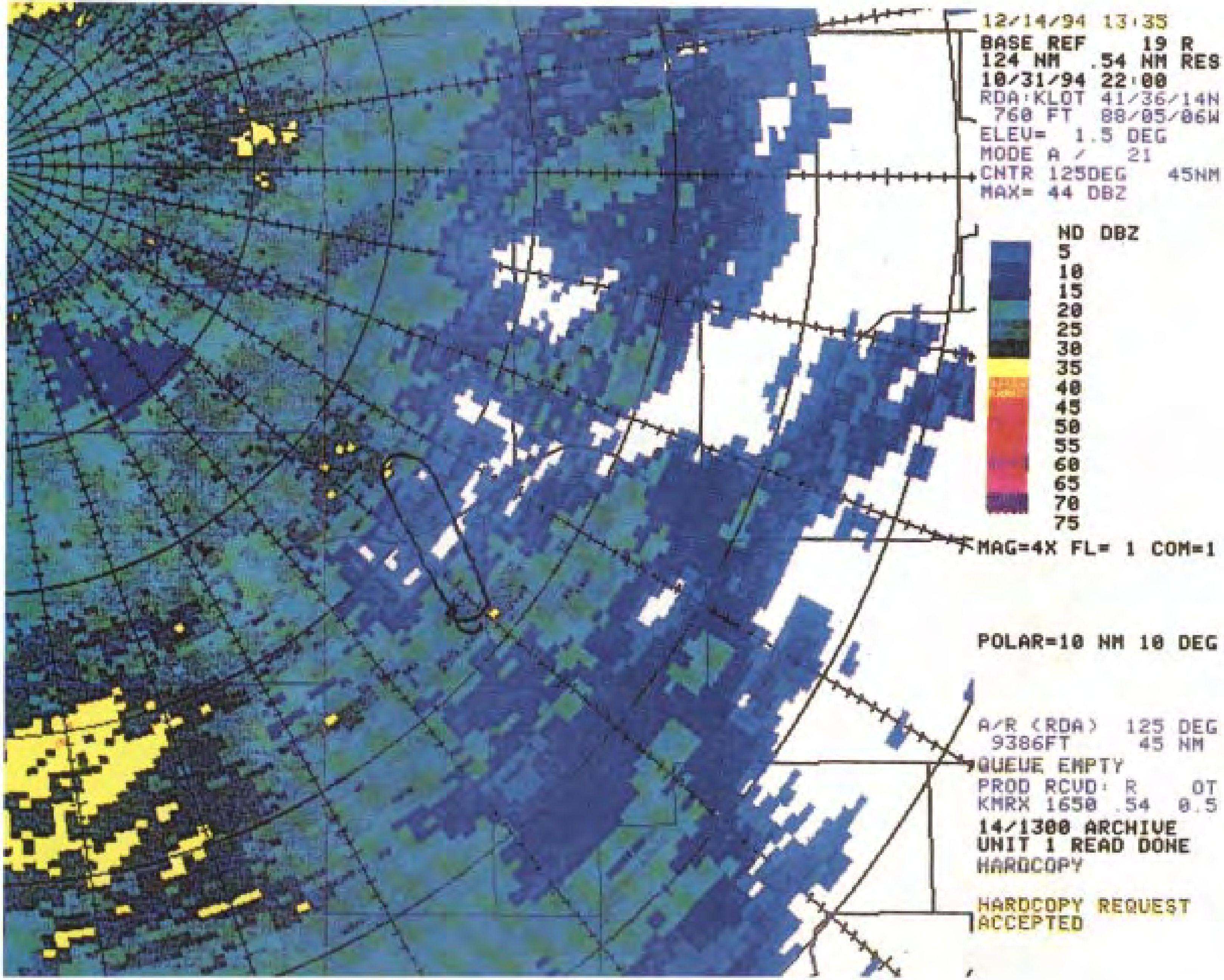
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:48
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG - 45NM
MAX= 44 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 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


12/14/94 13:35
BASE REF 19 R
124 NM .54 NM RES
10/31/94 22:00
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

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.

III

Note: The above values should only be viewed as possible estimates.

The following was obtained from the Forecasters' Guide On Aircraft Icing; 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

IV

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.

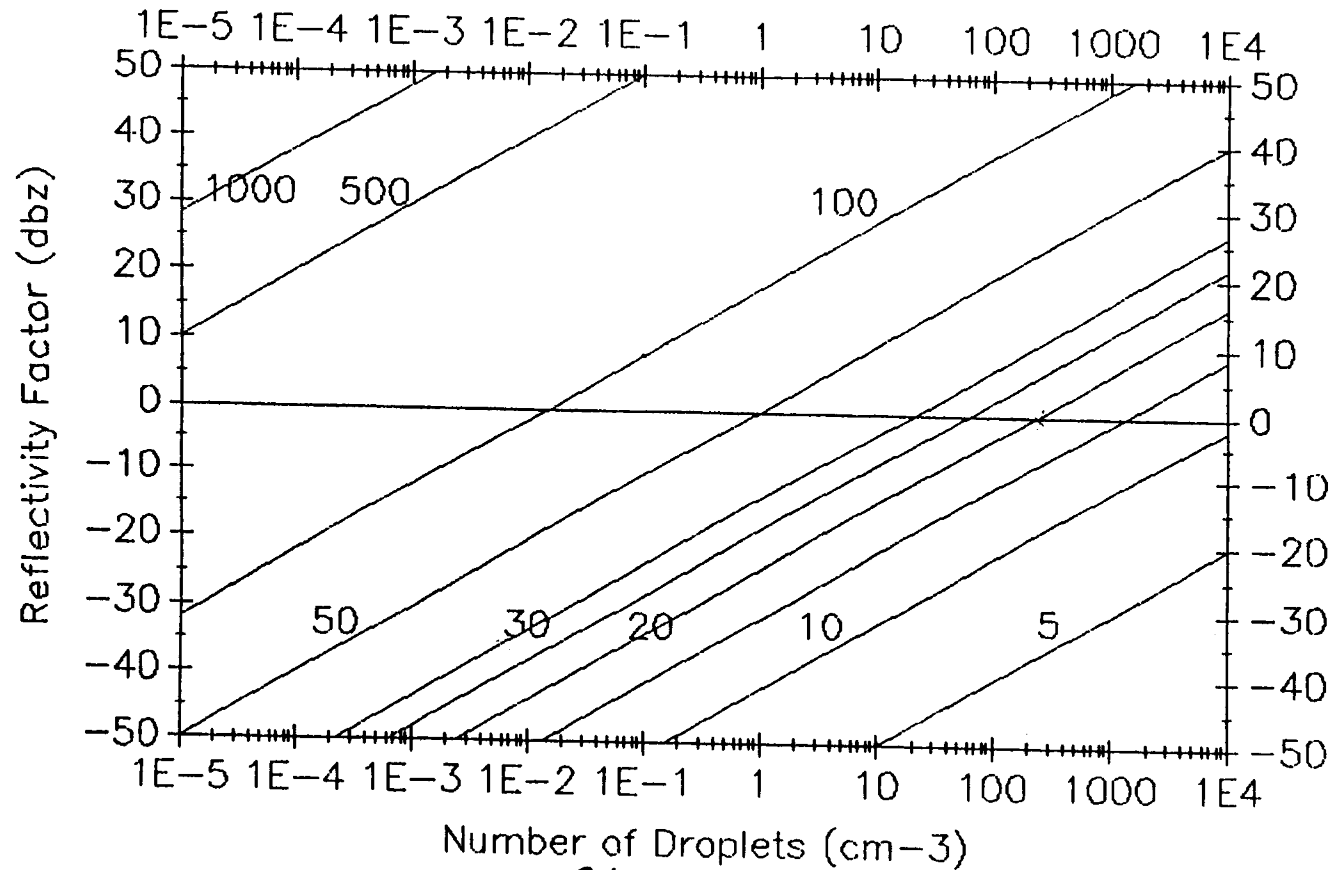
25 dBZ // .00001 drops per cubic centimeter // drop diameter 2,000 microns // LWC = .042 gram per cubic meter.

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)



$$LWC = \frac{\pi}{6} N D^3 / 10^6$$

Penn State Univ. $LWC = g m^{-3}$ $N = cm^{-3}$

D @ μm

for monodisperse droplet distribution

APPENDIX H

LISTING OF PREVIOUS INCIDENT AND ACCIDENT HISTORY

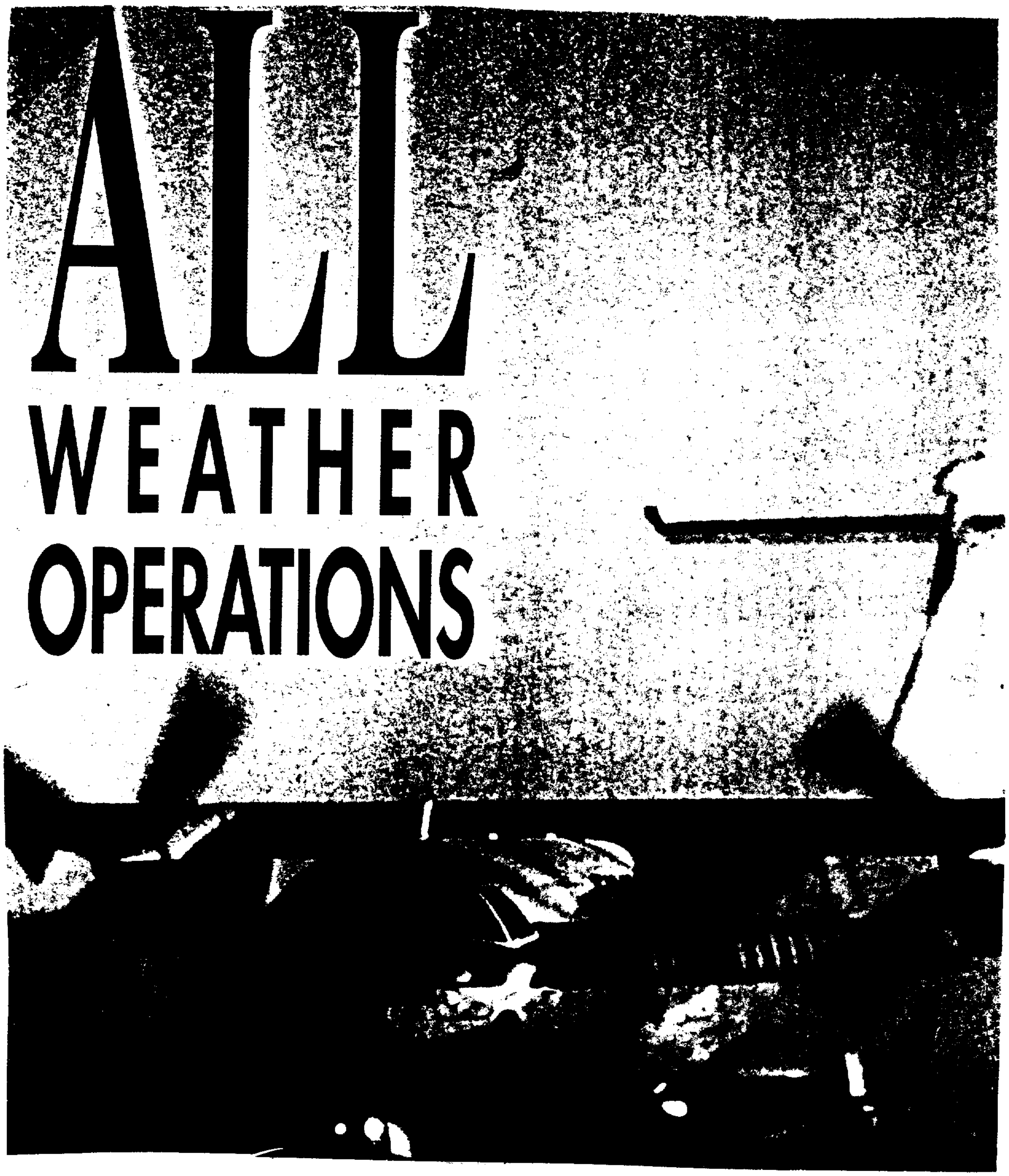
FOR THE ATR 42/72 AIRCRAFT

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

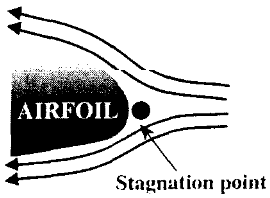
There are a great number of occasions, referred to as "icing conditions", where an aircraft is subject to accretion of frozen water under various forms.

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.

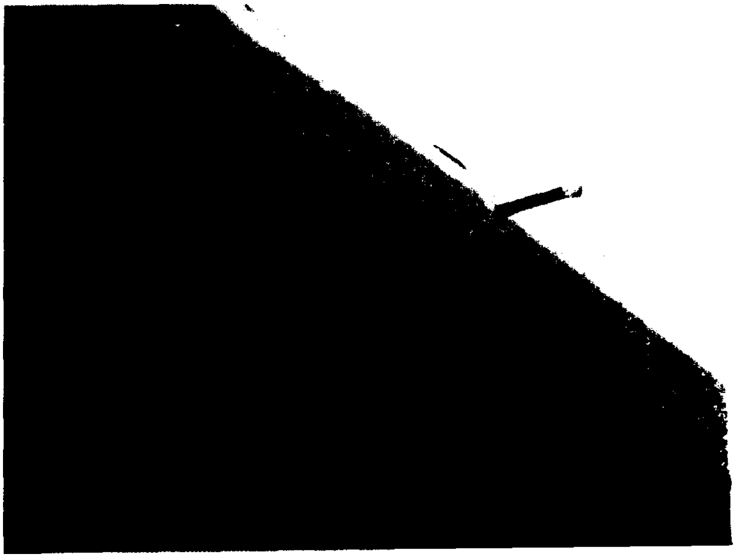
Ground icing conditions exist when the temperature is at or below 5° C (410 F), when operating on ramps, taxiways and runways where surface snow, standing water or slush is present. In such conditions, limited aircraft surfaces can be contaminated during aircraft operations on ground (tests have shown that such ground contaminants cannot impact airfoils).

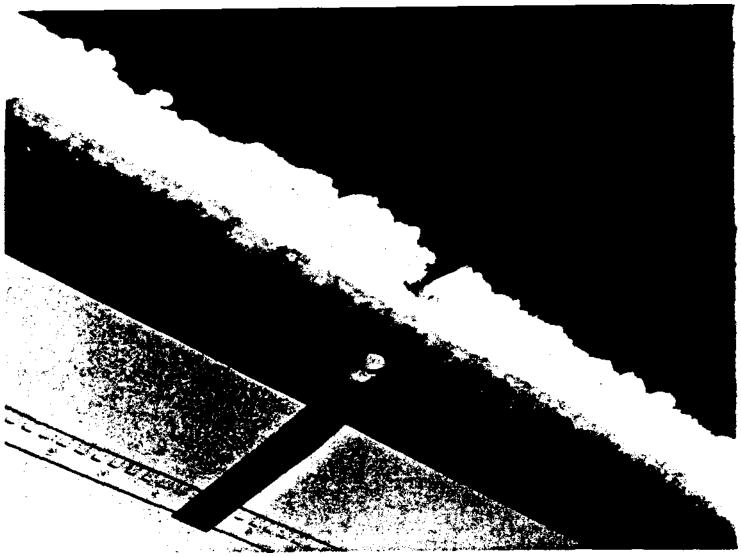
ATMOSPHERIC ICING can occur when the Outside Air Temperature (OAT) on the ground and for take-off is at or below 5° C (41”F) or when TAT in flight is at or below 7° C (45° F), and visible moisture in any form is present (such as clouds, fog with visibility of less than one mile, rain, snow, sleet and 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

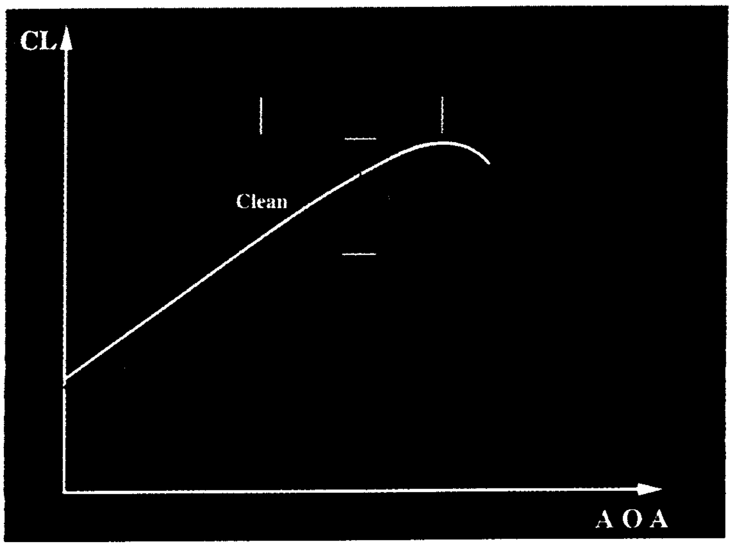


Fig. 3- Effect of certified ice shapes on lift curve - Flaps 30°, gear down standard de-icers

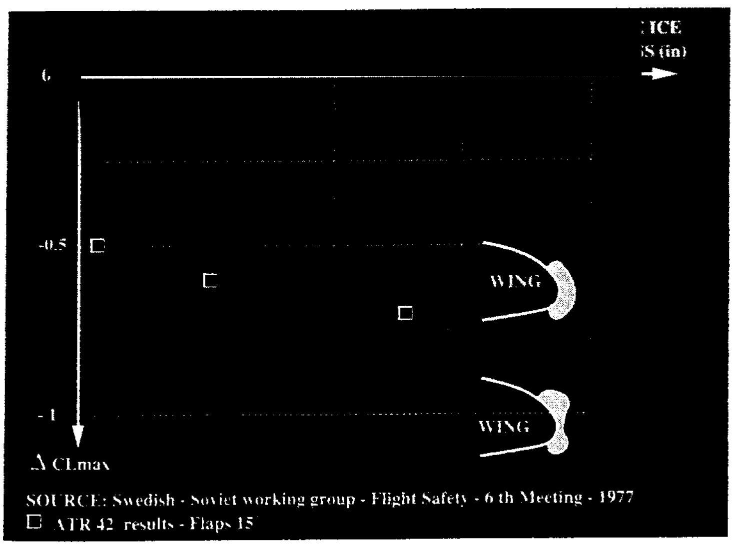


Fig. 4- Effect of ice shape on CLmax - Wind tunnel tests - Flaps 15°

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.

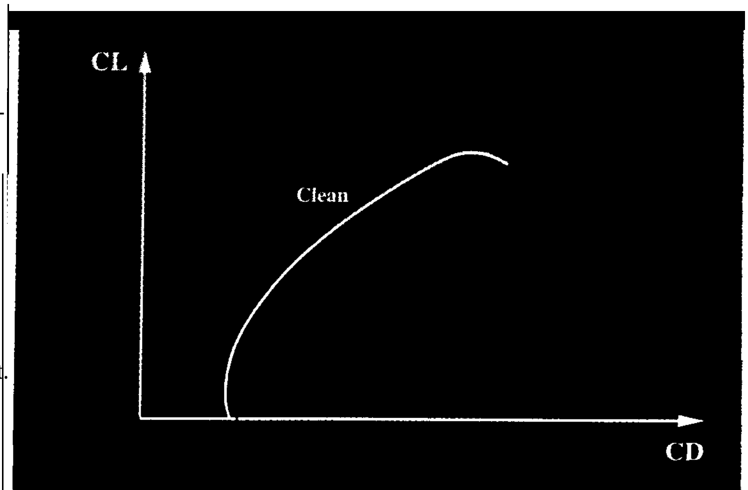


Fig. 5- ATR 72- Effect of certified ice shapes on drag polar. Flaps 0° . Standard de-icers

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.

Advisory Circular

U.S. Department of Transportation
Federal Aviation Administration

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 :

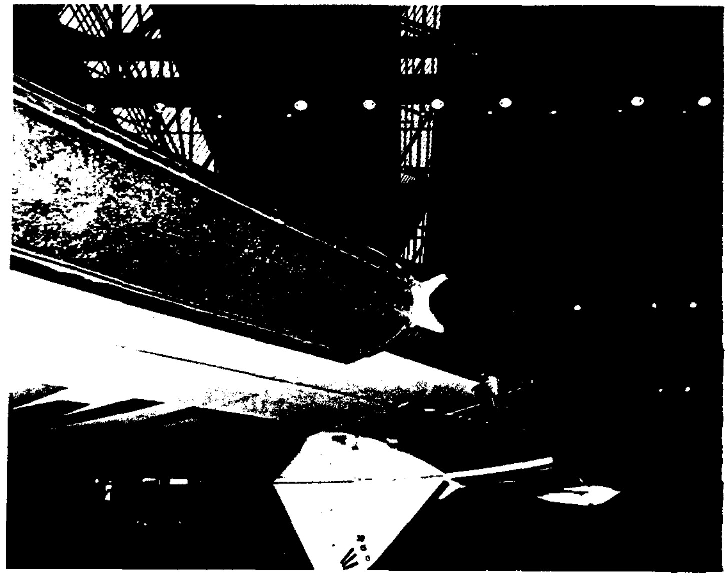
1. PURPOSE. To emphasize the "Clean Aircraft Concept" following ground operations in conditions conducive to aircraft icing and to provide information to assist in compliance.
2. RELATED FEDERAL AVIATION REGULATIONS (FAR) SECTIONS. Sections 121.629, 91.209, and 135.227.

§ 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 C_{Lmax} 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).

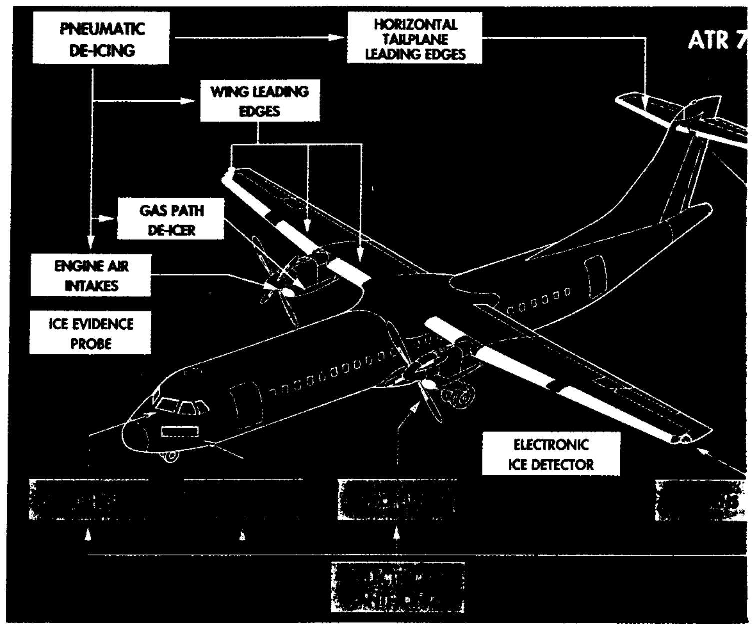
The main purpose of this special condition is to ensure that the safety level and margins in icing conditions as defined by regulations remain equivalent to what exist without ice. JAR Authorities and FAA have been approached in order to promote this Special Condition as a basis for future requirements 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.

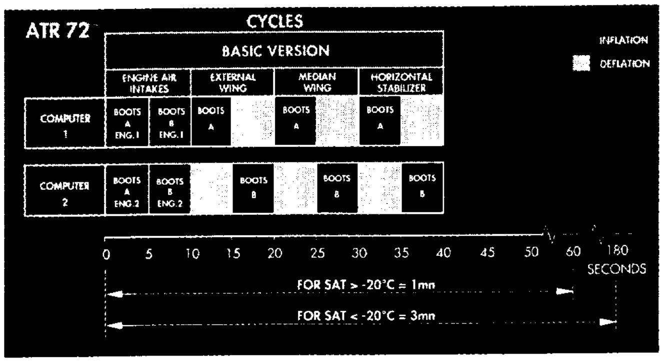


Fig. 8- Pneumatic de icing **system**

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.

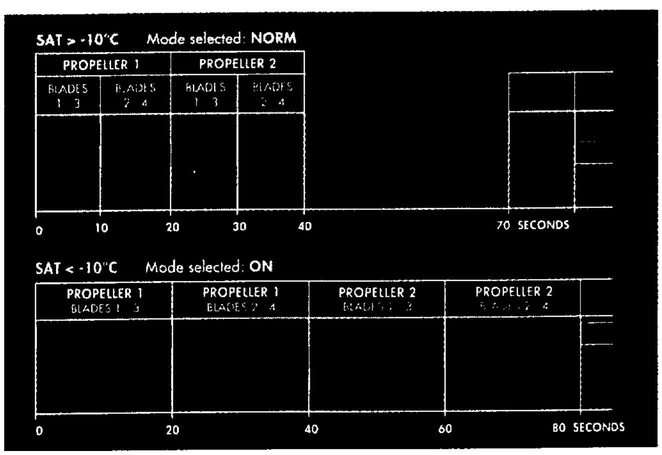


Fig. 9- Electrical ice protection lime sequence diagrum

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).

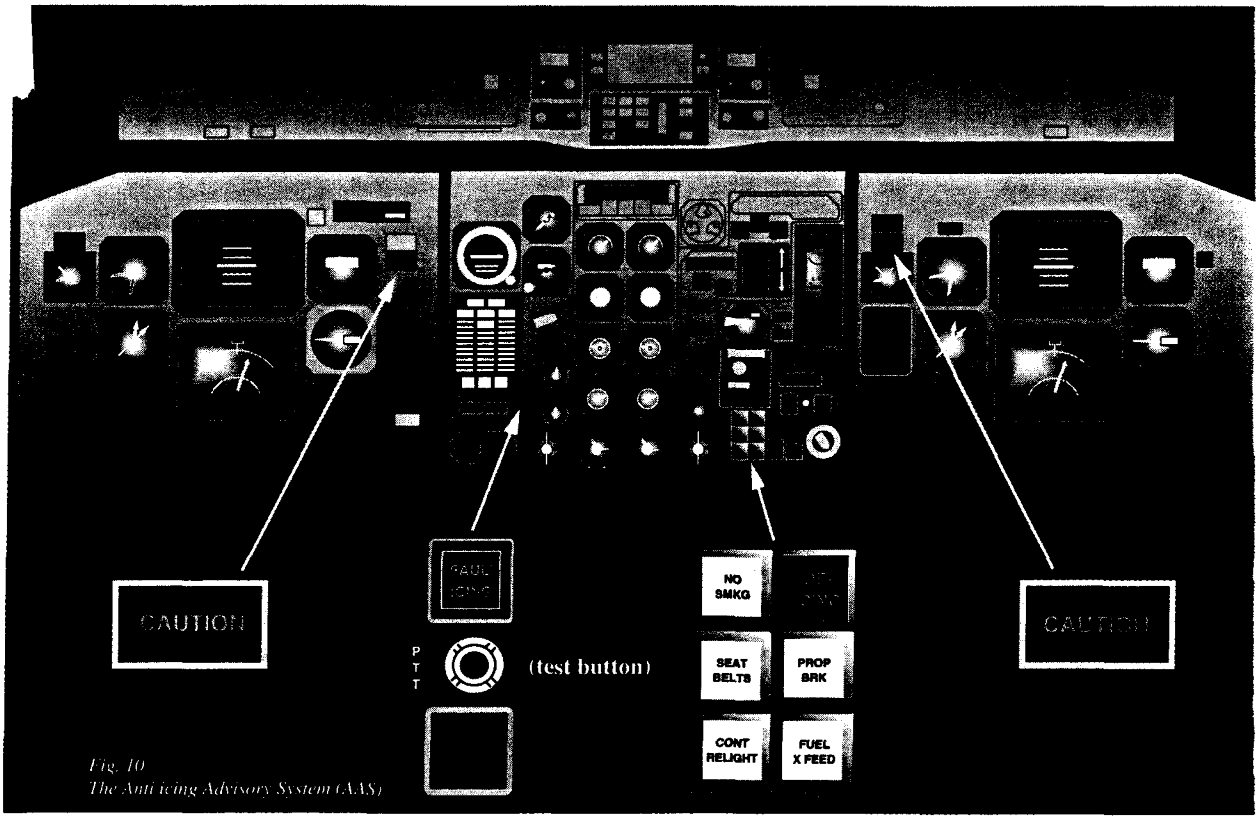


Fig. 10
The Anti icing Advisory System (AAS)

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

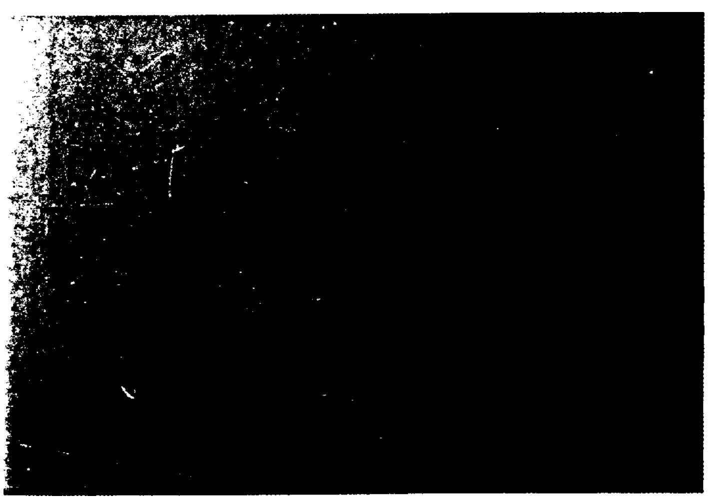
The technology adopted by all the new tech nology turboprop manufacturers is the pneumatic system for the following reasons:

- 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

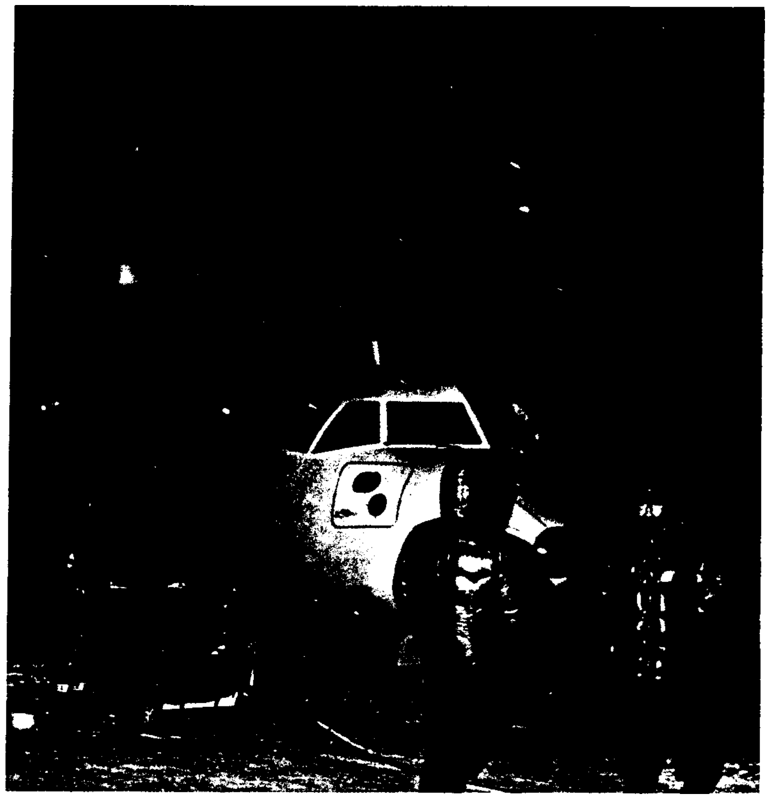
These procedures (recalled hereafter) essentially maintain safety margin through increases in minimum speed for each phase of the flight.

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.

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.

An aircraft de-iced before take-off is in no case an anti-iced aircraft.

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

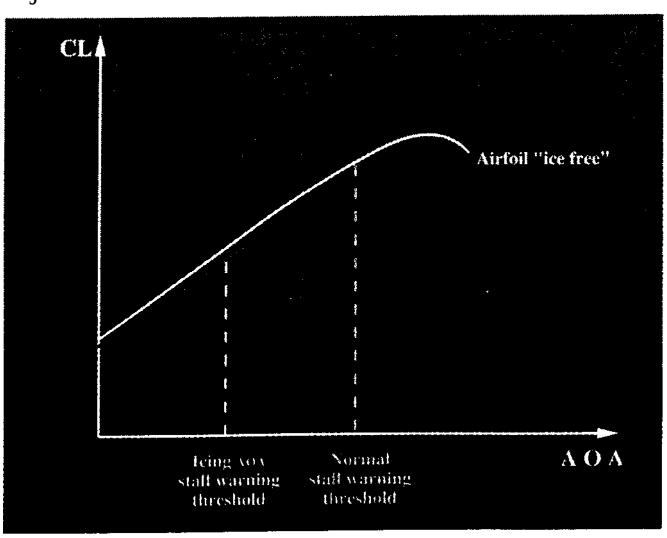
1. Starting on aircraft batteries is possible without special precautions down to -15° C (5° F).
2. When starting the engine in extremely cold conditions:
   - start up time is slightly increased;
   - oil pressure raising time is considerably increased: OIL LO PRESS red warning, may be activated for 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.

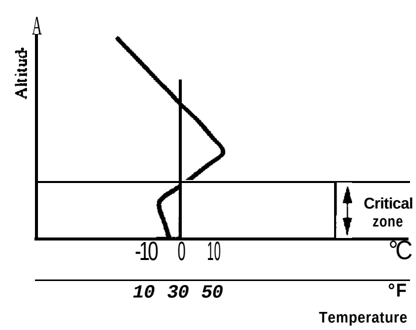


Fig. 13- Temperature inversion is a zone where temperature increases with altitude.

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 kinding 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 advisable 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°

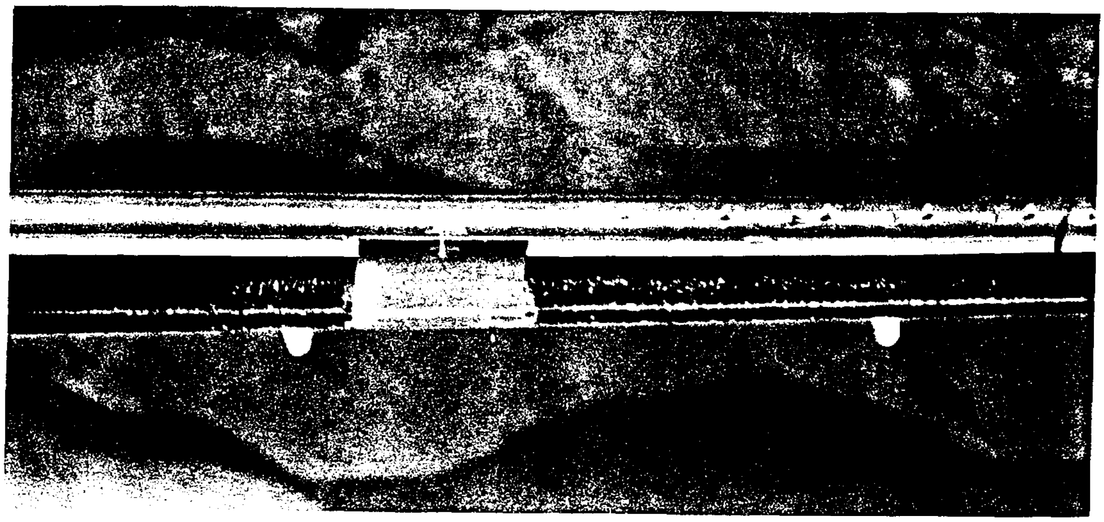
Ice Accretion Pattern

- 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

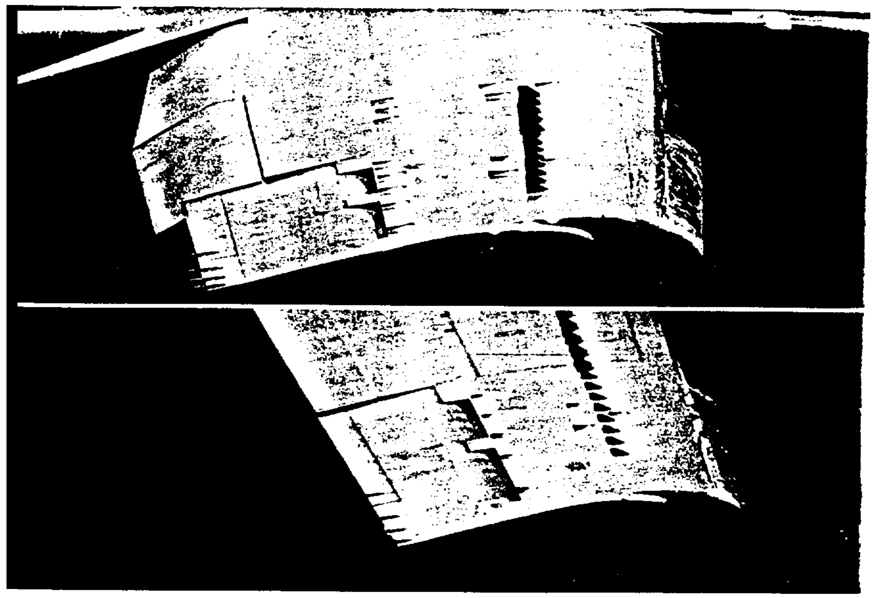


180 Micron Tests
(Outside Certification Envelope)

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

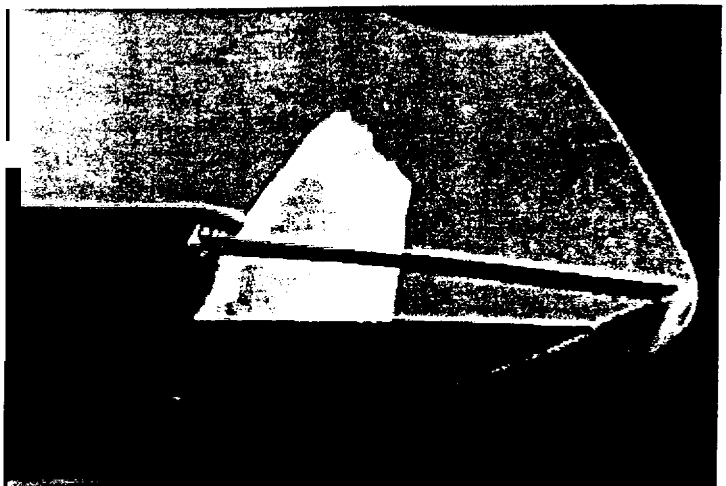
- In checking the handling characteristics in this test, the autopilot was used to simulate the accident scenario. The autopilot was engaged at 175 KIAS and was capable of holding the lateral forces. The aircraft was then accelerated to 185 KIAS and the flaps retracted to copy the accident scenario. No abnormalities were noted.

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.

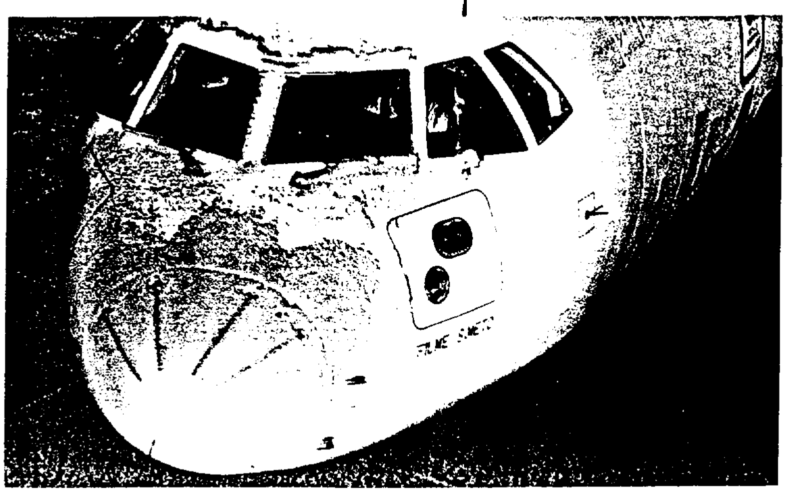
In addition to the tests described above, a number of other tests were conducted, including failure modes of outboard boots and aileron horn heat as well as operation at 77 percent Np. Details of these tests will be covered in the video.

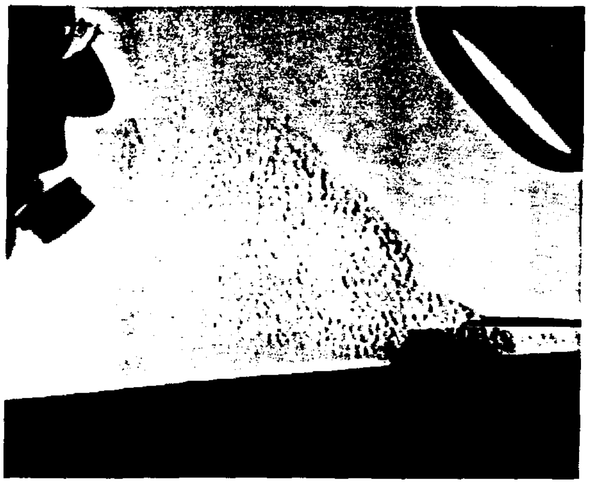


Ice Evidence Probe

The maximum lateral forces noted, even with the asymmetric ice accretion, were approximately 35-to-40 pounds.

180 Micron Exposure



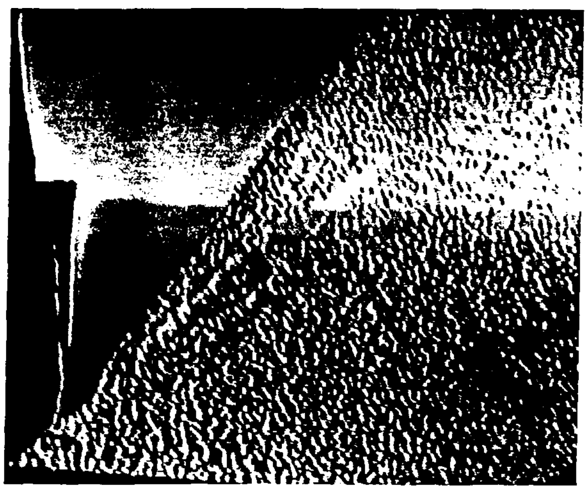


After 30 seconds of exposure.

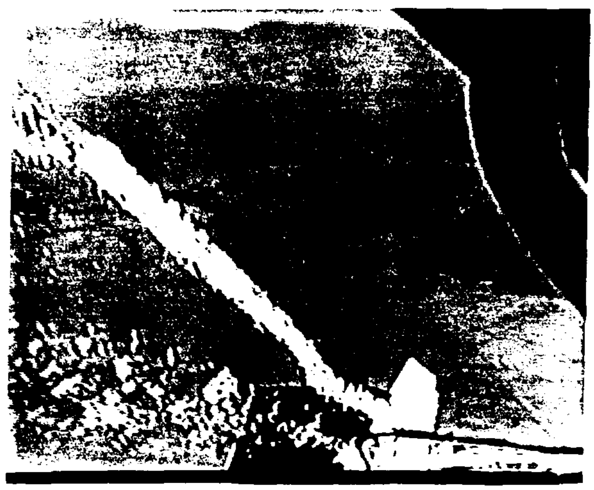
After one minute of exposure.

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.



PB96-910402
NTSB/AAR-96/02
DCA95MA001

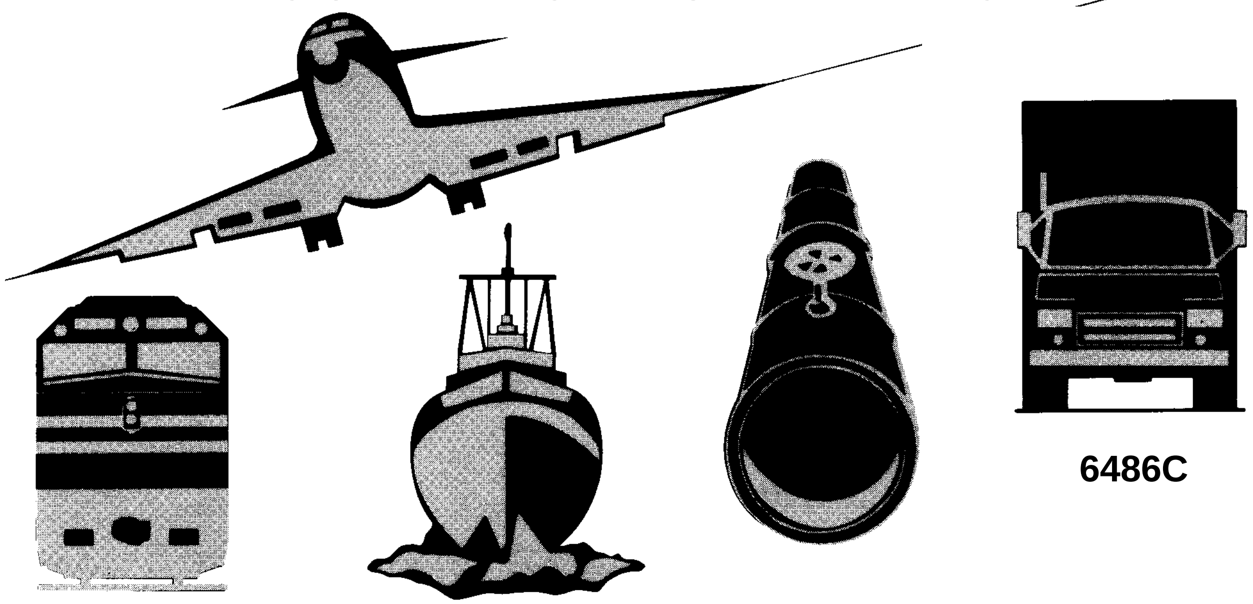
NATIONAL TRANSPORTATION SAFETY BOARD

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 II: RESPONSE OF BUREAU ENQUETES-ACCIDENTS TO SAFETY BOARD'S DRAFT REPORT



6486C

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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

Adopted: July 9, 1996
Notation 6486C

Abstract: Volume II contains the comments of the Bureau Enquetes-Accidents on the Safety Board's draft of the accident report. The comments are provided in accordance with Annex 13 to the Convention on International Civil Aviation. 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.

MINISTERE DE L'AMENAGEMENT DU TERRITOIRE, DE L'EQUIPEMENT ET DES TRANSPORTS
SECRETARIAT D'ETAT AUX TRANSPORTS

INSPECTION GENERALE DE L'AVIATION CIVILE
ET DE LA METEOROLOGIE

BUREAU ENQUÊTES-ACCIDENTS

CONFIDENTIEL

Le Bourget. le 13 mai 1996.

COMMENTS OF THE BUREAU ENQUETES ACCIDENTS (FRANCE)

ON THE NATIONAL TRANSPORTATION SAFETY BOARD

DRAFT FINAL REPORT ON THE ACCIDENT

OF SIMMONS AIRLINES FLIGHT 4184

AT ROSELAWN, INDIANA ON OCTOBER 31, 1994

SUBMITTED PURSUANT TO ANNEX 13 TO THE

CONVENTION ON INTERNATIONAL CIVIL AVIATION

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4. RECOMMENDATIONS 268

5. APPENDICES 274

INTRODUCTION

The BEA appreciates the invitation extended to it by the NTSB, as required by Annex 13 to the Convention on International Civil Aviation, to comment on the draft accident investigation Final Report. This will serve as the BEA's comments on that draft Final Report. We understand that the Board, as required by Section 6.9 of Annex 13, will either amend the draft Final Report to include the substance of these comments, or append these comments to the Final Report.

However the BEA wishes to express its disappointement about its absolute non participation to the investigation phase related to analysis, findings, causes and safety recommendations, despite the initial commitment from the NTSB and despite its repeated efforts to provide the NTSB investigators with relevant views and documentation. This presently leads to a major disagreement between two Investigative Authorities on facts, analysis and on the accident causes, and, moreover, to the risk that the safety recommendations will not be properly taken into account by all the parties of the aviation community worldwide, because they will be based on an arguable report.

EXECUTIVE SUMMARY

General

The BEA strongly disagrees with substantial portions of the Factual, and with the Analysis, Conclusions, and Probable Cause sections of the report. In the BEA's view, except for the Recommendations section, the present report is incomplete, inaccurate, and unbalanced, It appears to have been influenced by an a priori belief on the probable cause of this accident The BEA strongly believes that today one-sided approach is detrimental to the cause of international aviation safety.

The Factual section selectively reports the facts of this accident. Some relevant facts are omitted and some other which are included are simply not accurate or their presentation is misleading. The BEA regrets it, since it had already advised the NTSB of a number of significant omissions, inaccuracies, and misrepresentations through his three sets of comments to the earlier drafts of this section, and since it was agreed that many of these errors would be rectified.

The Analysis and Conclusions sections are hampered by the incomplete and inaccurate Factual section. "Many of the issues which are discussed are addressed in an incorrect or incomplete manner. Those sections also regrettably omit any discussion of several highly relevant issues for safety and for the understanding of this accident and fail to address a true combination of factors which has caused it. They clearly are inconsistent with the safety recommendations which follow.

Given the facts of this accident, the current Probable Cause statement, which ignores critical causal factors, is unbalanced, not correct, and detrimental to the public concern for safety.

Accordingly, the BEA considers that the report requires substantial reworking. Acknowledging the necessity, for achieving true aviation safety to take into consideration all relevant aspects of the aviation system, outside any national consideration or any a priori sharing of blame or liability, it has expended significant efforts to prepare in these comments such a substantial reworking of all or part of the quoted sections, to assist the NTSB in making the necessary revision and facilitate the inclusion of the comments.

Probable Cause Statement

This accident was caused by a combination of factors, as reflected in the following BEA-proposed Probable Cause Statement :

> The Probable Cause of this accident is the loss of control of the aircraft by the flight crew, caused by the accretion of a ridge of ice aft of the de-icing boots, upstream of the ailerons, due to a prolonged operation of Flight 4184 in a freezing drizzle environment, well beyond the aircraft's certification envelope, close to VFE, and utilizing a 15 degree flap holding configuration not provided for by the Aircraft Operating Manuals, which led to a sudden roll upset following an unexpected Aileron Hinge Moment Reversal when the crew retracted the flaps during the descent.

The contributing factors to this highly unusual chain of events are :

1. The failure of the flight crew to comply with basic procedures, to exercise proper situational awareness, cockpit resource management, and sterile cockpit procedures, in a known icing environment, which prevented them from exiting these conditions prior to the ice-induced roll event, and their lack of appropriate control inputs to recover the aircraft when the event occurred :

2. The insufficient recognition, by Airworthiness Authorities and the aviation industry worldwide, of freezing drizzle characteristics and their potential effect on aircraft performance and controllability ;

3. The failure of Western Airworthiness Authorities to ensure that aircraft icing certification conditions adequately account for the hazards that can result from flight in conditions outside 14 CFR Part 25, Appendix C, and to adequately account for such hazards in their published aircraft icing information ;

4. The lack of anticipation by the Manufacturer as well as by Airworthiness and Investigative Authorities in Europe and in the USA, prior to the post accident Edwards AFB testing program, that the ice-induced Aileron Hinge moment reversal phenomenon could occur.

5. The ATC's improper release, control, and monitoring of Flight 4184.

Associated Findings and Analysis

The NTSB's record in this investigation clearly shows that this flight crew had entered icing conditions, and yet failed to comply with mandatory requirements pertaining to such conditions contained in the applicable flight manuals, Federal Aviation Regulations, and explicit company policies, which, if followed, would have prevented this accident.

The situation was greatly exacerbated by the lack of proper situational awareness, cockpit resource management, and sterile cockpit procedures, which resulted in their failure to exit the known icing conditions prior to the ice-induced roll event and their subsequent surprise and lack of appropriate control inputs to recover the aircraft when the event occurred.

In the BEA's view, the operation of any airplane with unpowered flight controls in this fashion and environment, would severely jeopardize the safety of the flight. Accordingly, the BEA believes that these factors must be the focal point of the analysis, findings, and probable cause statement in this accident report. This is particularly true in light of the other more recent accidents involving cockpit failures by flight crews, which led to the FAA's pending in-depth review of a flight crew training program.

Thus, the BEA strenuously disagrees with the current Analysis, Findings, and Probable Cause Statement sections, which ignore, or address in a very shallow fashion, very important issues in this accident, and only addresses in an excessive mode the aircraft and the manufacturer's and Airworthiness Authorities' responses to certain prior incidents. This excessive approach is simply no supported by the NTSB's own record of investigation.

Report Causal Factor No. 1:

> ATR failed to completely disclose to operators and incorporate in the ATR- 72 AFM and FCOM and training programs, adequate information concerning previously known effects of freezing drizzle and freezing rain conditions on the stability and control characteristics, autopilot and related operational procedures when the ATR-72 is operated in such conditions.

Comment :

This probable cause finding (and the associated analyses and findings) is not supported by the record of investigation and is wrong.

ATR disseminated to its operators extensive information and warnings reminding them that prolonged exposure to freezing rain conditions is to be avoided. ATR also provided operators and flight crews with additional information designed to facilitate the recognition and avoidance of such conditions, which exceed the certification limits of all turboprop aircraft. ATR very specifically advised operators that such conditions could effect roll control forces leading to an autopilot disconnect and a resulting roll to a large bank angle until the crew took over the controls. ATR described appropriate recovery procedures and introduced them into ATR training programs. ATR also modified simulator packages for icing operations to simulate such roll departures.

In fact, the investigative record clearly shows that American Eagle/Simmons passed on to its flight crews these ATR warnings that, in icing conditions outside those specified in 14 CFR Part 25, Appendix C, the ATR 42/72 aircraft performance and controllability may be affected in such a way that autopilot self-disconnect and subsequent roll excursions could occur; that roll efficiency would nevertheless be maintained; and that recovery could be readily achieved by making firm aileron inputs to counter the roll excursions, and by applying basic stall recovery techniques.

In addition to stating that ATR did not provide operators with the above-referenced information, the report also states that an "aileron hinge moment reversal" mechanism was disclosed in the icing related incidents it reviews, and criticizes ATR for failing to issue warnings to specifically describe such an event. These "facts" are wrong and this assertion is untrue.

The basis for this assertion is the claim that an "aileron hinge moment reversal" was involved in the incidents of Mosinee, Ryanair, Air Mauritius, Burlington, and Newark and was therefore known to ATR.

On the contrary, the DFDR data from Mosinee, Ryanair, Air Mauritius and Burlington incidents confirm that they were all stall departures following ice accumulations which resulted from flight crew failures to follow the basic procedures for operation in icing conditions by failing to select aiframe de-icing, to maintain minimum airspeeds or proper propeller speed settings.

No "aileron hinge moment reversal" was involved in Ryanair or Air Mauritius. The momentary modification of the aileron hinge moment in Mosinee and in Burlington which occurred after the asymmetrical stall commenced had no direct effect on these incidents. Both the NTSB and ATR determined that the Newark incident involved severe turbulence. From a review of the Newark DFDR data after Roselawn, because of the high level of turbulence, it cannot be determined whether or not any aileron hinge moment modification was involved in the incident,

The incorrect assertion of prior knowledge is all the more surprising that the NTSB was the primary investigation authority for the Mosinee incident, with full access to the facts and data involved. It had full access to the BEA's report, which incorporated ATR's own analysis and was involved with the FAA in several meetings with the BEA, the DGAC and ATR The NTSB's level of participation and knowledge of the Mosinee incident was at least as great as any other entity investigating the incident. The NTSB had absolutely no recommendations or suggestions for any other corrective action, warnings, or any other response to the incident.

This assertion is also surprising because the NTSB not only received the full and open cooperation of the manufacturer, but also encouraged and participated in the manufacturer's extensive efforts after the Roselawn accident that led to the initial discovery of the ice-induced "aileron hinge moment reversal" phenomenon.

The NTSB knows of the extensive wind tunnel testing, high speed taxi tests, flight testing, and considerable efforts spent by the manufacturer after Roselawn for the first-ever USAF tanker freezing drizzle/rain testing program for civil or military aircraft at Edwards AFB. The NTSB knows from its own involvement in the testing that the phenomenon of an “ice-induced aileron hinge moment reversal” and its associated flow separation behind the boots at low Angle of Attack was discovered for the very first time as a result of this exhaustive post-Roselawn investigation

The BEA also wonders about the differences which a previously disseminated information on the phenomenon of an “ice-induced aileron hinge moment reversal” had it been identified, would have brought to the crew’s behaviour The warnings which were provided to all operators, and which in turn were provided by Simmons to its flight crews, identified that the weather environment of concern could affect roll control forces leading to an autopilot disconnect and a resulting roll to a large bank angle until the flight controls were taken over by the crew. The fact that such a change in aileron control forces might or might not be caused by an “aileron hinge moment reversal” is not a piece of information which would have added to the warning provided to the flight crews.

What is most disturbing about the report's position on this point is that it obscures the safety concern disclosed in this accident that this flight crew was so oblivious to the icing conditions they encountered that they ignored the multiple warnings, instructions, and regulations they already had received regarding proper operations in such conditions. To suggest that a more specific warning about an "aileron hinge moment reversal" phenomenon would have had any impact on this flight crew is not supportable by the NTSB's record of investigation,

Report Causal Factor No 2:

> The French DGAC's inadequate oversight of the ATR-42 and ATR-72 and necessary corrective action to assure continued airworthiness in icing conditions.

Comment :

The BEA strongly disagrees with this erroneous probable cause finding (and the associated analyses and findings) The DGAC has consistently fulfilled its obligations as the primary certification Authority for the ATR-42 and ATR-72 aircraft. The joint FAA/DGAC Special Certification Review Report confirmed that the ATR 42 and 72 were properly certified in full accordance with both US and European certification standards, that the DGAC acted correctly and properly in its certifications of the different ATR model aircraft, and that the DGAC and FAA properly applied the Bilateral Airworthiness Agreement ("BAA") between the U.S. and France in their certifications of the aircraft.

Despite this, the report's findings state that ATR airplanes have a unique susceptibility to ice-induced aileron hinge moment reversals. This is not accurate. The concern about ice-induced aileron hinge moment reversals caused by freezing drizzle droplets applies to all aircraft with unpowered controls.

This is amply evidenced by (I) the Post-Roselawn review of other turboprop icing related events, which has disclosed similar characteristics for those airplanes, and (II) the FAA's recently proposed Airworthiness Directives relating to restrictions on operations in icing conditions, which result from the FAA's post-Roselawn accident investigation of how ice accretion resulting from freezing drizzle impacts on different models of aircraft. These proposed AD's apply to virtually every model of turboprop aircraft in the world.

The suggestion that the DGAC provided inadequate oversight and inadequate corrective action with respect to the ATR aircraft also, is not supported by the NTSB's investigative record regarding prior ATR icing incidents. The investigative record demonstrates that the DGAC was actively involved in investigating the ATR previous icing events, considered whether these events warranted any corrective actions, and required that the manufacturer take decisive corrective action whenever this was appropriate.

This probable cause finding, and the associated analyses and findings, to the effect that the DGAC failed to require the manufacturer to take additional corrective actions and that this "led directly to this accident" appears to be based on the erroneous assumption that the DGAC had identified, from earlier ATR icing incidents, the "ice induced aileron hinge moment reversal" which was involved in the Roselawn accident.

Neither the DGAC nor the NTSB, FAA, BEA, or ATR identified, from their investigation of these earlier incidents, the “aileron hinge moment reversal” phenomenon which was involved in the Roselawn accident. This phenomenon was not identified until after the Roselawn accident.

Thus, the BEA entirely disagrees with the statement that the DGAC’s failure to require ATR to take additional corrective action “led directly to this accident. ”

Report Causal Factor No. 3:

> The French 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 BAA and ICAO Annex 8.

Comments :

This probable cause finding (and the associated analyses and findings) appears to be based on a misunderstanding of the BAA and ICAO Annex 8, is not supported by the record of investigation, and is wrong.

The pertinent sections of the BAA (section 6) and of Annex 8 (Section 4.2.2), require the Exporting State to provide to other airworthiness authorities information obtained during the investigation of major incidents or accidents only where those incidents or accidents "raise technical questions regarding the airworthiness of [the aircraft]" or otherwise identify information which is "necessary for the continuing airworthiness of the aircraft and for the safe operation of the aircraft. "

There is no factual basis whatever in the NTSB's record of investigation to support the suggestion that the DGAC failed to provide the FAA on a timely basis with critical airworthiness information developed from previous ATR icing events. Prior to the Roselawn accident there had never been an ATR-72 accident of any type, nor had there been any ATR-72 icing incidents involving roll control issues.

With regard to the ATR-42 icing related incidents which were reviewed by the NTSB and occurred prior to the Roselawn accident, the facts demonstrate that the DGAC fully complied with its obligations under the BAA and Annex 8. In the one incident which did disclose an airworthiness issue (Mosinee -- S/N 91), the DGAC worked closely with the FAA to identify corrective actions, passing on adequate information to the FAA and other Airworthiness Authorities. In the other incidents, no investigative Authority including the BEA and the NTSB determined that any aircraft airworthiness or safe operation issue was involved.

To the extent that the report is suggesting that the DGAC failed to disclose to the FAA information indicating that the ATR was susceptible to an aileron hinge moment reversal of the type which caused the Roselawn accident, this suggestion simply ignores the fact that none of the parties which had investigated any of the prior incidents, including the NTSB, had identified this phenomenon before the Roselawn accident.

Recommendations

The BEA notes with interest the disparity between the broad scope of the recommendations which the NTSB makes as a result of this accident and the selective focus of the report's statements of the findings and proposed Probable Cause. The BEA generally does not disagree with the NTSB recommendations, but suggests several changes. To supplement its proposed revisions to the current recommendations, the BEA suggests the addition of recommendations to ensure that (1) flight crews "report icing conditions to ATC/FSS, " as required by the Airman's Information Manual; (2) air traffic controllers solicit PIREPS regarding "icing of light degree or greater, " as required by FAA Order 7110.65, Air Traffic Control; (3) NTSB and FAA provide on a timely basis all pertinent information from their accident and incident investigations respectively to the Investigative and Airworthiness Authorities of the country of certification and manufacture of the aircraft involved; and (4) FAA take all necessary steps to recall to the Airlines and Flight crews, the rules and procedures regarding cockpit discipline, cockpit resource management and situational awareness, which were missing in this accident.

Conclusion

The BEA firmly believes that if the draft Final Report is reworked as suggested here, then the long-term legacy of the Roselawn accident and its investigation will be the development of critically important safety lessons with regard to not only the dangers posed by freezing drizzle and the need to modify icing certification and operational standards, but the other important issues discussed herein as well. Such safety lessons will benefit the entire aviation industry worldwide.

1. FACTUAL INFORMATION

1.1. HISTORY OF THE FLIGHT

The BEA believes that the NTSB's *History of Flight* section omits critical factual information which is necessary for a complete analysis and understanding of this accident. In this regard, the BEA has set forth below its comments in respect to what it believes is a more complete History of Flight.

American Eagle Flight 4184 was a scheduled FAR Part 121 flight from Indianapolis Airport, Indiana (IND) to O'Hare International Airport in Chicago, Illinois (ORD) on October 31, 1994. The aircraft was an ATR 72-212, MSN 401, registered by Simmons Airlines as N40 1AM and operating as American Eagle.

Flight 4184 was the second of five flight segments scheduled for the first day of a five day pilot trip pairing. The First Officer was scheduled to fly the entire five days. The Captain, who had flown the previous three days, was scheduled to fly only the first four legs on the first day, and was to be replaced thereafter by another Captain. Several pilots indicated that this was possibly the first time the Captain and the First Officer had flown together.

The first officer was the flying pilot for this leg.

The pilots reported for duty before 10.39 (CST)(1). They flew Flight 4101, departing Chicago O' Hare, (ORD) at 11.39 and arriving at Indianapolis, IN (IND) at 12.42 CST. The accident occurred at 15.59 during their subsequent return flight (Fight 4184) en-route from IND to ORD.

Prior to the departure of Flight 4184, the flight crew received a combined flight plan and weather package. According to Simmons/American Airlines' policy, the meteorological information provided by American to the crew of Flight 4184 in the Flight Release did not contain AIRMET information, nor did it contain any information regarding forecast turbulence or in-flight icing conditions along Flight 4 184's intended route of flight. In this regard, *AIRMET Zulu Update 3 for icing and freezing level* was applicable to Flight 4 184's route of flight from Indianapolis to Chicago, but was not included in the Flight Release, This AIRMET stated :

Light occasional moderate rime icing in cloud and in precipitation, freezing level to 19,000 feet. Freezing level 4,000 to 5,000 feet northern portion of area sloping to 8,000 to 11,000 feet southern portion of area.

Flight 4184 was scheduled to depart the IND gate at 14.10 and arrive at the ORD gate at 15.15. Flight 4184 blocked out of the IND gate at 14.14. However, because of airport reconfiguration due to anticipated deteriorating weather conditions, the aircraft was held on the ground for approximately . *42* minutes. In this regard, the flight crew requested and received taxi instructions from the ground controller at 1417:15.

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(1) All times are Central Standard Time (CST) unless otherwise specified.

At 1452:31, the Clearance Delivery controller called the ZAU TMC for release of the flight. The TMC said ". . . he is released, that fix (LUCIT intersection) in the hold so he might do some holding when he gets up here but he's released". At 1453:19, the Ground Controller advised the flight crew". . . you can expect a little bit of holding in the air and uh you can start'em up, contact the tower when you're ready to go".

Flight 4184 was cleared for take off at 1455:20 and became airborne at 14.56. There were 64 passengers, 2 flight attendants, and the 2 pilots on board the aircraft. The zero fuel weight was 40,586 pounds, the takeoff gross weight was 45,586 pounds and the center of gravity was 22 percent mean aerodynamic chord.

As established by the aircraft's Digital Flight Data Recorder (DFDR), the aircraft climbed to its cruise altitude at 170 kts indicated airspeed (KAIS). The autopilot was engaged one minute after takeoff during the climb.

About 16 minutes after take off, the aircraft leveled off at an altitude of 16,300 ft and accelerated to 190 kts KIAS, One minute later, the aircraft initiated a descent toward an altitude of 10,000 ft. During the descent, the propeller speed was increased from 77% NP to 86% NP which is required whenever the aircraft encounters icing conditions. At 1516:32, the aircraft airframe deicing system was activated taking the aircraft anti-icing/ deicing system to Level 111 which is required whenever the aircraft is accreting ice, At 1517:50, the aircraft reached the altitude of 10,000 ft. At 1518:07, Flight 4184 was cleared by the Chicago TRACON BOONE Sector Controller to enter a holding pattern at the LUCIT Intersection located 19 miles south of the Chicago Heights VOR. An expect further clearance (ECF) of 15:30 was given which was revised one minute later to 15.45 by the BOONE Controller.

The recorded sound on the Cockpit Voice Recorder (CVR) began at 1527:59. The CVR recorded the next 30 minutes of the flight. However, only some 15 minutes of the CVR recording was transcribed by the NTSB. The remainder of the CVR's recorded information was severely edited out of the transcript provided to the BEA.

At 1524:39, the Captain advised the BOONE Sector Controller that Flight 4184 was entering the hold. The first holding pattern circuit was flown between 1524 and 1532:20. DFDR data established that the first holding pattern was flown at an airspeed of approximately 175 KIAS with the wing flaps in the retracted, O degree position, which is the only flap configuration for which performance data is provided in the ATR- 72 Airplane Operating Manual (AOM) for holding. The Airframe deicing system was deactivated at 1523:12, just before entering the holding pattern. The propeller speed was reduced to 770/0 NP at 1525:00. The Total Air Temperature (TAT) at this time was +2. 5°C.

The ATR-72 AFM requires that “Level II” anti-icing measures be activated and that the propeller speed be maintained at 860/0 NP whenever the aircraft is being operated in icing conditions. The ATR-72 AFM Limitations Section (Section 2.06.0 1) defines “icing conditions” as existing whenever the TAT in flight is below +7 degrees C and visible moisture in the air in any form is present. The definition of visible moisture expressly includes clouds. At the time Flight 4184 entered the hold and throughout the rest of its flight in the holding pattern the DFDR recorded the in flight TAT below +7 degrees C. The meteorological data for the area of the holding pattern establishes that Flight 4184 was operating in and out of clouds for most of the 33 minutes it was in the hold prior to the accident.

At the time the CVR recording commenced at 1527:59, the Junior Female Flight Attendant is present in the cockpit conversing with the crew and “loud music similar to a standard broadcast radio station” is being played in the cockpit. The “loud” radio music continues for the next 18 minutes of the holding pattern and cockpit conversations with the Junior Female Flight Attendant continued for approximately 15 minutes.

The second holding pattern circuit was flown between 1532:20 and 1541:47. At 1533:13, the Captain stated : “man this thing gets a high deck angle in these turns”. At 1533:17, the Captain said : “we’re just wallowing in the air right now”. The DFDR data traces do not show any indication of “wallowing”. The First Officer then stated at 1533:19 “you want flaps fifteen ?” The Captain then said : “I’ll be ready for that stall procedure here pretty soon”. In response, the first officer “chuckled”. At 1533:24, the Captain stated : “do you want kick’em in (it’ll) bring the nose down”. At 1533:25, the First Officer responded by stating “sure”.

The CVR transcript then records the “sound of several clicks similar to flap handling being moved” at 1533:26 followed by the Captain stating at 1533:29 “guess Sandy’s going ‘ooo’”.

At 15.33:26, DFDR data indicates that the flap handle was moved to select the Flap 15 configuration. The ATR-72 AFM does not provide for a Flap 15 configuration for holding. After extension of the flaps, the IAS was 175 kts and the AOA (angle of attack) decreased down close to zero degrees. The DFDR traces, again, do not reveal any evidence that the aircraft was “wallowing” before or after flap extension.

At 1533:56, a single tone which could have been the caution alert chime of the aircraft Anti-icing Advisory System (AAS) was recorded on the CVR. There is no discussion regarding the chime by the flight crew. However, during this same time, the Captain was engaged in extensive discussions with the Junior Female Flight Attendant in the cockpit regarding warning systems demonstrating the Ground Proximity Warning System (GWPS) to her. The GPWS warning “too-low, terrain, too-low terrain” was recorded by the CVR at 1534:23.

At 1538:43, the crew received an updated EFC (Expect Further Clearance) of’ two two zero zero” (16:00 CST) from the BOONE Sector Controller. This extended Flight 4 184’s anticipated holding time by 30 minutes by moving the EFC from 15:30 to 16:00.

Between 1538:55 - 1542:34, the CVR transcript indicates that the Pilot and Junior Female Flight Attendant's "non-pertinent conversation continues". During this time, at 1541:07, a second single tone similar to the Caution Alert Chime was recorded on the CVR. The DFDR indicates that the TAT was +2 degrees C.

The chime for the aircraft's Anti-Ice Advisory System (AAS) provides the flight crew an aural indication that ice was accumulating on the aircraft. There is no indication on the CVR or DFDR that the flight crew had or had not previously activated the Level 11 anti-icing measures required to be used in icing conditions, and before ice actually accretes on the aircraft. The flight crew at 1541:09 selected Level 111 activating the airframe de-icing system followed by an increase in the propeller speed to NP 86°/0. At 1542:20 the "sound of eight clicks" was recorded by the CVR, which are not identified on the CVR transcription. The CVR transcript contains no comment from the crew about icing conditions at this time or about having previously entered icing conditions.

The third holding pattern circuit was flown between 1541:47 to 1551:55. Shortly after the third holding pattern was commenced at 1541:47, the Junior Female Flight Attendant apparently left the cockpit (at 1542:40, the CVR recorded "clicks similar to cockpit door being opened and closed"). The NTSB provides the full CVR transcript only after the Junior Female Flight Attendant departed from the cockpit, The full transcript commences at 1542:41.

At 1543:27, the crew received information from dispatch through the ACARS system and the ACARS system was discussed by the Captain and First Officer while the First Officer made an attempt to transmit the EFC time and the fuel data. It appears that the flight crew had difficulties in operating the ACARS system

At 1545:48, the radio music playing in the cockpit stopped, and the Captain made a cabin announcement through the Public Address system. He apologized for the delay and advised that connecting flights might also be delayed. The First Officer continued to operate the ACARS system. Thereafter, the Captain and the First Officer continued to discuss the ACARS system through 1548:26.

At 1548:34, the First Officer commented to the Captain: “that’s much nicer, flaps fifteen”. At 1548:46, the Captain replies : “ I’m sure that once they let us out of the hold and forget they’re down, we’ll get the overspeed”. The First Officer responded with a “chuckle” at 1548:48.

At 1548:43, one pilot (not identified in CVR transcript) mentioned : “I’m showing some ice now”. There is no response to this comment transcribed, nor is there any discussion whatsoever between the pilots regarding this icing observation

At 1549:05, 22 seconds after the comment “I’m showing some ice now”, the Captain unfastened his seat belt and he left the cockpit at 1549:07. The Captain did not provide the First Officer with any instructions before leaving the Flight Deck. The Captain was then absent from the cockpit for over 5 minutes (1549:07 - 1554:20),

The fourth holding pattern circuit commenced immediately after the Captain left the cockpit. This holding pattern was flown between 1550:44 and 1557:22.

Between 1549:05, when the CVR recorded the “sound of ding along similar to flight attendant call bell” and 1552:00, while the First Officer was alone in the cockpit, he was involved in at least two, and possibly three separate intercom conversations, with the Junior Female Flight Attendant, the Senior Female Flight Attendant, and the Captain.

At 1551:39, the Captain, still out of the cockpit, used the aircraft intercom system to communicate with First Officer and engaged in the following conversation :

INT-1 (1551:40) : “getting busy with the ladies back here”,

INT-2 (1551:41) : “oh.”

INT-4 (1551 :43) : [sound of snicker]

INT- 1 (155 1 :45) : “yeah, so if I don’t make it up there within the next say, fifteen or twenty minutes you know why”.

INT-2 (1551 :49) : “OK”

INT- 1 (1551 :50) : “OK”

INT-2 (1551:51) : “I’ll uh, when we get close to touchdown I’ll give you a ring”

INT-1 (1551:53) : “there you go”

INT-2 (1551:54) : unintelligible word.

INT-1 (1551:55) : “no, I’ll be up right now. There’s somebody in the bathroom so (unintelligible words).

CAM (1551:55) : “[wailing sound similar to “whooler” pitch trim for two seconds]”

INT- 1 (1551 :59) : “talk to you later”

INT-2 (1552:00) : “OK”

At no time during his intercom conversation with the First Officer did the Captain inquire about the status of the flight. In this regard, there was no discussion about the icing conditions the flight was operating in.

At 1554:20, a sound similar to Captain’s seat moving laterally and forward was heard, and at 1554:47, following the Captain’s return to his seat, he resumed discussions with the First Officer about ACARS messages. There is no indication that the Captain had used the opportunity while walking through the aircraft to observe the status of the ice on the aircraft.

At 1555:23, the Captain asked : “and you haven’t heard anymore from this chick in, this controller chick, huh ?“ The First Officer replied : “no, not a word. . .“

At 1555:42, the First Officer states : “we still got ice” without further comments. The First Officer’s statement was not acknowledged by the Captain. There was no discussion whatsoever regarding the icing conditions being encountered either at that time, or since the First Officer’s first mention that the aircraft was operating in icing conditions and the activation of Level 111 de-icing equipment over 14 minutes before (at 1541 :07). Throughout this time, the DFDR shows that the TAT was +2. 2°C.

There is no indication at this time, or at any other time during the flight, that the flight crew notified ATC that they had encountered and were operating in icing conditions.

Following the First Officer’s statement “we still got ice”, the CVR transcript indicates the next sound is “similar to paper being torn from ACARS printer” which is followed by the Captain saying “here” (1555:47), the First Officer’s reply “get a message ?“ (1555:58), and the Captain saying “you did” (1555:59). The Captain then decides to call the American Eagle Chicago Operations Control (AEC), saying “I’ll be right back. K, I’m a talk to the company”. (1556: 11) He asked whether AEC was aware of the Flight 4184 delay and discussed flight connections.

At 1556:14, the BOONE Sector Controller attempted to contact Flight 4184 to issue a clearance saying “descend and maintain eight thousand”. The flight crew did not respond. The Captain proceeded with his call to AEC.

At 1556:24, the CVR recorded a TCAS (Traffic Alert Collision Avoidance System) warning : “traffic, traffic”. There was no acknowledgment of this warning by the flight crew nor was there any discussion whatsoever between them regarding the alert.

At 1556:27.8, while the Captain was still speaking to the AEC, Chicago ATC again issued a clearance to Flight 4184 to descend to 8000 ft and advised the crew to expect 10 more minutes “till you’re cleared in”. The First Officer acknowledged at 1556:50.1 saying only “thank you”. At 1556:45, the aircraft initiated a descent to 8000 feet in the V/S (vertical speed) AP mode.

At 1557:16.3, three minutes after returning to the cockpit and 12“ before the upset, the Captain asked the First Officer : “are we out of the hold ?“. He was told by the First Officer : “no we’re just goin’ to eight thousand”.

At 1557:20, during the descent, the DFDR data indicates that the power was reduced to Flight Idle. The propeller rotation speed was 86 % and, TAT was 4 degrees C. The autopilot was still engaged in V/S - HDG SEL AP modes. The aircraft initiated a right turn and the bank angle stabilized at 15 degrees. The airspeed was 176 KIAS.

At 1557:22.1, the CVR records the sound of “repeating beeps similar to overspeed warning” (the flap overspeed warning) at an airspeed of 186 KIAS. At 15.57:26.2, the Captain stated : “I knew we’d do that”. The flaps were then retracted to the flaps O position. During the flaps retraction, the AOA increased gradually from -1 degree to 6,5 degrees, the speed was maintained, the bank angle was maintained, and the left aileron deflection slightly increased to 2 degrees upwards, then decreased rapidly towards neutral position.

At 15.57:28.5, the autopilot disconnected. The left aileron then deflected abruptly downwards. The aircraft rapidly rolled to the right to a maximum bank angle of 77 degrees. The airspeed was 187 KIAS, propeller rotation speed was 86%, and the TAT value was 4 degrees C.

The First Officer was flying the aircraft when the roll occurred. The Captain said “oh” at 1557:29.9 with the First Officer saying “oops, #“ at 1557:32.8. Following the initiation of the roll, there was no discussion between the flight crew members regarding what was occuring nor was there any conversation between them in respect to aircraft’s attitude. The First Officer did not ask for any help in controlling the aircraft or in responding to the event.

The DFDR further indicated that as the AOA decreased through 6 degrees, the ailerons moved to a nearly neutral position while the aircraft stopped rolling at 77 degrees, right wing down. Shortly thereafter, the aircraft rolled back to the left to a minimum angle of approximately 59 degrees right wing down. The AOA was reduced down to 1.2 degrees, then increased again to 6 degrees.

At 1557:33, the left aileron deflected again to 8 degrees downwards and the aircraft rolled again to the right. At this point, according to the DFDR, the Captain was twice briefly pulling more than 10 DaN (22 lbs) on the pitch control column. DFDR data further shows that the First Officer and the Captain were pulling on the control column at different times without coordination. The CVR records no attempt to either transfer the controls to the Captain, or to coordinate flight control inputs.

The aircraft rolled rapidly to the right and continued to roll through an inverted position and through wings level, while simultaneously the aircraft's pitch attitude decreased to 55 degrees nose down. The aircraft continued to roll to the right an additional 144 degrees, while the airspeed steadily increased to over 260 KIAS.

At 1557.44, the DFDR data revealed the aircraft began to roll to the left and that the pitch attitude reached a maximum of 73 degrees nose-down. The airspeed increased to 296 KIAS.

From the time of the autopilot disconnection, the DFDR data indicates nine momentary spikes on the pitch axis corresponding to either the Captain's or the First Officer's inputs in excess of 10 daN (22 lbs). However, the elevator deflection momentarily spiked to 8 degrees "nose up" with a mean value of approximately 3 degrees "nose up". During the entire time from the roll initiation, the rudder deflection was erratic and never exceeded 2 degrees. The maximum available rudder deflection was 3.5 degrees. During the same time period, the aileron deflected erratically fluctuating between an 8 degree "left wing down" position and the "right wing down" stop, and returning to the O degree position for 6 seconds at 1557:43. During this entire time, the Power Level Angle (PLA) was left at the Flight Idle position.

The last seconds of DFDR data indicate a rapid, large input on the elevator.

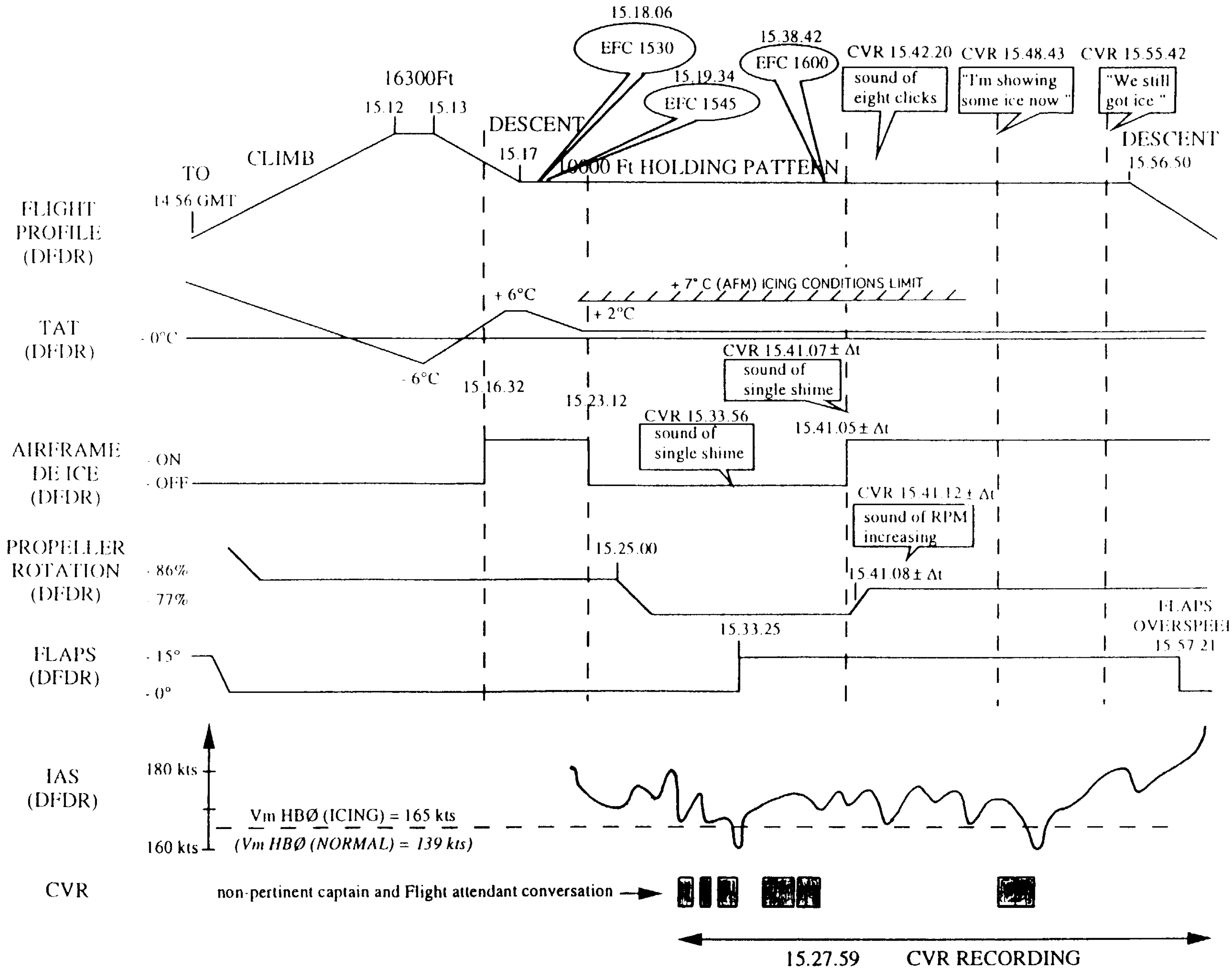


FIGURE 1 : FLIGHT 4184 PROFILE AND MAJOR DFDR EVENTS

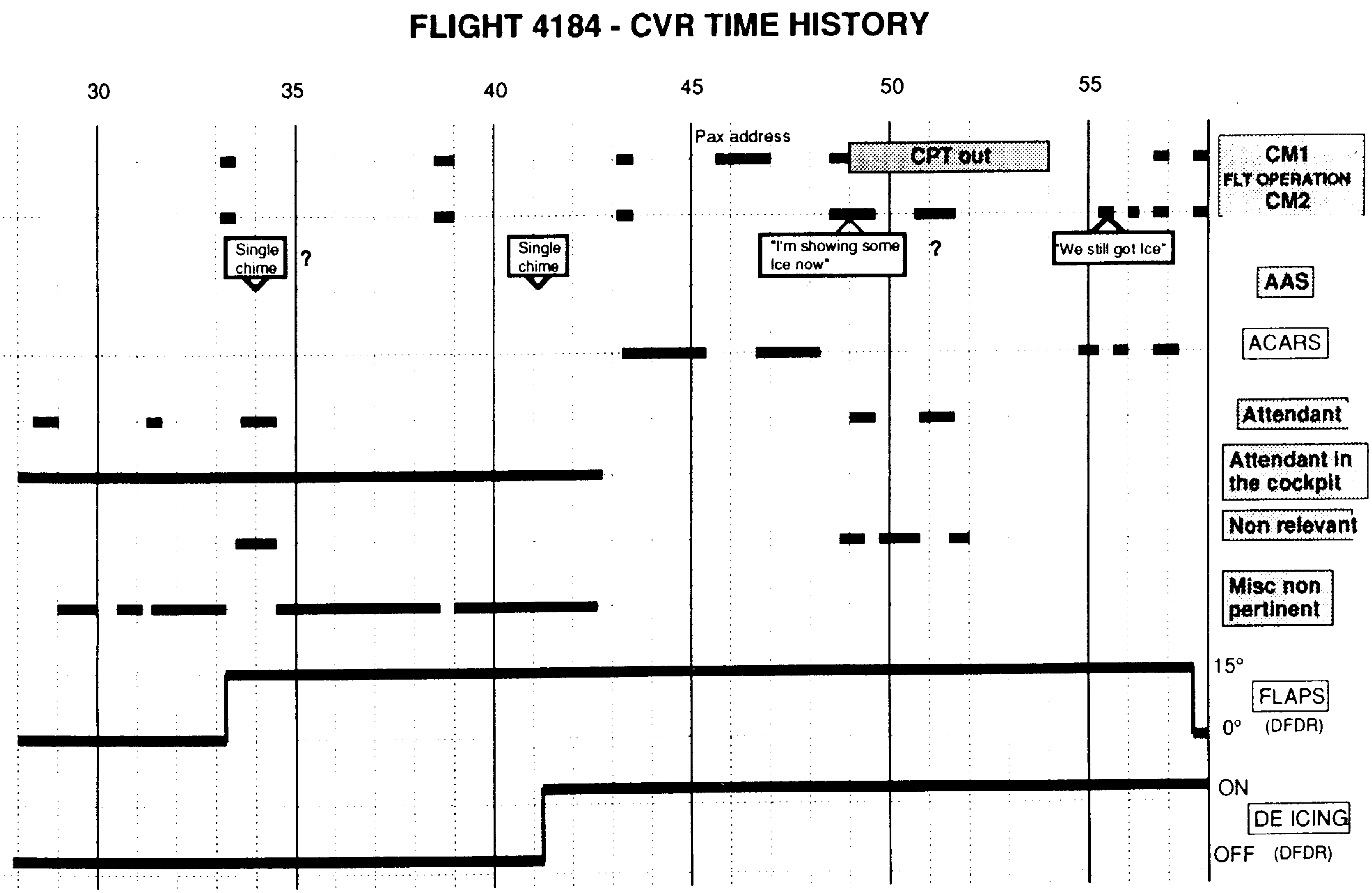


FIGURE 2 : FLIGHT 4184 CVR TIME HISTORY

Flight 4184 CVR transcript by NTSB was highly unedited

FIGURE 3 : FLIGHT 4184 DESCENT TO LUCIT - HOLDING

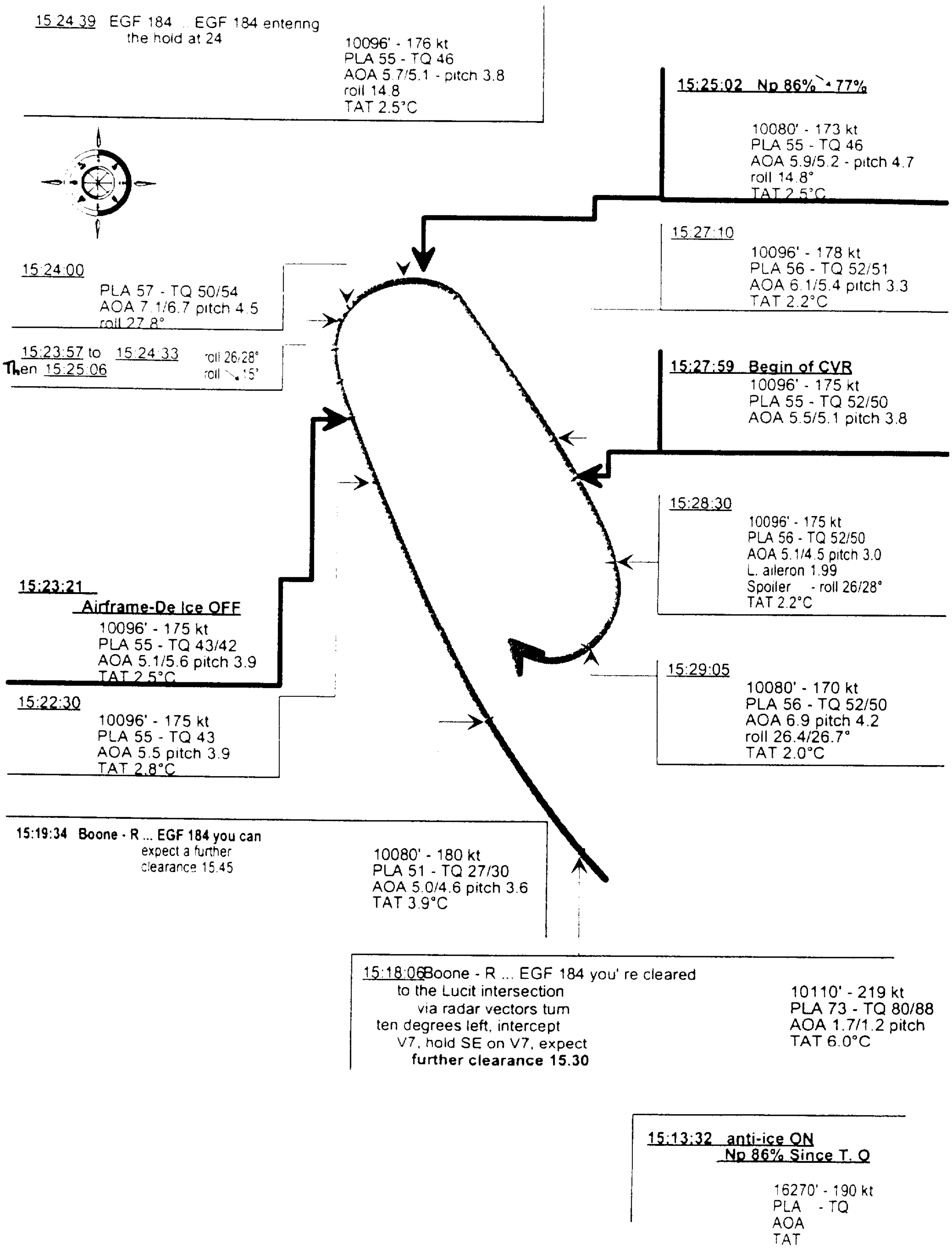


FIGURE 4 : FLIGHT 4184 SECOND HOLDING PATTERN TIME HISTORY

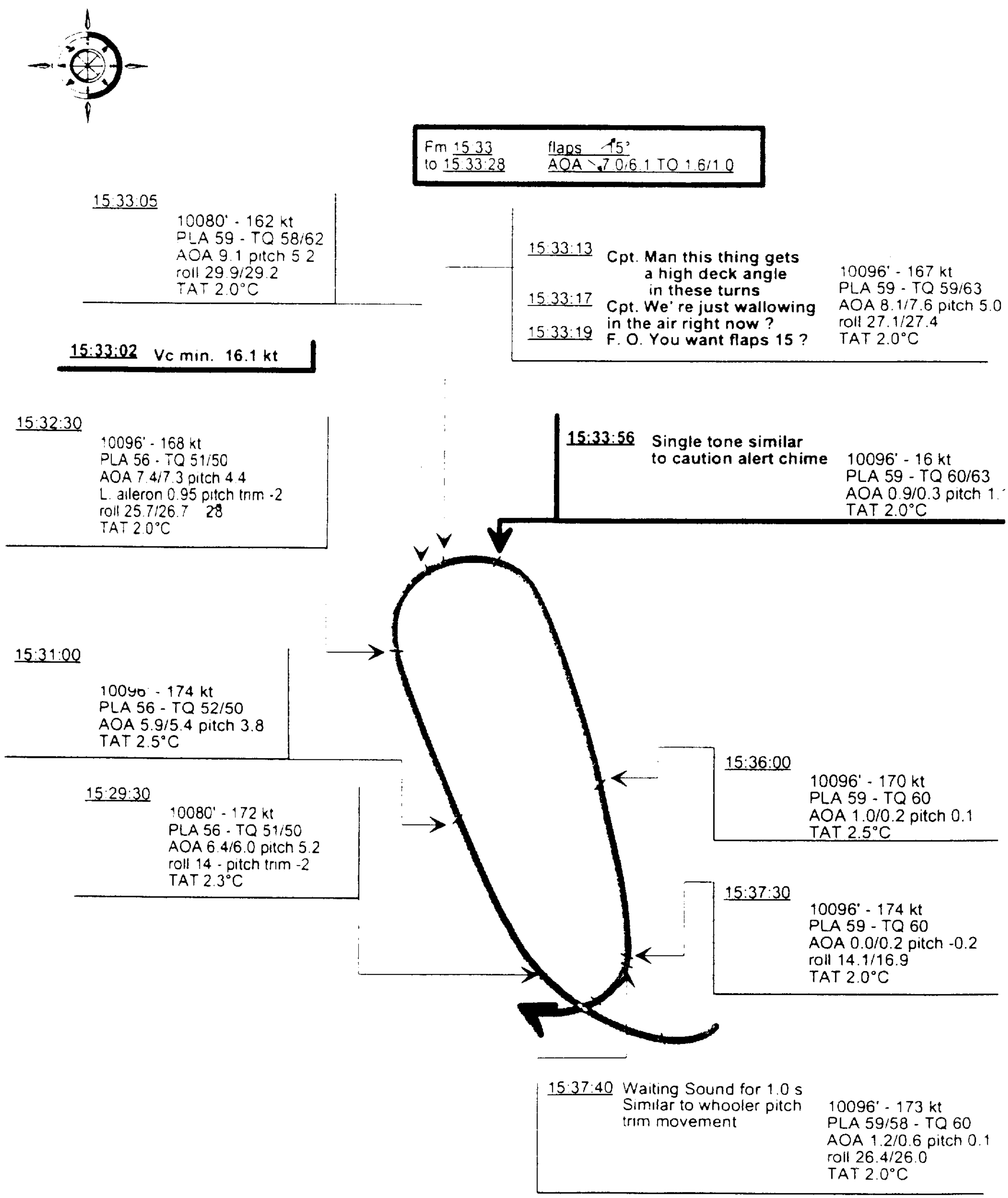


FIGURE 5 : FLIGHT 4184 THIRD HOLDING PATTERN TIME HISTORY

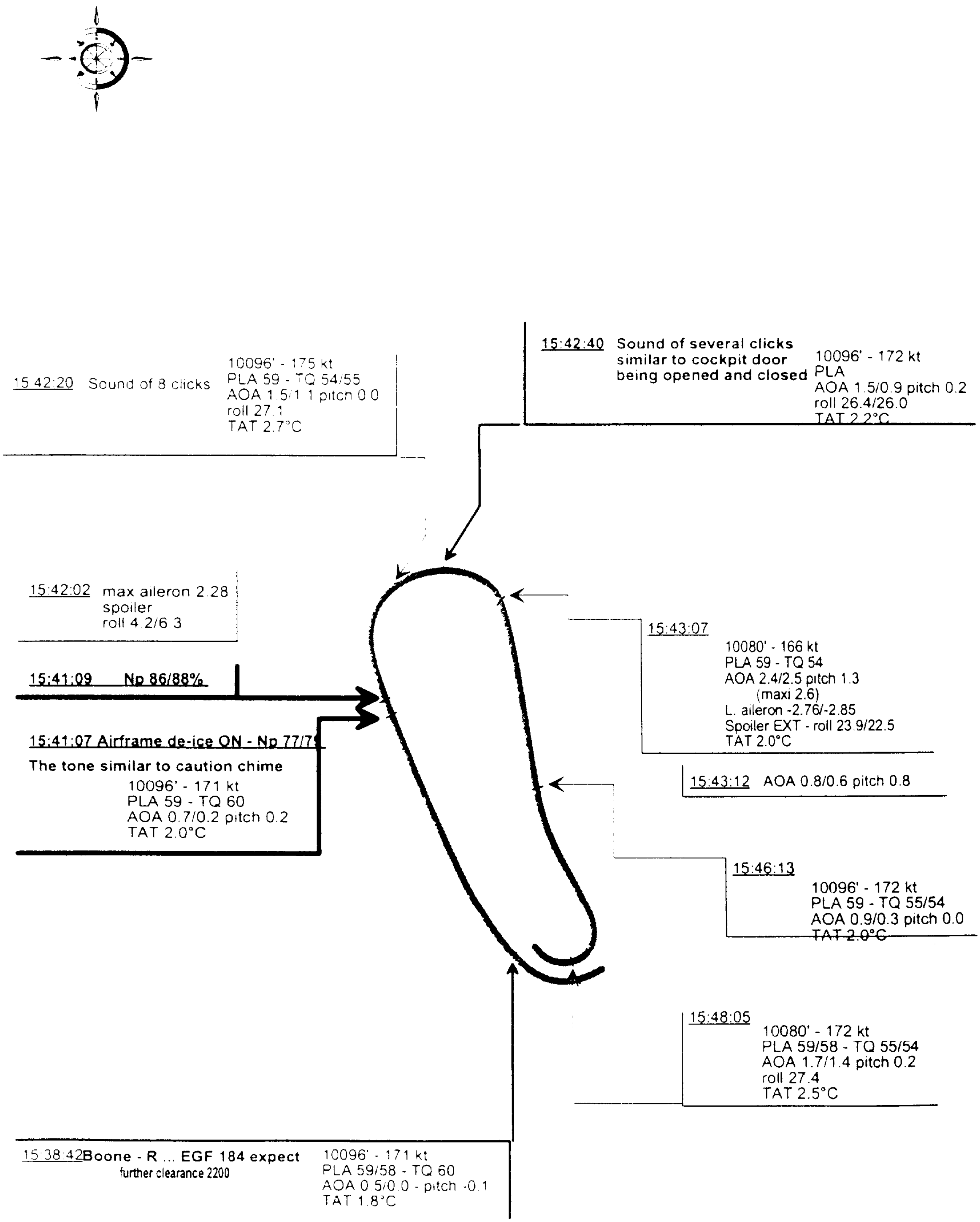


FIGURE 6 : FLIGHT 4184 FOURTH HOLDING PATTERN TIME HISTORY

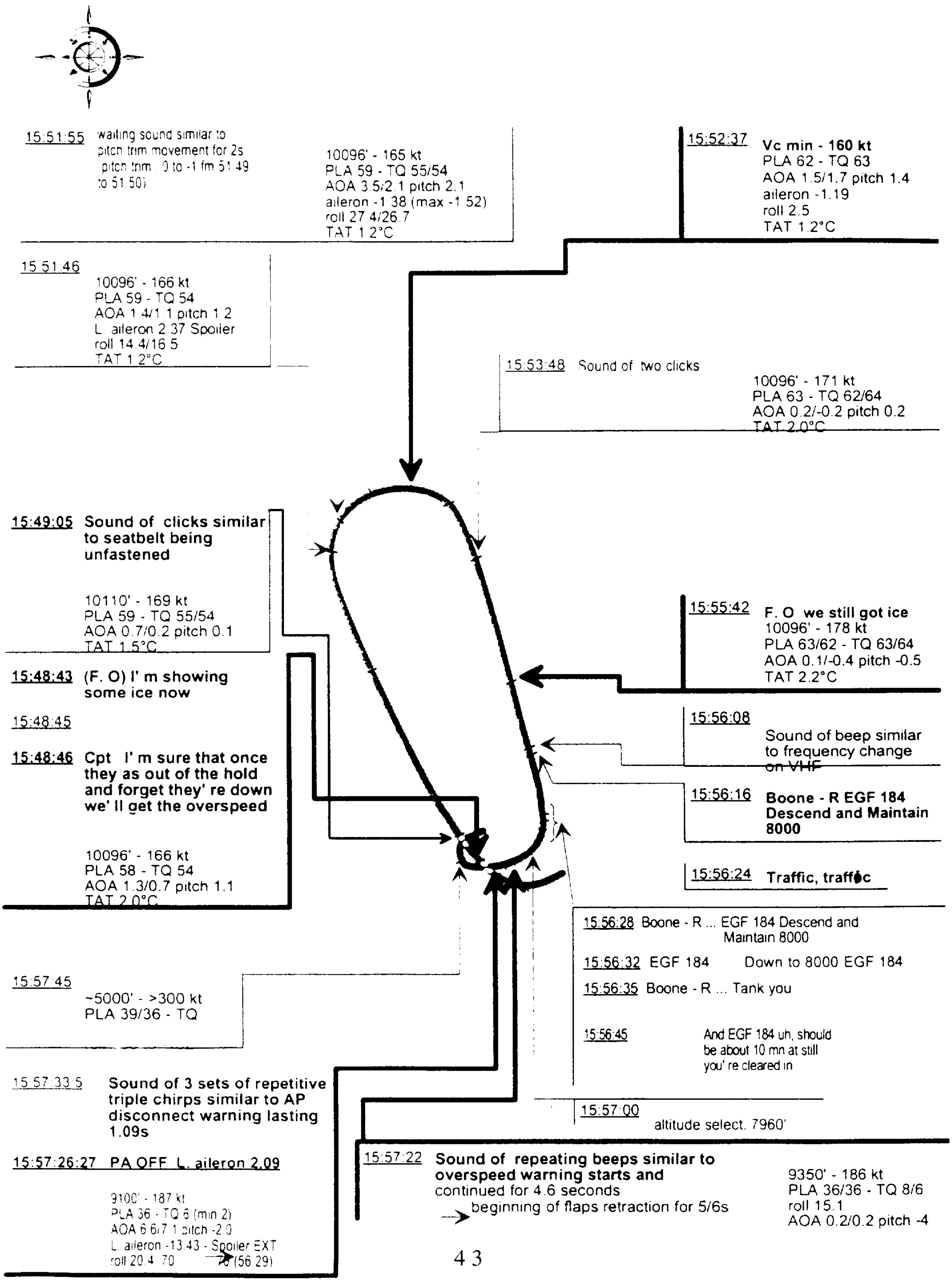
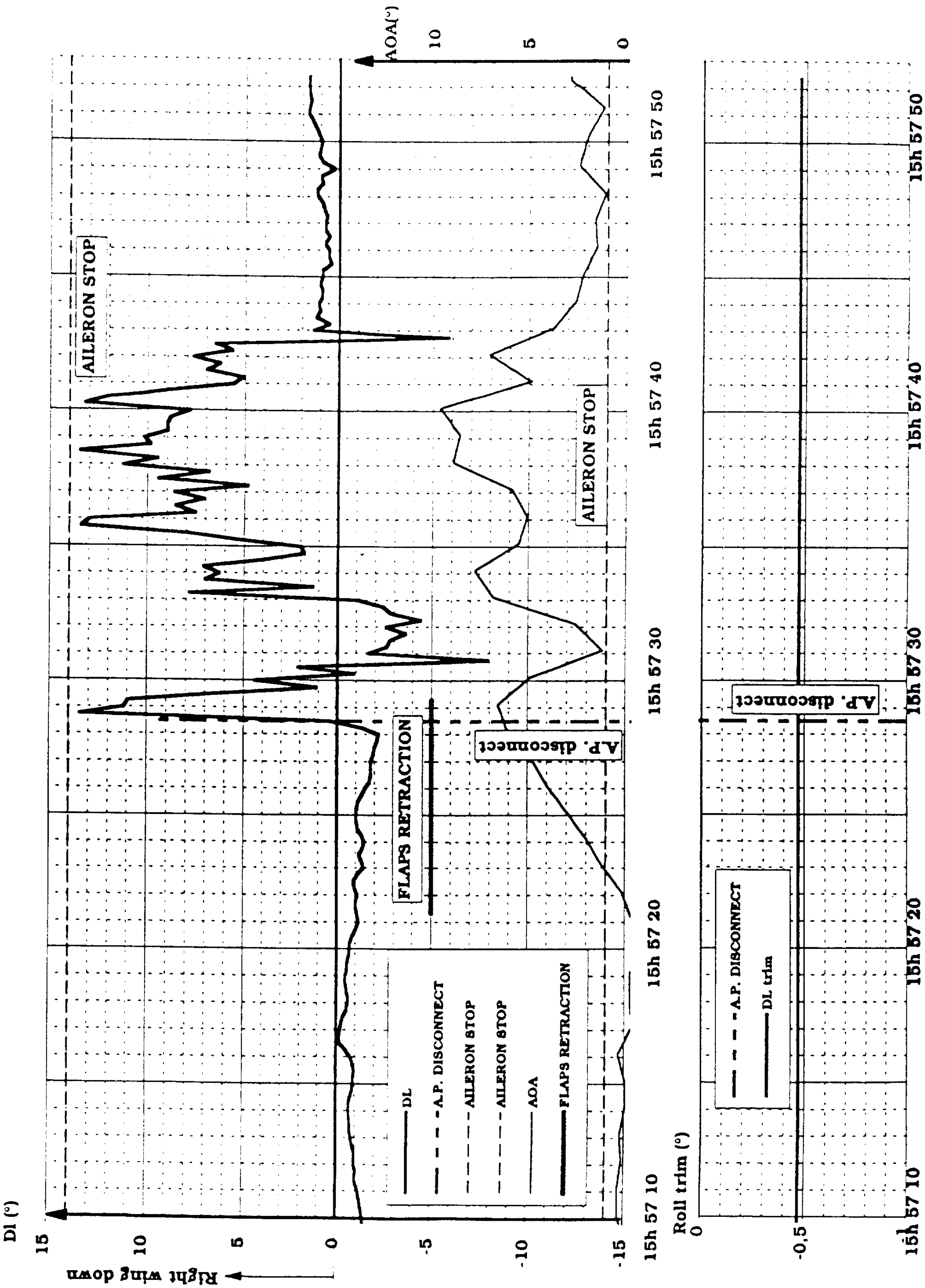


FIGURE 7 : FLIGHT 4184 - ROLL CONTROL ACTIONS AT ROLL UPSET



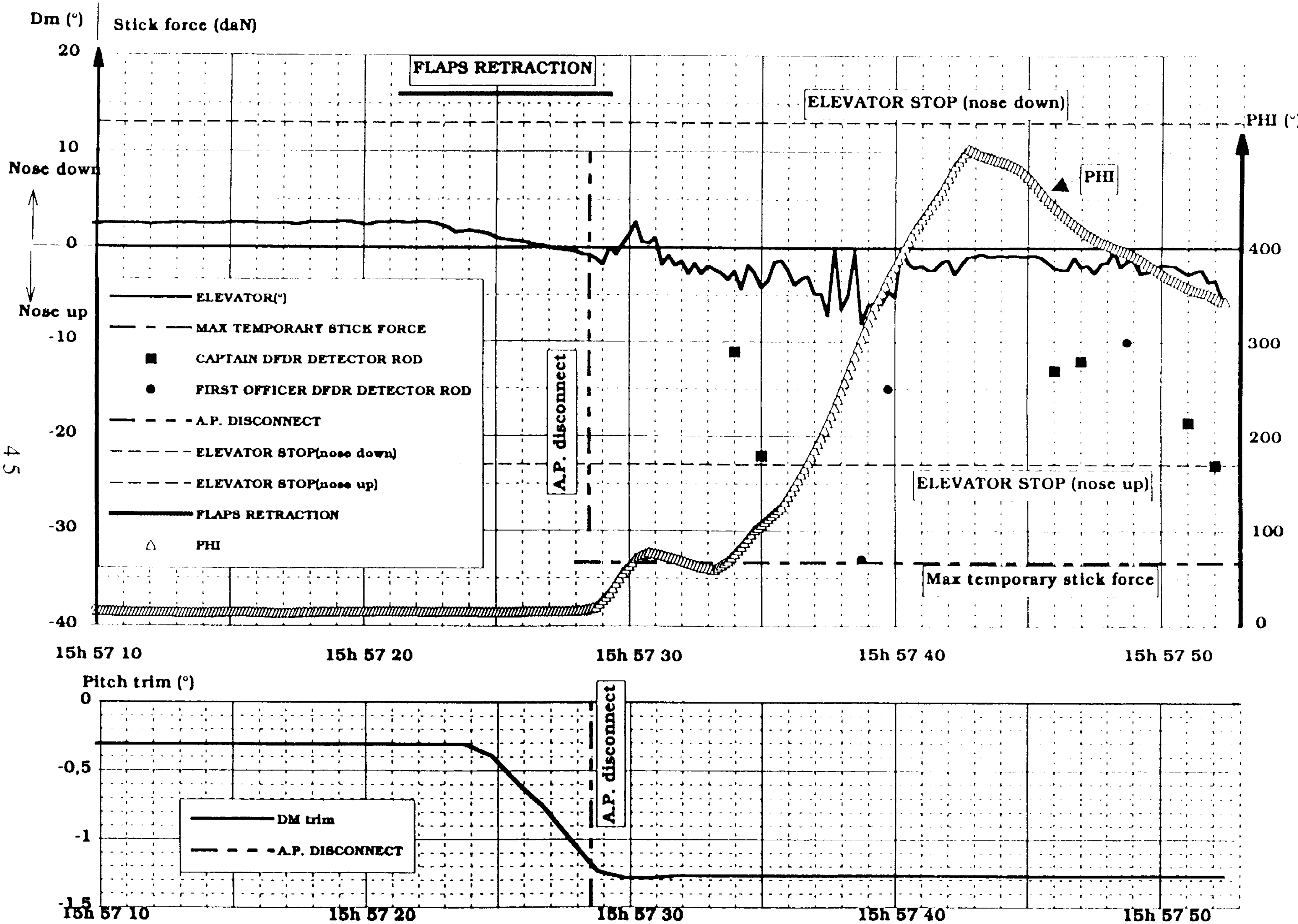


FIGURE 8 : FLIGHT 4184 - PITCH CONTROL ACTIONS AT ROLL UPSET

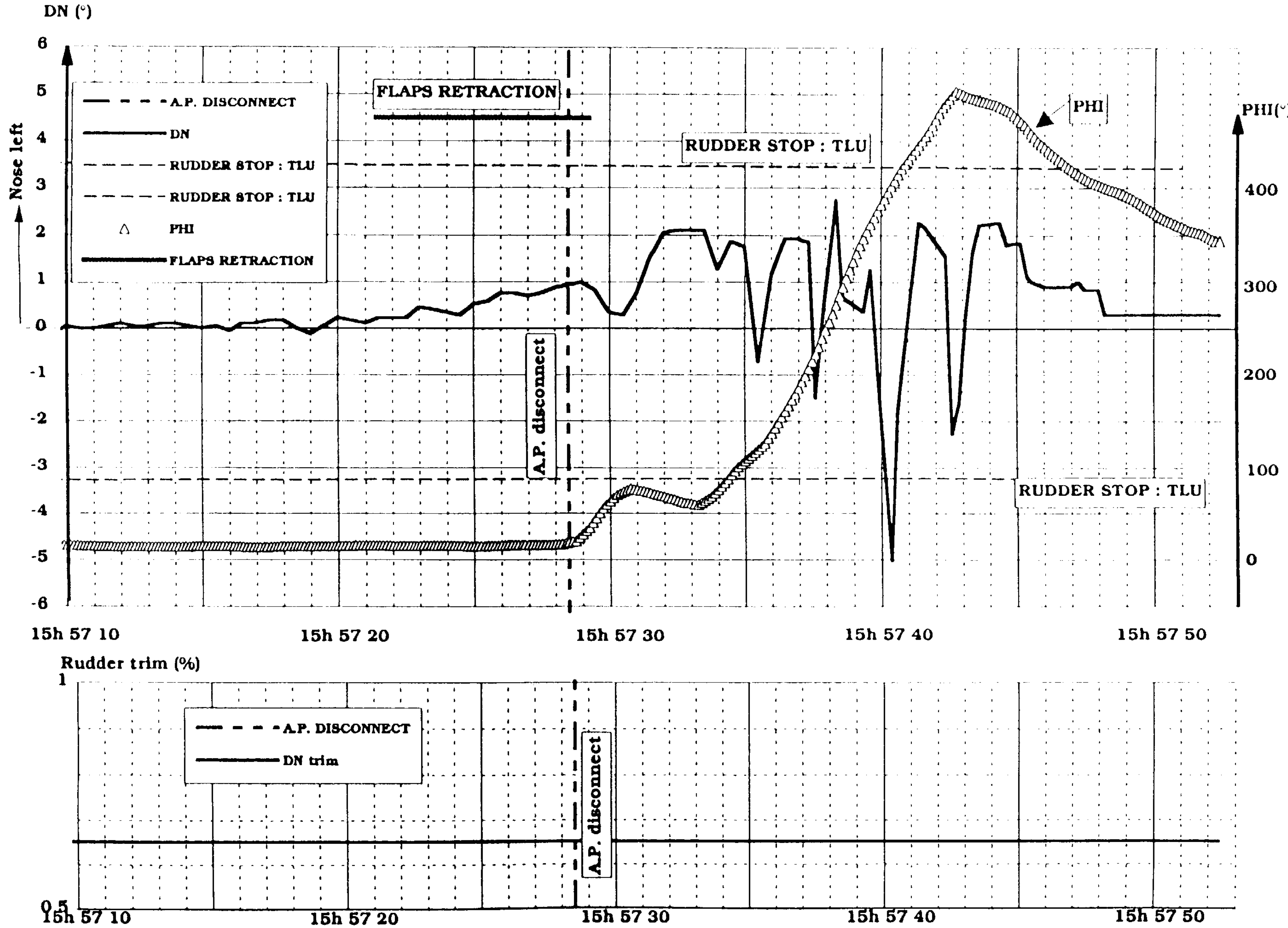


FIGURE 9 : FLIGHT 4184 - YAW CONTROL ACTIONS AT ROLL UPSET

1.2. PERSONNEL INFORMATION

1.2.1 THE CAPTAIN

The NTSB's Report states that the Captain's airman certification history was "found to be unremarkable". However, the NTSB has not mentionned that the FAA's Airman Certification Records for the Captain show that on March 10, 1993, he failed an ATR-42 check ride. The FAA's records indicate that the Captain attempted to add an "additional aircraft rating" for the ATR-42 and that he failed to competently demonstrate a single engine non-precision approach. In this regard, FAA Form 8060-5, dated March 10, 1993, listed the reason for disapproval as :

> "Failed - S.E. [single engine] non precision approach". The Captain passed the aural exam satisfactory on 03-10-93.

1.2.2 THE FIRST OFFICER

The NTSB's Report states that the First Officer's airman certification history was "found to be unremarkable". However, the NTSB's Report does not set forth facts which would explain how the First Officer could accumulate over 3,657 hours of flight time in the ATR, well over two-thirds of his total flight time of 5,176 hours, and yet not have been type certificated for the ATR and was not a licenced A.T. P.

1.3. AIRPLANE INFORMATION

The NTSB's report omits critical factual information in respect to the ATR 72 icing certification criteria (Special Condition B6) and certification process, as well as information regarding the ATR 72's ainti-icing advisory system (AAS) and stick pusher stall protection system. This important factual information is necessary for a complete analysis and understanding of this accident. The BEA provides its comments in respect to these issues in sections 1.3.1, 1.3.2 and 1.3.3 below.

1.3.1. ATR 72 ICING CERTIFICATION

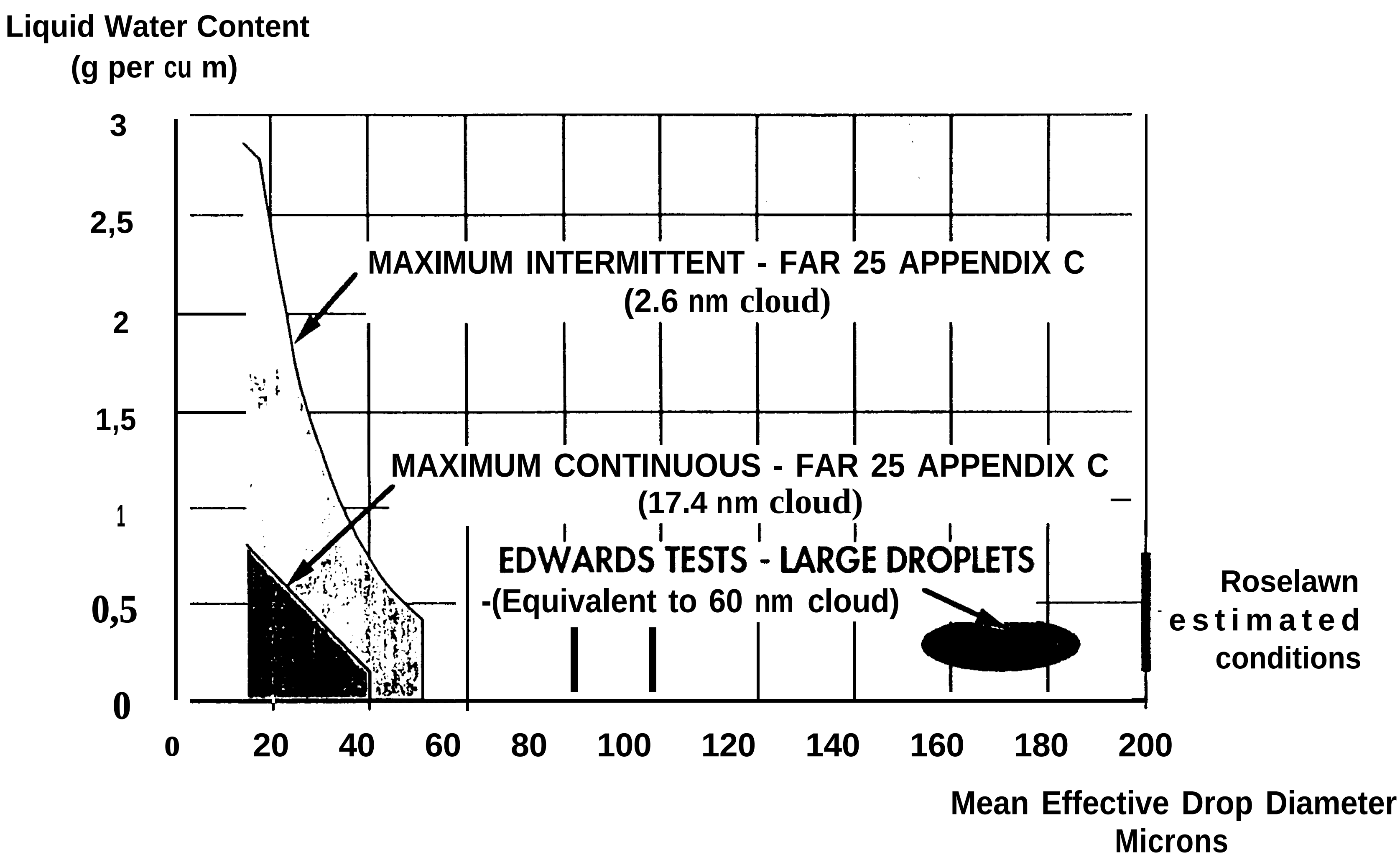
1.3.1.1. PURPOSE

Since certification for flight in icing conditions was desired for the ATR-72, a comprehensive certification plan was established and agreed upon by the Airworthiness Authorities for the demonstration of compliance with the applicable airworthiness requirements.

1.3.1.2. AIRWORTHINESS REQUIREMENTS

1.3.1.2.1. Standard Regulatory framework

Current JAR/FAR 25 airworthiness standards are very explicit in respect to the definition of icing conditions and the related demonstrations which must be performed to demonstrate compliance of the sytems with the requirements. (Refer to JAR/FAR 25.1419 and associated Appendix C). However, FAR 25, Appendix C is vague in respect to aircraft handling and performance requirements in icing conditions.



ROSELAWN conditions were far outside App "C" certification envelope

FIGURE 10 : FAR 25.1419 & APPENDIX "C" CERTIFICATION ENVELOPE

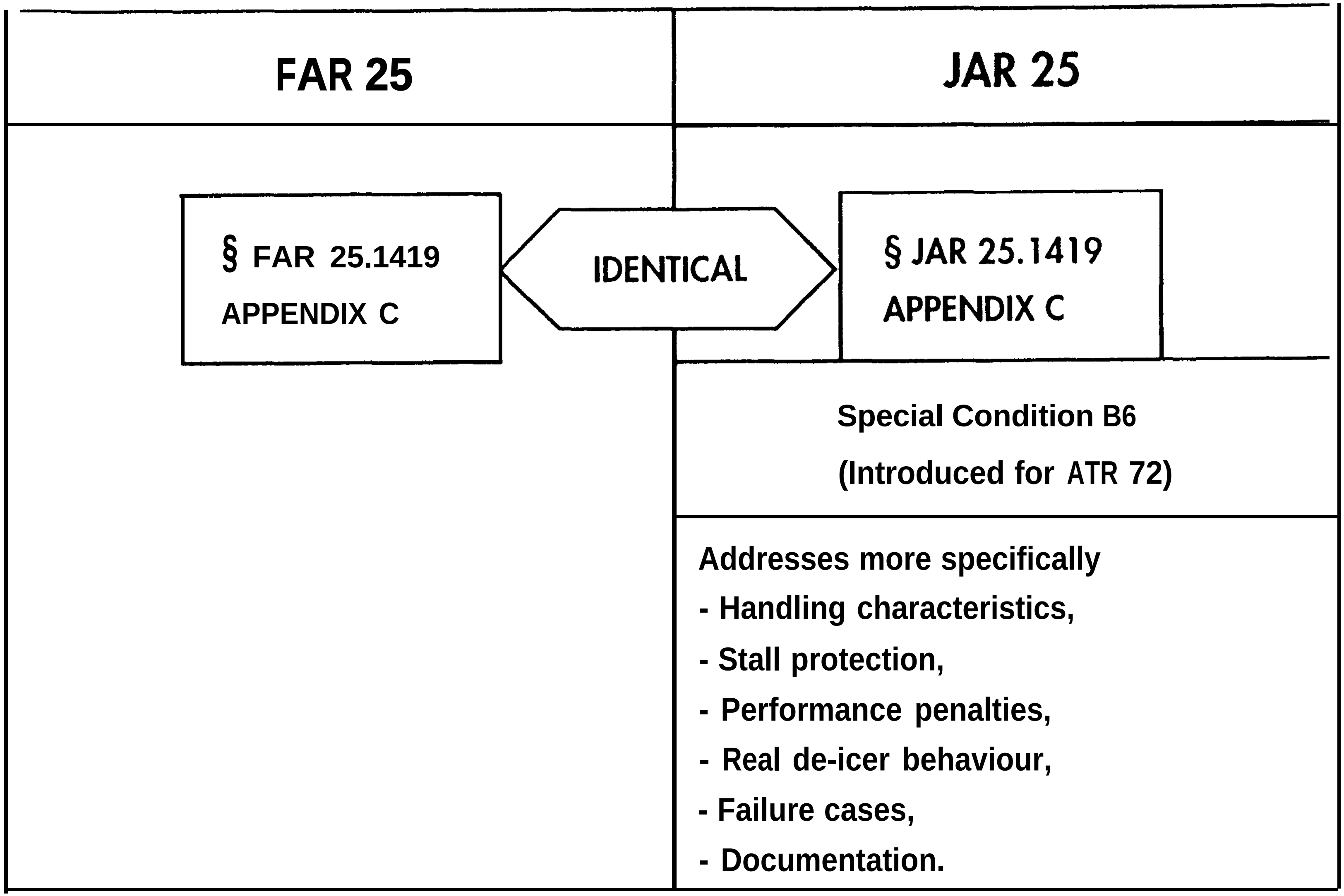
1.3.1.2.2. DGAC ATR 72 B6 Special Condition

Because JAR/FAR 25.1419 does not address aircraft handling and performance requirements in icing conditions, a comprehensive Special Condition was established by the DGAC and was part of the ATR 72 certification basis. The main purpose of Special Condition B6 is to assess handling characteristics and performance aspects which take into account the aerodynamic penalties due to ice accretion in terms of drag, lift and other aerodynamic characteristics, This Special Condition included interpretative material to define a methodology and associated criteria for :

a) definition for ice shapes in typical flight phases according to the applicable meteorological conditions (JAR/FAR 25, Appendix C), taking into account “intercycle “ ice shapes, as well as the possible failure or malfunction of the ice protection system.

b) the assessment of ice shape effects on performance and handling qualities. This assessment included flight test demonstrations with simulated ice shapes, with special attention on the determination of tailplane stall margins, and

c) confirmation of the validity of previous theoretical ice shapes leading to flight tests in natural icing conditions to ensure that performance and handling degradations have been established on a conservative basis, with special attention to stall warning.



ATR 72 Icing Certification Standard encompassed current FAR 25.1419

FIGURE 11 : SPECIAL CONDITION B6 - ICING CERTIFICATION

1.3.1.3. ICING CERTIFICATION PROCESS

The icing certification process was conducted utilizing the following tools

ice codes

"artificial" ice shapes tests

"'natural icing" tests.

* Ice codes, were validated by icing wind-tunnel and natural icing tests and approved by Airworthiness Authorities. The ice codes were used to determine impingement limits and to define accretion shapes with the most critical droplets (within appendix C conditions). The corresponding most critical ice shapes create a double horn accretion on the unprotected parts of the leading edge.

* Flight tests with simulated ice shapes were performed in order to identify :

a) aircraft performance, for a given flight phase, with the most critical simulated ice shapes.

b) Establish the stall characteristics and stall speeds, the stall warning settings, the minimum operational speeds (V2, VFTO, VRF) and realize the push over tests with full flaps.

c) Demonstrate that the ATR aircraft can safely operate in the event of de-icing system failure.

* Flight tests, in identified natural icing conditions (liquid water content, droplet diameter, temperature) through a dedicated flight test program, were performed in order to demonstrate the systems performance against a variety of required icing conditions.

1.3.1.4. CERTIFICATION APPROVAL PROCEDURE

All the results and findings of the agreed certification program were formalized in recorded certification documents which were reviewed and approved by the Airworthiness Authorities. In addition specific certification flights were performed with representatives of various Airworthiness Authorities flights crews.

Approval of the engine and propellers for use in icing conditions was the responsibility of the powerplant suppliers who worked directly with their primary certification authorities; ATR also had to demonstrate the proper integration of the engine and propeller on the aircraft in icing conditions. Flight tests in natural icing conditions substantiated this demonstration.

Icing Wind Tunnel tests were also used to demonstrate the regulatory compliance of, among other items, the effectiveness of the snow ingestion protections and to validate the effectiveness of the ice protection systems.

1.3.1.5. CERTIFICATION FLIGHT IN NATURAL ICING CONDITIONS

Two flight test campaigns (14 + 14 flights) under measured natural icing conditions were conducted for the certification of the basic ATR72-200 (with 14SF propeller) and ATR 72-210 (with 247F propeller).

Over these two campaigns the ice protection systems and the aircraft behavior were thoroughly evaluated. From the 28 flights performed in icing conditions, 17 have been retained as certification flights (10 +7) which cover a wide range of conditions within the Appendix C :

- Altitude : from 6500 ft to 17000 ft,
- Airspeed : from 120 kts to 200 kts
- SAT : from - 14°C to -5°C.
- MVD : from 15µm to 47 µm*,
- LWC : from 0.12 g/m^3 to 1.80 g/m^3,
- Both Maximum Continuous and Maximum Intermittent Icing.

<u>Note*</u>

During the certification flight V418 of A/C 98, freezing drizzle or rain had probably been encountered. The basic instrumentation did not allow to idenfity accurately these conditions (the FSSP measurement is limited to 47µm) but the visual cue identified at Edwards was present on the side windows. Only performance degradation was noticed. No detrimental handling repercussion was experienced.

The selected tests in natural icing conditions aim at covering the range of cloud characteristics specified in JAR 25 Appendix C. In particular, this wide range of conditions respect the recommendation of ACJ 25-149 52.55 with states :
“The critical ice accretion on unprotected parts will normally occur during the hold near 15000ft at about -10°C so as to give a total temperature of around O°C”.

FSSP : Forward Scattering Spectrometer Probe to measure the diameter of the supercooled droplets.

Further, the acceptability of these tests conditions is qualified in
ACJ 25-1419 §3.4 as follows :
“The natural icing tests carried out on the airplane will be judged for their acceptability by the evaluation of the icing conditions through which the aeroplane has flown in relation to the envelope of conditions of Appendix C“.
The selected tests in natural icing conditions were agreed by DGAC and FAA.

Since the most critical ice shapes were double horn types, natural conditions prone to their appearance were searched for. These conditions are characterized by medium size droplets (20μm) and temperature (SAT) close to - 10°C. This explains why a large proportion of the Flight Tests Condition covered these conditions.

Furthermore, in the NTSB Memorandum of the Airplane Performance Group dated December 2, 1994 it is recorded : “The coverage of the certification was, however, described by the NASA/FAA group members as typical to above average for a turboprop certification effort given the apparent difficulty in finding natural icing conditions in certain areas of the certification envelope”.

The ice protection systems have demonstrated acceptable performance.

Handling characteristics and performance flight tests were conducted in the continuous maximum and intermittent maximum icing conditions to demonstrate the compliance with the French DGAC Special Condition B6. The Special Condition requirements which address handling characteristics and performance, exceed normal certification and industry practices.

1.3.1.6. FAA/DGAC Special Certification Review Report Conclusions (Source SCR)

The Special Certification Review Team appointed by the FAA and the DGAC to conduct a complete review of the ATR 42 and ATR 72 aircraft Certification after the accident, performed an in depth analysis and concluded :

> The Certification program for the ATR72 was conducted in a manner consistent with other FAA icing certification program and 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 FAR/JAR 25.1419.
>
> The ATR42 and ATR72 series airplanes were certificated properly in accordance with the FAA and DGAC certification bases as defined in 14 CFR parts 21 and 25 and FAR25, including the icing requirements contained in Appendix C of FAR/JAR25 under the provisions of the BAA between the United States and France.

1.3.1.7. Freezing Rain and Freezing Drizzle.

NACA TN 1855 served as the basis to establish FAR 25 Appendix C icing conditions. NACA TN 1855 (1949 ISSUE) gives only limited information about “Freezing Rain”precipitations. In this regard, the associated physics were qualified as purely speculative since”observational data are not available for this class “.. .“for this reason , the values for the proposed Condition (item 50, table I) were calculated “.

The term “Freezing Drizzle “is not at all mentioned in the a.m document. The **FM** document ADS-4 “ENGINEERING SUMMARY OF AIRFRAME ICING TECHNICAL CONDITION DATA”, Issue 1964, calls NACA TN **1855** as a basic reference.

It does neither suggest any knowledge about “freezing drizzle”. Moreover, the a.m document page 1-24 § 1.4.6 “freezing rain design considerations” requires that :
“The possible effects of freezing rain should be considered for components not usually protected - such airspeed static vents, fuel vents , fuel tank vents, exposed control horns, cables . . .“
The FAA AC20-73 “AIRCRAFT ICE PROTECTION” issued in 1971 does neither address “Freezing rain” nor “Freezing Drizzle”.

All above mentioned documentation were part of the basic Certification package for ATR 42 & ATR 72.

As a matter of fact, at the time of Certification of both ATR 42/72, neither the ATR A/C manufacturer nor the Aeronautical Community had a clear knowledge about the definition and associated conditions which now correlate to the “Freezing Drizzle” icing conditions.

. Moreover, the Tail-plane Icing Workshop II, San Jose April 21-23, 1993 referred to this lack of standards to characterize Freezing Rain and Drizzle. Refer to the FAA Technical Center, Dick JECK, Communication entitled “Characterization of Freezing Rain and Freezing Drizzle Aloft”

quoting :

-“*Another question to ask is whether we want to characterize freezing rain physically for the engineering purposes. At the moment, no design values . . are officially promulgated anywhere*”.

“*We don’t know what the mean value is, there are so few measurements on drop sue in freezing rain*”.

“*Freezing drizzle is listed separately here because it is generally thought that it differs mainly in drop size. The other characteristics are probably about the same.* ”

Therefore Freezing Drizzle only differed by the droplet size 50 µm to 1000µm, respectively 250µm to 5000µm for Freezing Rain, while being generated by the same ice process. A new “Coalescence” process for Freezing Drizzle started to be identified by 1992 thanks to CASP II research program (ref. AGARD LS-197 Issue 1994 § 4.3 “Winter Storms Research in Canada “).

In between, FAA CT-88/ 8-1 March 1991 provided improved information on Freezing Drizzle/Rain Conditions over previous ADS - 4 (page I 1-9 § I.1.7). Subsequent recommendations common to “Freezing rain” and “Freezing Drizzle” were made : “Glaze icing is major concern in both freezing rain and freezing drizzle. Care should be exercised both in - flight and taxiing since glaze ice can collect quite rapidly on all surfaces even during short time”.

Whereas the Freezing rain section § 1.1.6 states that :

"pilots are cautioned to avoid flying in freezing rain conditions because rapid ice accretion on all surfaces results in rapid reduction of aircraft performance and loss of windshield visibility". It is quite clear that only drag is of concern with no reference to any Handling Qualities problem. Edwards flight tests were the very first opportunity as to identify accretion related to Freezing Drizzle and its consequential effects. This was no doubt a major contribution to the Aeronautical Community's understanding of Freezing Drizzle.

These tests clearly put into perspective the major difference between ice accretions induced by captation at positive AOA's (flap 0°configuration) - leading mainly to drag penalty - as opposed to collection at negative AOA (flaps 15°) which produce upper wing ice accretions potentially leading to aileron hing moment reversal.

1.3.2. ATR72 ANTI-ICING ADVISORY SYSTEM

- General description

In order to assist the crew when operating in icing conditions, an Anti-icing Advisory System (AAS) is installed on the ATR 42 and ATR 72 aircraft.

This system mainly includes an Ice Detector located on the left wing under surface which delivers a signal to the aircraft Multi Function Computers (MFC) when ice accretion is detected, which in turn generate indications in the cockpit.

The AAS is an advisory system only and it first belongs to the crew, to observe the atmospheric conditions, to visually monitor the ice accretion and to apply the relevant procedures.

- Cockpit indicating and control

The AAS indicating and control are located on the cockpit center panel (See Figure 1) and include :

- ICING amber light and associated FAULT amber light,
  ICING AOA pushbutton (AOA=Angle Of Attack) including a green light.

The AAS also illuminates the DE ICING blue light on the center panel. This DE ICING light is illuminated whenever the AIRFRAME de-icing is selected.

The AAS also illuminates the master CAUTION light on the crew alerting panel, associated with a single chime caution.

- Ice Detector and ICING signal

The Ice Detector, located on the left wing leading edge lower surface, includes a 1/4 inch diameter and one inch long probe, vibrating along its axis at a given frequency. The ice accretion on the probe changes this frequency and the Ice Detector triggers a signal when the ice accretion reaches 0.5 mm thickness.

The probe is heated during seven seconds, just following a detection, and it is ready to collect ice again, if icing conditions still remain.

The ice signal is kept present during one minute after the last detection in order to deliver a continuous signal while icing conditions exist
(See Figure 12).

The ice detector signal illuminates the cockpit ICING amber light.

The associated FAULT amber light is illuminated together with an aural single chime warning and master CAUTION light on the crew alerting panel when a fault is detected by the Ice Detector internal monitoring.

- Ice protection Warnings

In all cases, the ICING light is illuminated each time some ice accretion is detected.

When ice is detected but the Flight Controls Surfaces Horns anti-icing were not previously selected ON, the ICING light is flashing.

When ice is detected but the AIRFRAME de-icing was not previously selected ON, there is an aural single chime caution and an illumination of the master CAUTION, even if the Horns anti-icing was selected before (See Figure 2).

If ice accretion is not detected for more than 5 minutes and the AIRFRAME de-icing is still selected ON, then the DE ICING blue light flashes in order to avoid an unjustified use of the airframe de-icing boots.

- stall warnings

The stall warning threshold (cricket sound and stick shakers) is decreased in icing conditions.

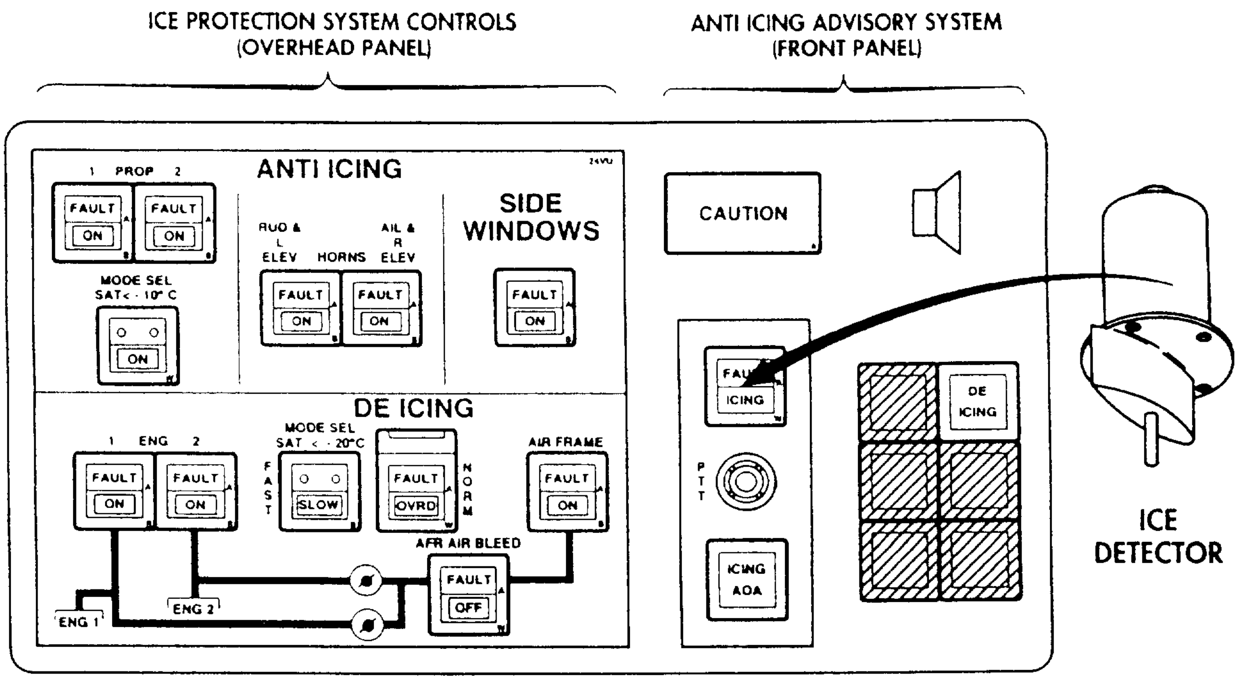
The ICING AOA is illuminated when the Horns anti-icing is selected and at this time the stall warning threshold is lowered to the icing conditions setting.

In order to extinguish the ICING AOA, the reselection of the Horns anti-icing is not sufficient, the crew must still push the ICING AOA button and at this time only the stall warning threshold returns to the normal setting.

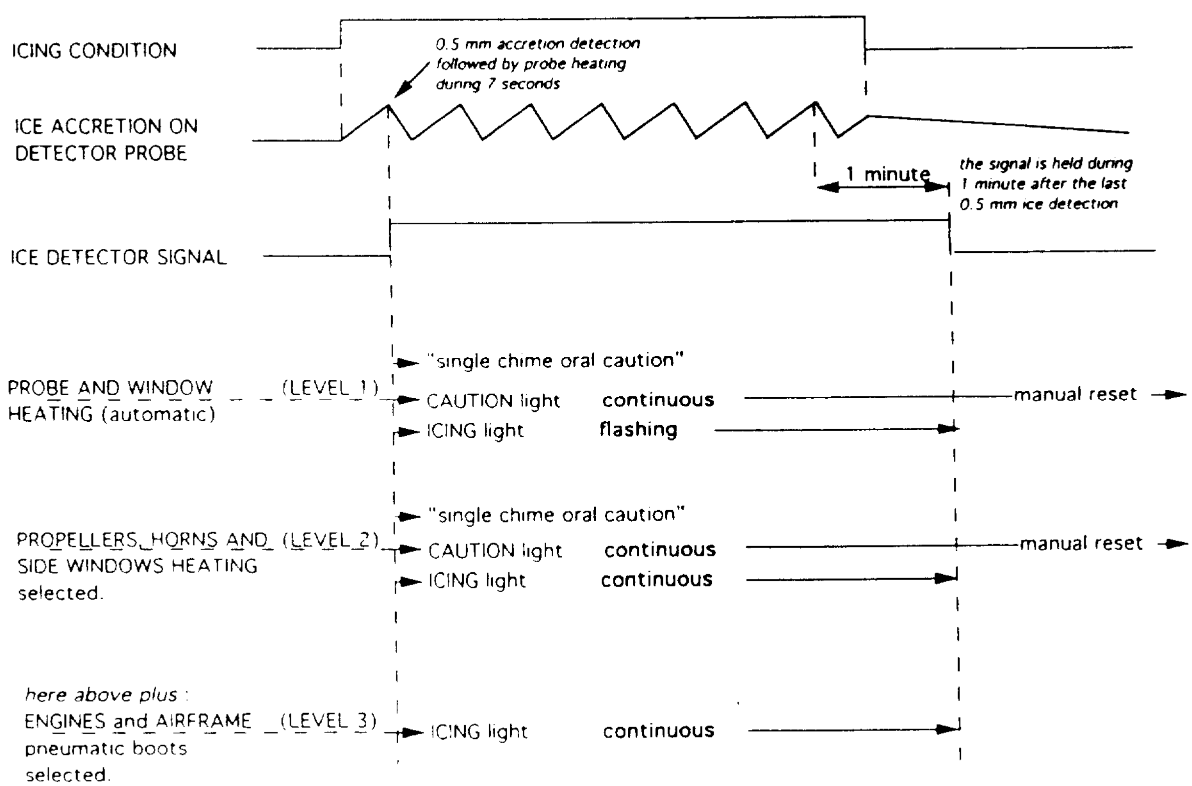
- Propeller rotation speed

The propeller rotation speed is not controlled nor monitored by the AAS. The normal procedure requires the increase in the propeller rotation speed, from 77% to 86%, as soon as and as long as icing conditions are present. This should be done when the propeller anti-icing is selected as part of the Level II procedure.

FIGURE 12 : ATR 72 ANTI-ICING ADVISORY SYSTEM (AAS)



ATR 72 ANTI-ICING ADVISORY SYSTEM (AAS) : An effective warning logic to back up crew awareness



1.3.3. ATR 72 STICK PUSHER STALL PROTECTION SYSTEM

As the NTSB knows, the stick pusher is now well recognized in aircraft design and was initially introduced for other aircraft which could present catastrophic characteristics at high A.O.A. Such unacceptable characteristics were typical of the T-tail configuration, which can be prone to locked deep stall phenomena.

The object of the stick pusher concept is to restore an artificial stall identification triggered before the critical A. O.A is reached, by applying a powerfull nose down input on the pitch axis as soon as the aircraft A.O.A reaches a preset value. The selection of this pre-set A.O.A is the result of extensive progressive stall demonstrations. Due to the catastrophic consequence of a locked deep stall, it was obviously not desirable nor requested, to demonstrate aircraft behavior beyond the stick pusher setting. Numerous development flight accidents with other aircraft models confirmed the possible catastrophic consequence of flight demonstrations beyond stick pusher A. O. A..

Since this concept was first introduced, to prevent the occurence of such a phenomenon, new less radical applications were adopted in the aviation industry to prevent appearance of marginally acceptable phenomena occuring at high angles of attack.

For the ATR aircraft, the stick pusher concept was fully incorporated in the design before first flight in anticipation of possible deep stall problems. This phenomena was not revealed during the development testing, while wing dropping tendencies were detected at very high A.O.A. The available stick pusher function was therefore selected to prevent any appearance of this phenomena within the certificated flight enveloppe.

The stick pusher A.O.A setting was the result of extensive flight test demonstrations ; including Power ON dynamic stall demonstrations in turn,

The selected A.O.A insures that all certification criteria are met during this demonstration which, due to its dynamic aspect, causes A.O.A to go beyond the stick pusher setting.

These demonstrations were performed for each flap configuration up to angle of attack values 10O/o higher than the pusher activations thresholds.
The results were fully notified to the Airworthiness Authorities :
on ATR 42 within the frame of the basic certification process,
on ATR 72 the results were also specifically given to the FAA in response to a specific request from the FAA.

This information was also provided to the NTSB in answer to the Review item F2- 1 raised by the NTSB Performance Group in charge of the Flight 4184 investigation.

1.4. ATR 72 ICING OPERATING PROCEDURES

The NTSB's Report omits important factual information in respect to the warnings which were provided to American Eagle/Simmons' flight crews by both ATR and American Eagle regarding the hazards of conducting flight operations in icing conditions, including icing conditions which exceed Appendix C conditions. This factual information is critical to a complete investigation and analysis of this accident because it has a direct bearing on the flight crew's performance vis-a-vis the warnings they had been provided about flight operations in such conditions. The BEA provides its comments in respect to this issue in sections 1.4.1 and 1.4.2 below as an addition to the NTSB's Draft Report, section 1.17.6. Flight and Airplane Operating Manual.

1.4.1. AFM/FCOM AND MANUFACTURER INFORMATION

The following information was contained in ATR's Airplane Flight Manual (AFM) and Flight Crew Operating Manual (FCOM) at the time of the accident.

ATR's AFM and FCOM provide specific procedures in respect to the operation of the ATR-42/72's anti-icing system (Level II) and de-icing system (Level III). In respect to the ATR's Level II anti-icing system, the AFM and FCOM provides instructions under the section entitled *Operation in atmospheric icing conditions*. In this regard, the AFM states :

> *Operations in atmospheric icing conditions require SPECIAL CONCERNS as ice accretion on airframe and propellers SIGNIFICANTLY modifies the aerodynamic characteristics.*
>
> *The main aspects to consider are as follows :*
> *Even small ice accretion, which may be difficult to detect visually, are enough to affect the aerodynamic efficiency of airfoils. For this reason, ALL ANTI ICING PROCEDURES and SPEED LIMITATIONS MUST BE COMPLIED WITH as soon as and as long as ICING CONDITIONS are met and even before ice accretion actually takes place.*

The ATR-42 AFM also contains the express prohibition that :

> *Operation in freezing rain must be avoided.*

This same prohibition was not included in the ATR-72 AFM by inadvertence. However, for Simmons Airlines and their flight crews, the prohibition was clearly applicable to both aircraft types. The American Eagle Flight Manual Part I Information Bulletin specifically states :

> *"the AFM 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, glaze ice, freezing rain, etc.) The only existina exception is the ATR-42/ 72 AFMs, which state that flight in freezing rain '... SHOULD BE AVOIDED. . . "*

With respect to holding, ATR's Flight Crew Operating Manual (FCOM), and the applicable performance charts for holding, do not provide for the use of a Flap 15 degree configuration in holding. The FCOM specifically states :

Holding charts are established:

in clean configuration

- *with air conditioning in normal mode*
- *with NP=86% and NP=77% propeller speed*
- *at VmHBO in icing conditions*

This minimum maneuvering speed covers the whole flight envelope in normal conditions and in icing conditions without appreciable increasing of consumption.

When using air conditioning in high mode, fuel consumption is increased by 2.5%.

All charts are established with a center of gravity location corresponding to 25%.

The temperature effect is negligible.

ICING CONDITIONS

Tables are computed only with NP = 86%

The only holding speed provided for in ATR's FCOM, therefore, is the VmHBO for icing conditions covering both normal and icing conditions. The selection of this minimum speed for both non-icing and icing conditions was done to avoid crew errors.

In respect to other information provided by ATR, immediately after receiving the DFDR following the Mosinee incident, which was recognized to have occurred in freezing rain outside aircraft certification limits, ATR issued an *ALL OPERATORS INFORMATION MESSAGE* to advise them of the incident and what had occurred. This bulletin fully described the incident and advised all operators that the freezing rain conditions encountered by the aircraft affected aileron forces to the point of disconnecting the autopilot, and caused the aircraft to roll until the pilot took over control. ATR's Message stated :

1. *The A/C was submitted to freezing rain.*
2. *This freezing rain affected control forces on the ailerons in such a manner the autopilot was no longer able to maintain the bank angle in the procedure turn.*
3, *As a consequence, the A.P. was normally disconnected by its monitoring s ystem.*
4. *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 wing heaviness was present for about 20 seconds as long as incidence [A. O.A] was not significantly reduced.*

ATR's Message also reminded all operators of the 1982 FAA Advisory Circular AC 20-117, which emphasized to the aviation community that freezing rain will eventually "*exceed the capability of most ice protection equipment*" and that "*flight in freezing rain should be avoided where practical*". The FAA's Advisory Circular specifically states :

> *It is emphasized that aircraft ice protection systems are designed basically to cope with the supercooled could 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 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.* (*Emphasis added*).

After the Mosinee incident, the FAA issued a Priority Letter AD (89-09-05) restating the warning to avoid freezing rain, and requiring that the AD be placed in the ATR-42 Flight Manual. The AD stated :

> "*When operating in the icing conditions, use of the autopilot is prohibited (for purposes of this AD, icing conditions exist when outside air temperature is between +10 degrees C and -10 degrees C and visible moisture in any form is present.*
>
> **WARNING: *Prolonged operation in freezing rain should be avoided. Ice accretion due to freezing rain may result in asymmetric wing and associated increased aileron forces necessary to maintain coordinated flight. Whenever the aircraft exhibits buffet onset, uncommanded roll, or unusual control forces, immediately reduce angle-of-attack and avoid excessive maneuvering*".** (*Emphasis added*).

In addition to the design modification for the ATR 42 implemented by ATR after the Mosinee incident (vortex generators), ATR also submitted proposed AFM and related FCOM changes to the DGAC. The DGAC, in turn, forwarded the proposed changes to the FAA on March 21, 1989 for its consideration along with the proposed design modifications. (Appendix 1).

ATR's proposed changes to the AFM LIMITATIONS SECTION restated that ***"operation in freezing rain shall be avoided"*** and warned that freezing rain could result in asymmetrical wing lift. A procedure for exiting freezing rain zones was provided. The proposed procedural language stated :

> *WARNING : Ice* accretion clue to freezing rain may result in *asymmetric wing lift and associated increased aileron forces* necessary to maintain coordinated flight. *Should the aircraft enter into a freezing rain zone, the following procedures must be adhered to :*
>
> *a autopilot shall not be used,*
>
> *b. Speed shall be increased in keeping with performance and prevailing weather conditions (turbulence), that is :*
>
> *flaps retracted: 180 kt minimum*
>
> *flaps extended: as closed as possible to VFE for the airplane configuration.*
>
> *c. excessive maneuvering shall be avoided.*
>
> *d. freezing rain conditions shall be left as soon as possible. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course.*

The related draft **Operation *Engineering Bulletin* (OEB)** submitted by ATR to the DGAC gave specific information about freezing rain, repeated the FAA's warning in Advisory Circular AC 20-117, and stated that such zones must be avoided by pilots. The OEB stated in part :

> *Zones where freezing rain is likely to be encountered MUST BE AVOIDED.*

The ATR's OEB also provided the following specific procedures for exiting freezing rain zones :

> *Procedure*
>
> *Nevertheless, should the aircraft enter in a freezing rain zone, the following procedures must be applied.*
>
> *a) Do not use Auto Pilot.*
>
> *b] Increase speed in keeping with performance and prevailing weather conditions (turbulence]*
>
> *Flaps retracted : 180 kt minimum*
>
> *Flaps extended : as close as possible to VFE for aircraft configuration.*
>
> *c) Avoid excessive maneuvering.*
>
> *d) Leave freezing rain conditions as soon as possible. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course.*

In accordance with its preference for design changes over special operating procedures for long term operational safety, the FAA adopted and imposed the vortex generator modification, but did not adopt the proposed AFM manual changes. Considering that these procedures addressed a condition outside the certification requirements, the DGAC did not request their insertion in the manuals. Consequently, the corresponding FCOM changes were also not incorporated in the U.S or France. However, the German and Canadian Airworthiness Authorities did incorporate this information in their operation manuals.

The identified warnings and instructions were subsequently incorporated into a comprehensive brochure prepared by ATR for all operators of its ATR-42 and ATR-72 aircraft. In December, 1991, 193 copies of this ATR *All Weather Operations* brochure were sent directly to American Eagle / Simmons Airlines, enough to provide individual copies to each of its pilots. In addition, nine copies were delivered with the accident aircraft, S/N 401, in 1994 when it was delivered to the airline.

The brochure again quotes FAA Advisory Circular 20-117 and states in a bold block :

> 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 reminds ATR-42 and ATR-72 pilots that freezing rain is beyond aircraft certification and lists the steps for pilots to avoid such zones. These steps are the same steps incorporated into ATR's Operation Engineering *Bulletin* discussed above.

Procedures were also given in this brochure for ATR-42 and ATR-72 pilots if they entered into a freezing rain zone. These procedures provided :

> *SHOULD THE AIRCRAFT ENTER IN A FREEZING RAIN ZONE, THE FOLLOWING PROCEDURE SHOULD BE APPLIED :*
>
> A/P engaged.
>
> RETRIM ROLL L/R WING DOWN "messages"
>
> MONITOR
>
> *In case of roll axis anomaly,* disconnect *AP* holding the control *stick* ***firmly.*** *Possible abnormal rolls will be felt better when piloting manually.*
>
> SPEED INCREASE
>
> Increase the speed as much as performance and weather conditions (turbulence) will allow. Extend flaps as close as possible to respective VFE.

In addition to the above actions, ATR also modified its simulator training data package to introduce a "stall with ice accretion without the icing AOA push-button "ON". This data package incorporated into the flight training simulator program a wing drop to approximately 60 degrees bank which required a firm response by the pilot to stabilize the wings, an increase in speed, and a smooth rotation to recover initial attitude. The same event is also presented in icing conditions without ice accretion with the icing AOA push-button "ON".

1.4.2 AMR EAGLE/SIMMONS' FLIGHT MANUAL AND OTHER PERTINENT DOCUMENTATION

The ATR AFM and FCOM provisions quoted above are also set forth in the American Eagle/Simmons AFM and AOM. Simmons Airlines testified that the ATR ALL WEATHER OPERATIONS brochures were not given to Simmons pilots, however, it is the BEA's understanding that all of the information regarding flight in icing was incorporated into the American Eagle/Simmons Airlines AFM and AOM manuals by the airlines. Therefore, the information set forth by ATR in its *All Weather Operations* brochure was also incorporated by American Eagle/Simmons into the various manuals it provided to its flight crews.

The BEA has set forth below a list of additional American Eagle/Simmons' documents which demonstrate that ATR provided specific warnings and instructions to Simmons' flight crews in respect to flight operations in icing conditions, and which also establish that American Eagle/Simmons' company policies provided extensive warnings to its flight crews which thoroughly covered the hazards of operating in such conditions.

As discussed in Section 1.4.1 above, immediately after receiving the DFDR data following the Mosinee incident, which was recognized to have occurred in freezing rain far beyond certification limits, ATR issued an *All Operators Information Message* to advise operators of the incident and what had occurred.

This bulletin fully described the incident and advised all operators that the freezing rain effected aileron forces to the point of disconnecting the autopilot causing the aircraft to roll until the pilot took over control. Simmons incorporated all of this information, along with a complete factual description of the Mosinee incident including the DFDR data, in a January 23, 1989 memorandum entitled Loss *of Aircraft Stability.* (Appendix 2) This memorandum was provided to "All flight Crewmembers" by Dave Wiegand, Simmons' Director of Flying. This memorandum, which Mr. Wiegand referred to as "a restatement of company operating policies" contained the following "operating policies" in respect to flight operations in icing conditions :

Simmons Airlines aircraft will not be released or flown into known severe icing conditions.

***If** icing or adverse weather is experienced. make a PIREP so your fe[[ow pilots may benefit from your experience. This is important if the weather is better or worse than forecast.*

Supercooled water droplets in liquid form at temperatures above freezing, can freeze on impact with the aircraft. Exercise caution when operating your aircraft near the freezing level in visible moisture.

If freezing rain is encountered, you should exit the condition immediately. This diversion should consist of a turn towards better conditions and/or a climb to a 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.

However, our aircraft are not to be operated in known freezing rain or severe ice. If these conditions are experienced, the procedure is to exit these conditions immediately.

The *American Eagle Flight Manual - Part 1 Information Bulletin* dated 10 January, 1994 also states on page 1 :

. . . the AFM 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.*

The *Simmons Flight Operations News Letter* dated December 1993 (NTSB Exhibit 2T- 1, p. 3-4) entitled *Aircraft Ice* states in part :

The ATR has been tested in all kinds of icing conditions and must demonstrate various performance parameters in conditions corresponding to a failure of the deicing system.

Any time 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 possibte 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 of total ice build up and any potentiat problem related to ice accumulation.

The American Eagle Flight Manual - Part 1, Section 6, Page *8,* issued 17 November 1992 (NTSB Exhibit 2-A, p. 48 - attachment “O”) defines various icing conditions, their effect on airplane performance and actions to be taken under various icing conditions. “Moderate” icing is defined as follows :

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

American Eagle/ Simmons’ Flight Manual, Part 1 para. 43 *Use of anti-ice/deicing* provides further instructions flight crews in respect to the use of anti-icing/de-icing equipment as follows :

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

The American Eagle/Simmons' ATR-42/72 AOM and the Simmons' *Airlines Winter Operations Handout* provides the pilots with significant company policies to be followed in icing conditions. It addresses the detection of ice and states in part :

Detection of Ice

The presence of ice formation may be detected through either visual cues (e.g. buildup of ice on windshield wipers, prop spinners, engine inlets, wings leading edges or icing evidence probes) or from the Ice Detection System. The Ice Detection System is not a substitute for crew vigilance in detecting ice formation. Certain types of ice formation may be slow to trigger the Ice Detection System or may not trigger it at all. For example, ice which is building slowty and sublimating at approximately the same rate may cause considerable delay in triggering the detector or fail to trigger it at all.

Also, freezing participation which tends to flow prior to freezing may flow off the detector prior to freezing, failing to trigger the detector. Yet this same precipitation will flow aft on the wing and freeze creating a potentially dangerous situation Crew vigilance must be used to detect the formation of ice as soon as possible.

The American Eagle/Simmons' ATR-42/72 Operating Manual, issue 04 Nov. 92 provides the following information regarding freezing rain :

> ***Freezing Rain***
>
> *Freezing rain consists of large supercooled water droplets which may form clear icing after impacting the aircraft in negative temperature conditions.* ***If*** *the static air temperature is slightly negative, these large droplets may not be freezing immediately upon impact with the aircraft. As a result, clear icing can build up behind the leading edges.*

The American Eagle/Simmons' ATR-42/72 Operating Manual also discusses crew vigilance in respect to the detection of ice. American Eagle's AOM states :

> *Crew vigilance in observing formations 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 spinner [42], ice evidence probe [72], and wing leading edges and engine inlets.*

Finally, with respect to **holding speed,** the American Eagle ATR 42/72 AOM provides :

> *When holding is anticipated to be of short duration, holding should be accomplished with the aircraft clean at the flap zero Conservative Maneuvering Speed. If a hold will be of an extended or indeterminate time period, the VmHBO speed for Icing Conditions should be used as a holding speed.*

1.5. ATR FLIGHT TRAINING

The NTSB's report omits critical factual information regarding the training information and simulator data packages provided by ATR for the ATR 42 and ATR 72 aircraft in respect to flight operations in icing conditions and unusual attitude training specifically relating to ice-incuced stall and roll departures. This important factual information is necessary for a complete analysis and understanding of this accident since it has a direct bearing on the training information made available to pilots by ATR. Such information has been largely ignored by the NTSB. The BEA provides its comments in respect to these issues in sections 1.5.1, 1.5.2 and 1.5.3 below.

1.5.1. ATR TRAINING CENTER (TOULOUSE - FRANCE)

The ATR Training Center (ATC) located in Toulouse is in charge of the development of training material for its own application within its two simulators as described below, as well as material for worldwide Training Centers.

1.51.1. HARDWARE CONFIGURATION

There are two kinds of simulators :

AMS : This is a fixed base simulator devoted to Systems/Avionics management and procedures training. There is no artificial visual imagery system. That means that only equivalent IFR flight conditions are allowed for training.

FFS : Full Flight Simulator aims at crew training for basic flight dynamics and handling skills throughout a city pair leg from take-off up to cruise level down to approach/landing.

A synthetic imagery system is used to render the visual cues necessary to close the crew flight control loop.

1.5.1.2. SOFTWARE CONFIGURATION

a) general

. The data package consists of a 6 degrees of freedom (D.O.F) modelling based on combined data from Wind Tunnel and Flight Testing.

. Upon qualification by ATR Flight Test Center, any revised data package is then approved for release and readily incorporated in ATC simulators.

. A proposal for data package update is then submitted to airlines training centers.

b) ATR Icing Data Package for Simulators.

As early as 10/21/1988, an effective ATR42 ICING MODELISATION (Document GO 5 D04826) was added to the basic aerodynamic model to obtain a representative performance of known icing effects on the ATR 42 further to the experience gained from former icing event investigation.

- It comprized a post stick shaker stall with random roll upset (intensity and direction).

- Three icing severity levels were afforded (high-medium-low) to take care of cruise or de-icer failure ice shapes.

- Final tuning was done in Toulouse AMS with flight test pilots.

- It was first implemented by Flight Safety International on the ATR 42 simulator in HOUSTON by 08 Feb 1989 prior to completion of the ATC Simulator on 18 May 1989.

- It allowed flight crew familiarization with the roll upset situation and subsequent stall recovery procedures.

. An additional Icing Modelization package (D05 147) was further made available at FSI Houston by 29 August 1989 and updated on the ATC Simulator as well.

. Furthermore, the ATR 72 aerodynamic Data Package Icing Complement (DO 5481) was integrated into the ATR 72 ATC simulator by 26 June 1990 further to the knowledge gained from the MOSINEE incident investigation. This coding was forwarded to the ATR 42/72 Houston Simulators at the same time as well :

- Three icing severity levels were still afforded,
- The icing formulation and aerodynamic data were providing :
  . An abrupt asymmetrical stall with roll upset.
  . Increased Roll control forces during the recovery.

. This package in Particular allowed flight crew training for unusual attitude situation as depicted in item 12 of the training syllabus referred to in parag. 1.5.1.3 hereafter.

Moreover, a additional data package ATR72 DO 6243" Anti-Icing Fluid Type II" was integrated on both ATC et FSI Simulators since 7 January 1993.

1.5.1.3. ATC TRAINING SYLLABUS

The ATR Flight crew Training documentation, at december 1993 ISSUE page 34/35 shows that the Full Flight Simulator (FFS) briefing notes for session 8 "handling and stall demonstration" are clearly addressing unusual situations such as :

- item 11 : stick pusher presentation with stall recovery technique AP ON & OFF

  item 13 : stall in icing conditions Level II activated (A.O.A light ON) to observe the speed diference due to the lower stall alert threshold then followed by a stall recovery procedure.

  item 14 : stall approach / recovery technique to apply everytime the stick shaker is activated.

The item 12 hereafter is even more significant as it anticipates the unusual situation resulting from a lack of selection of level II/III de-icing configuration although ice may be accreting :

- position HIGH will generate a rapid speed decay,

  no warning until stick shaker / pusher apart from an instability on ailerons,

  an abrupt wing drop (random),

  the recovery technique Max Power / Wings level follows.

ITEM 12 : ***STALL WITH ICE ACCRETION WITHOUT AOA ON***

- *A/C preparation is same as above and instructor should insert ice accretion in HIGH position.*
- *PF* is *advised of approaching stall by the aileron instability.*
- *When stick-pusher is triggered one wing drops to around 80° bank.*

Procedure :

- *PF advances PL's* forward to white marks and requests "Max *power, flaps 15 °", and simultaneously, he levels the wings.*
- *He stabilizes the wings, using both hands, allowing the lAS to increase to white bug speed , and then smoothly rotates in order to recover initial altitude.*

He requests "Flaps O°" at RED BUG speed.

At any time, the instructor has control on the time of occurence and severity of icing conditions.

. On the AMS simulators from ATC, actual ice build up on the Ice Evidence Probe (IEP) is simulated by a light "switched on" within the same vision area from the Captain.

- A few seconds time lag was implemented before the AAS is triggered.

- Therefore, a fast pilot reaction to select Level III would avoid triggering of the AAS single chime.

On the FFS simulators, the perception of icing conditions would rely entirely on the synthetic imagery system, close to vision through windshield, where penetration in clouds is rendered quite realistically.

- It therefore allows for detection of “visible moisture in the air in any form”.

  The crew has to determine if “icing conditions’’ are then prevailing.

In summary, the identification of any aerodynamic phenomena since 1988 led ATR manufacturers to readily improve their training facilities in a continuous manner.

1989 - Crew training to A/C recovery technique after a post-stall roll upset.

- 1990- Training to recover from abnormal icing encounter as derived from MSN 91 MOSINEE with abrupt roll upset after failure to select Level II.

- 1992- Training to the effect of de-icing fluids type II

- 1992- Training to recover out of trim situation further to a bad ground de-icing of tail plane airfoil.

1.5.2. AMR EAGLE TRAINING CENTERS

The following gives the delivery dates of ATR icing model for Simulators.

	FSI HOUSTON ATR 42	FSI HOUSTON	FSI WILMINGTON ATR 42/72	AMR (EX ATI) ATR 42
ATR 42 ICING MODEL DOC 4826 DOC 5147 (ADD TO 4826)	8 FEB 89 29 AUG 89	18 MAY 89 29 AUG 89	18 MAY 89 29 AUG 89	18 APR 89 4 JUL 89
ATR 72 ICING MODEL DOC !5481	N/A	26 JUN 90	26 JUN 90	N/A

Flight Safety International also gave evidence that ATR icing document DO 4826 was received in January 1989 and readily implemented prior to the completion of the ATC simulator,
It was further updated with DO 5147 as well.

It is also confirmed that by February/March 1993, date of the last check of the flight 4184 Captain, FSI had implemented ATR 72 icing model D05481 and was also currently running an “Handling and stall demonstration”FFS training session equivalent to ATC FFS8 session (stalls and unusual attitudes as for ATC items 11 to 14).

1.6. METEOROLOGICAL INFORMATION

This section consists in a brief summary of the BEA "STUDY OF METEOROLOGICAL INFORMATION AS A CONTRIBUTION TO THE NTSB REPORT (dated April, 1996), appended to the present Document, as Appendix 3.

The NTSB provided the BEA numerous data and documents which were used in this study :

general plotted and analysis and ground charts,

available data issued from radiosoudings,

weather radar and satellite imagery,

available ACARS data transmitted during the flight, pertinent PIREPS and testimonies,

CVR and ATC records and DFDR environment parameters.

1.6.1. GENERAL SITUATION

A low pressure area covered the United States to the east of the Mississippi. An active disturbance was associated to this low pressure area.
Between 15:15 and 15:58, the ATR 72 was flying in this area, in the layer between 12000 and 9000 ft, in and out the clouds, then from 15:45 in the dense cloud layer.

1.6.2 CLOUDS CONDITION

The flight took place at the edge of a stable cloud layer whose mean top was at 9 000 ft and the maximum at 10 500 ft. Turbulence did not exist or was very light, certainly limited to the maximum level of the tops, possibly associated with an effect of the strong wind whose laminarity was disturbed by the proximity of the warm frontal surface (wind shift).

A more unstable layer was located just above, adjoining the previous one (top 14000 ft), reaching 18000 ft at the level of the warm sector. **After 15:50 these layers thickened noticeably, while the rainy area linked to the depression was moving to NE, this being revealed by the intensification of the precipitation echoes detected on the Lockport weather radar. This confirms the detection of supercooled rain and drizzle drops as precipitation.**

1.6.3. CONDITIONS OF TEMPERATURE AND LIQUID WATER CONTENT

The precipitation detected on the Lockport radar was partly generated by the cloud layers located above 10 000 ft and played a role in the enlargement of water droplets and drops contained in the layer in which Flight 4184 was flying, where temperatures varied betwwen -2 and -4 °C (SAT). This can be directly linked to the water vapor and liquid water contents through the air mass mixing ratio (saturing or not), depending on the aircraft location in time and space (holding pattern legs) :

- outside the cloud layer (humid air),
- in the cloud layer, without precipitation (saturated air),
- in the cloud layer, with precipitation (saturated air with increasing liquid water content).

ln fact, on the basis of adiabatic theory, a decrease in temperature from -2 to -4°C at approximately 3000M (10 000 ft) would induce a global increase in cloud liquid water content (LWC) of 0,7 g/kg dry air, which corresponds to 0,65 g/m^3, without taking into account the extra liquid water due to the precipitation falling from the layers above. ln this case, temperature variations must be correlated to the corresponding areas traversed.

1.6.4. ICING CONDITIONS

Calculation of the time spent by the ATR 72 in precipitation leads to a cumulative time of almost 24 minutes out of a total time of more than 30 minutes in such conditions in the holding pattern, with static air temperature varyimg between -2 and -4 °C (total air temperature between + 1.5 and + 3.5 °C). This duration is based on precipitation echoes detected on the weather radar in the area *of* the holding pattern of the aircraft, which means, by deduction, drop size diameters detected of about 100 µm or more (see appendix 3).

Between 15:24 and 15:29 and then from 15:33 to 15:35, the aircraft was flying intermittently and briefly in low to moderate precipitation (15-20 dBz). SAT varied between -2.5 and -4 °C (LWC = 0.45 g/m^3) and TAT between +1, 5 and +2.8°C. **The crew, who had activated the airframe de-icing at 15:16.32, switched it off at 15:23.22, and although the NP had remained at 86% since take** off **(during climb, cruise, initiation of the descent phase), they reduced it to 77% at 15:24.13 (DFDR time, steady state). At 15:33.56 a caution alert single chime was recorded on the CVR which was not acknowledged by the crew.**

Between 15:37 and 15:39.30, the plane passed through a light precipitation area (5 to 15 dBz) ; then, from 15:40 to 15:45, precipitation became moderate (15-20 to 25 dBz), and precipitation was also falling from upper layers. Temperatures varied between -2.5 and -4°C (LWC = 0.45 g/m3) and TAT between +1.8 and +2. 2°C. **In that interval a caution alert single chime sounded, which can be considered to be the aural warning from the ice accretion detector 15:41.07 ; the crew immediately activated the airframe de-icing and modified RPM, increasing NP from 77% to 86%.**

At 15:48, the aircraft left an area of generally light precipitation (5 to 15 **dBz), including precipitation from an upper layer ;** SAT varied between -2.3 and -3.2°C (LWC = 0.27 g/m^3), TAT by +1.8 and +2.5°C. **At 15:48.32, one of the pilots remarked "I'm showing some ice now".**

At 15:55.42, the copilot said "we still got ice", getting no answer from the Captain. The ATR had been flying under precipitation becoming moderate for more than four minutes (10 to 20 dBz) with SAT between -2.6°C and -3.5°C (LWC = 0.27g/m^3) and TAT between + 1.2°C and +2.2°C.

From 15:56 until 15:58, the plane was descending, from 10000 ft. to about 9000 ft, in moderate precipitation (20 to 30 dBz). SAT varied between -1.2 and -3.5°C (LWC = 0.5 g/m^3] and TAT between +2.8 and +4.5°C.

1.6.5. ICE ACCRETION

The aim of this paragraph is not to discuss the size of water drops and droplets in clouds or in precipitation. The radar echoes considered are precipitation echoes ; the minimum diameter for drop detection being about 100µm.

Using parameters set out in this study (liquid precipitation, air temperature, liquid water cotent), it is possible to make a simple ice accretion calculation, using the “Lucas Aerospace” diagram : accretion per minute in relation to liquid water content. The values calculated are provided for information only and are no more than a rough estimate. Ice accretions (rime or glaze) would have reached 1 to 2mm/mn, which overall represents a thickness of between 30 to 65mm during the time spent in the holding pattern for more than 30 minutes, independently of freezing drizzle or freezing rain falling in the layer or from the layer above for about 24 minutes.

As an example, for the different major phases described above, the following rough values were obtained (regardless of drop size or water runoff capacity and liquid precipitation) :

- between 15:24 and 15:35: thickness of 10 to 12mm,
- between 15:37 and 15:45 : 11 to 13mm,
- between 15:46 and 15:48 : 2mm,
- between 15:51 and 15:55: 4mm,
- between 15:55 and 15:58 : 4 to 6mm.

No calculation or information could lead to a conclusion as to the possible shape of ice accreted on the wing, nor regarding an ice ridge behing the de-icing boots. **However, we can assume, considering the size of the drops (100µm or more), the temperature of about -2°C and the aircraft configuration (flaps at 15°, leading to AOA reduction through 0°) that water drop impacts occurred both aft of the upper wing leading edges and that, due to a deficiency in heat transfer, significant water run-back could have occurred aft of the de-icing boots. These observations mainly relate to the time from 15:37 to 15:45 (including the AAS warning time) and between 15:51 and 15:58 (last minutes before the accident).**

1.6.6. AVAILABLE METEOROLOGICAL INFORMATION FOR THE FLIGHT 4184

. **Flight release**

As specified in the NTSB Report, the available AIRMET, which stated icing in precipitation, was not released to the flightcrew by the Dispatcher. But the flightcrew received all other pertinent information about the weather situation including the disturbance area as well as winds and temperatures in altitude.

. Hazardous in flight Weather Advisory Service (HIWAS)

This AIRMET was also broadcast over VOR frequencies. In the CVR transcription there is no information on a listening of the AIRMET through HIWAS. However there is no evidence that the flightcrew did not select a HIWAS frequency in order to listen an up-to-date weather information before the CVR started (15:27.59).

. **Center Weather Service Unit (CWSU)**

One out the five operational units of the Air Traffic Control System Command Center (ATCSCC), based in Virginia, is the Central Flow Weather Service Unit (CFWSU) which provides 24 hours service to the ATSCC in particular. This service consists in providing a Meteorological support to the 20 ARTCC (Air Route Traffic Control Center).

Regarding the Chicago Weather Service Unit (CWSU), there was no weather Advisory in effect about freezing precipitation or icing conditions at the time and in the area of the accident.

Several PIREP's on icing were reported to the ATC by flightcrews operating in the Chicago area. But no information regarding the deal with these PIREP's is known, nor the precise actions, of the CWSU as well as of the CFWSU meteorologists, that day.

1.7. FLIGHT RECORDERS

The BEA believes that factual information set forth in sections 1.7.1 and 1.7.2 below is critical to a complete understanding of the data obtained from Flight 4 184's DFDR and CVR.

1.7.1. CVR

Note 2 of the NTSB Exhibit 12A, Cockpit Voice Recorder Transcript, AMR flight 4184, states that "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".

The recording started at 1527:59, uninterrupted until 1557:57.1.

The CVR group, consisting of representatives from the parties to the investigation, collectively transcribed the tape in its entirety, directly on a micro-computer, and had the opportunity, to review the end product only by displaying through the computer screen. The NTSB took alone the decision to publish the public CVR transcript (Exhibit 12A) in an incomplete and edited version. The deleted parts were considered by the NTSB as "non-aviation related conversation or non pertinent and flight attendant conversation". The CVR group members were not consulted upon the reasons for editing in this manner.

The correlation between CVR and DFDR timing was obtained by adding to DFDR a time bias of 4 seconds (i.e Time CVR = time DFDR + 4 seC). However, in this document, all CVR and DFDR events were given in correct sequence but dated without bias such as to avoid any mismatch with source material.

1.7.2. DFDR

The following complementary information has to be added :

Two specific labels on DFDR record represent a discrete signal indicating when the force applied on the Captain or F/O Control Column Rod (pitch) is exceeding 10 daN (22 lbs). This discrete signals have three valid states :

- Neutral = 3
- Down = 2
- UP = 1

Exceeding the a.m threshold triggers a different micro switch closure on either direction up/down. As long as the force is exceeding 10 daN, a ground signal is sent to the acquisition Unit (FDAU).

FDAU function is to scrutinize the a.m signal 16 times per second (i. e each 62,6 ms Cycle) but the output data is proceeded once per second based on the outcome of the three last sampling.

The “exceed signal” is only validated after ground is detected twice over the three last cycles. Therefore, it would mean that an “exceed signal” :

- shorter than 62,5ms is not recorded.
- longer than one (1) second is recorded for sure.

Any signal in between will or will not be recorded depending upon its position in the one second data processing cycle.

Concerning Flight 4184, the parameter has been validated during aircraft rotation at take off, since this particular discrete was active, with an elevator deflection up on the F/O side which correlates with the flying pilot at that time.

1.8. TESTS AND RESEARCH

The NTSB's report omits significant factual information regarding prior ATR 42 incidents as well as the extensive post-Roselawn accident investigation. This information is critical to a complete understanding of this accident because it makes clear that none of the prior ATR 42 incidents disclosed an ice-induced "aileron hinge moment reversal" phenomenon. In this regard, none of the prior incidents exhibited the unique characteristics involved in the Roselawn accident, namely an outer wing flow separation at an AOA well below the icing stall warning threshold, without any prior noticeable drag build-up and without any significant asymmetrical lift loss. This fact becomes even more apparent when the factual record of the extensive post-Roselawn accident investigation is fully examined. The BEA discusses these critival facts in sections 1.8.1 and 1.8.2 below.

In respect to the NTSB's treatment of the Bilateral Airworthiness Agreement (BAA) the certification process between the FAA and DGAC under the BAA, and the exchange of airworthiness information between the FAA and DGAC under the BAA, the BEA believes that the report is highly deficient. Critical factual information is missing regarding the respective roles of the DGAC and FAA during the certification of the ATR aircraft. Further, the report appears to ignore the communications which occurred between the FAA and DGAC in respect to continuing airworthiness.

The BEA discusses these issues in sections 1.8.3, 1.8.4 and 1.8.5 below.

1.8.1. PREVIOUS ATR-42 INCIDENTS

Five prior icing related ATR 42 incidents were considered as being possibly relevant by the NTSB :

AMR Eagle/Simmons Airlines ATR-42 on approach at Mosinee, Wisconsin, December 22, 1988. (MSN 9 1);

.Air Mauritius ATR-42 in cruise over the Indian Ocean, April 17, 1991 ; (MSN 208);

.Ryan Air ATR-42 in cruise over South Wales , August 11, 1991. (MSN 161);

.Continental Express ATR-42 on approach at Newark, New Jersey, March 4, 1993. (MSN 259); and,

.Continental Express ATR-42 in cruise over the Burlington area, Massachusetts, January 28, 1994. (MSN 153)

1.8.1.1. SUMMARY OF PREVIOUS ATR 42 INCIDENTS

a) <u>AMR/SIMMONS ATR 42 s/n 91 on December 22, 1988 on Approach Mosinee</u>

During approach, in level flight at 6000ft, when flying in conditions later on clearly established as freezing rain, not using the airframe de-icing system, (although ATR was initially advised that the de-icing was “on”) during a right bank turn with 0°flap and autopilot engaged at 157 kt (engine torque 22-23%) and at an AOA of 10.2°, the aircraft progressively rolled out to a 0° bank angle, while aileron and rudder positions were maintained.

When the AOA reached 11.5°, the autopilot disengaged, the ailerons immediately deflected to about 12,5° and the aircraft rolled to the left to an 80° maximum bank angle. The maximum aileron deflection was recorded at 12.5°.

Recovery was achieved by a prompt reaction of the crew, which applied maximum power and brought the wings back to a level position by quickly positioning the ailerons opposite to the initial roll upset. The loss of altitude was 600 feet.

The NTSB conducted the investigation. The BEA participated in this investigation with the NTSB, mostly in meetings in Washington (December 29-30, 1988 and March 2-3, 1989) and Chicago (March 19-20, 1990).

On January 16, 1989, the DGAC disseminated a telex message to all concerned Airworthiness Authorities (including the FAA) which reminded the authorities of the importance of observing the minimum operating speed in icing conditions. In this message, special notes also drew their attention to the purpose of the AAS system ‘that gives a better information for managing” the flight in icing conditions and to the fact that “no aircraft is approved for flight in freezing rain conditions”.

On January 17th, 1989, ATR issued an All Operators Telex providing a detailed briefing about this incident, reporting that it had occurred in freezing rain and referencing the language and the recommendation of the FAA Advisory Circular 20.117 that such conditions be avoided.

On January 24 1989, ATR generated a complete incident analysis based upon DFDR read out that was provided to the DGAC, and to the BEA. Based upon the initial pilots' report, ATR assumed in this analysis that the airframe de-icing had been selected ON prior to the incident". The BEA issued a comprehensive report of this event, based on CVR transcript, DFDR data study and all available environmental information, which was provided to the NTSB by the BEA in Washington on March 2nd and 3rd, 1989 (See attendees list attached next page). During that meeting, the NTSB informed the participants that the pilots had changed their statement and that the airframe de-icing was not selected ON prior to the event. ATR did not re-issue its analysis.

3/2/89 - NTSB Meeting to Discuss ATR-42 Icing Characteris[tics] and 12/22/88 Incident

Attendees — Please give name, organiza[tion] and a telephone contact.

Gene Doub	NTSB - IIC	(312) 377-8177
Jack Drake	NTSB	(202) 382-6825
Xavier CHAMPION	Aerospatiale	61-93-80-59
Eric DORMOY	DGAC	(1) 45.52.51.27
GILBERT CATTANEO	Flight Test Center (DGAC)	42 48 30 00
Philippe GOURGUECHON	Pilot Inspector DGAC	(1) 40 43 46 27
J.C. ANTOINE	B.E.A. Investigator	33 (1) 4828 5002
Don ELAM	FAA	(202) 267-9632
BOB McCRACKEN	FAA SEATTLE	206 431 1979
DENNIS GROSSI	N.T.S.B.	(202) 382-6692
Steve Corrie	NTSB	382-6537
Glen Salottolo	NTSB	382-6671
CHRISTIAN TYNELSKI	ATR SUPPORT INC	(703) 430 36 36
EDMOND BOULLAY	DGAC Rep to FAA	202 944 6054
Gwendolyn Adams	NTSB (NSF)	202 382 6619

ATR proposed to the DGAC, and through the DGAC to foreign Airworthiness Authorities (including the FAA), to amend the manufacturer's AFM and FCOM in order to further emphasize the risk of flying in freezing rain and to provide procedures for inadvertent encounters with such conditions. The FAA did not accept the proposed manual changes, but rather, mandated the development of a design change which aimed at moving the ice-induced type of asymmetrical stall seen in Mosinee beyond the icing stall warning threshold. The DGAC and ATR then proposed to retrofit the entire ATR 42 fleet with the addition of vortex generators derived from the configuration developed for the ATR 72. The retrofit was monitored by the DGAC but no French AD (Airworthiness Directive) was published. However, the FAA issued an AD requiring the installation of the vortex generators on the ATR-42 aircraft *.

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* the retrofit of all the North American fleet of ATR 42 with vortex generators allowed the FAA to delete the temporary restriction of use of the autopilot in icing conditions imposed just after the incident.

In its draft Memorandum, dated March 5, 1990 the NTSB's I.I.C proposed the following probable cause for this incident :

"The National Transportation Safety Board determines that the probable cause of this incident is a stall induced by the accretion of moderate to severe clear icing due to freezing rain. Factors contributing to the incident are the lack of a hazardous weather advisory for severe icing being issued by the National Weather Service, lack of recognition of the severe icing condition by the flight crew, and the non-use of the airframe deice system by the flight crew." (Emphasis added.)

The NTSB did not issue a final report.

In its Brief of Incident data base, the NTSB only issued findings and a simple probable cause :"a stall induced by the accretion of moderate to severe clear icing".

b) Air Mauritius ATR 42/SN 208 on April 17. 1991 over the Indian Ocean.

While cruising at flight level 160 in clouds with SAT at about -3°C, with autopilot engaged, with anti-icing system ON, with airframe deicing system OFF and at 77% NP (minimum required was 86%), the aircraft experienced a progressive loss of speed from 183 to 160 kt (engine torques 710A) with a 10kt/mn rate. At 160 kt, two roll excursions were controlled by the autopilot.

When the crew disconnected the autopilot, the AOA increased to 11° and the aircraft rolled to the right, achieving a 40° maximum bank angle when the pilot released the effort applied on the control wheel on the roll axis, during the nose down maneuver. Recovery was performed without any controllability difficulty along with applying full power. The DFDR data did not show any tendancy of the ailerons to move uncommanded.

Following this incident and the later ATR 42 S/N 161 incident, which also occurred at the improper NP77% setting, the DGAC undertook with the manufacturer a study aiming at determining the airflow disturbance and the loss of speed generated by ice contained propeller blades when NP is set at 77% instead of the required 86% in icing conditions. Moreover, the DGAC required an improvement of the AFM, check-list and operational procedures to re-inforce the requirement of a minimum Propeller RPM (86%) in icing conditions.

ATR incorporated a brief of this incident in their Monthly Report dated April 1991 and sent it to all operators and Airworthiness Authorities (including FAA Washington, Seattle and Brussels).

c) **Ryanair ATR 42-S/N 161 on August 11. 1991 over South Wales** *.

While cruising at flight level 180 with autopilot engaged, with anti-icing system ON, with airframe deicing OFF, and at 77% NP (instead of 86% as required in icing conditions), the speed progressively decreased, starting from 180 kt, at the rate of 8 kt/mn. When reaching 145 kt (engine torques 68%) with an AOA of 10°, a g-break was recorded, then the stall warning and stick shaker were activated and the autopilot disconnected.

The applied elevator input (5° nose-up) led to an AOA varying between 10° and 13°. The aircraft stalled with an initial roll of 12,6° left wing down immediately followed by a right wing down to a 49.9° bank angle. The nose-up elevator input remained for 12 seconds, in a stall condition.

Recovery was performed as soon as the crew pushed on the control column to decrease the AOA and restored the wings level position. Shortly afterward, the flight crew reported to ATC very heavy icing conditions at flight level 180 (the aircraft flew through a cold front with freezing rain). The DFDR data did not show any tendancy of the ailerons to move uncommanded at any time during the stall.

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*. A similar event occurred in cruise at about 16,000 fleet with a British Aerospace ATP flying through the same cold front, in freezing rain conditions,

The investigation was conducted by the DGAC, with the BEA assistance, on behalf and with the Irish Air Navigation Service Office. The actions taken by the DGAC and by ATR were identical to those initiated after the Mauritius incident.

ATR incorporated a Brief of this incident in their Monthly Report dated August 1991 and sent it to all operators and Airworthiness Authorities (including FAA Washington, Seattle and Brussels).

d) <u>Continental Express ATR 42 S/N 259 on March 4. 1993 at Newark</u>.

The aircraft leveled at 3,150 feet to intercept the final approach descent path. It remained at this altitude during about 15 mn, at flaps 0 setting, with TAT varying between 0 degrees C and -2 degrees C.

Severe turbulence and icing conditions prevailed. Anti-icing was ON, the NP setting was set at 77% (minimum required was 86%) and airframe de-icing was ON. The autopilot was ON with noticeable activity to maintain a wings level altitude. The airspeed was fluctuating at about 170-190 kt with peaks between 140-208 kt. After the aircraft initiated final descent, the crew set engine torques at 30%. A banking tendency developed to the right. The autopilot disconnected at an AOA of 7°, at a speed of 170 kt and the ailerons deflected to 7° to the right, then were positioned on the opposite stop (14°). The roll excursion was limited to 52° right.

Recovery was performed while controllability remained difficult, due to the high level of turbulence, until touch down.

The NTSB conducted the investigation and sent a DFDR copy to the ATR Manufacturer.

ATR generated a study based on the DFDR read out and communicated this information to the NTSB, the DGAC and the BEA. However, the analysis of the aircraft performance and controllability from the DFDR data traces was seriously hampered by the extreme levels of turbulence present during the entire period.

The NTSB did not provide the BEA with any information on its investigative results. Meteorological data required for a proper characterization and evaluation of the prevailing atmospheric conditions was requested from the NTSB by the BEA, but was never provided. The existence of freezing rain conditions and its correlation with the flight crew's observations could not therefore be confirmed. The narration of the incident filed in an anonymous manner by the pilots into the NASA ASRS data base, which somewhat differs from their previous report made in 1993 right after the incident and from what the DFDR data traces show, was not communicated to the BEA, DGAC or ATR.

Based upon the available data and since no noticeable aircraft performance degradation could be detected from the DFDR data, the BEA, DGAC and ATR concluded that the incident had been primarily generated by the severe turbulence. The side contribution of unidentified ice contamination was acknowledged as a possible factor only, however, all aircraft responses were consistent with the documented effects of the turbulence.

The NTSB later issued a factual report stating that the Newark incident occurred in "severe turbulence with strong horizontal gusts and icing conditions".

e) <u>Continental Express ATR 42 S/N 153 on January 28.1994 at Burlington</u>

While cruising at flight level 160, with the autopilot engaged, and with the airframe de-icing ON, the aircraft experienced a progressive loss of speed from 200 kt to a speed (144 kt), lower than the minimum speed authorized in icing conditions, at an average rate of 6kt/mn.

Correlatively, the engine torques decreased form 72% to 66% in the same period. When the AOA reached 11.5°, the autopilot automatically disconnected at the stall warning and a g- break was noted. The aircraft stalled. After the stall commenced the ailerons briefly deflected to about 10° left and the aircraft rolled on the left with a maximum bank angle of 54°.

Recovery was performed by the crew by promptly pushing on the control column and by applying full aileron deflection in a direction opposite to the initial roll upset.

The NTSB did not investigate the incident.

ATR received the DFDR directly from the Airline. The DFDR analysis found that the high level of drag and resultant loss of speed were consistent with severe ice accretion conditions. A momentary modification of the aileron hinge moment was noted after the stall commenced, but it had no effect on the incident. The manufacturer communicated all available information to the BEA. It was analyzed by the DGAC as well, which questioned the ATR conclusion regarding the presence of severe icing given that the accurate weather conditions were not known.

The DGAC requested a review of the ice codes which had been applied to the ATR-42, to compare this to the changed industry ice codes used for the ATR-72, as the ATR-72 had no history whatsoever of icing incidents involving roll control. This study was underway at the time of the Roselawn accident.

1.8.1.2. COMPARISON OF FLIGHT 4184 AND PREVIOUS ATR-42 EVENTS CIRCUMSTANCES AND CHARACTERISTICS

The factual data of each previous incident have been compared to identify possible similarities.

a) Configuration Comparison

All of the ATR-42 events reported prior to the Roselawn accident occurred in the flaps 0 configuration. The airplane S/N 401, instead, encountered icing conditions conducive to ice accretions in the flaps 15 configuration and experienced a roll upset when the crew changed the configuration from flaps 15 to flaps 0.

b) Flight Phase Comparison

The aircraft S/N 208, 161 and 153 incidents occurred in cruise phase at high altitude with torque values (between 65 and 71%) corresponding to this phase.
The aircraft S/N 91 and 259 incidents occurred when descending on approach for landing with torque values (between 20 and 30%) corresponding to this phase.

The airplane S/N 401 was performing four successive circuits in the same holding pattern, at 10000ft altitude. The accident initiated at the top of descent with torque set at idle.

c) Compliance with icing procedures at the time of the events

Icing procedures were not respected in all of the prior ATR-42 incidents.

In this regard, Aircraft S/N 91 and 208 accreted ice with airframe de-icing system "OFF". Aircraft S/N 161 showed a late selection (150" before the event) of this system. Aircraft S/N 259, 153 and 401 had the de-icing system "ON".

The published procedures for flight in icing conditions require a minimum propeller setting of NP 86%. Propeller RPM settings were left at NP 77% for aircraft S/N 208, 161 and 259, which did not ensure a proper propeller de-icing and generated a highly turbulent airflow over the wing. The flight crew of S/N 401 left the propeller RPM at NP 77% while operating in icing conditions, as established by their late selection of NP 86%, only after ice had accreted and the ice detection system aural warning was triggered. The NP 86% setting was made simultaneously the Level III activation of the de-icing boots. The proper propeller RPM was observed for Aircraft S/N 91 and 153.

Aircraft S/N 153 and S/N 161 were flying below the minimum airspeeds authorized in icing conditions when the incidents occurred.

d) Comparison of meteorological conditions

Aircraft S/N 91 encountered icing rain conditions for approximately 10 minutes. Similar conditions may have been experienced by aircraft S/N 259, although it could not be established from the available data.

For aircraft S/N 151, 208 and 153, factual meteorological data are very limited but the speed reduction rates (8 to 10 kt/mn) correspond to ice accumulations which cannot be obtained with accretion rates compatible with FAR 25 Appendix C conditions. These conditions were therefore outside Appendix C but were encountered for less than 10 minutes.

Aircraft S/N 401 has encountered established freezing drizzle / freezing rain conditions, the only one for such a duration of about 24 minutes.

The aircraft S/N 259 encountered severe turbulence throughout its incident as shown by the DFDR read outs which include vertical load factor variations of about ± 0,3g. Other events occurred in an atmosphere considered as calm and for aircraft S/N 401 no turbulence was reported and recorded.

e) Comparison of performance degradation

It is possible to make fairly precise aircraft drag assessments, thus allowing a comparison with the predicted drag for an unpolluted aircraft, for all the events, using the same methodology.

The accuracy of such comparison could only be questioned for the S/N 259 (Newark) incident, due to the prevailing severe turbulence.

On this basis, all aircraft evidenced a very high degradation in drag (and/or in propeller traction). The computed drag increase, expressed in drag counts (DC) are to be compared with a figure for an unpolluted aircraft of about 300 to 400 DC. For instance the aircraft S/N 153 exhibited a + 100% drag increase.

Also, a fairly precise assessment of the lift was made using the same methodology in each incident, thus allowing a comparison with the predicted lift for an unpolluted aircraft.

These losses in lift, estimated at the time when the anomaly appeared in the prior incidents, are all of the order of ACL/CL = 0.2/0.9, that is greater than 20%.

Based upon the foregoing, Aircraft 401 can be characterized by the absence of significant drag performance degradation, which is at the limit of that discernible by the method used (+3°A). This condition, never before observed in anv ice-related event, was eventually associated in the further post-Roselawn investigations with the very specific accretion shape found in the Edwards AFB flight tests which related to the unique combination of the meteorological conditions and of the outer wing negative angle of attack, during the phase of accretion, resulting from the flaps configuration and the speed selected by the Flight 4184 crew.

The only recorded degradation of aircraft 401 performance corresponds to a loss of 10 to 15 kt in airspeed during some turns, which is mainly attributed to the turn technique.

f) Comparison of Angles of Attack

The angles of attack indicated here correspond to the disconnection of the autopilot which was at the point of stall on all prior incidents except S/N 259. The figures are those recorded by the DFDR (AOA vane). All prior incidents occurred at an AOA value close to the value (11.2°) corresponding to the stall warning threshold in icing conditions except for two aircraft : S/N 259 and S/N 401.

The dynamic of the aircraft S/N 259 incident, associated to large, almost instantaneous variations of the vertical load factor and the existing rolling moment at the time of the auto pilot disconnection, created a local angle of attack on the (right hand) dropping wing higher than the figure recorded in the DFDR. This value was, however, still lower than the icing stall warning threshold.

In the accident of aircraft S/N 401, the autopilot disconnection occurred after changing Flap configuration from 15 degrees to 0 degrees at an angle attack of approximately 6 degrees and far below figures recorded in any previous incidents.

g) Roll Initiation Mechanisms

All prior incidents occurred at high angles of attack (at or about at the icing stall warning). The initial roll phenomenon was of the pure asymmetrical stall type for aircraft 161 and 208 to which no aileron hinge moment modification could be associated. Aircraft 91 and 153 also involved a sudden asymmetrical stall, but to which some aileron hinge moment modification was associated. The DFDR data from the aircraft S/N 259 incident did not permit, and does not today permit, any further elaboration or analysis of the roll initiation mechanism.

Aircraft S/N 401 is unique in that there was no significant loss of lift and the roll upset was entirely due to the sudden deflection of the left aileron upwards to its stop, at an angle of attack far below stall, and caused by the profound alteration of the hinge moment constituting the "ice-induced aileron hinge moment reversal" phenomenon discovered in the post-Roselawn investigations.

Unique Characteristics Of The Roselawn Accident

The analysis of all significant parameters in the previous ATR-42 events and the aircraft S/N 401 accident highlights the unique characteristics of the latter event :

- This is the only roll control icing event involving an ATR 72.

- Ice was continuously accreting during the holding duration, and probably intensively in freezing drizzle / freezing rain conditions for almost 24 minutes, in icing conditions beyond Appendix C.

- The aircraft was holding in icing conditions in the flaps 15 configuration at a speed close to VFE, resulting in a negative outer wing local AOA during the accretion phase.

- The roll upset occurred at an angle of attack (about 6°) which is less than half the stall warning threshold in icing conditions, while torque was at a steady value of 6 % since the initiation of descent toward 8000 feet.

- There was very little degradation of the aircraft performance in terms of drag and lift.

- The autopilot disconnected due to its internal monitoring system.

- An abrupt aileron hinge moment reversal appeared at the autopilot disconnection and was not associated to other characteristics of an aircraft asymmetric stall which was involved in all other events.

1.8.2. POST FLIGHT 4184 ACCIDENT ACTIONS

Extensive work has been done after the ATR72 A/C401 accident in order to understand and, if possible, reproduce the type of aileron anomaly experienced during Flight 4184 and never experienced before and to find the probable cause of this accident.

€ Dry wind tunnel tests at S5/CEAT (Nov. to Dec. 1994).

These tests were performed to find which type of ice shape might cause an aileron anomaly similar to the one experienced during this accident. Hypothetical ice shapes resulting from the following, have been tested :

- runback on the aileron horn,
- ice shapes on the vortex generators,
- hoar frost on the aileron and the horn,
- lugs in front of the aileron,
- ramps in front of the aileron,
- specific shapes behind the wing de-icers (pseudo runback shapes).

The findings were that among all the probable tested hypothesis (7 different scenarios), only an arbitrary triangular shape (located downstream of the external de-icers, over the span of both external de-icers and having an approximate thickness of 1”) provides a phenomenon similar to the one extracted from the flight 4184 DFDR (low drag and aileron hinge moment anomaly occurring at low AOA).

€ High speed ground test (Dec. 1994) With a quarter round shape (3/4” then 1” in height) over the whole aileron span of the right wing at the upper active limit of the de-icers. These tests correlated with the dry wind tunnel test finding : flow separation then aileron suction at low AOA.

€High speed ground and flight test (Jan. 1995) with a quarter round shape (3/4" in eight) over 25% of the aileron span of the right wing at the active limit of the de-icers. These tests correlated again with the dry wind tunnel test findings : flow separation then aileron suction at low AOA.

All the previous tests were performed to reproduce the A/C 401 behaviour. The main finding is that this behaviour can be reproduced using a 3/4" to 1" shape located over the aileron span downstream of the active limit of the outer wing de-icers.

The next steps consisted in the search of icing conditions which could have led to such a shape. The weather reports mentioning the possible occurrence of large supercooled droplets in the accident area it has been decided to conduct flight test at Edwards behind a tanker simulating these large droplets and to find an icing wind tunnel capable to produce large droplets.

€ Edwards test phase 1 (December 94). Numerous tests simulating normal operating and system failures under FAR 25 Appendix C (40 to 70 µm) and far beyond FAR25 Appendix C icing conditions (150 to 250 µm). It appears that only a prolonged flight (17 mn) under large supercooled droplet conditions can produce a ridge downstream of the external boot active limit on the wing upper surface.

The ridge chordwise position varies from 8% to 9% and the accretion cross-section varies according to the flap position (respectively 0° to 15°). The main findings of this campaign are :

The ATR72 fully complies with all certification requirements for flight in icing conditions,

For droplet diameter up to 70 µm the aircraft did not experience any anomalies of handling problems and the systems operated as intended,

For 180 µm droplet diameter, far beyond the requirements, the systems efficiently shed the ice on the boots and the aircraft only experienced a roll anomaly before the stall warning, after a prolonged exposure at flap 15 and a stall conducted at flap 0°. Nothing noticeable occurs for the two other tested conditions : prolonged exposure then stall at flap 15° and prolonged exposure then stall at flap 0°.

A clear and obvious visual cue (a granular ice pattern) develops on the unheated part of the side windows within 30 sec. under large supercooled droplets conditions.

Performance (drag) assessment could not and were not performed after these tests.

€ Icing wind tunnel test at Modane/ ONERA (Feb. / Mar. 1995) have been performed on a 1/12 scale and a full scale model. The aim of these tests was to evaluate the ability of the new spraying rig to produce large droplets, to verify the validity of the French scaling law, to study the freezing process at Roselawn conditions and to validate the modified ONERA icing code for large droplets. The main findings are that a ridge could develop at those conditions at the active limit of the de-icers (on the full scale model only) and that the observed impingement limits are in good agreement with the predicted one.

€F<u>light tests with simulated “Edwards ice shape"</u> (January / February 1995). Further to icing tanker tests and wind tunnel tests, simulated “Edwards ice shapes” have been tested in flight (on ATR42-500 S/N 443 and ATR72-2 10, S/N 441) to assess the effects of the spanwise distribution, of the ridge height and of the chordwise location. During the flight 23 of A/C441 the anomaly of the flight 4184’s has been nearly reproduced. The ice shape configuration were :

- symmetrical on left and right wing,
- ice shape upstream of 75% of both aileron span,
- height : 3/4”,
  chordwise location : between 8 and 9%,
  cross-section derived from the Edwards Flap 15° accretion pattern.

Test with asymetrical ice shape (upstream of R.H. wing only) resulted in similar aircraft behaviour.

At this step it appeared that flight with Flap 15 under prolonged operation into freezing conditions could lead to a ridge formation which could induce a flow separation upstream of the aileron and then a roll anomaly appearing at a specific A.O.A.

With this knowledge the following actions were undertaken within 4 months :

€ **define, certify and retrofit the appropriate aircraft modification (external wing boots extension up to 12.5% of the chord),**

€**Edwards test phase 2 (March 1995) to validate the boots extension,**

€**provide the crew with means to recognise these conditions,**

€define new procedures within the AFM to cope with, leave and continue safe flight after an inadvertent freezing drizzle encounter (prohibition of holding flap15 under icing condition,...),
€contribute to the ATR operators and flight crew information with the publication of the freezing drizzle brochure,
€implement within the flight simulator a "freezing drizzle simulation" for pilot training.

Moreover, on behalf of the DGAC, most of the French aeronautical partners (Airworthiness Operations and ATC Authorities, National Weather Service, operators, aircraft manufacturers) actively participate in the French National Icing Committee, initiated by the BEA, which addresses several icing topics (atmosphere characterisation, prediction, detection, computing code, simulation, training and information dissemination).
The French Aircraft Manufacturers also participate as task co-ordinator in the European project EURICE dedicated to icing atmosphere characterisation and prediction and to the critical review of both operational and certification requirements.

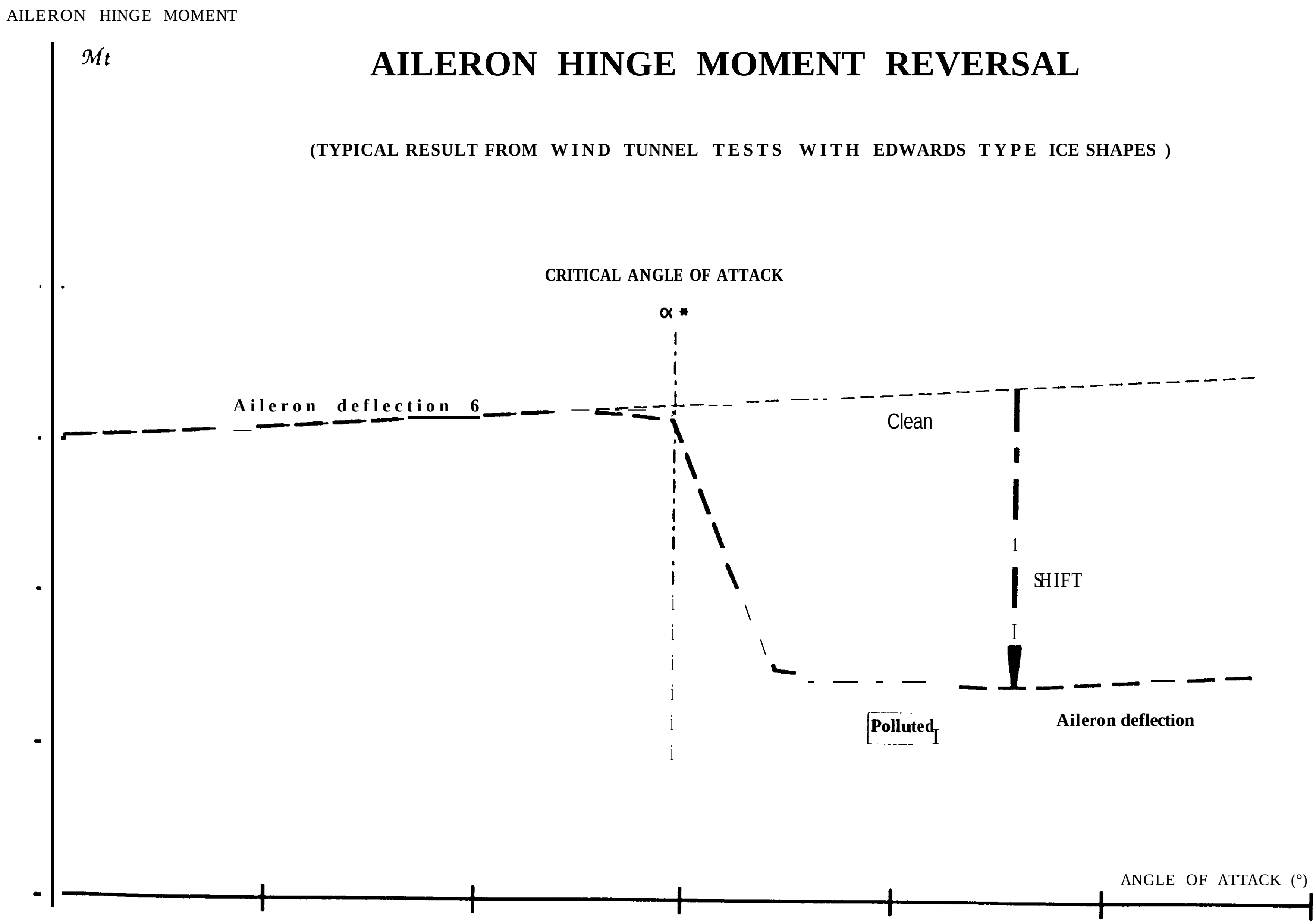


FIGURE 13 : HINGE MOMENT REVERSAL IDENTIFICATION

1.8.3. BILATERAL AIRWORTHINESS AGREEMENT (BAA)

The Bilateral Airworthiness Agreement (BAA) is an “enabling” document developed by two countries when they have competent civil Airworthiness Authorities and their manufacturers produce “Civil Aeronautics Products” which they desire to export to the other country. It is a mutual agreement which facilitates the importation and exportation of aircraft between such countries. This agreement is technically oriented, and is intended to:

1. prevent unnecessary repetitive certification activities by facilitating cooperation and acceptance of findings between the Airworthiness Authorities of the contracting states; and,

2. to ensure that the product certified meets the level of safety required by the contracting states during its service life.

The Bilateral Airworthiness Agreement between France and the United States was effected by an exchange of notes signed on August 29 and September 26, 1973.

1.8.4. CERTIFICATION PROCESS BETWEEN FAA, AND DGAC UNDER THE BAA

The ATR-42 certification was conducted between 1981 and 1985 by the DGAC acting as the primary certification Authority, in other words, the airworthiness authority of the state of manufacture (Exporting State).

The FAA certified the ATR-42 under the Bilateral Airworthiness Agreement (BAA), relying partially on the DGAC's prior certification of the aircraft. During its certification process of the ATR-42, the FAA raised 90 specific technical issues in addition to those which had been raised by the DGAC. The FAA required these issues to be addressed by ATR to the satisfaction of the FAA. The FAA also performed thorough flight testing of the ATR-42 before granting it a U.S. type certificate in October of 1985.

The same procedures were applied during the certification of the ATR-72. The DGAC's certification of the ATR-72 was conducted between 1987 and 1989, with the DGAC acting as the primary certification authority. During its certification of the ATR-72, the FAA raised 19 technical issues and performed thorough flight testing of the ATR-72 before granting a U.S. type certificate in September of 1989.

Under U.S. law the FAA is required to make an independent determination that FAA standards are met before issuing a type certificate under the BAA, regardless of how much the FAA relies on the certification work of the

These BAA certification procedures are still in force between France and the United States to address reciprocal acceptance of airworthiness certification work on their respective aircraft, and to provide a framework for appropriate actions as necessary to work towards common safety objectives.

The Special Certification Review Team jointly appointed by the FAA and DGAC following the Roselawn accident confirmed that the DGAC and FAA acted correctly and properly in their certification of the different ATR model aircraft. The ATR-42 and ATR-72 certifications were confirmed to have complied with all FAA and DGAC certification standards, and the BAA was found to have been properly applied in these certifications.

1.8.5. CONTINUING AIRWORTHINESS INFORMATION EXCHANGED BETWEEN FAA AND DGAC UNDER THE BAA, AND KNOWLEDGE OF THE NTSB REGARDING ICING RELATED INCIDENTS ADDRESSED IN THE NTSB's REPORT

Paragraph 6 of the BAA between the United States of America and France provides in pertinent part :

> "[The aeronautical authorities of the exporting State shall assist the aeronautical authorities of the importing State] in analyzing those major incidents occurring on products to which the BAA applies, and which are such as would raise technical questions regarding the airworthiness of such products".

This BAA provision requires the aeronautical authorities of the Exporting State to assist the aeronautical authorities of the State conducting an investigation in its analysis of a major incident or accident when the incident or accident "raises technical questions regarding the airworthiness of such products", and when the matter has been duly reported to the Aeronautical Authorities of the Exporting State with all information which is available to the State of Occurrence being provided to the Aeronautical Authorities of the Exporting State.

This obligation in the BAA is based in part on Section 4.2.2 of Annex 8 of the Convention on International Civil Aviation, which provides in pertinent part :

> The State of Design of an aircraft shall transmit [to States which have registered the aircraft] 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). . . .“ (Emphasis added.)

Thus, unless incidents raise questions about the airworthiness of a product or its ability to operate safely, the airworthiness authority of the State of Design has no obligation to report the details of the incident to other Airworthiness Authorities.

To fulfill these BAA and Annex 8 obligations with respect to the ATR products, the DGAC has:

a) assisted the FAA in analyzing major incidents which involve U.S. registered ATR airplanes and which “raise technical questions regarding the airworthiness of such products” when they are properly reported and documented to the DGAC, and

b) provided the FAA with information “necessary for the continuing airworthiness of the aircraft and for the safe operation of the [ATR] aircraft” when such information is identified.

It should also be noted that Annex 13 to the Convention on International Civil Aviation provides that the State of Occurrence of an accident or serious incident has the responsibility for investigating the event unless the State of Occurrence formally delegates that responsiblity to another State.

Since the NTSB is the primary aviation accident investigation Authority of the United States, the NTSB has the primary responsibility for investigating all such accidents and incidents occurring in the U.S.

lt should also be noted that Section 6.14 of Annex 13 provides that if the State of Occurrence conducts an investigation into “an incident which involves matters considered to be of interest to other States, ” then the State of Occurrence “should forward to them the related information as soon as possible. ”

1.8.5.1 PRIOR TO THE ROSELAWN ACCIDENT, THREE INCIDENTS, DISCUSSED BY THE NTSB OCCURRED INVOLVING U.S. REGISTERED AIRCRAFT IN THE U.S.

Mosinee incident -AC 91- 12/22/88.

After this incident, the DFDR data was properly provided to the BEA by the NTSB. An investigation was conducted by the NTSB which, as the primary investigative authority of the State of Occurrence, was responsible for the investigation. The NTSB also requested and received the assistance of the FAA, BEA, DGAC and ATR. The NTSB provided all these parties with the DFDR readout, pilot reports, and weather information for use in their investigation.

Based on their investigation, the BEA, DGAC, and ATR developed an analysis of the incident. This analysis was fully presented by the BEA, DGAC, and ATR to the NTSB and the FAA, in Washington on 02 and 03 March. 1989. Corrective actions proposed by ATR were subsequently reviewed by both the DGAC and the FAA and jointly discussed in Seattle on 21 April 1989.

Design and system modifications were mandated by the DGAC and implemented on the ATR fleet in 1990 and 1991. ln addition, Operating Manual changes were proposed by ATR to the DGAC, which in turn, recommended them to other Airworthiness Authorities, including the FAA for the U.S. The FAA did not adopt the proposed Manual changes, in accordance with its standard policy of preferring design modifications.

Newark incident- AC 259- 03/04/93 .

In this incident, the DFDR traces were forwarded by the NTSB to the BEA which in turn forwarded copies to ATR. The NTSB requested, and was provided by ATR, a copy of ATRs earlier study regarding the effects of a NP 77% setting for the propellers. However, the NTSB did not request further assistance from the BEA, DGAC, or ATR in the investigation of this incident. The NTSB, which was responsible for the investigation by virtue of its being the primary investigative authority of the State of Occurence, provided to the BEA, DGAC, or ATR none of the further information developed by the NTSB and FAA during its investigation of the incident. Consequently, the ability of the DGAC, BEA and ATR to further conduct their own investigations and to effectively assist the NTSB in its investigation was limited.

Nevertheless, based on the DFDR readout, the BEA, DGAC, and ATR were able to determine that the incident involved a failure by the flight crew to follow the AFM and AOM procedures (NP 77% instead of the required 86%) while the anti-icing systems were activated.

In addition, the DFDR readout indicated that high levels of turbulence were involved which could alone explain the aircraft behavior. Neither the BEA nor the DGAC were ever advised of the final determinations by the NTSB in its investigation, or that any further assistance was desired by the NTSB.

Burlington incident - AC 153- 01/28/94.

After the incident, the DFDR and pilot reports were sent to ATR by the airline, and ATR forwarded the DFDR readout and the pilot reports to the BEA for its analysis. Neither the NTSB, which had the responsibility to conduct the investigation by virtue of its being the primary investigative authority of the State of Occurrence, nor the FAA, requested any assistance from the BEA or the DGAC in respect to the conduct of the investigation. The NTSB never forwarded any weather information or any other information whatsoever on the incident to the BEA or the DGAC.

ATR analyzed this incident based on the information available to it and presented its preliminary conclusions to the BEA and the DGAC on 15 February 1994. A draft report was provided by ATR to the DGAC on 17 March 1994.

The DFDR data established that there was a substantial failure by the flight crew to follow the AFM and AOM procedures for flight operations in icing conditions as the flight crew was flying below the minimum airspeed for such conditions and was losing speed due to ice accretions. The aircraft stalled causing the autopilot to disconnect.

Given the unusual lift loss and drag increase noticed during that incident, and given the fact that the ice-induced stall occurred at 86% NP, the DGAC required ATR to conduct an additional study of the ice codes used for the ATR 42. That additional investigation was in progress at the time of the Roselawn accident.

1.8.5.2 PRIOR TO THE ROSELAWN ACCIDENT, TWO INCIDENTS OCCURRED INVOLVING NON-US REGISTERED AIRCRAFT OUTSIDE THE U.S.

Ryanair incident -AC 161- 08/11/91

The DFDR, pilot reports, and weather conditions, along with information provided by other aircraft operating in the area of the incident, were provided to the BEA and the manufacturer by the airline with the agreement of the Irish Civil Aviation Authority.

The ATR investigation concluded that the cause of the incident was an aerodynamic stall. The stall was the consequence of an ice accretion which resulted from a failure by the flight crew to respect AFM and AOM procedures for flight operations in icing conditions.

The results of the ATR investigation were presented in Toulouse to the BEA and the DGAC on 13 September, 1991. The conclusions were accepted by the BEA and DGAC and presented to the Irish Civil Aviation Authority in Dublin, Ireland on 7 November, 1991. The investigation report was not sent to the FAA since the incident did not "raise technical questions regarding the airworthiness of [the ATR aircraft]". ATR did, however, report this incident to all ATR operators.

Air Mauritius incident - AC 208- 04/17/91.

In this incident, the DFDR, pilot reports, and weather conditions were provided to the BEA and to the manufacturer by the airline with the agreement of the Civil Aviation Authority of Mauritius. The investigation conducted by ATR concluded that the cause of the incident was an aerodynamic stall which was the consequence of ice accretion resulting from a failure by the flight crew to respect AFM and AOM procedures for flight operations in icing conditions.

ATR's investigation report was presented in Toulouse to the BEA and the DGAC on 12 June, 1991. The conclusions were accepted by the BEA and DGAC and were provided to the Civil Aviation Authority of Mauritius on 17 October, 1991, which raised no further comment on it. The investigation report was not sent to the FAA since the incident did not "raise technical questions regarding the airworthiness of [the ATR aircraft]. " ATR did. however, report this incident to all ATR operators.

1.9. AIR TRAFFIC CONTROL

In the NTSB's Report some important information is missing in respect to the actions of Air Traffic Control. The BEA provides its comments and additional data below.

The investigative record indicates that on the afternoon of the accident, a weather system was moving through the south area of Chicago Center. The South Area Supervisor, Chicago Air Route Traffic Control Center (ARTCC), testified at the NTSB Public Hearing that "conditions were right for light to moderate icing to occur. " In this regard, Chicago ATC controllers were aware that icing conditions were forecast for the area they were in charge of. Further, ATC controllers in charge of the 15:00 to 23:00 shift, had been given a clear briefing upon expected weather conditions by the Supervisor with the explicit warning that "Icing Kills". He testified at the NTSB Public Hearing that he wrote NTSB Exhibit 3G, the "south area weather briefing" which states : (see next page)

> Icing Kills - it's your job to know the freezing level in your sector, and the tops & bases. That is the fastest way out of the ice. Pass on the PREPS. Use Depts [departures] off your airports to solicit this critical info." (Emphasis added.)

"ICING KILLS"

SOUTH AREA WX. MONDAY EVENING SHIFT

COMPUTER PROBLEMS TONITE!

RAIN ALL SHIFTS. TOPS 18 TO 20 THOU

T-STORMS DEVELOPING IN THE SOUTH. TOPS WILL BE FL300. LOTS OF LT CHOP ↓ 80

FR LVL: 8,000. → EXPECT LT RIME / MIXED.

THE ENTIRE SHIFT WILL BE IMPACTED BY THIS WX. SYSTEM.

PROGRAMS: STL - 'TILL AFTER MIDNIGHT -
FWR - LOTS OF SPACE TO ZOB
ORD 80-RATE
JFK - GRD STOP.

WATCH FOR REROUTES!

"ICING KILLS - IT'S YOUR JOB TO KNOW THE FREEZING LEVEL IN YOUR SECTOR, AND THE TOPS & BASES,.. THAT IS THE FASTEST WAY OUT OF THE ICE. PASS ON THE PIREPS. USE DEPTS OFF YOUR AIRPORTS TO SOLICIT THIS CRITICAL INFO."

He further testified that he "wanted to highlight to the controllers how important it was to stay alert and stay on top of the weather conditions in their particular sectors. " He also testified that he gave a copy of this weather briefing to each sector. including the Boone Sector, and that he took the original and hung it next to the weather radar scope.

During the NTSB Public Hearing, The Supervisor also testified regarding what ATC's response would have been had a pilot complained about holding in icing conditions on the day of the accident. He responded by stating:

> Very responsive. The first thing the controller would ask is if the pilot wanted an altitude change to get out of the icing conditions. The rest of the scenario would be based upon the pilot's transmissions and requests. (Emphasis added)

He also testified that Flight 4184 was the only flight holding at LUCIT intersection, and that if the flight crew had complained about icing conditions while holding at LUCIT intersection, there were "four other altitudes" that would have been available, 5,000 feet through 9,000 feet. ln addition, he testified that "higher altitudes could have been coordinated and could have been worked out on request. " The supervisor further testified that "icing conditions [were] a valid reason" to request a different altitude, and that the "aircraft would [have been] allowed to hold at any altitude that it wished. " Finally, He confirmed that at no time while Flight 4184 was holding at LUCIT intersection did the flight crew make any request for a speed change or an altitude change.

The record also indicates that Flight 4184 was a scheduled flight of only 1 hour and 5 minutes between Indianapolis and Chicago. However, because of delays for low ceilings and visibility at Chicago O'Hare International Airport, Flight 4184 was held on the ground for approximately 42 minutes, and held in the air for approximately 35 minutes prior to the accident.

ln respect to the release of Flight 4184, the Chicago Center Traffic Management Coordinator (TMC) released Flight 4184 from a 42 minute ground hold which had been implemented by Air Traffic Control System Command Center (ATCSCC) despite having been informed by the ZAU Traffic Management Coordinator (TMU) that conditions were such that the flight would likely be required hold in the air before reaching its destination. In this regard, FAA Order 7110.65 states that 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 enroute 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 (Emphasis added.)

Once Flight 4184 was airborne, the BOONE Sector Controller, who was a trainee, placed the aircraft in a hold at LUCIT intersection to accommodate incoming traffic from the west. Flight 4184's Expected Further Clearance (EFC) time was extended on four separate occasions. However. despite the fact that it was mandatory for the BOONE Sector Controller to report those arrival delays to ATCSCC which are expected to meet or exceed 15 minutes, neither the Central Flow Control Facility (CFCF), nor the Traffic Management Unit (TMU) were advised that Flight 4184's holding time had exceeded 15 minutes.

ln respect to the solicitation of PIREPS, FAA Order 7110.65J, Section 6 entitled *Weather Information* provides that ATC controllers are required to "solicit PIREPS when requested or when one of the following conditions exist or are forecast for your area of jurisdiction." One of the conditions for which ATC controllers are required to solicit PIREPS is "icing of light degree or greater." (Emphasis added.)

1.10. ADDITIONAL INFORMATION - WORLDWIDE FLEET ICING EVENTS

1.10.1. FOUR DIFFERENT AIRPLANES ICING EVENTS

1. FOKKER 27 G-BMAU accident on January 18, 1987 on final at EAST MIDI.AND AIRPORT (UK)

Reference : AAIB report 7/88

It was a British Midlands Airways training flight. The purpose of the flight was an instrument approach with one engine simulated failure. On final approach, the airplane struck the ground. Wings and elevator leading edge were covered with one inch of clear ice.

Weather situation on the airport area was characterized by a stationnary warm front with stratus and stratocumulus layers between 900 and 1700 feet. Freezing level was on ground.

The investigation led by the AAIB highlighted a loss of directional control and apparently then a stall. Deicing systems had not been activated and speed fell below the normal approach speed.

2. BRITISH AEROSPACE ATP 6 G6BMYK incident on August 11, 1991 near OXFORD (UK)

Reference : AAIB report 4/92

While the airplane was climbing to FL 160 buffeting then roll oscillations occurred. The left wing stalled without warning and vertical speed increased.

The crew activated the de-icing system and manually recovered the aircraft below the cloud layer. After this recovery, a loss of ailerons efficiency was noted by the crew. The crew did not detect ice accretion.

A cold front prevailed in the area. The freezing level was at FL 110 and an altostratus - altocumulus layer was present between FL 90 and FL 130. At the level where the airplane was flying the SAT was -2° C to - 5°C and moisture was very high.

The investigation underlined that there were falling water drops as big as one millimeter-diameter inside the cloud. The accretion rate was calculated to be about 1/2 inch per minute.

At that time, the industry understanding of freezing precipitation or of supercooled drops precipitation associated the freezing rain phenomenon to a temperature inversion in the atmosphere. The conditions encountered by the ATP aircraft were not considered to be freezing rain.

3. EMBRAER 120 BRASILIA F-GFEP incident on November 22, 1991 on approach to CLERMONT-AULNAT AIRPORT (FRANCE)

Reference : BEA report 7/92

This was an Air-Littoral flight from Lyon-Satolas to Clermont-Aulnat. Due to high traffic on the airport the airplane was flying one circuit in the holding pattern. After the ATC clearance to descend down to 4500 feetwas given, the flight crew disconnected the auto-pilot at 4700 feet in order to manually capture the altitude.

The stick shaker abruptly activated and the airplane stalled. After a prompt recovery it stalled again and then once again. While the first officer activated deicing systems, the captain applied full power and executed the final recovery with an altitude loss of 1200 feet.

After landing, accretions of ice (cleared to mixed ice) still covered the leading edge of wing tips and elevator (3 cm X 6 cm thickness) and the upper wings (0.5 cm thickness).

A stratocumulus layer extended over a large part of France. On the area of incident, the base was at 2000 feet (-1.5°C) and the top was at about 5500 feet (-7/-8°C) to 6300 feet (-3/-5°C) limited by a temperature inversion.

The investigation underlined a high rate of liquid water content inside the upper part of the cloud up to 1.0/ 1.2 g/m3 with an increase of droplets size.

The BEA issued a recommendation asking for a review of certification criteria, in terms of icing conditions more severe than those admitted in Appendix C,

4. ANTONOV AN-12 accident on January 31, 1971

Reference : MAK (Interstate Aviation Comittee - CEI). ISASI FORUM 9/95.
The following comments concern the data recorded during the accident which occurred on January 31, 1971 on an AN-12 airplane, serial 12996 :

"The command for flap extension was given at the 21 -st second. At the same time air speed decreased and the transition period of flap extension coincided with the aileron oscillations. It had been misunderstood by the captain as non-symmetrical flap extension and the command to bring the flaps up was given at the 25-th second.

At this time the airspeed dropped to 172 KIAS, despite the oil pressure increase in inboard engines torque-meter to 30 kg/cm2. The aileron oscillations were due to the hinge moment reversal on the ailerons, and occurred at the C_L = 0,95 in case of the ice accretion on the wing.

The sudden aileron deflection to the left bank, practically to the limit, was initiated at the 25-th second. This deflection was due to the high forces on the yoke's lateral channel ; the yoke was "breaking out" from the pilot's hands. The pilots were able to bring the yoke back from the extreme left position by applying a great deal of force. However they failed to hold it in the neutral position, since the necessity to counteract the left bank (f = 15-20°) made them turn the yoke to the right. That, in turn resulted in repeated snatching the yoke out of the pilot's hands completely to the right due to the hinge moment reversal on the ailerons. "

1.10.2. WORLDWIDE TURBO PROP ICING EVENTS

From the current BEA accident data base, 23 significant icing events can be identified since 1985 until 1994.
Among them, 11 events could be classified as “loss of control”.

This data base demonstrates that icing incidents / accidents affect virtually all types of turboprop aircraft. However, more events were reported for recently manufactured aircraft than for older aircraft types.

A LIST OF SOME EVENTS OCCURRED SINCE 1985

AIRCRAFT MODEL	LOCATION	DATE	INJURIES/DAMAGE	ICING CONDITIONS EVENT
Short 360	UK	86/01/31	0/Destroyed	Loss of control
Cessna 441	USA	86/03/03	8/Destroyed	stall
Be 99	USA	86/05/16	0/Substantial	Stall
Fokker 27	UK	87/01/18	0/Destroyed	Loss of control
DHC3 otter	Canada	87/01/31	0/Substantial	stall
piper PA 23	USA	87/04/28	0/Destroyed	Loss 01 control
Be 1900	USA	87/11/23	18/Destroyed	Loss of control
BAe Jetstream 31	USA	87/12/24	0/Destroyed	Loss of control
Mitsubishi Mu 2	USA	88/11/06	1 /Destroyed	Loss of control
Cessna 404	Canada	89/11/08	0/Destroyed	Stall
NA Commander 500	Canada	89/12/04	0/Substantial	Loss of directional control
BAe Jetstream 31	USA	89/12/26	6/Destroyed	Stall

A LIST OF SOME EVENTS OCCURRED SINCE 1985

AIRCRAFT MODEL	LOCATION	DATE	INJURIES/DAMAGE	ICING CONDITIONS EVENT
Cessna 208	USA	90/01/29	2/Destroyed	stall
Cessna 208	USA	90/02/27	1 /Destroyed	stall
BAe Jetstream 31	USA	91/01/30	0/Destroyed	Loss of control
BAe ATP	UK	91/08/11	0/None	Stall with severe uncontrollable roll oscillation
Embraer 120	France	91/11/22	0/None	Stall
Lockheed Neptune	USA	92/02/08	2/Destroyed	Stall
NA Commander 500	USA	92/11/23	0/Substantial	Loss of control
NA Commander 500	USA	93/01/11	0/Substantial	Stall
HS 748	Canada	93/11/11	7/Destroyed	Loss of control on final
BAe Jetstream 41	USA	94/01/10	4/Destroyed	Loss of control on approach
SAAB-F 340	UK	94/03/23	0/None	Loss of control (left wing dropped)

1.11. ADDITIONAL PERTINENT DOCUMENTATION

The following list of additional documents is considered by the BEA as an interesting source of information in the frame of the forthcoming :

1. The *American Eagle's Crew Resource Management* publication, adapted from American Airlines, outlines the training program utilized by American Eagle/ Simmons in respect to training its flight crews for *Techniques for Effective Crew Coordination*. (NTSB Exhibit 2-E). The preface to this publication entitled *CRM Overview* states in part :

> The purpose behind American's CRM program is to enhance crew coordination and situation awareness in order to decrease the chances of an aircraft accident attributable to flight crew behavior and to increase crewmembers' ability to deal with mechanical and environmental factors that could easily cause an accident.

The following *Techniques for Effective Crew Coordination* are set forth in the *American Eagle Crew Resource Management* publication and are considered by American Eagle to be the "four critical areas" in respect to techniques for effective crew coordination :

1. *Technical Proficiency :*

Do crew members know their aircraft and procedures?

2. *Situation Awareness and Management :*

How do you recognize a deteriorating situation? Once recognized, how do you deal with the workload?

3. *Communications :*

Did everyone know the plan?

4. *Teamwork :*

Was the crew functioning as a team?

The BEA will discuss the actions of the Flight 4184 flight crew in the context of these "four critical areas" in the *Flight Crew Performance section.*

2. Advisory Circular No. 120-51A (NTSB Exhibit No. 2D) entitled *Crew Resource Management Training* also provides guidance in respect to assessing the Crew Resource Management (CRM) issues involving this accident. Appendix 1 of AC No. 120-51A provides "Crew Performance Marker Clusters" which can be utilized to assess the performance of flight crews. Although the BEA will not provide an exhaustive analysis of the flight crew's performance in the context of these "marker clusters", the BEA strongly recommends that the NTSB conduct a thorough review of the actions of Flight 4184's flight crew in this context.

3. Section 4, para. 90, of American Eagle's Flight Manual entitled *Nonessential duties during critical phases of flight (Sterile Cockpit] (FAR 121. 542)* sets forth procedures for flight crews during such phases of flight. Paragraph 90 states in part:

A. Crewmembers will not perform duties during a critical phase of flight except those duties required for the safe operation of the aircraft.

B. The Captain will permit no activity during a critical phase of flight which could distract any flight crewmember from the performance of his duties or which would interfere in any way with the proper conduct of those duties. Nonessential activities prohibited during critical phases of flight include eating meals, engaging in nonessential conversations within the cockpit and nonessential communications between the cabin and cockpit crews, announcements pointing out sights of interest, non-operational company radio calls such as confirming passenger connections, filling out company logs and reading of any publication not related to the proper conduct of the flight.

Section 4, para. 91 *Sterile Cockpit Definition* further defines "critical phases of flight (sterile cockpit)" in part as follows:

> *A. Critical phases of flight (sterile cockpit) include all ground operations involving movement of the aircraft under its own power, including takeoff and landing, and all operations below 10,000 feet MSL, except cruise flight. A critical phase of flight may also include any other phase of a particular flight as deemed necessary by the Captain. (Emphasis added.)*

4. Federal Aviation Regulation 14 CFR §121. 542 *Flight Crewmember Duties* states in part:

> *(a) No certificate holder shall require, nor shall any flight crewmember 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 nonsafety related purposes as ordering galley supplies and confirming passenger connections, announcements made to passengers promoting the air carrier or pointing out sights of interest, and filling out company payroll records are not required for 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 would 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 crews, 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 purposes of this section, critical phases of flight include all ground operations involving taxi, takeoff and landing, and all other flight operations conducted below 10,000 feet, except cruise flight.

5. The National Transportation Safety Board's. Safety Recommendation dated February 3, 1994 sent to the Honorable D. R. Hinson, Administrator FAA and proposing criteria to evaluate flight crew performance and errors made in major accidents, states in part :

"*The nine* error types are defined below.

Primary Errors *.--Eight of the nine descriptive types of errors are considered primary errors ; that is, they are not dependent on making a prior error.*

1. Aircraft handling : Failure to control the airplane to desired parameters.

2. *Communication* : *Incorrect readback, hearback ; failure to provide accurate information ; providing incorrect information.*

3. *Navigational* : *Selecting wrong frequency for the required radio navigation station ; selecting the wriong radial or heading ; misreading charts.*

4. *Procedural* : *Failure to make required callouts, making inaccurate callouts ; not conducting or completing required chacklists* or *briefs ; not following prescribed checklist procedures ; failure to consult charts or obtain critical information.*

5. *Resource management* : *Failure to assign task* responsibilities or distribute tasks *among crewmembers ; failure to prioritize task accomplishment ; overloading crewmembers ; failure to transfer / assume control of the aircraft.*

6. *Situational awareness* : *Controlling* aircraft *to wrong parameters.*

7. *Sysstems operation* : *Mishandling of engines or hydraulic, brake, and fuel systems ; misreading and mis-setting instruments ; failure to use ice protection ; disabling warning systems.*

8. *Tactical* decision : *Improper decision making ; failure to change course of action is response to signal to do so ; failure to heed warnings or alerts that suggest a change in course of action.*

1.12. ADDITIONAL COMMENTS ON NTSB FACTUAL SECTION

The following additional comments refer to portions of the NTSB's draft report as it was delivered to the BEA.

p. 4, line 5.

The Beech Baron's crew asked the ATC for a diversion from 12,000 feet down to 10,000 feet.

p.4, line 23.

Modify as follows : "... the level III airframe deicing, the propeller RPM remaining at 86 percent from the beginning of the flight (climb and cruise)".

p. 6, lines 9-10.

Modify as follows : . . . . . The airframe deice system was deactivated at 1523: 22 and propellers speed was reduced to 77 percent at 1524 : 13".

p. 8, line 8 to 21.

Delete : " the following exchange . . . . . ." because some exchange is missing.

Add : "...." in intervals where quotations are missing.

p. 8, line 22.

Add a few words on demonstration made by the flightcrew to the stewardess about some systems functioning.

Moreover, the single caution alert chime sounding at 1533 : 56 during the demonstration should be noted as well as the absence of flight crew comment about it.

p. 9, line 19.

After " . . . by an unintelligible word(s) " add : "pronounced by either the same pilot (or the other one) likely the First Officer.

p. 10, line 2.

The phrase " During the Captain's absence both the " should be modified to read : " During the duration of the Captain's absence , for a period of four minutes and 29 seconds, both the . . . . ."

p. 14, line 11.

The BEA requests that this line be modified to read : "column force momentarily exceeded 22 pounds",

p. 14 (Graph).

Replace the graph dated "February 25, 1995 with the latest version dated " January 23rd, 1995".

p. 17, line 14 to p. 18, line 24.

According to Exhibitits 2A and 14A about the Captain, some facts are veiled such :

- he was aware of previous incidents,

information about work time and flight time for previous three days was known.

p. 18, line 3.

After the phrase " The Captain transitioned to the ATR and . . . " add the phrase : " after having failed once on March 10, 1993 to pass his ATR type rating examination ...,"

p. 19, lines 3 to 7.

According to Exhibit 2A and 14A, in the First Officer's background, add aircraft type ratings and especially : "the First Officer was neither ATP nor ATR 42 / 72 type rated".

p. 20, line 25.

Add the shift time of Danville Sector Controller which is missing.

p. 21, line 8.

Add the shift time of Boone Sector Controller which is missing.

p. 21, line 10.

Add another sentence : "His precise functions for this shift were . . . (to be detailed)", because "on-the-job training and instructing" and possible other tasks must be explained.

p. 21, line 19.

Add the shift time of Boone Sector Developmental Controller which is missing.

p. 23, line 7.

Modify as follows : "The EADI also displays red chevrons..."

p. 23, line 15.

The EADI does not display an "eyelid", it is the stand-by horizon which includes an eyelid.

p. 24, lines 3-4.

Modify as follows : "... weather radar and displays 3 levels of detectable precipitation with four separate colors. According to the ATR 72 Flight Crew Operating Manual (FCOM) and the Pilot Handbook PRIMUS 800 Color Digital weather Radar, the colors are used to depict the various densities of the clouds in which precipitation occurs :

Level	Weather Mode	Map Mode	Rainfall rate mm/hr
Level 0	No detectable clouds	Black	< 1
Level 1	Normal clouds	Green	1 to 4
Level 2	Dense clouds	Yellow	4 to 12
Level 3	Severe storm	Red	> 12

(Ref BEA Study of Meteorological information as a Contribution to the NTSB Report, para 1.6).

p. 29, lines 20-22.

This sentence is not factual. This information was not provided by ATR. It looks as an hypothesis and therefore it has to be removed for the Factual section. After the sentence ending "manufacture. " in line 22 , the BEA requests that the NTSB add the following new sentence : " The resulting uncomplicated design provides an inherent safety advantage ."

p. 29, lines 22 to 25.

Replace the phrase beginning "However, ... susceptible to ...." with the phrase :

"However, during certain extreme flow separations possibly occuring outside the authorized flight envelope, this type of control system, which has been selected on all certificated turboprop aircraft, may be susceptible to...".

p. 30, line 21 to p. 31, line 6.

The BEA considers this paragraph to be wrong, inaccurate, and irrelevant to the Roselawn accident. Therefore, this paragraph should be deleted.

p. 31 (Graph).

The graph shown on page 31 entitled "Right Aileron Hinge Moment" is not understandable by the ordinary reader. It should be either explained or deleted.

p. 32, lines 20-24.

The sentence should be changed to read :

"These SPS AOA values remain constant for operations in any type of icing conditions as defined in 14 CFR Part 25, Appendix C".

p. 36, line 15.

Modify as follows : "... there is not enough heat transfer to instantaneously freeze the water ...".

p.36, line 16.

After : "... that contacts the probe" add a foot-note number.

The foot note will be : "This information is provided to the flightcrews in the AOM which states (Ice and Rain Chapter, P. 42- issue 23 June 93) :

"... ice which is building slowly and sublimating at approximately the same rate may cause considerable delay in triggering the detector or fail to trigger it at all. Also, freezing precipitation which tends to flow prior to freezing may flow off the detector prior to freezing, failing to trigger the detector ..."

"Crew vigilance must be used to detect the formation of airframe ice as early as possible".

p.36, line 18.

Add after line 18 the following new sentence : "In fact, freezing drizzle conditions simulated during the Edwards Air Force Base Tanker Tests were always detected by the Rosemont ice detector probe within 30 seconds after the immersion into the tanker plume".

p. 37, line 15-16

Modify as follows : " . . horizontal and vertical stabilizer leading edge boots (if that one installed) ... ",

p. 37, line 17.

Modify as follows : "... Ice accretion, the AAS alert being only an ultimate adviser". The present statement of the NTSB is not coherent with the other NTSB statement p. 145, line 6-7.

p. 38, line 18.

After "... the chord of the upper wing surface", add the following phrase : "Thus, in the specific case of ATR 42 / 72 aircraft, the design of de-icers is such that their use is required as soon as ice accretion begins, even if has not yet accreted".

p.40, line 6 or new p.42, line 15.

Foot note 33 **:** Different definitions of freezing drizzle and freezing rain are provided in this Report, certainly by several writers without any final check. Currently, only one definition of these phenomena is internationally agreed : drizzle drop sizes are between 50 and 500 µm and rain drop sizes above 500 µm.

p. 40, line 18.

Add : "However this Special Condition B6 was included in JAR 25 as NPA 25D219 in 1991".

p. 44, lines 4-5.

This sentence as written makes no sense. The BEA requests that this sentence be deleted and replaced with the following sentence extracted from the NTSB Performance Group memorandum dated December 2, 1994, which is more accurate :

"The coverage of the certification envelope was, however, described by the NASA / FAA group members as typical to above-average for a turboprop certification effort given the apparent difficulty in finding natural icing conditions in certain areas of the certification envelope".

p. 47, line 9.

"... Unacceptable . . ." is a term suggesting an analysis and must be deleted. In the factual section "control anomalies" is sufficient in itself.

p. 47, line 17.

It is wrong to write "weather observed in the area". There were only later limited testimonies on the ground (Lowell airfield, car driver at Demotte) and from aircraft (B727 KIWI 17 and 24...).

p. 47, lines 18-19.

Regarding droplets and drops "in the size range of about 40 to 400 µm". there is neither factual information nor objective study which allows determination of such sizes. It is an assumption that must be deleted in the factual section, to be reported in the analysis section.

p. 49, lines 7 to 10

This paragraph is badly and insidiously elaborated (factual section!). [t should be modified as follows : "The original certification test program did not include an evaluation of airplane characteristics with asymmetrical ice shapes since such an evaluation is not standard practice",

p.57, line 2

1.7 Meteorological Information,

The BEA Contributive Study to the NTSB Report attached to the BEA Extended Comments is based on the all available weather and pertinent factual information. It is more detailed and accurate in terms of concrete arguments than the NTSB "Meteorological information" chapter hereafter elaborated. (Ref. BEA Extended Comments, para., 1.6.).

p.69, line 6 or new p.73, line 3

After "... KLOT radar site" add : " . . but it is only reliable for this area located in the cold air mass to the west of the cold front".

(Ref. BEA Study of Meteorological information as a Contribution to the NTSB Report, para. 1.6).

p.71, line 5

In fact this altitude of 17,000 feet is the lower value determined by both the NTSB and the BEA using the Mc Idas computer. This determination included some uncertainty about cloud top temperature between - 13°C and - 16°C which corresponded to an altitude of 17,000 feet to 19,000 feet (Ref. BEA Study of Meteorological Information as a Contribution to the NTSB Report, paragraph, p.).

p.71, line 6

After ". . generated by windshear", add this phrase : "These Kelvin - Helmoltz waves did not correspond to the 10,000 feet layer, therefore did not have any influence on the water drops coalescence process in the area which the N401AM was flying ".

(Ref. BEA Study of Meteorological Information as a Contribution to the NTSB Report, paragraph, 1.6)

p.78, line 6 or new p.82, lines 8-9.

After "... 0.3 to 0.7 grams per cubic meter" add : "adding that this content did not include freezing precipitation falling from the cloud layer above the level the N401AM was flying at". (Ref. BEA Study of Meteorological, information, para,, 1.6).

p.78, lines 15 to 18 or new p.82, lines 17 to 20

Contradiction with the footnote 33 p 40 (on new p.42). In fact this one corresponds to the International Definition.

p.79, line 1.

After "... aft of the protected surfaces", add "and everywhere on the aircraft".

p.86, lines 12 to 14.

The BEA reiterates its requirement for an accurate description of how CVR transcription was performed by modifying the text as follows, in order to provide an accurate record :

"The CVR group, consisting of representatives from the parties to the investigation, collectively transcribed the tape in its entirety, directly on a micro-computer, and had the opportunity to review the end product only by displaying through the computer screen. The NTSB took alone the decision to publish the public CVR transcript (Exhibit 12A) in an edited version, after editing sections which the NTSB considered as "non-aviation related conversation or non pertinent conversation". CVR group members were not consulted upon the reasons for editing in this manner.

p.87, line 13

From the January 23, 1996 version of DFDR analysis, it seems that the *last seconds of operational data were recovered.*

P.100, line 13.

The BEA recommends the following modification to the wording to provide a more factual information : replace "at low AOAs" by "at lower AOAs than expected".

p.102, line 21

The BEA strongly believes that the last NTSB statement will be misinterpreted unless it is presented in the proper historical context and that the NTSB should incorporate the following statement which accurately reflects the state of icing knowledge prior to, and after, the Edwards Flight Tests :

"However, prior to full scale icing tanker flight tests conducted at Edwards Air Force Base, there was no theoretical or experimental evidence available to ATR or to the aviation community, to suggest that an increase in the severity of the ice accretion contamination on a airfoil could tend to lower the AOA at which the aileron hinge moment shift occurs so far below the certified icing SPS AOA thresholds. It was only after the Edwards Flight Tests that experimental evidence became available which demonstrated that this was possible".

p.103, line 2.

1.16.2 Previous ATR 42 and 72 Icing Events.

In this section, the Aviation Safety Division of the NTSB :

- veiled some essential facts about investigations led by the NTSB with the participation of French Authorities or conducted by the French Authorities in case of incidents that occurred abroad outside the USA,
- suspected the FAA, the DGAC and the BEA of laxism,
- omitted to admit that the Aviation Safety Division did not investigate an incident and failed to provide some resulting information of other incidents to the French Authorities.

The BEA firmly requires that the truth be re-established.

p.103, line 9

The NTSB's statement is not fully supported by factual meteorological evidence. The following text should be modified since it. represents a more factual description of the weather conditions :

"... following 5 occurred in weather conditions well outside of Appendix C conditions and in 2 occasions at least consistent with freezing rain conditions, and . . .".

p.104, lines 10 to 12.

The BEA does not that this summary does not convey complete information of the effect of propellers being operated at 77 percent rather than the required 86 percent. The Engineering Division possessed this complete information and should have provided it in the final NTSB Report.

p. 104, lines 24-25 and p.105,1ine 1

The BEA considers the NTSB statement to be outrageous and absolutely wrong. The NTSB veiled and hid the active participation of the FAA, the BEA, the DGAC and ATR in the investigation between December 1988 and March 1990, and especially meetings held on behalf of the NTSB in Chicago in February 1989 and in Washington (final meeting) in March 1990.

p.107, lines 22 to 25.

Immediately after the incident, the Simmons Airlines Systems Manager reported the event to ATR in a fax dated 12.22.88 indicating that Anti-icing (Level 3) de-icing and all systems functioning normal by at the time of the incident. However it is now confirmed that the level 3 (de-icing) system was OFF.

It is worth indicating that the ATR analysis, based upon the earlier info, assumed that level 3 was on hence the proposed mechanism with a ridge of ice accreting aft of the boots. The ATR analysis should be reconstructed with the latest information which significantly changed the ice accretion pattern and therefore its impact on air flow separation.

This further differentiates A/C 91 from A/C 401 flight in freezing rain with de-icing system off is a combination of rare occurrence.

p. 109, line 1 and following.

To present a balanced report, the BEA recommends that extract from another ALPA letter dated 30 Nov 89 be inserted since it indicates quite an opposite judgment on the ATR attitude towards operation in icing conditions.

The BEA would also like to draw the attention of the Board Members that both in Scandinavia, over the North Sea and adjacent Countries and in Canada, no ATR aircraft icing related incidents were reported and that serious incidents only occurred in the USA.

p.109, lines 24-25.

As in page 104 - 105, the BEA is extremely disappointed that the NTSB does not mention the investigation led by the BEA and the DGAC for the Mauritius Authorities.

p.111, lines 14-15.

The BEA is outraged by the NTSB 's refusal to take into account this other investigation led by both the BEA and the DGAC on behalf and with the Irish Authorities.

(Ref. BEA Extended Comments, para. 1.8.1).

p.114, line 23 to 25.

The NTSB states that the investigation "was commenced on March 5, 1993", but omits to mention that it did not provide any information to be BEA before October 1995. Moreover, the NTSB only mentions the ASRS report, unknown at that date the BEA, the DGAC and ATR. Thus the BEA requires that the following more accurate information be inserted :

"The pilots of the Continental Express flight provided an early pilot report which was corrected later by the following ASRS, report dated 16.3.94 regarding the events.

p.115, line 2.

The BEA requests that the first full pilot statement be reproduced in order not to eliminate a relevant information ;

Add after "area" :

"... area and complicated by the cruise prop RPM setting rather than icing prop RPM setting. A combination of workload and fatigue probably caused me to miss properly setting the correct icing RPM when we entered icing conditions".

p.116, line 2

The following more accurate information should be inserted :
"concluded in its "Preliminay Report" dated March 25, 1993 and based upon the early pilot report that".

p.116, line 3

Moreover, foot note 56 refers to "the only report produced by ATR".
The Aviation Safety Division ignores the fact that it provided no information, not even factual information, about this Newark Incident.
Therefore, the BEA respectfully asks the Board Members whether the Aviation Safety Division usually watts for a preliminary analysis by the Manufacturer (even though the NTSB does not provide any information) before the NTSB conducts its own investigation without concluding on a probable cause, as of May 1996.
(Ref. BEA Extended Comments, para., p).

p.l17, 1ine 2 to 4

Exactly ! But this wording, according to its meaning, is very simplistic ans poorly presented and unsubtle.
The BEA can only make the same comment as on page 116.

p.119, line 17-23.

The BEA considers that the NTSB statement is contradictory with the factual evidence : information known by the NTSB about some incidents was hidden or veiled from the French Authorities and ATR.
Regarding the last phrase : "The DGAC and FAA did not recommend or require ATR or its operators . . .", the BEA can only question the behaviour of the NTSB in this matter : what did the NTSB recommend ?

p.120, line 10 to 12

The BAA, fully in line with ICAO Annex 8, § 4.2.3, specifies that the collaboration between the Exporting State (State of Manufacture) and the Importing State (here, the State of Occurence) is conducted under the authority of the State of Occurence. The BEA recommend that the NTSB clarify the processus of exchange of information between the different Aeronautical Authorities (NTSB, BEA, FAA, DGAC), the airlines, and the aircraft manufacturer under the BAA,

p.121, lines 18 to 25 and p. 122, lines 1 to 22.

This specific A320 event is irrelevant in the frame of this accident investigation. There are numerous examples of incorrect information and poor communication between NTSB/FAA/US Airlines, and their foreign equivalent to support the proposed finding.

p.124, line 2.

The BEA request that the ATR analysis be properly reported by adding “with airframe de-icing on” after “freezing rain”.

p.126, lines 19-25.

The BEA considers that this statement results from a general knowledge of control surfaces behavior in presence of flow separation and cannot be derived from the a.m. icing tests, as it could be inferred from the current wording, which should be amended.

p.129, lines 13 to 17.

This statement is in contradiction with the official ATR report and should be rewritten as follows :

"In the 104 to 140 MVD tests (outside FAR 25 Appendix C envelope) during which accretion occurred at flaps 15, the subsequent stall maneuver resulted in hinge moment reversals prior to shaker AOA, only when the maneuver was performed at flaps 0".

p. 129, line 19.

The momentary peak of 77 lbs mentioned is misleading since it resulted from a combination of exaggerated lift asymmetry resulting from the partial wing pollution behind the tanker, and from the large 20 lbs initial out of trim clearly revealed by the DFDR traces. Hence BEA request that this clarification is added to the original wording.

p.144, lines 9-10.

The BEA requests this wording be modified in order that the NTSB takes into account that :

In complement to ATR generated "All Operators Telexes" specifically covering incidents, ATR incorporated Briefs concerning all other incidents in their Monthly Reports addressed to all operators and Airworthiness Authorities. These briefs report all of the significant technical incidents that have occurred during the corresponding period.

p.145, lines 2 to 5.

The BEA's investigation of the ATR training center simulator software packages revealed that a more representative icing encounter simulation is available to compensate for the lack of external environmental representations. Refer to section 1.5.1 of this document for more details. This ultimate refinement is available for installation on all simulators. The NTSB's statement is unduly critical and does not take into account the associated instructor comments. Furthermore, this NTSB statement is not coherent with the NTSB's statement on page 37 line 17.

p. 145, lines 9-20

This factual information is very attractive but it is surprising that it is not used in the Analysis Section of the NTSB Report.

p. 147, lines 16-17

The BEA strongly disagrees with this NTSB statement :

Holding at 10,000 feet in icing condition and even more so when these conditions refere to moderate to severe icing condition constitutes a critical phase of flight during which the sterile cockpit rule applies. The BEA position is strongly supported by the further NTSB own recommendation to AMR to encourage the pilot to observe the sterile cockpit rule in icing conditions, and to the FAA to enforce this application.

p.153, line 2

The BEA checked the content of this brochure edited in 1992 and the word "freezing drizzle" does not appear.

p.159, lines 7 - 8.

The BEA considers this NTSB statement unfair, particularly since ATR specifically pointed out during the Technical Review Meeting that data or algorithms for training simulators were continuously updated on the basis of acquired knowledge resulting from analysis of in-service reported incidents. The corresponding training software is incorporated in the Toulouse ATR simulator and is made available to other training centers. The BEA independantly checkoff that the roll anomaly upset detected in the Mosinee incident was properly incorporated into ATR's simulator software by mid June 1990, and that Flight Safety International's (FSI) Houston Center Simulator had been updated with this information in 1990 as well.

Refer to section 1.5 of this document. It is very likely that the accident crew was trained using this updated software which included the following two flight characteristics of the Mosinee incident i.e., a marked asymmetrical stall and roll control heaviness.

p. 159, lines 13 to 15.

The BEA absolutely insists that this section be deleted in its entirety, as agreed in NTSB TRM. During the Technical Review Meeting, Gilbert Defer specifically informed the NTSB that this testimony in the Hearing had been taken out of context and that the NTSB was not accurately reporting his testimony.

2. ANALYSIS

The BEA generally does not disagree with the Recommendations proposed in this Report. However, it sees little connection between those Recommendations and the Report's Probable cause,

This Probable Cause is developed through an highly selective analysis of the ATR aircraft characteristics, and of the relationship between the DGAC, the FAA and ATR.

This results in very different perceptions of this accident leading to discordant conclusions.

The BEA did undertake a conscientious effort to study the current draft Analysis section and to list all the necessary observations, corrections, and detailed commentaries required to address its many deficiencies. Under such circumstances, considering that the result would be an unusable document, it is more appropriate for the BEA to submit its Annex 13 Comments on the Analysis of this accident in the form of a revised and corrected Analysis which is presented in the following sections.

2.1. METEOROLOGICAL FACTORS

The icing conditions in which the flight 4184 was operating do not appear to be exceptional in terms of meteorological conditions, considering the results highlighted by the present study. The conditions were light to moderate icing, since the flight was taking place in a stable cloud layer at negative temperatures, close to O°C. **These moderate icing conditions, conducive to ice accretion, were seriously aggravated by liquid precipitation (supercooled drops of rain or drizzle) generated in this layer or originating in an upper layer,** This explanation can be considered to be typical of a meteorological forecast lacking in detail, such as the AIRMET broadcast's summary concern with icing conditions. **The excessive duration of the flight in such conditions, with no recorded comments (as shown by the CVR transcript) on the severity of the icing, nor any upon the procedures to be applied in the conditions, seems incomprehensible on the part of the flightcrew.**

Another major element is the domain of aircraft certification in icing conditions. The reference is appendix C of JAR - JAR 25 regulation, which sets the certification limits. This regulation does not consider the existence of supercooled droplets or drops having a diameter over 40µm (continuous maximum atmospheric icing conditions) with a liquid water content over 0.8 g/m^3 in the cloud layer nor the case of freezing drizzle or freezing rain.

Thus the BEA's study points up the following five findings :

1. According to the content of the flight release, the crew was aware of the existence of light to moderate icing on the Indianapolis - Chicago route at the levels at which they were flying.

2. In an available AIRMET, valid before and for the flight, rainfall was forecast at the altitude of Flight 4184 with negative air temperatures.

3. Precipitation was detectable on the airborne radar on WX position.

4. The flight in the holding pattern lasted over 30 minutes in a cloudy atmosphere with liquid precipitation and at a SAT varying betwwen -2 and -4°C. This was in complete contradiction with the limits specified in the certification and operational procedures.

5. Procedures relative to flights in icing conditions, specifically those related to the surveillance of environment, static temperature, ice indicators, and detectors, as well as some visual cues, were not respected by the flightcrew. In addition, standard procedures relating to propellor speed adjustment and anti-icing and de-icing system activation in icing conditions were not properly applied.

In conclusion, overall crew vigilance and awareness did not correspond to the basic rules to be applied on such a flight, occurring in icing conditions conducive to ice accretion.

2.2. HISTORY OF FLIGHT

2.2.1. HOLDING TECHNIQUE

The holding pattern is flown with Auto-Pilot in the Altitude-Hold Mode. Under these conditions, the airspeed must be maintained by manual adjustment of the engine torque. It is observed that throughout the entire holding patterns the number of these adjustments is very limited. As a consequence, airspeed variations of more than 10 knots are noticed during each holding turn, leading the airspeed to decay marginally below the minimum authorized speed (Vm HBO-icing) which was computed at 165 Kt for this holding.

Utilization of higher holding speeds, which could have been authorized by the Air Traffic Controller, would have minimized the crew's feeling related to the aircraft "wallowing in the air", even during the phases where airspeed was reduced as the result of their limited power adjustments. This higher holding speed would have precluded the flight crew's ad hoc decision to use a different flap setting than the one provided for in the aircraft manuals and which was initially selected by the crew. This would have increased the safety margin with the minimum authorized speed while eliminating the risk of inadvertently reaching the maximum authorized speed limit.

The flight path of the aircraft is controlled laterally by modification of the bank angle, through selection of either of the High Bank or Low Bank options of the Auto-Pilot. Analysis of the resulting trajectory indicates that pilot selection was adequate.

2.2.2 ANALYSIS OF HOLDING PATTERN SEQUENCES

• Meteorological Conditions

During the hold, Flight 4184 was operated in and out of clouds with liquid water content (LWC), between 0,3/ 0,7 g/m^3, in temperatures close to freezing, with freezing precipitation(with a high content of large supercooled droplet MVD > 100 µm) conducive to what is now referred to as "freezing drizzle" resulting in moderate to severe icing conditions.

. Description of Holding Conditions

The holding conditions imposed by the ATC and accepted by the crew were characterized by :

- a repeatedly extended period of holding, which progressed from a "bit of holding" to 15 minutes, then 30 minutes then 45 minutes.

- Flight level at 10000 ft, close to freezing level (SAT) and speed of 175 kt.

Four successive holding patterns of approximately 9 minutes each, were conducted in an isolated stack.

- The ATC monitoring of the Flight 4184 holding conditions was characterized by a lack of attentiveness.

• Holding Technique

The first holding pattern was conducted at 175 kt at Flap 0°, Propeller NP set at 77%, airframe de-icing (Level III) OFF. The resulting AOA was approximately 6°.

• The subsequent holding patterns were conducted at 175 kt, with 10 to 15 kt speed decay during each turn due to limited torque corrections, at Flap 15, propeller NP at 77%. The NP setting was changed to 86% when the second AAS single chime was triggered and after airframe de-icing system(Level III) was selected. During the Flaps 15 phase the resulting AOA was slightly negative.

This phase ends at 15.57.33 during the descent to 8000 ft, with the sounding of the V_{FE} overspeed signal.

€ Accretion mechanism

These events resulted in a two phase ice accretion mechanism during the hold :

- a first phase of approximately 10 minutes, with Flap 0, where ice accreted with a positive AOA, airframe de-icing system OFF, propeller NP at 77% (the required 86% was not used although in icing conditions).

- a second phase, with Flap 15 (negative AOA), with 8 minutes with Level III OFF, NP 77%, 86% still not respected in icing conditions, followed by 16 minutes with Level III activated, NP at 86%.

€ Due to the nature of the icing conditions (SCLD, freezing drizzle), the resulting intermittent ice accretion covered the leading edge, as well as aft of the de-icing boots on the lower surface of the wing during the Flap 0° phase (positive AOA) and the upper surface of the wing during the Flap 15° phase (negative AOA).

- At 15:41, the airframe Level III de-icing eliminated the leading edge accretion, but some residual accretions were present on both upper and lower surfaces of the wing aft of the de-icing boots.

During the subsequent phase of accretion at Flap 15° (negative AOA) this residual ice accretion beyond the boot active area probably became a good collector of incoming water drops, resulting in the formation of a unique ice ridge aft of the boot on the upper surface of the wing.

- The Roll Upset

At the V_{FE} overspeed signal, the crew retracted the flaps which resulted in a progressive increase of AOA.

At the critical value (4,8°) a flow separation initiated aft of the ridge and at the trailing edge of the outer wings and progressively developed. This resulted in a right wing down tendancy, initially controlled by the Auto Pilot until it disconnected when the full development of the flow separation triggered the hinge moment reversal and the subsequent aileron deflection up to its stop.

2.2.3. FLIGHT CREW PERFORMANCE

The BEA strongly believes that the NTSB's highly edited CVR transcript contains significant information regarding crew performance issues which could provide important safety lessons to all flight crews so that the chain of events involved in this accident can be avoided thus preventing the recurrence of other accidents in the future. The BEA believes that the NTSB should take this opportunity to squarely address these issues with the goal of improving aviation safety.

The NTSB's lack to timely address these issues following this accident is particularly disturbing. The poor cockpit discipline, lack of cockpit resource management, and lack of situational awareness involved in this accident created an obligation on the part of the NTSB to address such safety issues to prevent their reoccurrence. The BEA's concern in this regard has been confirmed by the recent announcement by the FAA that it has initiated an in-depth review and analysis of flight crew training programs.

The cockpit atmosphere lacked the conservative and attentive nature to detail which is required when operating a commercial aircraft. Indeed, the CVR transcript is replete with "non-essential communications" and activities which denote a lack of professionalism and crew coordination by the crew. Such conduct is particularly unacceptable when the aircraft is being operated in an acknowledged icing environment. Complacency replaced vigilance and social discourse replaced proactive safety awareness and sound operational procedures which could have, prevented this accident.

Flight Crew task allocation between Captain and First Officer as defined by the Airplane Operating Manual is mandatory :

- the Flying Pilot, flies the Airplane,
- the Non-Flying Pilot, is in charge of Communication and Navigations,

The BEA provides its additional Annex 13 comments regarding the performance of Flight 4184's flight crew below.

2.2.3.1. COCKPIT RESOURCE MANAGEMENT

As a preliminary matter, the BEA notes that the *American Eagle's Crew Resource Management* publication, adapted from American Airlines, outlines the training program utilized by American Eagle/Simmons in respect to training its flight crews for *Techniques for Effective Crew Coordination*. (NTSB Exhibit 2-E). The BEA has provided some text of this publication in Section 1.11 *Additional Pertinent Documentation*. The BEA has also mentioned Advisory Circular No. 120-51A (NTSB Exhibit No. 2D) entitled *Crew Resource Management Training* which also provides guidance in respect to assessing the Crew Resource Management (CRM) issues involving this accident. Appendix 1 of AC No. 120-51A provides "Crew Performance Marker Clusters" which can be utilized to assess the performance of flight crews.

The BEA recommends that the NTSB conduct a thorough review of the actions of Flight 4184's flight crew in the context of these "marker clusters".

As discussed in the comments below, the BEA believes that the actions of Flight 4184's flight crew violated American Eagle/Simmons' policies regarding cockpit resource management because the flight crew did not exhibit proper and effective crew coordination procedures or cockpit resource management techniques.

2.2.3.2. THE FLIGHT CREW'S USE OF FLAPS 15 WAS NOT PROVIDED FOR BY THE ATR AIRPLANE OPERATING MANUAL

American Eagle/Simmons Operating Manual (AOM), ATR's Flight Crew Operating Manual (FCOM), and the applicable performance charts for holding do not provide for the use of a Flap 15 degree configuration in holding. The flight crew's use of a Flap 15 configuration inducing an AOA of approximately 0 degrees while holding in icing conditions created the critical ice ridge beyond the de-icing boots which ultimately led to the roll upset when the Flaps were retracted from 15 to 0 degrees with an AOA increasing to 5.6 degrees and thereby directly contributed to the accident.

2.2.3.3. THE STERILE COCKPIT RULE WAS APPLICABLE TO FLIGHT 4184 WHILE HOLDING AT LUCIT INTERSECTION

Section 4, para. 90 and 91 of American Eagle's Flight Manual entitled *Nonessential duties during* critical phases of *flight (Sterile Cockpit] (FAR 121. 542)* and *Sterile Cockpit Definition,* respectively, set forth the policy of American Eagle/Simmons in respect to the Sterile Cockpit Rule. The BEA has provided text of these critical documents in Section 1.11 *Additional Pertinent Documentation.* The BEA has also set forth in this Section the complete text of Federal Aviation Regulation 14 CFR § 121.542 *Flight Crewmember Duties.*

The FAA's original NPRM (Notice of Proposed Rulemaking) confirms that the intent of the sterile cockpit rule was to specifically address situations such as those which occurred in this accident. In this regard, the NPRM published in the Federal Register on 28 August 1980 makes clear that the Sterile Cockpit Rule was proposed by the FAA with the intent of eliminating "distractions caused by flight crewmember performance of duties and activities unnecessary for the safe operation of aircraft ."

The FAA's review of data from NASA and the ASRS (Aviation Safety Reporting System) revealed numerous examples of this problem. Significantly, the FAA identified a "third major category of distractions" which involved "unnecessary communications between the flight crew and cabin crew. "

To the extent that the NTSB relies upon the testimony of the FAA during the NTSB Public Hearing to suggest that Flight 4184 was not operating in a “critical phase of flight”, the BEA strongly disagrees. The BEA questions the relevance of the FAA witness wether he was authorized by the FAA, to make a determination as to whether Flight 4184 was operating in a “critical phase of flight” within the meaning of CFR Section 121.542. Based upon an analysis of all available information regarding this accident, the last thirty (30) minutes of Flight 4184 was clearly a “critical phase of flight” within the meaning of American Eagle’s Flight Manual as well as FAR 121.542. The factors which clearly demonstrate that Flight 4184 was operating in a “critical phase of flight” are as follows :

1. Flight 4184 was a FAR Part 121 air carrier flight.

2. Although the “critical phase of flight” as defined in FAR 121.542 “includes . . . all other flight operations conducted below 10,000 feet, except cruise flight”, the regulation does **not** exclude flight operations conducted at 10,000 feet or above. Indeed, it would be irrational and counter to safety of flight to suggest that a “critical phase of flight” could not occur at or above 10,000. Depending upon the circumstances, a “critical phase of flight” can occur at **any** altitude. This was confirmed by American Airlines recent policy change which now requires that American’s flight crews observe “sterile cockpit” procedures i.e., no extraneous conversation, below 25,000 feet when operating in Latin America, rather than 10,000 feet.

3. Flight 4184 was **not** operating in cruise flight. Rather, Flight 4184 was operating in a holding pattern which is significantly different than cruise flight. In this regard, air speeds are reduced, fuel consumption is of prime importance, the aircraft is operating at lower altitudes and, there are typically more aircraft operating in the immediate vicinity. In addition, when an aircraft is operating in a holding pattern, the flight crew experiences an increased workload which requires more crew coordination, crew communication, and situational awareness, particularly when operating in known icing conditions. In this regard, the flight crew must be more attentive to ice accumulation, ATC clearances and traffic alerts, navigational demands are increased, the crew is required to perform more flight planning and, the crew is required to operate the aircraft more.

4. Flight 4184 was operating in icing conditions conducive to ice accretion in precipitation, It is significant that flight 4184 was **not** transiting an area of icing. Rather, Flight 4184 was operating in known icing conditions and was lingering in that environment for a significant period of time. American Eagle/Simmons' policies mandate that flight crews exercise vigilance when operating in icing conditions and that flight crews avoid icing conditions when possible. Further, such crew vigilance was also critical to assure timely detection of potentially hazardous ice accretions and to request ATC for an alternate holding altitude.

5. Flight 4184 was holding in one of the busiest air traffic control areas in the country, if not the world, in preparation for a clearance to perform an instrument approach into Chicago's O'Hare International Airport, which is one of the busiest airports in the world. Constant and careful monitoring of ATC communications is not only mandatory by regulations and company procedures, but is also dictated by basic airmanship when operating in such a high density traffic area.

6. Flight 4184 was waiting for a clearance from Chicago ARTCC to descend below 10,000 feet. Irrespective of the EFC (expect further clearance) time provided by ATC, the clearance to descend below 10,000 feet could have come at any time.

7. American Eagle's AOM states that a critical phase of flight may also include "any other phase of a particular flight as deemed necessary by the Captain."

Based upon these factors, an operational environment existed which established that Flight 4184 was operating in a "critical phase of flight" while holding at LUCIT Intersection. In this case, both the Captain and the First Officer failed to exercise their joint authority and responsibility in not declaring, complying with, and enforcing a sterile cockpit condition. Under the Sterile Cockpit Rule, it is the Captain and/or the First Officer's responsibility to declare a sterile cockpit. In this case, the Captain and the First Officer should have declared that Flight 4184 was entering a "critical phase of flight" and prohibited all activity which could have distracted or interfered with the safe operation of the aircraft.

The edited CVR transcript clearly indicates that Flight 4184's crew violated applicable Federal Aviation Regulations and American Eagle /Simmons' policies and procedures by not mandating and enforcing a sterile cockpit environment while operating in moderate to severe icing conditions in the holding pattern. Instead of exercising proper crew vigilance, cockpit/crew resource management, and situational awareness, the crew was engaged in almost constant non-essential activities and conversations which had no bearing upon the safe and proper operation of the aircraft. The BEA discusses these issues in more detail below.

2.2.3.4. AMERICAN EAGLE/SIMMONS' POLICIES MANDATE THAT FLIGHT CREWS EXERCISE CREW VIGILANCE WHEN OPERATING IN ICING CONDITIONS AND THAT FLIGHT CREWS AVOID ICING CONDITIONS WHEN POSSIBLE.

The BEA analysis of Flight 4184 crew proper decision making is made in reference to the criteria established by the NTSB, presented in section 1.11 of this Document, as Primary Error NO 8.

Numerous documents make it clear that American Eagle/Simmons' policies mandated that flight crews exercise vigilance when operating in icing conditions, and that flight crews avoid icing conditions when possible. In this regard, the BEA refers specifically to the following documents :

(1) the *Simmons Flight Operations News Letter* dated December 1993 (NTSB Exhibit 2T-1, p. 3-4) entitled *Aircraft Ice ;*

(2) the American Eagle Flight Manual - Part 1, Section 6, Page 8, issued 17 November 1992 (NTSB Exhibit 2-A, p. 48 - attachment "O") which defines various icing conditions, their effect on airplane performance, and the diversion actions to be taken under various icing conditions ;

(3) the Flight Manual, Part 1 para. 43 *Use of anti- ice/deicing* which provides instructions for flight crews in respect to the use of anti-ice /deicing equipment as an aid in descending or ascending through icing conditions ;

and 4) the American Eagle Flight Manual [NTSB Exhibit 2-A, p. 79] which specifically states :

> . . . Also, freezing precipitation which tends to flow prior to freezing may flow off the detector prior to freezing, falling to trigger the detector. Yet this same precipitation will flow aft on the wing and freeze creating a potentially dangerous situation. <u>Crew vigilance must be used to detect the formation of ice as soon as possible.</u>

The BEA has provided text of these critical documents in Section 1.4.1 and 1.4.2.

Based upon these documents it is clear that American Eagle/Simmons' policy mandated that flight crews exercise vigilance when operating in icing conditions and that flight crews avoid icing conditions when possible.

There is a little doubt that the icing conditions encountered by Flight 4184 were at least "moderate" and possibly "severe". In this regard, the Edwards flight tests demonstrated that operations in freezing drizzle conditions for a prolonged period of time, as was the case for Flight 4184, causes significant ice accretions to form on the frame of the aircraft's windscreen, cockpit side windows, wiper blades, spinners, and ice detector probe.

In this regard, Captain Jack Walters testified at the NTSB Public Hearing that Simmons' flight crews are trained by American Eagle to look for these specific visual indicators to determine if the airplane is collecting ice.

Proper monitoring of the outside air temperature, precipitation, and the ice accumulating on the aircraft should have informed the crew that they were operating in a freezing precipitation environment. These conditions were likely encountered by Flight 4184 and the flight crew should have requested a different altitude or holding pattern to avoid these icing conditions.

The BEA considers that the crew did not observe the 14 CFR121.561 requirements relative to Pireps.

Finally, it is significant to note that the Airman's Information Manual (AIM) specifically mandates that the crew of Flight 4184 "report icing conditions to ATC/FSS, and if operating IFR, request new routing or altitude if icing will be a hazard."

Moreover had the crew of Flight 4184 provided ATC with a PIREP of their known icing conditions, it is reasonable to assume that on their request they would have promptly been issued a clearance and would have immediately exited the area, thus avoiding the accident.

2.2.3.5. THE DFDR AND CVR DATA SHOW THAT THE FLIGHT CREW WAS DISTRACTED WHILE MANAGING THE AIRCRAFT'S DE-ICING AND ANTI-ICING EQUIPMENT IN ICING CONDITIONS

The BEA analysis of Flight 4184 crew operation of aircraft Systems is made in reference to criteria established by the NTSB, presented in section 1.11 of this Document, as Primary Error No 7.

There is no issue about the definition of icing conditions.

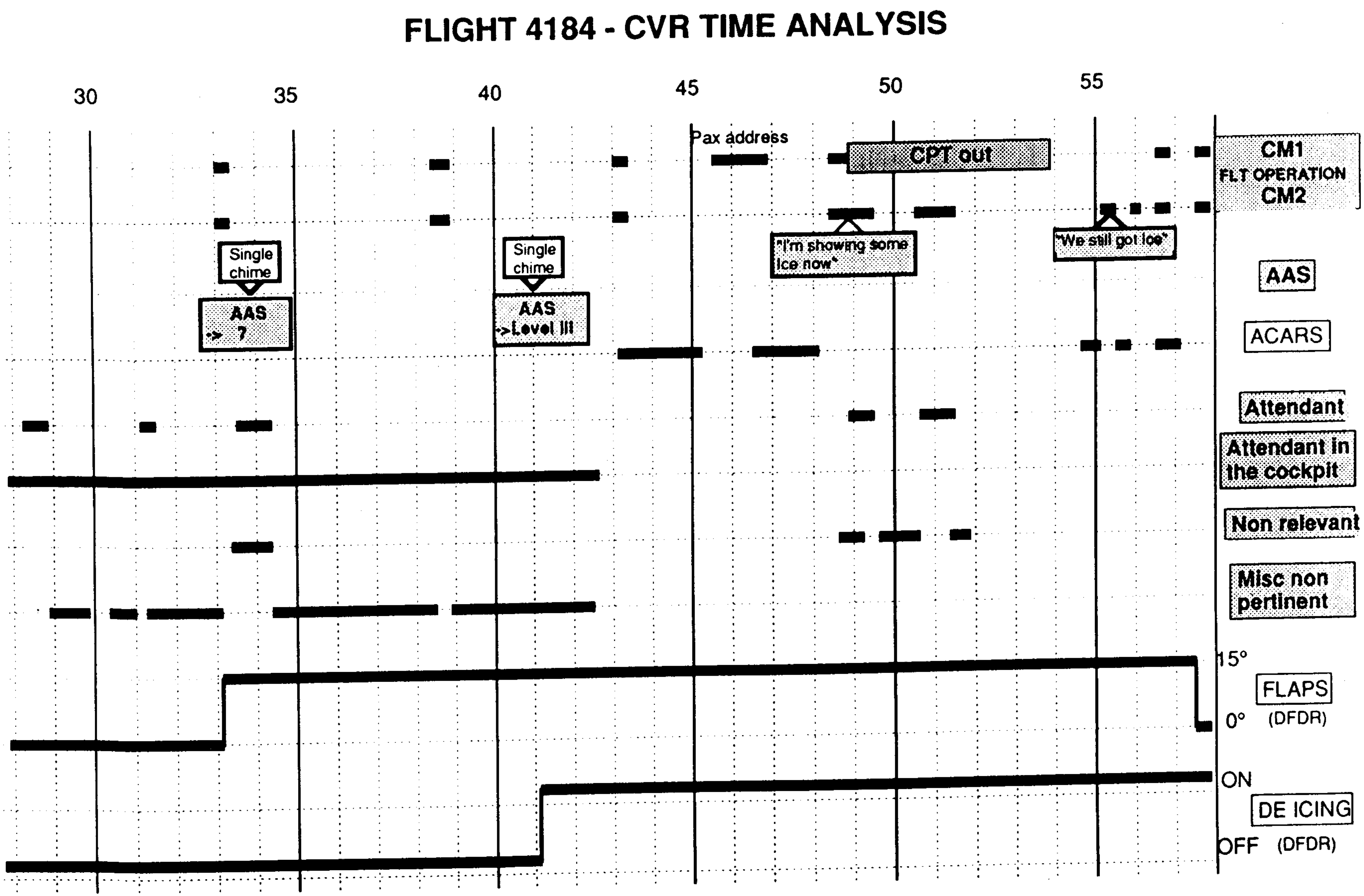
ATR's AFM provides specific procedures in respect to operation of the ATR-72's anti-icing system (Level II) and de-icing system (Level III). ATR's AFM, Section 3.04 *Procedure for operation in atmospheric icing conditions*, provides that Level II anti-icing systems, which consist of Propeller 1 and 2, Horn 1 and 2, Engine 1 and 2, Side Window and NP 86% minimum, are to be activated when icing conditions exist. These systems must be activated prior to the activation of the Level III De-icing System which consists of the airframe de-icing system (boots) and which are used only when ice starts to actually accrete on the aircraft.

The DFDR data indicates that at 1516:32, the airframe de-icing system was activated. This means that Flight 4184 was probably accreting ice. At 1524:30, the airframe de-icing system was turned off. At 1524:50, twenty seconds later, the flight crew selected NP 77% whilst they still were in icing conditions. According to ATR's AFM and AOM procedures, NP 77% is not to be selected in icing conditions. NP 86% at least, on the other hand, must be utilized when the Level II anti-icing systems are activated. Based upon this information, the BEA suggests that two separate hypotheses are possible in respect to the crew's actions: (1) the remaining components of the Level 11 anti-icing system were de-activated (Engine 1 and 2, Propeller 1 and 2, Horn 1 and 2, and Side Window) at or about the same time the crew selected NP 77%; or (2) the flight crew left the remaining components of the anti-icing system ON.

The BEA has investigated and analyzed prior icing incidents and has found that this had occurred in the past.

At 1528:00, the CVR transcript starts. At 1533:56, the CVR recorded a "single tone similar to a caution alert chime. " The DFDR data and the meteorological conditions, information set forth in the BEA's meteorological study show that between 1523 and 1534, Flight 4184 was intermittently operating in liquid precipitation with a SAT between -2.5 and -4,0 degrees C. During this time period, the flight crew maintained NP 77% and the airframe de-icing was deactivated. This lack of action by the flight crew was in violation of the ATR-72 AFM/AOM. In this regard, the Simmons Airlines Winter Operations Handout also specifically provides :

FIGURE 14 : FLIGHT 4184 CVR TIME ANALYSIS



More than 15 mn of Non Relevant & Non Pertinent conversations

Crews are cautioned to remain alert to these conditions and frequently check Static Air Temperature (SAT) indications during cruise and descent. If SAT indications reach a value of 5 degrees C or less, good operating practice would dictate that icing equipment be operated accordingly.

Further, while the aircraft was flying the second northern right turn in the hold, from 1532:30 to 1534:30, a large decrease of 14 kts was recorded on the DFDR. The analysis of this speed reduction indicates that it was caused by the following : turn technique initially conducted at constant torque with a high bank angle representing a large contribution to the speed decay; fluctuating winds with a magnitude of up to 40 kts from the south southwest (210 degrees); ice accretion resulting from icing conditions with freezing precipitation confirmed by the BEA study.

Although it was impossible to accurately evaluate the different individual contributions to the large speed decrease, there is no question that part of this speed decrease was attributable to the ice accretion. The NTSB's own analysis indicates a first small drag increase 24 minutes before the roll upset, at 15.33. Thus, the 1533:56 caution alert chime might have corresponded to the aircraft's ice detector system (AAS), which would have responded within 30 seconds after the first ice accretion began. This view is supported by the fact that during the Edwards AFB flight tests, the AAS system activated the aural icing warning within 30 seconds of encountering the artificial freezing precipitation conditions. Significantly. the 1533:56 caution alert chime was never acknowledged by the flight crew according to both the CVR and the DFDR data.

At 1541:07, a “single tone similar to caution alert chime” sounds. The DFDR data indicates that the flight crew then activated the airframe de-icing system, Two seconds later at 1541:09, the flight crew increased NP from NP 77% to NP 86%. This DFDR data is confirmed by the increased noise which can be heard on the CVR tape.

AT 1542:02, the CVR transcript records “8 clicks” which could have corresponded with the activation of the following anti-icing systems: pushbuttons for Engine 1 and 2, Propeller 1 and 2, Horn 1 and 2, Side Window, and the engine continuous relight knob. However, during the BEA’s investigation, the BEA had the opportunity to participate in two test flights during which the BEA listened and recorded on the CVRs various sounds generated in the cockpit. No clicks were audible on the CVR. Moreover the activation of two push-buttons of the airframe de-icing system is not audible on Flight 4184’s CVR. This suggests that Level II was operating prior to activation of Level III on Flight 4184,

Finally, it is very significant to note that between 1524 and 1541, when the aircraft was not properly configured for flight in icing conditions, the extensive “non-pertinent conversations” between the flight crew and the 1st Female Flight Attendant were occurring in the cockpit. Contrary to the NTSB’s view that these conversations are “non-pertinent”, the fact that these conversations occurred during this critical time period makes them highly pertinent. This is also the same point in time when the NTSB believes that Flight 4184 was experiencing an increase in drag attributable to ice accretion.

2.2.3.6 THE EXTENSIVE "NON-PERTINENT CONVERSATION" BETWEEN THE FLIGHT CREW RAISES SIGNIFICANT SAFETY ISSUES REGARDING CREW INTERACTION AND HOW SUCH INTERACTION CAN IMPACT SAFETY OF FLIGHT.

When the NTSB extensively edited the CVR transcript to delete the "non-pertinent conversations" between the Flight Crew and the Junior Female Flight Attendant, the NTSB deprived itself of an important and unique opportunity to analyze and comment upon male-female crew interactions and how such interactions can interfere with crew vigilance, cockpit procedures and aviation safety. In this regard, the unedited CVR transcript contains significant information which mandates that the NTSB conduct a thorough review and analysis of these issues.

The CVR transcript indicates that when the recording began the sound of "loud music" was being recorded by the Cockpit Area Microphone (CAM), and the Junior Flight Attendant was on the flight deck and remained in the cockpit for the following approximately 14 minutes. Although the CVR transcript is highly edited, both the edited and the transcribed conversations make it clear that the Junior Flight Attendant was involved in an extensive conversation with the Flight Crew. This discussion involved comments by the Flight Attendant as to how easy the flight crew's job was, how much she liked dealing with the passengers and, the length of the delay in arriving in Chicago. During this same period, the extensive conversations between the Captain, First Officer, and the Flight Attendant consisted of irrelevant and gratuitous demonstrations for the Flight Attendant regarding the functioning of various airplane systems such as the glide slope "pull-up" aural warning and the Ground Proximity aural "terrain" warning.

It is highly significant that during this 14 minute period (1528:00 - 1542:38), 11:14 minutes of conversation between the 1st Female Flight Attendant and the flight crew were not transcribed but simply characterized by the NTSB as "non-pertinent pilot and flight attendant conversation continues". Again, **the fact that these extensive conversations are considered by the NTSB to be "non-pertinent" conversations which do "not directly concern the operation, control or condition of the aircraft" makes them highly pertinent.**

As discussed above, Part 1 of American Eagle's Flight Manual prohibits "non-essential conversations within the cockpit and non-essential communications between the cabin and cockpit crews" during a "critical phase of flight". Similarly, FAR 121. 542(b) prohibits this kind of conduct because "non-essential communications between the cabin and cockpit crews" are "not required for the safe operation of the aircraft, " These "non-essential conversations" directly contributed to the flight crews lack of vigilance in respect to monitoring and deviating from the known icing conditions the aircraft was holding in. A prudent flight crew, devoting their full attention to the operation of the aircraft instead of carrying on long non-pertinent, non-safety related discussions with flight attendants and other irrelevant conversations, would have carefully monitored the known icing conditions, monitored existing weather information, and analyzed the changing atmospheric conditions which had been deteriorating to assess its potential impact upon the safety of their flight.

2.2.3.7. THE CREW DID NOT EXERCISE PROPER COCKPIT RESOURCE MANAGEMENT TECHNIQUES OR CREW DISCIPLINE IN RESPECT TO MANAGING THE WORKLOAD OF THE FLIGHT

The BEA analysis of Flight 4184 Crew Ressource Management refers to criteria established by the NTSB, presented in Section 1.11 of this Document, as Primary Error No 5.

The NTSB's CVR transcript, even in its edited form, clearly demonstrates that the flight crew did not exercise proper resource management techniques in respect to sharing the workload of the flight particularly in known icing condition. In addition to the extensive "non-pertinent conversations" between the Captain and the Junior Female Flight Attendant which are discussed above, it is very important to note that between 1549:05, (when the CVR recorded the "sound of ding along similar to flight attendant call bell"), and 1552:00, the First Officer was completely preoccupied with at least two, and possibly three separate intercom conversations with the Junior Female Flight Attendant, the Senior Female Flight Attendant, and the Captain, which had no bearing on the operation of the aircraft.

The First Officer was alone in the cockpit throughout this entire period of time with complete responsibility for handling the entire workload of the flight. In addition to his extensive conversations on the intercom, the First Officer was also attempting to fly the aircraft, stay within the holding pattern, adjust the bank angle on the autopilot, monitor ATC, receive ACARS messages, etc. This situation increased the First Officer's workload dramatically and clearly represents substandard crew resource management and task sharing techniques. Finally, and most importantly, the First Officer's increased workload severely diminished his ability to carefully monitor the known icing conditions the aircraft was holding in.

2.2.3.8. THE CAPTAIN LEFT THE COCKPIT AFTER ICING WAS OBSERVED, AND THE FLIGHT CREW FAILED TO EXERCISE PROPER SITUATIONAL AWARENESS AND COCKPIT RESOURCE MANAGEMENT TECHNIQUES IN RESPECT TO RESPONDING TO THE ICING CONDITIONS

Without ignoring the physiological needs, it was not appropriate for the Captain to leave the cockpit. As discussed above, there were numerous factors which clearly indicated that Flight 4184 was operating in a "critical phase of flight" which mandated that the Captain declare a sterile cockpit condition. These same factors also mandated that the Captain remain in the cockpit. By leaving the cockpit, the Captain increased the First Officer's work load dramatically. This was particularly inappropriate given the fact that the aircraft was operating in moderate to severe icing conditions.

As discussed above, the DFDR data indicates that at 1516:32, the airframe de-icing system was activated for the first time by the flight crew. Thus, it is clear that Flight 4184 had been operating in icing conditions intermittently for at least 32 minutes when the Captain left the cockpit at 1549:07. The Captain was subsequently absent from flight deck for 5:25 minutes. During this time he engaged in a "non-essential conversation" which had no bearing on the safe operation of the aircraft.

The Captain returned to the cockpit at 1554:13, approximately two minutes later. Approximately one and one half minutes after the Captain returned to the flight deck, the Co- Pilot stated "we still got ice" at **15:42.** The Captain did not acknowledge this comment. Based upon the foregoing, it is clear that the Captain was not exercising proper situational awareness or proper vigilance in respect to monitoring the icing conditions.

By leaving the cockpit, the Captain also deprived himself of any opportunity to monitor and request a clearance to deviate from the icing conditions. At no time while the Captain was at the back of the aircraft on the intercom with the Co-Pilot or, when he returned to the cockpit, did the Captain inquire about the icing conditions.

Further, there is no indication that the Captain observed the aircraft's propeller spinners or any other visible part of the airframe for ice accretion while he was walking back and forth through the aircraft cabin. The Captain's lack of vigilance in this regard was directly contrary to American Eagle/Simmons' policies discussed above.

It is very significant that there is no evidence on the CVR transcript that the flight crew discussed the operation of the aircraft's deicing and anti-icing equipment or, that they monitored or discussed the type of ice accumulation or ice accretion rate. Further, there is no evidence that the crew notified ATC that they had encountered icing conditions or, considered giving ATC the Pirep required by Simmon's policies or that they discussed any alternative altitude, holding pattern or route to exit the icing conditions.

In this regard, the FAA Principle Operations Inspector (POI) for Simmons Airlines testified at the NTSB Public Hearing and responded to questions regarding various flight related functions perform by the crew of Flight 4184. The POI stated that given the environment in which Flight 4184 was operating in, ". . . I think I would expected more exchange [verbal communication] between the First Officer and the Captain about the amount - that the ice was there . . ."

Finally, by leaving the cockpit, the Captain completely lost what little situational awareness he had regarding the operation of the flight. In this regard, it is significant to note that at 1557:16.3, approximately 4 minutes after he returned to the cockpit, and **12** seconds before the autopilot disconnected, the Captain asked the First Officer: "are we out of the hold ?"

In sum, the flight crew's actions were directly contrary to American Eagle/Simmons' policies, as well as basic professional airmanship, which mandate that flight crews exercise crew vigilance when operating in icing conditions, and that flight crews avoid icing conditions when possible.

2.2.3.8.1. Flight Planning

The flight crew did not discuss nor revise the flight planning when the weather conditions and the holding situation should have caused him to do so.

2.2.3.8.2. The Flight Crew Was Preoccupied With The ACARS System

The flight crew spent a considerable amount of time attempting to operate the ACARS system, which is a non-essential task.

Moreover, operation of the ACARS system, particularly by the First Officer who was flying the aircraft, prevented any proper scanning of the instruments and hampered other essential flight related activities.

This is supported by the FAA Principle Operations Inspector (POI) for Simmons Airlines testimony at the NTSB Public Hearing. The POI, after having reviewed the transcript of the CVR, stated that it was his perception that the crew "probably was" distracted from flight related duties while attempting to send ACARS information during the period, 1548 to 1555. It was also during this period that two references to icing conditions were recorded on the CVR.

2.2.3.8.3. Listening To "Loud" Broadcast Music While In The Holding Pattern Was Not Appropriate

The CVR transcript begins at 1527:59 with "music similar to [a] standard broadcast radio station" emanating from ADF-2 and continues until 1545:48. Of the 31 minutes transcribed in the CVR transcript, broadcast music was playing in the cockpit for over 18 minutes. Further, the CVR transcript indicates at 1528:21, that the music was "loud'.

The flight crew's use of the ADF radio to listen to "loud" music while in the holding pattern is not promoting vigilance and situational awareness.

2.2.3.8.4. The Flight Crew Did Not Respond To A Traffic Alert and Avoidance System (TCAS) Advisory

The CVR transcript indicates that there was a TCAS alert "traffic, traffic" at 1556:24. However, there is no evidence in the CVR transcript that the crew responded to the TCAS warning. In this regard, there is no discussion between the Captain and Co-Pilot about the warning, what caused the warning or, how they would resolve the conflict. Further, there is no evidence that the crew attempted to contact ATC to determine whether there were any aircraft in the vicinity which could have generated the warning. The flight crew's lack of acknowledgment of the TCAS alert raises several significant questions in respect to the crew's resource management, as it refers to the non flying Pilot (the Captain) primary tasks.

2.2.3.9. THE DFDR DATA INDICATE A LACK OF APPROPRIATE CONTROL INPUTS TO RECOVER THE AIRCRAFT AFTER THE ROLL UPSET OCCURRED.

Flight 4184's DFDR data indicates that from the point in time when the autopilot disconnected until the end of the reliable DFDR data there is no obvious indication of the continuous coordinated control inputs which would have been appropriate to counter the roll upset.

From the time of the autopilot disconnection, the DFDR data indicates nine momentary spikes on the pitch axis corresponding to either the Captain's or the First Officer's inputs in excess of 10 daN (22 lbs). However, the elevator deflection momentarily spiked to 8 degrees "nose up" with a mean value of approximately 3 degrees "nose up". During the entire time from the roll initiation, the rudder deflection was erratic and never exceeded 2 degrees. The maximum available rudder deflection was 3.5 degrees. During the same time period, the aileron deflected erratically fluctuating between an 8 degree "left wing down" position and the "right wing down" stop, and returning to the 0 degree position for 6 seconds at 1557:43. During this entire time, the Power Level Angle (PLA) was left at the Flight Idle position.

The last seconds of DFDR data indicate a rapid, large input on the elevator.

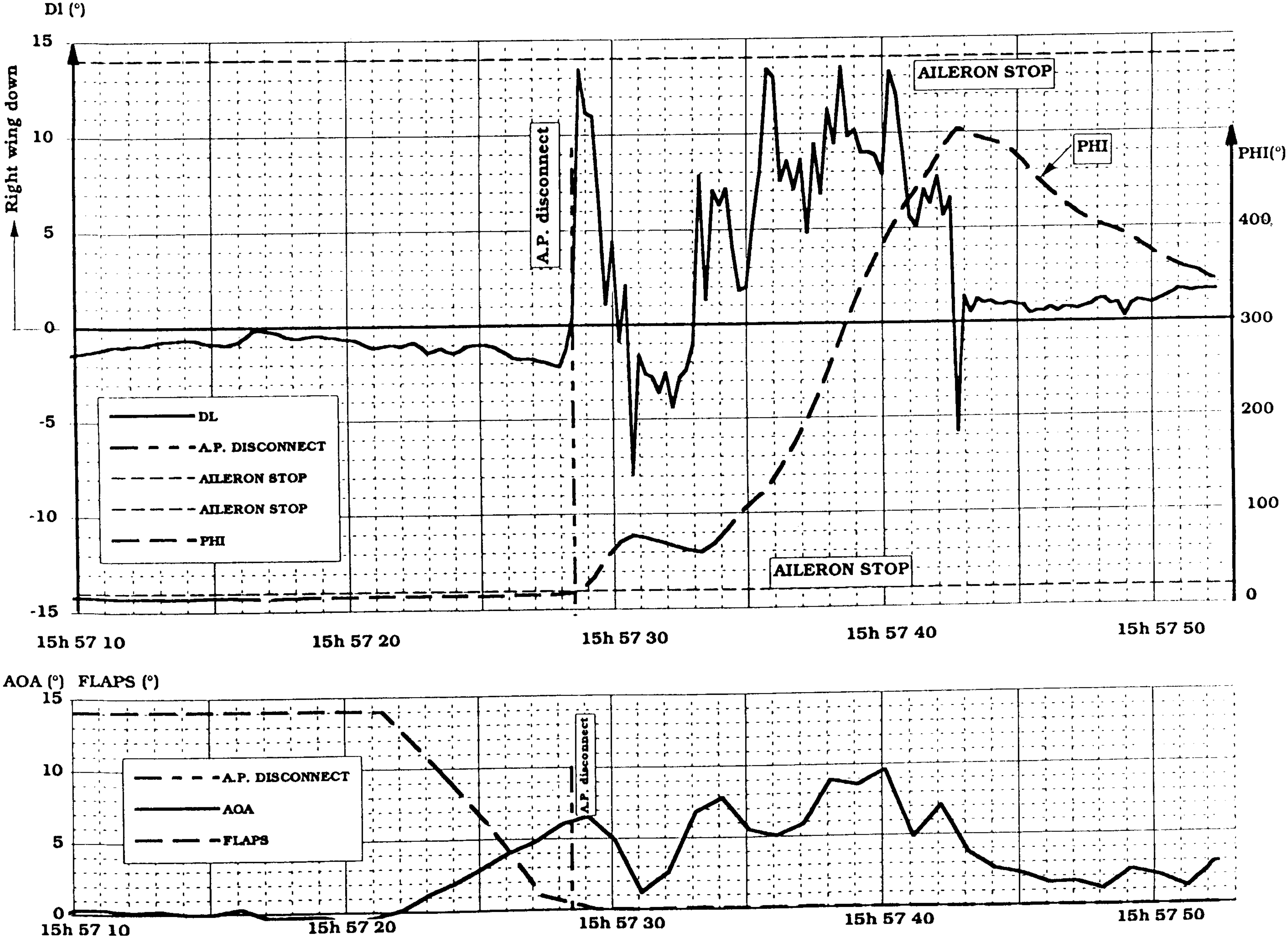


FIGURE 15 : ROLL CONTROL INPUTS / ACTIVITY AFTER ROLL UPSET

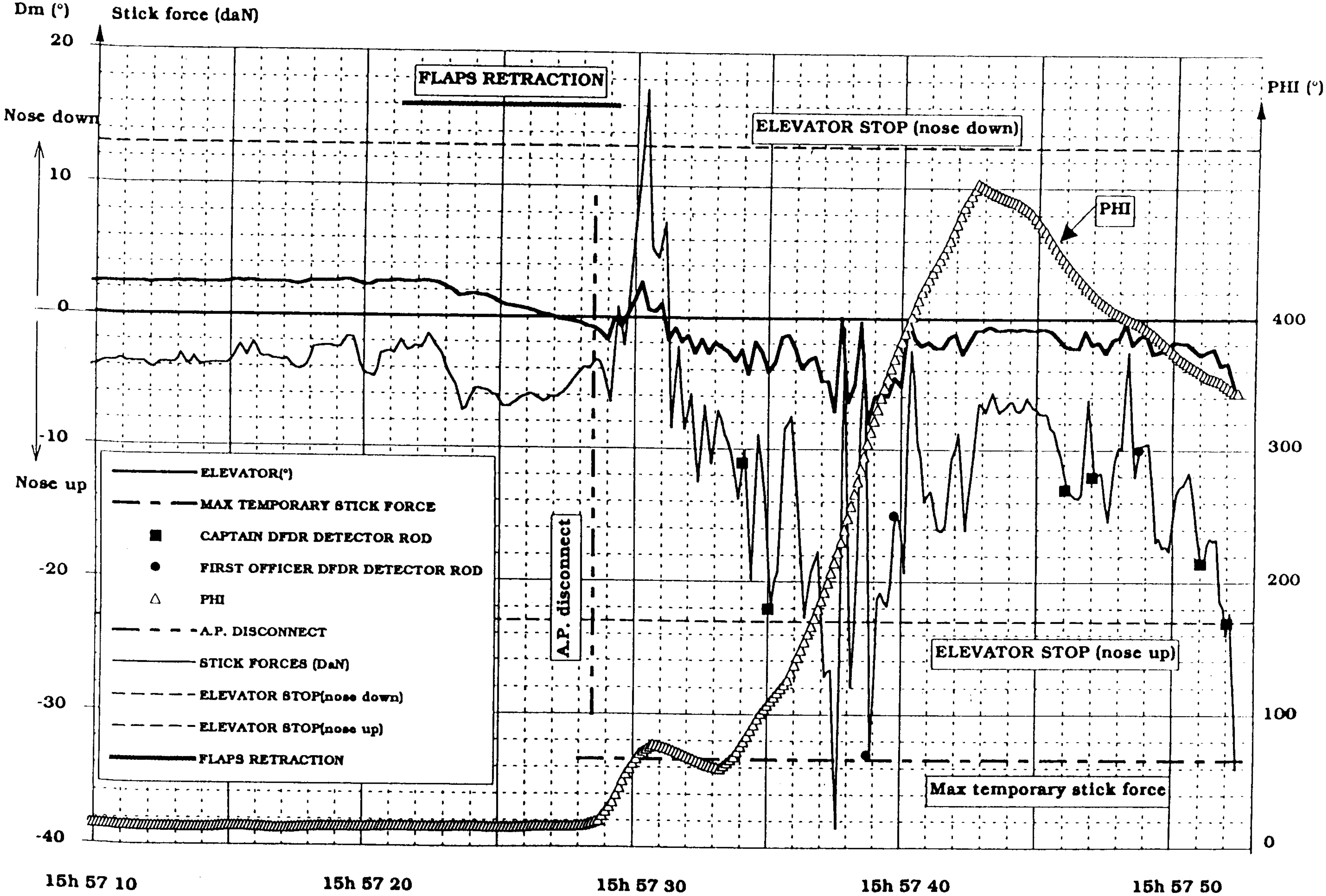


FIGURE 16 : PITCH CONTROL INPUTS / ACTIVITY AFTER ROLL UPSET

A limited control activity mainly during inverted flight

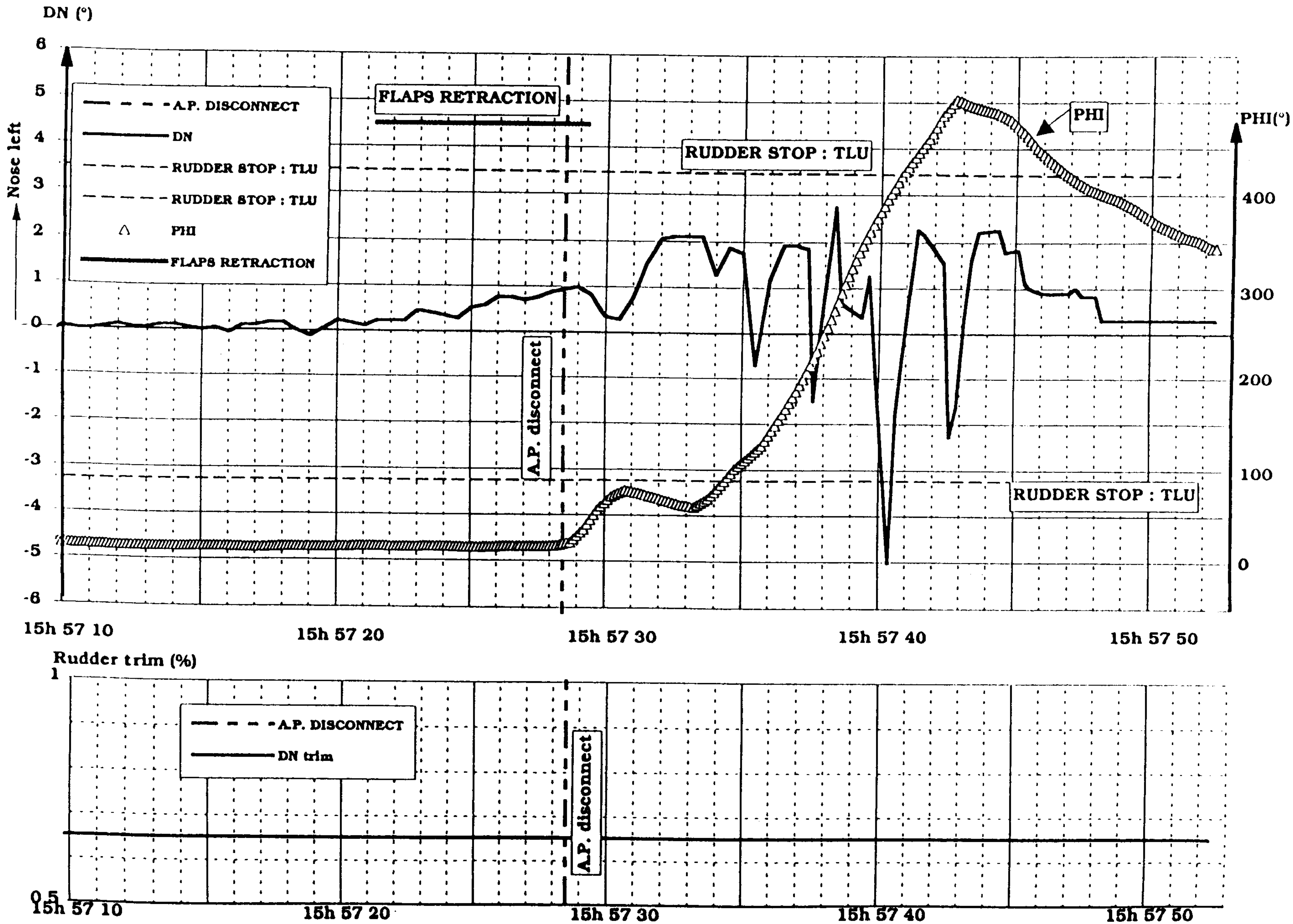


FIGURE 17 : YAW CONTROL INPUTS / ACTIVITY AFTER ROLL UPSET

In addition, the CVR transcript shows that there was almost no discussion between the flight crew in respect to how to respond to the roll upset. Following the initiation of the roll, there was no discussion between the flight crew members regarding the aircraft's attitude or airspeed, nor was there any conversation between them in respect to how to respond to the aircraft's attitude. Further, the First Officer never asked for any help in controlling the aircraft or in responding to the event, nor is there any indication that the Captain exercised his command authority to take over the controls, nor to identify the unusual attitude of the aircraft or to appropriately comment the First Officer's inputs. This shows that the flight crew, probably disoriented, did not identify the unusual attitude nor understood the fast moving evolutions of the aircraft.

The flight crew's lack of appropriate control inputs and lack of communication was due in large part to the fact that they were preoccupied with multiple distractions prior to the roll upset which affected their situational awareness to such an extent that they were precluded from effectively responding after the roll upset which took them by surprise.

The BEA notes with regard to these multiple distractions affecting situational awareness that, in light of the other more recent accidents involving cockpit failures by flight crews, the FAA recently undertook an in-depth review of Airline flight crew training program, which is still pending.

2.2.4. CAPACITY OF AIRCRAFT RECOVERY

Based upon the following investigation, the BEA concludes that Aircraft S/N 401 was fully recoverable.

1. STRUCTURAL INTEGRITY

The analysis of the wreckage, made difficult by the extensive fragmentation of the aircraft, revealed no damage existing before the impact. Also, the spectral analyses of the CVR recordings show no abnormal noises that can be associated with the break of structural elements or equipment.
In addition, the review of the maintenance actions carried out on the aircraft and discussions with the mechanics in charge of this maintenance reveal no signs of abnormal removal, replacement or repair of structural elements or equipment in the wing area. Finally the scenario based on the hypothesis of box structure trailing edge deformation in the flap area has been eliminated, the wind tunnel tests show that such a deformation, not detected by analyzing the wreckage, would not affect the hinge moments.

Based upon the foregoing, the BEA concludes that the aircraft was perfectly in conformity with its definition and that its structural integrity was perfect up to the last seconds before impact.

2. SYSTEM INTEGRITY

The same analysis on the equipment revealed no damage existing before the impact.

The analysis of the 115 DFDR parameters which allowed the operation of the main equipment and the CVR to be monitored, in particular the comments made by the two pilots, showed no evidence of anomalies.

All recordings confirm normal and coherent operation of the various items of equipment, in particular those associated with the deicing systems and the primary and secondary flight controls.

Also, the specific scenario calling the systems - spoiler runaway - into play and which can explain the roll dynamics, cannot explain the aileron suction and must therefore be eliminated.

Other secondary scenarios have also been eliminated as their execution leads to incoherence with the DFDR recordings and require additional failure hypotheses with probabilities too low to be retained.

The BEA can therefore conclude that the aircraft was perfectly in conformity with its definition and that the various systems were operating normally in particular those related to deicing and flight controls until the last seconds before impact.

3. EFFICIENCY OF THE AILERONS IN PRESENCE OF AIRFLOW SEPARATION

The probable accident scenario involves three phases :

- a two phase ice accretion mechanism, in conditions outside appendix C with a second phase, performed at a very low angle of attack corresponding to flap 15 configuration and at a high speed near to the VFE of this configuration. This accretion is characterized by a unique ice ridge downstream of the boots,
- an upper wing surface flow separation phase initiating at the ridge and at the trailing edge and appearing at a critical angle of attack reached during the increase in the angle of attack related to flap retraction,
- a roll initiation phase, resulting both from the local asymmetrical lift loss and the roll moment created by aileron suction, both directly due to the flow separation.

The possibility of counteracting this roll initiation is directly related to the capacity to develop an opposing roll moment using the aileron and spoiler control surfaces. This implies :

- that these control surfaces retain their efficiency (capacity to create a roll speed for a given deflection),
- that the loads required to obtain this deflection remain compatible with those that a pilot can develop (maximum temporary force).

The conservation of the efficiency of the aileron-spoiler pair in the presence of a separated flow has been demonstrated by the following :

- it is at the origin of the rapid roll initiation subsequent to aileron suction,
- the many wind tunnel tests conducted with various types of accretion which confirm that this efficiency is maintained at the level of the one obtained with undisturbed flow,
- tests on ATR 42 and ATR 72 with artificial shapes downstream of the boots confirm that this efficiency is maintained,
- the analysis of the behavior of the ailerons and the associated roll moments during previous incidents demonstrates that efficiency is maintained,
- the theoretical approach is difficult. The bidimensional studies reveal a separation initiating on the trailing edge and propagating upstream. Changes in the lower surface and upper surface pressures allow the changes in the hinge moments and local lift to be qualitatively explained but the effect of an aileron deflection, which could confirm that efficiency was maintained, has not yet been studied.

In conclusion, the experimental data obtained from the wind tunnel tests and the post-Edwards flight tests conducted with natural and artificial pollution confirm that efficiency was maintained in spite of the presence of airflow separation upstream of the control surfaces.

4. ANALYSIS OF FORCES REQUIRED TO DEFLECT THE AILERONS

Several approaches can be used to assess the forces to be applied on the control wheel in order to maintain the position of the ailerons, in the presence of a flow separation at the time of AP disconnection :

- by directly measuring these forces, during flights with natural accretions made at Edwards (asymmetrical pollution limited spanwise),
- by directly measuring these forces, during flights with artificial accretions intended to reproduce the aircraft 401 roll upset at AP disconnection,
- by directly measuring these forces, during high-speed ground runs with random shapes causing massive separation forward of the ailerons,
- by laboratory tests on an AP servomotor simulating the dynamics of the roll control channel and leading to AP disconnection,
- by theoretical studies simulating the dynamics of the roll control channel using aerodynamic coefficients measured in wind tunnel in separated flow and calibrated to reproduce the flight test results.

All these analyses, in particular, the many flights made with artificial shapes show a load level controllable by one pilot, close to the maximum temporary force given in FAR PART 25.143. Without invoking the assistance that could be given by the second pilot on request.

All these elements confirm that the force level required to control the ailerons in separated flow conditions, at the origin of the roll anomaly, were near to the maximum temporary force level.

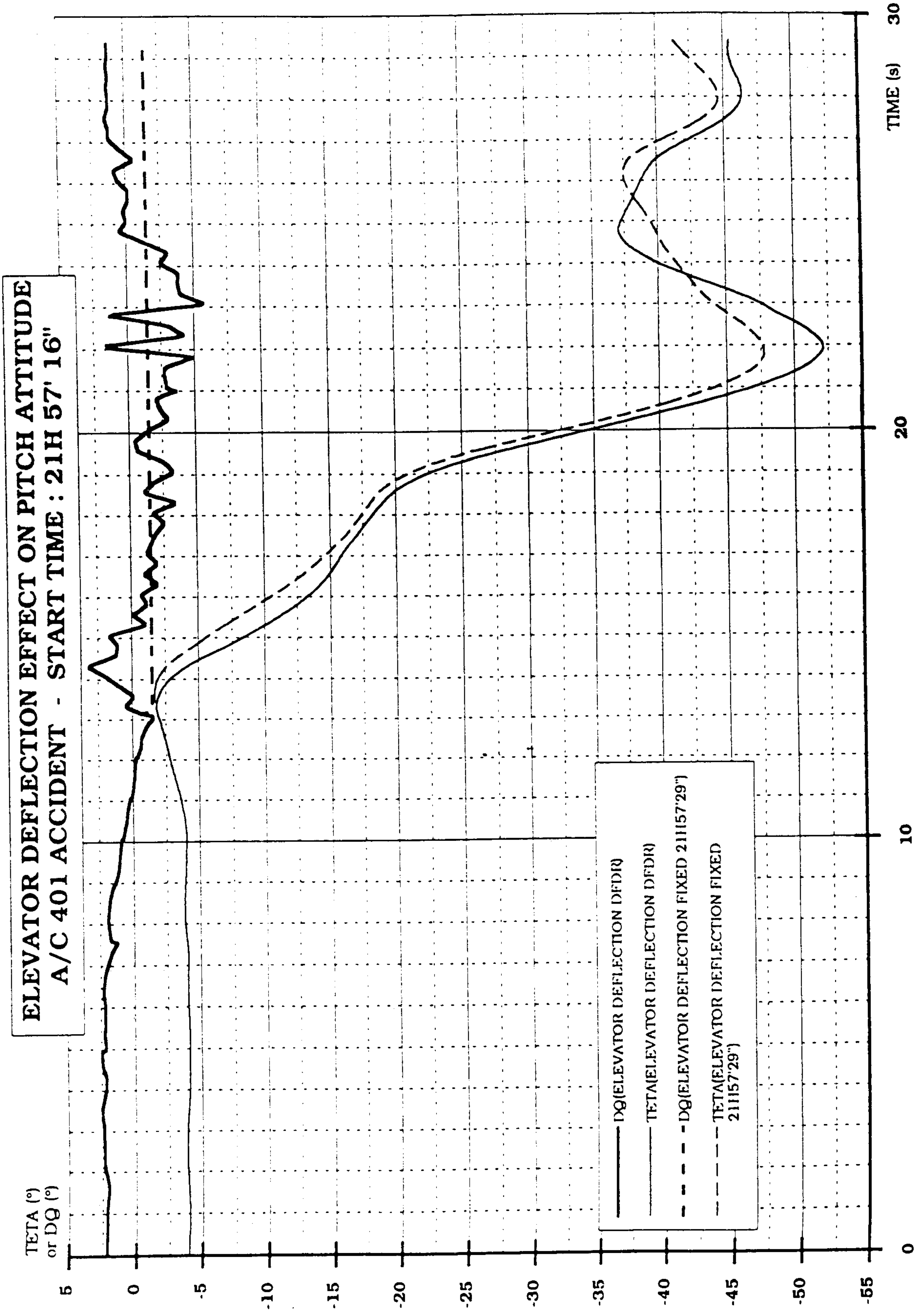
5. CAPACITY OF CONTROLLING ROLL INITIATION AND FLIGHT PATH

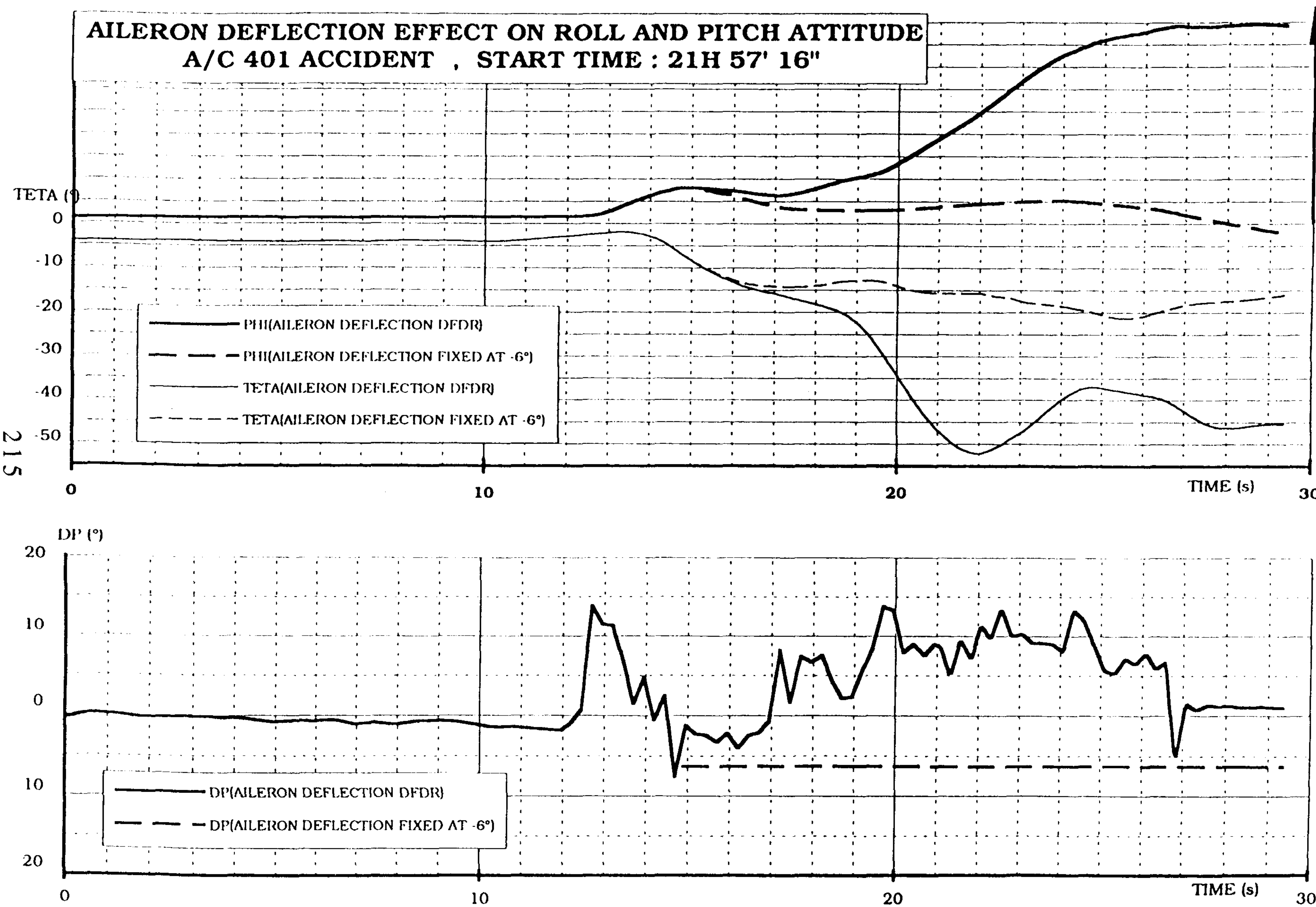
The simulation software used with 6 degrees of freedom and incorporating the effect of the accretions on the various aerodynamic coefficients allows to accurately reconstruct the Flight path of aircraft S/N 401, after AP disconnection, using as inputs to be model, the control surface deflections recorded on the DFDR.

It also allows to predict the Flight path resulting from different control surface deflections. It is thus possible to determine (fig. 18) that the deflection of the elevators contributes only marginally to the longitudinal movement whose amplitude is mainly due to roll initiation.

Moreover, assuming a counteracting steddy deflection limited to 6° on the ailerons and applied after the maximum conventional crew reaction time used in cruise (3 seconds) after disconnection, the Flight path is rapidly controlled (fig. 19). The lateral attitude is kept close to wings level and the longitudinal attitude does not exceed 22° before returning to 0°.

FIGURE 18 : EFFECT OF A CONSTANT PITCH INPUT ON RECOVERY





A constant 6° roll input after 3 sec would allow for recovery

FIGURE 19 : RECOVERY CAPABILITY THROUGH CONSTANT ROLL INPUT

This theoretical analysis, based upon a model which was accurately calibrated by flight tests with artificial shapes, confirms the capacity to control roll initiation by a 6° aileron deflection well below the aileron stop (14°) and with forces consistent with those mentioned in the previous paragraph.

The results of this theoretical analysis of the recovery capacity are also supported by the many flight simulations of the scenario of S/N 401 with an ATR 72 equipped with artificial shapes.

6. CONCLUSIONS

The many investigations conducted subsequent to the accident, the results of which were forwarded to the NTSB, permits the following conclusions :

- during flight 4184, aircraft S/N 401 was in conformity with its type definition and the integrity of the structure and the good operation of the systems was maintained until the last seconds before the impact,
- the efficiency of the ailerons was maintained in spite of the presence of a flow separation upstream of these control surfaces,
- the forces required to control the ailerons remained within the capacity of one pilot (let alone two pilots) in spite of the presence of the flow separation,
- an aileron deflection of around 6° maintained in the direction opposite to the roll initiation would have been sufficient to stop the roll departure and the nose-down tendancy of the aircraft.

Based upon the foregoing, the BEA concludes that aircraft S/N 401 was fully recoverable.

2.2.5. CREW RESPONSE TO ROLL UPSET

Aircraft recovery following SLD induced roll upsets have been flight tested with the Edwards testing simulated ice shapes glued on the wings : aircraft recovery was repeatedly shown to be physically possible, with one pilot alone using his yoke only. Such a recovery requires a firm pilot's action to overcome the jerky forces which otherwise would drive the roll control wheel in the direction of the upset. Time reaction is also critical, as the roll upset, if not counteracted in the first few seconds, could develop a high rate of roll which would aggravate the pilot disorientation.

2.3. PREVIOUS ATR ICING INCIDENTS AND ADEQUACY OF DGAC/ATR ACTIONS

The following analyses of previous ATR-42/72 incidents incorporates the results of all tests and research conducted after the Roselawn accident Therefore, these analyses may also review some of the assumptions formulated during the previous analyses of these events.

2.3.1. MOSINEE INCIDENT

The Mosinee incident was the first of five events analyzed by the NTSB, experienced by an ATR-42 aircraft in icing conditions outside the icing certification envelope. These conditions were clearly shown to be freezing rain, associated with a temperature inversion phenomenon. This incident involved an auto-pilot disconnection, at an angle of attack very close to the icing stall warning threshold, with evidence from the DFDR data traces of a rolling moment induced by an asymmetrical lift loss and with evidence of an aileron self deflection. The recovery was readily accomplished by the flight crew. The investigation later revealed that the flight crew had not activated the airframe de-icing equipment prior to the incident, while the aircraft was accreting ice.

ATR's initial response to this first incident was to immediately re-emphasize to all operators the hazards associated with flight operations in freezing rain using the FAA's Advisory Circular 20.117 material. ATR subsequently proposed a design modification to the ATR 42 (Vortex Generators) and also and to proposed changes to the AFM/FCOM to incorporate procedures applicable to inadvertent encounters with such conditions.

These proposed changes were submitted to the DGAC, which in turn submitted the proposed manual changes to other Airworthiness Authorities, including the FAA. The FAA, as stated in its subsequent NPRM (Notice of Proposed Rulemaking) regarding the introduction of the vortex generators modification, declared that as a matter of policy, hardware changes were preferred to procedural changes. Based upon its ATR-72 development activities, ATR demonstrated the benefit of the addition of VG'S (vortex generators) for maintaining to a higher angle of attack the lateral control and stability of the aircraft in the presence of asymmetrical ice build-up on the wing. This design change was an appropriate response to the Mosinee incident, because it had the potential to prevent autopilot self-disconnections prior to the stall warning, as observed during this incident. The effect of VG'S in presence of freezing rain induced accretions could not be checked, since the nature and definition of such accretions were (and are still) unknown. However the manufacturer did demonstrate, by using asymmetrical artificial ice shapes, located on the wing leading edge, the VG'S ability to postpone, at increasing angles of attack, a flow separation over the outer wing airfoil.

The changes to the AFM/FCOM, as originally proposed, were incorporated by ATR, when accepted by Airworthiness Authorities. In accordance with its preference for design changes over special operating procedures for long term operational safety, the FAA adopted and imposed the vortex generator modification, but did not adopt the proposed AFM manual changes. "Considering that this(ese) procedure(s) addressed a condition outside the certification requirements, the DGAC did not request its (their) insertion in the manuals".

Consequently, the corresponding FCOM changes were also not incorporated in the U.S or France. However, the German and Canadian Airworthiness Authorities did incorporate this information in their operation manuals. The same information was, however, repeated to all operators and their pilots in ATRs *All Weather Operations* brochure published in 1991.

In its *All Operator Message* issued immediately after the incident, ATR also disseminated to all of its operators, the information regarding the characteristics of the incident and drew its operators' attention to the hazards of freezing rain, quoting the FAA Advisory Circular stating that such conditions should be avoided.

ATR's analysis of the Mosinee incident was reviewed and accepted by the BEA. The BEA used the results in its own analysis which was presented to the NTSB. At that time the conclusion was that unusual ice accretion patterns may have been caused by the speculated aircraft's sustained flight in freezing rain conditions, and it was concluded that such conditions could have been the origin of an aileron hinge moment modification which occurred about at the stall threshold when the autopilot disconnected. However, the absence of documented freezing rain ice shapes and of any industry standards for such ice accretions gave no basis to support or test such speculation. Several other factors limited any further analysis of this matter by ATR, or by any other party involved in the investigation, including the NTSB.

a) The worldwide industry belief that freezing rain conditions, which are beyond the certification envelope of all aircraft, were rare occurrences, and that it would be impractical to protect aircraft against their effects. Further, it was believed that such conditions were generally “predictable, recognizable and avoidable” [AC 20.117].

b) The absence of certification criteria to cover the consequences of inadvertent encounters and the absence of documented effects in terms of ice accretion patterns.

c) The fact that the event occurred at about the stall threshold, which was further addressed by the vortex generators modification.

d) The fact that the crew had failed to activate the airframe de-icing equipment at the time, which fact was revealed by the NTSB to the other investigating parties after the manufacturer’s analysis was published, was an aggravating factor in the incident. Application of the normal and required de-icing procedures for flight in icing conditions may well have prevented the incident.

e) The fact that the crew had not reported abnormal or excessive wheel efforts during the recovery and that the aileron effectiveness had apparently remained unaffected.

In the frame of the post-Roselawn accident investigation, the BEA made further inquiries about potential similarities between the ATR 42 Mosinee incident and the ATR 72 Roselawn accident and considered whether additional efforts might have allowed the investigating parties at that time to anticipate the Roselawn icing scenario.

Several factors made the ice accretion patterns involved in the Mosinee incident, significantly different from those that most probably developed in the Roselawn case, the first of which being the fact that aircraft S/N 91 accreted ice with the airframe de-icing boots OFF. Also, aircraft S/N 91 accreted ice in the flaps 0° configuration ; droplets sizes associated with the prevailing freezing rain conditions were probably higher than those involved in Roselawn ; the exposure time was not longer than 10 minutes. These differences resulted in ice accretion patterns with both large spanwise and chordwise extents on the wing airfoil and with limited protruding ridge height. Although such shapes cannot be accurately characterized, the BEA believes that their nature may not be very different from one of the Edwards tanker test cases, with the wing de-icer boots inoperative (test n°23) exhibited. In this respect :

a) both the Edwards tanker test (N°23, Flap 15 degrees) and the subsequent corresponding flight test in Toulouse with artificial ice shapes directly derived from the observations made at Edwards, show handling qualifies effects consistent with the Mosinee DFDR data, in that the roll control is not affected prior to an AOA very close to the icing stall warning threshold,

b) all available wind tunnel and flight tests data indicate that unusual ice accretion patterns with a large spanwise coverage would noticeably increase the drag, prior to any lateral control alteration.

Such was the case in the Mosinee incident.

c) all available wind tunnel and flight tests data indicate that unusual ice accretion patterns of that same type would generate high lift losses, of a genuine asymmetrical nature. Such was the initiating factor of the roll departure in the ATR 42 Mosinee incident.

d) both the Edwards tanker test (n°23) and the subsequent flight test in Toulouse with artificial ice shapes directly derived from the observations made at Edwards, show some degree of aileron hinge moment shift after the initiation of the roll motion due to the asymmetrical lift loss. Such was the case in the Mosinee incident.

The BEA therefore concludes that the ice accretions patterns, that the mecanism of the airflow disturbance generated by these ice shapes, that the resulting handling effects, involved in the ATR 42 Mosinee incident were different from the ice shapes, airflow separation and hinge moment reversal revealed by the post-Roselawn investigation.

As the consequence, should the investigating parties in the Mosinee incident have decided to conduct further testing and should have testing means been available - which was not and is still not the case - the BEA believes that the simulation of the Mosinee incident - flaps 0° configuration, de-icer boots OFF, freezing rain droplets - might have reproduced the characteristics of this incident but would not have allowed the anticipation of the Roselawn icing scenario.

2.3.2. AIR MAURITIUS AND RYAN AIR INCIDENTS

The analysis of the next two ATR-42 incidents showed that the roll excursions were primarily caused by asymmetrical lift loss. No alteration of the aileron hinge moment was evident from the DFDR data traces, nor can such evidence be seen todav in re-visiting the analyses of these traces. In both incidents, the following signs of the impending stall clearly existed :

a) Continuous drag increase and correlative speed loss at constant engine power,

b) Abnormal autopilot activity in roll prior to the disconnection,

c) G-break,

d) Stall warning.

In both incidents, the flight crews readily recovered from the stall. None of them reported either abnormal or excessive aileron wheel forces during the recovery. The existence of icing conditions outside the JAR/FAR icing envelope was indirectly shown by computing the drag build-up from the DFDR data traces and by comparing it with the certification criteria envelope. The effects of the ice pollution were clearly shown to be beyond what had been taken into account in certification. Still, the stalls occurred at angles of attack consistent with the icing stall warning threshold.

The "ice-induced aileron hinge moment reversal" phenomenon, which was discovered in the post-Roselawn accident investigation and testing, was not involved in the Air Mauritius and in the Ryanair incidents.

Based upon the foregoing neither of these incidents suggested to ATR an icing scenario of the type of that was discovered during the post-Roselawn accident investigation

Since the failure of the flight crew to observe the minimum Np setting (86 %) in icing conditions was a common fact in both cases, at DGAC request, ATR rightly investigated the effects of the lower than required Np setting (77 %) associated with severe icing conditions. ATR's tests and research involved both theoretical studies and flight testing. The results were presented to the DGAC and to the BEA. ATR showed that the combined effects of Np setting at 77% and of severe icing conditions were likely to cause unusual ice accretions on the propeller blades, which in turn could generate an highly turbulent airflow over the wing airfoil. Since an increased level of turbulence is known to cause the deposit of a rough, thin layer of ice over the entire airfoil, especially in severe icing environments, this mechanism was believed to be the origin of the abnormal drag build-up observed prior to the Air Mauritius and RyanAir incidents and of the stall at or about the icing stall warning threshold.

As a consequence, ATR took actions to re-emphasize the already existing limitations regarding the minimum Np setting in icing conditions. The aircraft check list was in particular amended for that purpose.

The BEA, the DGAC, and ATR still believe that the mechanism described above could contribute to the alteration of aircraft performance in severe icing environments. This mechanism was clearly not a factor in the Roselawn accident.

2.3.3. NEWARK INCIDENT

The prevailing icing atmospheric conditions were found by the investigating parties (NTSB, BEA, DGAC, and ATR) to be probably outside the scope of the JAR/FAR 25 Appendix C, This conclusion was based upon the general meteorological data available, the observations by the flight crews of unusual ice accretions, as well as ground reports of freezing precipitation in the area of the incident. These conditions, however, could not be precisely analyzed by the BEA because BEA requests for further information from the NTSB were not responded to.

The analysis of the aircraft's performance and controllability from the DFDR data traces was seriously hampered by the extreme level of turbulence which was present during the entire approach and landing phase of the flight and throughout the incident. Vertical and lateral accelerations and instantaneous speed variations of respectively ±0,3 ; +0,15 ; ± 10 kts were noted on the DFDR, preventing accurate computation of aerodynamic coefficients, as well as the alteration of aircraft performance. Sharp roll oscillations and pilot's inputs were also present along the entire flight path.

The interpretation of the autopilot disconnection, the roll excursions, and the aileron deflections was, <u>and is still</u>. extremely difficult. All such aircraft responses, however, are consistent with the documented effects of the turbulence itself. Although today, in the light of the post-Roselawn tests and research, possible correlation between some transitory aileron deflections and the increase of the aircraft AOA beyond 7° may be seen, the existence of any transient aileron hinge moment modification remains questionable.

Both wind gusts and roll motion could have created local wing tip angles of attack much higher than the recorded fuselage angle of attack and could have triggered unsteady airflow separations responsible for asymmetrical lift loss and rolling moments. Abrupt pilot inputs and induced roll oscillations cannot be rejected, either.

The interpretation of the DFDR data traces was, extremely difficult for a number of reasons. 1) the characteristics of the icing conditions could not be determined by lack of pertinent data ; 2) the flight crew observations did not correlate with any previous observations noted by, or reported to, ATR ; and, 3) the flight crew failed to respect the minimum Np setting in a severe icing environment which was again a contributing factor. Accordingly, none of the investigating parties, including the NTSB, BEA, DGAC and ATR, could identify the exact contribution, if any, of an ice-induced pollution of the airframe in the Newark incident. None of the same parties which investigated this event had any indication that an aileron hinge moment modification could be a significant factor as it was in the Roselawn accident.

Following the Roselawn accident, the BEA and NTSB reviewed the Newark DFDR. Because the DFDR readout disclosed that a high level of turbulence was involved throughout the incident, and would by itself explain the aircraft behavior, it cannot be determined whether the "ice-induced aileron hinge moment reversal" phenomenon which was discovered for the first time in the post-Roselawn accident investigation and testing was involved at all in the Newark incident.

2.3.4. BURLINGTON INCIDENT

This incident occurred early 1994 and its DFDR data was reviewed by ATR and the BEA. The aircraft experienced, prior to the autopilot disconnection, a continuous speed decrease of about 45 kts, without any pilot corrective action. The airspeed reached prior to the upset was below the minimum prescribed speed for icing conditions. In addition:

a) a g-break was apparent before the A/P disconnection,

b) the autopilot was disconnected by the stall warning,

c) the aileron briefly self-deflected after the stall commenced. ATR identified in its analysis a momentary aileron hinge moment modification. However, the predominant factor was clearly the asymmetrical lift loss in the stall which induced the roll motion. The momentary modification in the aileron hinge moment which occurred after the stall commenced had no effect on this incident.

d) The Np setting was 86%, in accordance with the published procedures. but the airspeed was below the specified minimums.

This incident was considered by the BEA, DGAC, and by ATR as an indication that unidentified ice accretion patterns, other than that caused by a turbulent airflow behind an improperly de-iced propeller might alter the aircraft performance and controllability. However, the stall nevertheless occurred at the icing stall warning threshold and a massive drag build up and the correlative airspeed loss should have triggered the crew's attention. Such severe drag increases were felt to be alwavs associated with these unusual ice accretions, as all incidents had indicated, including this one. Also, recovery actions were readily accomplished by the flight crew, and aileron effectiveness and control wheel forces were not reported to be abnormal.

Nevertheless, because the ATR-72 had no in-service history of any such roll control icing related events and was certified using different and modified icing codes from those used for the certification of the ATR-42, the DGAC required that ATR re-visit the determination of ice accretions within the Appendix C envelope, under the modified codes, for the ATR-42. This research was on-going at the time of the Roselawn accident.

2.3.5. CONCLUSION

Until the post-Roselawn tests and research, the freezing drizzle/freezing rain conditions were not perceived by the worldwide industry as a major threat to the safe operation of regional airline aircraft. These conditions were, and still are, omitted from the certification criteria. Although such conditions were generally understood to be hazardous and to be avoided, there was no absolute prohibition to fly into such conditions, based upon the assumptions that they were rare occurrences which could be recognized and avoided and that properly certificated aircraft would safely cope with short inadvertent encounters.

Neither regulatory environment nor the available means of experimental research did encourage the Western manufacturers and Airworthiness Authorities to focus on the characteristics of such conditions and on their potential effects on the aircraft performance and controllability, but rather, to re-emphasize good operational practices to avoid such conditions as ATR has emphasized, and in particular, re-emphasized following the Mosinee incident.

The BEA notes that among of the ATR 42 incidents, which all occurred in the clean, flaps 0°, configuration, and which **all** involved failure to follow icing conditions procedures <u>none</u>, exhibited the unique characteristics involved in the Roselawn accident, namely an outer wing airfoil flow separation at an AOA well below the icing stall warning threshold, without any prior noticeable drag build-up and without any significant asymmetrical lift loss.

Aileron hinge moment modifications could only be noted in two of these incidents - it is still doubtful that they existed in the Newark incident - and their contribution was perceived bv all investigating parties as a marginal characteristic of what was substantially concluded as an asymmetrical stall in severe icing conditions. There was no evidence that such modifications of the aileron hinge moment could become a predominant factor in different circumstances, since they had not initiated roll excursions or interfered with crew recovery actions in any of the incidents.

It is furthermore today understood that the prior ATR 42 incidents and the ATR 72 Roselawn accident involved different mechanisms and amplitudes of airflow separations. Prior incidents are attributed to extended airflow stalls over the wing, progressing from the airfoil trailing edge towards its leading edge at increasing angle of attack, until the asymmetrical nature of that stall results in a rolling moment and, in some instances only, deeper in the phenomenon, in some degree of aileron hinge moment shift. The mechanism revealed bv the post-Roselawn investigation, involves in a very different manner, complex local airflow seperation patterns. behind the ice ridge and at the aileron trailing edge which, at a critical angle of attack. could abruptly merge and drive an aileron hinge moment reversal.

ATR and the DGAC took appropriate actions to address the risk of asymmetrical stalls in severe icing conditions by restating warnings to operators to avoid such conditions and including several hardware changes and training actions. These actions were intended to :

a) provide early warnings to flight crews of an impending stall by enhancement of the autopilot roll servo monitoring and associated procedures, and by airspeed monitoring through procedures and through the implementation of the AAS system, Aileron hinge moment modifications could only be noted in two of these incidents - it is still doubtful that they existed in the Newark incident - and their contribution was perceived by all investigating parties as a marginal characteristic of what was substantially concluded as an asymmetrical stall in severe icing conditions. There was no evidence that such modifications of the aileron hinge moment could become a predominant factor in different circumstances, since they had not initiated roll excursions or interfered with crew recovery actions in any of the incidents.

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2.4. AIR TRAFFIC CONTROL

Based upon the information contained in the NTSB'S report, the Chicago Center Traffic Management Coordinator (TMC) improperly released Flight 4184 from a 42 minute ground hold when it had been informed by the ZAU Traffic Management Coordinator (TMU) that conditions were such that the flight would likely be required hold in the air before reaching its destination. The release of Flight 4184 under these conditions appears to be contrary to the policy set forth in FAA Order 7110.65, *Air Traffic Control Handbook,* to reduce congestion in the air traffic system and to limit the duration of airborne holding. Had Flight 4184 not been released prematurely, the flight would not have been required to hold at LUCIT intersection as long as it did, and the accident may not have occurred.

After Flight 4184 entered the hold at LUCIT intersection, Flight 4184's Expected Further Clearance (EFC) time was extended on four separate occasions. Further, despite the fact that it was mandatory for BOONE Sector Controller to report those arrival delays to the Air Traffic Control System Command Center (ATCSCC) which are expected to meet or exceed 15 minutes, neither the Central Flow Control Facility (CFCF), nor the Traffic Management Unit (TMU) were advised, that Flight 4184's holding time had exceeded 15 minutes.

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In this regard, it is significant to note that an altitude diversion could have been easily accommodated since Flight 4184 was the only aircraft holding at LUCIT intersection and multiple altitudes were available for diverting. The flight crew's failure to provide a PIREP of the known icing conditions they were operating in contributed to this accident.

Finally, the BOONE Sector Controller was required to solicit a PIREP from Flight 4184. In this regard, FAA Order 7110.65J, Section 6, entitled *Weather Information,* provides that ATC controllers are required to "solicit PIREPS when requested or when one of the following conditions exist or are forecast for your area of jurisdiction. " One of the conditions for which ATC controllers are required to solicit PIREPS is icing of light degree or greater (Emphasis added.) Had the BOONE Sector Controller solicited a PIREP from Flight 4184 and learned that they were holding in icing conditions, immediate precautionary action would have been taken by ATC to communicate with the crew regarding exiting the icing area, thus avoiding the accident. ATC'S failure to solicit a PIREP from Flight 4184 contributed to this accident.

2.5. THE DGAC'S CONTINUING AIRWORTHINESS MONITORING UNDER THE BILATERAL AIRWORTHINESS AGREEMENT

Pursuant to Paragraph 6 of the U.S.-France Bilateral Airworthiness Agreement and Annex 8 to the Convention on International Civil Aviation, the DGAC is required to:

a) assist the FAA in analyzing accidents and major incidents which involve U.S. - registered ATR aircraft and which "raise technical questions regarding the airworthiness of such products" when they are properly reported and documented to the DGAC, and

b) provide the FAA with information "necessary for the continuing airworthiness of the aircraft and for the safe operation of the aircraft" when such information is identified.

This BAA and Annex 8, however, in no way remove the responsibility of the primary investigative authority of the State of Occurrence to conduct a proper investigation of the accident or incident as the lead investigative authority under Annex 13 to the Convention on International Civil Aviation. The BAA and Annex 8 do not delegate to the Exporting State, or otherwise change in any way, the investigative responsibilities of the State of Occurrence. One of the most important of these responsibilities is the obligation of the State of Occurrence to forward to other States information on the investigation of "an incident which involves matters considered to be of interest to other States. "

The DGAC has consistently fulfilled its obligations as the primary certification authority for the ATR-42 and ATR-72 aircraft. The joint FAA/DGAC Special Certification Review Report confirmed that the DGAC acted correctly and properly in its certifications of the different ATR model aircraft, that the certifications complied with all applicable certification standards, and that the DGAC and FAA properly applied the BAA in their certifications of the aircraft.

The NTSB’s probable cause finding (and the associated analyses and findings) that the DGAC provided inadequate oversight of the continuing airworthiness of the ATR aircraft and inadequate corrective action to assure their continued airworthiness in icing conditions is not supported by the NTSB’S record of investigation and is wrong. This record demonstrates that the DGAC was actively involved in investigating ATR icing events, considered whether these events warranted any corrective actions, and required that ATR take decisive corrective action whenever this was appropriate.

This NTSB probable cause finding, and the associated analyses and findings, that the DGAC’s failed to require ATR to take additional corrective actions and that this “led directly to this accident” appears to be based on the erroneous assumption that the DGAC had identified, from earlier ATR icing incidents the “aileron hinge moment reversal” which was involved in the Roselawn accident. This presumption, as well as the analyses and findings which appear to be based thereon, are not supported by the NTSB’s record of investigation and are wrong.

Neither the DGAC nor the NTSB, FAA, BEA, or ATR identified from their investigation of these earlier incidents the "aileron hinge moment reversal" phenomenon which was involved in the Roselawn accident. This phenomenon was not identified until after the Roselawn accident. In suggesting that the DGAC should have required ATR to take additional corrective actions regarding a phenomenon that neither the DGAC nor the NTSB, FAA, BEA, or ATR had yet identified, the NTSB is clearly wrong. Thus, the BEA entirely disagrees with the NTSB's statement that the DGAC's failure to require ATR to take additional corrective action "led directly to this accident. "

The NTSB's probable cause finding (and the associated analyses and findings) that the DGAC failed to provide the FAA "with timely airworthiness information developed from previous ATR incidents and accidents in icing conditions, as specified under the BAA and ICAO Annex 8" appears to be based on an NTSB misunderstanding of the BAA and Annex 8, is not supported by the NTSB'S record of investigation, and is wrong. As noted above, the pertinent sections of the BAA (section 6) and of Annex 8 (Section 4.2.2), require the Exporting State to provide to other Airworthiness Authorities information obtained during the investigation of major incidents or accidents only where those incidents or accidents" raise technical questions regarding the airworthiness of [the aircraft]" or otherwise identify information which is "necessary for the continuing airworthiness of the aircraft and for the safe operation of the aircraft. "

There is no factual basis whatever in the NTSB's record of investigation to support the suggestion that the DGAC failed to provide the FAA on a timely basis with critical airworthiness information "developed from previous ATR incidents and accidents. " Prior to the Roselawn accident there had never been an ATR-72 accident of any type, nor had there been any ATR-72 icing incident involving roll control.

With regard to the ATR-42 icing related incidents reviewed by the NTSB, and which occurred prior to the Roselawn accident, the facts demonstrate that the DGAC also fully complied with its obligations under the BAA and Annex 8, as noted below. In the one incident which did disclose an airworthiness issue, the DGAC worked hand in glove with the FAA to identify corrective actions, passing on adequate information to the FAA and other Airworthiness Authorities. In the other incidents, neither the BEA nor the NTSB determined that any aircraft airworthiness or safe operation issue was involved.

To the extent that the NTSB is suggesting that the DGAC failed to disclose to the FAA information indicating that the ATR was susceptible to an aileron hinge moment reversal of the type which caused the Roselawn accident, this suggestion simply ignores the fact that none of the parties which had investigated any of the prior incidents, including the NTSB, had identified this phenomenon before the Roselawn accident.

The following is a discussion of the DGAC's compliance with its BAA and Annex 8 obligations in each of the prior ATR-42 icing related incidents.

Mosinee incident -AC 91- 2/22/88.

In respect to the Mosinee incident, a final investigation report, incorporating ATR's analysis and report, was provided by the BEA to the NTSB in direct meetings with the NTSB. The DGAC subsequently distributed to the Airworthiness Authorities in all countries where ATR aircraft were registered (including the FAA) appropriate information covering the corrective actions mandated on the ATR-42 fleet, and recommended manual changes to address the potential hazard resulting from flight in freezing rain.

Newark incident - AC 259- 03/04/93

In respect to the Newark incident, the DGAC investigated this incident along with the BEA and ATR. The BEA, DGAC, and ATR concluded from the DFDR readout that the incident involved high levels of turbulence and a failure by the flight crew to follow the AFM and AOM procedures while the anti-icing systems were activated.

Since these conclusions did not "raise technical questions regarding the airworthiness of [the ATR]" or otherwise identify information which was "necessary for the continuing airworthiness of the aircraft and for the safe operation of the aircraft, " the conclusions were not sent to the NTSB, FAA, or other Airworthiness Authorities,

The DGAC was hampered in its efforts to investigate this incident because the NTSB, which was the lead investigative authority by virtue of its being the primary investigative authority of the State of Occurrence, provided to the BEA and the DGAC only a limited portion of the information developed by the NTSB and FAA during their investigations.

At the time of the Roselawn accident, over a year and a half after the Newark incident, the NTSB still had not issued a Probable Cause finding on this incident. A Probable Cause finding has not been issued to this day, three years after the incident. A Factual Report regarding the incident was provided to the BEA only in October, 1995, two years after the incident. This Factual Report appears to conclude that the incident occurred while the flight was operating in severe turbulence, and in icing conditions.

Burlington incident - AC 153- 01/28/94.

The DGAC investigated this incident along with the BEA and ATR. ATR performed an analysis of the incident and provided its preliminary conclusions to the DGAC and the BEA. Those conclusions were that the incident involved a substantial failure by the flight crew to follow the AFM and AOM procedures for flight operations in icing conditions. The DGAC reviewed these conclusions, but questioned the conclusion regarding the present of severe icing because accurate weather conditions were not known. The DGAC required that ATR perform a study of the industry icing codes applied to the ATR 42 as the ATR 72 had no history of similar icing incidents which was in progress at the time of the Roselawn accident. Since the preliminary ATR conclusions were that the incident was caused by a failure of the flight crew to follow required procedures, rather than an aircraft airworthiness or safe operation issue, and since the DGAC had no evidence to indicate such an airworthiness or safe operation issue was involved, the DGAC did not send the conclusions to the NTSB, FAA, or other Airworthiness Authorities.

The DGAC was again hampered in its efforts to investigate this matter because the NTSB, which had the responsibility to conduct the investigation by virtue of its being the primary investigative authority of the State of Occurrence, failed to carry out that responsibility, apparently because the operator did not advise the NTSB of the incident. As a result, the NTSB failed to provide the BEA with any information at all related to this incident. The FAA also failed to provide the DGAC with any information on this incident.

Ryanair incident (A/C 161- 8/11/91) and Air Mauritius incidents (A/C 208 - 4/17/9 1) which occurred on non-US registered ATR-42 aircraft outside the U.S.

Both incidents were fully documented by the aeronautical authorities of the State of Occurrence, which provided the full documentation to the DGAC and the BEA. These incidents were then investigated by the DGAC at the request of, and on behalf of, these authorities. The BEA and ATR assisted the DGAC in this investigation.

ATR analyzed these incidents and provided its conclusions to the DGAC and the BEA. The DGAC and BEA reviewed these conclusions and found them to be accurate. The DGAC then sent these conclusions to the Civil Aviation Authority of Mauritius and the Irish Civil Aviation Authority, the State(s) of Occurrence. These conclusions raised no technical question whatsoever about the airworthiness or safe operation of the aircraft, as both matters involved stalls resulting from a failure by the flight crew to follow required operating procedures in icing conditions.

Since these conclusions did not "raise technical questions regarding the airworthiness of [the ATR] ," or otherwise identify information "necessary for the continuing airworthiness of the aircraft and the safe operation of the aircraft, " the conclusions were not sent to the NTSB, FAA, or other Airworthiness Authorities.

In conclusion, the only failures to disseminate information in the above-referenced four incidents were the failure of both the NTSB and/or FAA to disseminate to the BEA, DGAC, and ATR important information on the NTSB's and FAA's investigations of the Newark incident, and the failure of the NTSB to carry out its responsibilities as the primary investigation authority of the State of Occurrence with respect to the Burlington incident. The foregoing facts simply do not support the NTSB's finding that the DGAC failed to provide the FAA with timely airworthiness information developed from these incidents "as specified under the BAA and Annex 8," or the NTSB'S finding that this alleged failure to disseminate airworthiness information "raises concerns about the scope and effectiveness of the bilateral. "

The DGAC notes that since October 1994, U.S. operators have reported two icing related incidents involving ATR aircraft. Although the BEA has, on several different occasions, requested that the NTSB provide the BEA and DGAC with the relevant DFDR readouts, these data were not provided to the French BEA or DGAC until April 1996, more than six months after the incidents. This unfortunate situation has prevented the DGAC from conducting its own investigation and from providing timely assistance to the FAA and the NTSB in their investigation of these incidents.

2.6. ATR OPERATIONS IN ICING CONDITIONS

2.6.1. CERTIFICATION

The Certification program for the ATR 72 was conducted in a manner consistent with other FAA icing certification programs and 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 FAR/JAR 25.1419.

The handling qualities flight test programs addressed by the Special Condition B6 (refer to parag. 1,3. 1) for ATR 72-200 and ATR 72-210 included tests with both artificial ice shapes and natural icing conditions. As stated in the FAA "Special Certification Review" final report (page 14), "the scope of these (Ice-contaminated Configuration tests) programs generally exceeded normal certification and industry practices (without SC B6)".

The NTSB Memorandum (Trip Report & Status of airplane Performance Group Investigation on the AMR Eagle/Simmons ATR 72 accident at Roselawn, IN, DCA-95-MA-001) from Ch. Pereira, AE/DFDR, RE60 (dec 2,94) - refer to page 4 also confirmed that :

> "The coverage of the certification envelopes was, however, described by the NASA/FAA group members as typical to above-average for a turbo-prop certification effort given the apparent difficulty in finding natural icing conditions in certain areas of the certification envelopes. "

. As part of the SCR team work, the data shown parag. 1.3.1 relative to stall characteristics tests- with and without ice shapes and with natural ice - were extensively reviewed, (quote from SCR report page 37)"to determine if there were any lateral control anomalies. That was a specific request from NTSB to a member of the accident investigation team from NASA'.

The conclusion extracted from SCR report was :

> Some minor uncommanded aileron activity was noted on several stalls, but under the criteria of FAR/JAR 25.203, this activity was (and is) considered acceptable. All of these small uncommanded aileron movements occurred just at or after activation of the stick pusher. Additionally, for these tests conducted with ice shapes on the ATR-72-100/200, the stall stick pusher on the test airplane was set at the AOA threshold of the no-ice configuration (i.e.,approximately 5° more than the AOA threshold for the ice configuration). These aileron force anomalies are indicative of some aileron snatch tendencies following asymmetric left and right wing airflow separation as the stall progresses. All airplanes with aerodynamically balanced control surfaces can be affected in a similar manner. Therefore, these characteristics were not considered unusual at wing stall AOA, and were fully acceptable from a certification criteria point of view. The airplane was always controllable with normal use of controls.

In conclusion, the final SCR team conclusions confirm:

- 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 infrequent 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.

2.6.2. FLIGHT CHARACTERISTICS

2.6.2.1. INSIDE APPENDIX "C"

During the ATR-72 icing certification process, the aircraft exhibited normal behavior, free of any sort of roll anomaly, within the normal flight envelope, up to maximal angle of attack, even in the case of wing covered with ice shapes on unprotected surfaces, and even with ice shapes simulating the de-icer failure case. That result was confirmed by the EDWARDS tests performed with liquid water droplets within Appendix "C" envelope, i.e. below 40 µm.

2.6.1.2. OUTSIDE APPENDIX "C".

Certification rules do not request the execution of natural icing tests under SLD conditions, as those are not specified nor part of the certification envelope and are considered as excessively difficult to execute on purpose in nature. Nevertheless, during ATR 72 development they were met once. Data analysis of flight 418, development A/C MSN 98 [ATR 72-210) revealed that droplets above 47µm had been encountered. Normal assessment of handling qualities by the test crew performed in all configurations did not reveal any particular anomaly.

In that context, Roselawn is a very specific case, the study of which revealed a unique chain of events leading to the roll upset :

- Icing conditions far beyond Appendix “C” limits.
- Prolonged holding, leading to ice accumulation.
- Aircraft set at high speed with flap 15°, leading to negative AOA.
- Flap retraction leading to positive AOA.

After Roselawn, EDWARDS tests revealed the particular and very specific type of ice accretion resulting from prolonged exposure to SLD with 15°flap.

These holding conditions, never provided for in the Aircraft Operating Manuals led to a negative AOA which generated quite unusual ice shapes, in that the accretion concentrates on the upper wing aft of the deicing boots and with limited coverage of the wing lower surface.

- The severe anomaly in roll which was discovered at EDWARDS results from the following unique sequence : prolonged ice accretion phase in SLD conditions with Flap 15° configuration and stall demonstration performed at the Flap 0° configuration.

- Given the technology of unpowered flight control systems, all Commuter-class turboprop are affected by the same type of roll control problem, when submitted to the same SLD environment and same configuration changes.

- After full understanding of such a complex icing process, the ATR de-icing system was modified with extended overwing boots which were tested successfully at EDWARDS in SLD environment.

- Associated with AFM procedural changes (visual cues, flaps utilization), they provide the ATR fleet with a demonstrated level of safety in case of inadvertent encounter with SLD conditions, which is beyond the current icing certification standard.

This physical modification associated with these procedural changes have been recognized as an acceptable means of compliance, and therefore a terminating action to the ADs respectively issued by DGAC and FAA.

Recent industry tests and research conducted after, and as a result of the Roselawn accident, have provided valuable information on the potential effects of unusual ice accretions in the SLD environment. In light of this new information, the BEA understands that certification criteria will be changed to better address these conditions in line with the recommendations of the FAA/DGAC Special Certification Review (SCR) report. Changes in the regulatory standards are therefore being prepared in both France and the US to :

- identify the physical characteristics associated with large supercooled droplets outside of Appendix C conditions.

- establish criteria for acceptable aircraft behaviour in the presence of accretions resulting from these extreme conditions, as well as the same associated means of compliance.

2.7. ATR DISSEMINATION OF ICE RELATED INFORMATION

2.7.1. THE NTSB REPORT MISREPRESENTS FACTS AND ATR KNOWLEDGE

The Report's probable cause finding (and the associated analysis and findings) that ATR failed to completely disclose to operators "adequate information concerning previously known effects of freezing drizzle and freezing rain conditions on the stability and control characteristics, autopilot and related operational procedures when the ATR 72 is operated in such conditions" is not supported by the NTSB'S record of investigation and is wrong.

As described more fully in Section 2.7.2, in addition to making design changes to the ATR-42 and ATR-72, after the Mosinee incident (AC 91 - 22 December 1988), ATR also disseminated to its operators and flight crews extensive information and warnings reminding them that prolonged exposure to freezing rain conditions are to be avoided. ATR also provided to operators and flight crews additional information designed to facilitate the recognition and avoidance of such conditions which exceed the certification limits of all turboprop aircraft. ATR very specifically advised operators that such conditions could affect roll control forces leading to an au to pilot disconnect and resulting in a roll to a large bank angle until the crew took over the controls. ATR described appropriate recovery procedures and introduced them into ATR training programs. ATR also modified simulator packages for icing operations to simulate such roll departures.

Thus, contrary to the report, ATR did provide to operators "information that specifically alerted flight crews that encounters with freezing rain could result in sudden autopilot disconnects, rapid roll excursions, [and] guidance on how to cope with these events. "

In addition to stating that ATR did not provide to operators the above-referenced information, the NTSB also states that an "aileron hinge moment reversal" mechanism was disclosed in the icing related incidents it reviews, and criticizes ATR for failing to issue warnings to specifically describe such an event. The NTSB'S "facts" are wrong and its assertion is untrue.

The basis for the NTSB'S assertion is it's claim that an "aileron hinge moment reversal" was involved in the incidents of Mosinee, Ryanair, Air Mauritius, Burlington, and Newark and was therefore known to ATR. On the contrary, the DFDR data from Mosinee, Ryanair, Air Mauritius and Burlington incidents confirm that they were all stall departures following ice accumulations which resulted from flight crew failures to follow the basic procedures for operation in icing conditions by failing to select airframe de-icing, to maintain minimum airspeeds or proper propeller speed settings. No "aileron hinge moment reversal" was involved in Ryanair or Air Mauritius. The momentary modification of the aileron hinge moment in Mosinee and in Burlington which occurred after the asymmetrical stall commenced had no direct effect on these incidents. Both the NTSB and ATR determined that the Newark incident involved severe turbulence. From a review of the Newark DFDR data after Roselawn, because of the high level or turbulence, it cannot be determined whether or not any aileron hinge moment modification was involved in the incident.

The incorrect assertion by the NTSB of prior ATR knowledge is all the more surprising because the NTSB was the primary investigation authority for the Mosinee incident with full access to the facts and data involved. It had full access the BEA's report, which incorporated fully ATR's own investigation report, and was involved in several meetings with the DGAC, the BEA and the FAA. The NTSB'S level of participation and knowledge of the Mosinee incident was as great as any other entity investigating the incident. The NTSB had absolutely no recommendations or suggestions for any other corrective action, warnings, or any other response based on the Mosinee incident.

The NTSB's assertion is also surprising because the NTSB not only received the full and open cooperation of the manufacturer following the Roselawn accident, but also encouraged and participated in the manufacturer's extensive efforts after the accident that led to the discovery of the ice-induced "aileron hinge moment reversal" phenomenon. The NTSB knows of the extensive wind tunnel testing, high speed taxi tests, flight testing, and millions of dollars spent by ATR after Roselawn for the first-ever USAF tanker freezing drizzle/rain testing program for civil or military aircraft at Edwards AFB. The NTSB knows from its own involvement in the testing that the phenomenon of an ice-induced "aileron hinge moment reversal" was discovered for the very first time as a result of this exhaustive post-Roselawn investigation by ATR.

The BEA also would like to note that even if the phenomenon of an ice-induced "aileron hinge moment reversal" had been previously identified, there would have been no need to include this type of technical information in further a warning to flight crews.

The warnings which were previously provided by ATR to all operators, including Simmons, and which in turn were provided by Simmons to all its flight crews, identified that the weather environment of concern could result in an increase in roll control force which might cause a autopilot disconnect and a roll to a large bank angle until the controls were taken over by the crew. The fact that such a change in aileron control force might or might not be caused by an "aileron hinge moment reversal" is not a piece of information which would have added to the warning provided by Simmons to its flight crews. So long as the flight crews have been informed as to what they might experience in terms of their control of the airplane i.e., a ice-induced change in roll control forces an autopilot disconnect, a roll to a large bank angle, and the need to employ a firm manual control to recover, it is nonsensical to suggest that they need to know the scientific cause of the roll departure in order to deal safely with it.

The BEA respectfully submits that the NTSB does not promote aviation safety by ignoring its own role in the investigation of these prior incidents and by misrepresenting facts in order to advocate a position of prior knowledge by a manufacturer. The NTSB was the lead investigative authority for the most significant of the prior ATR icing incidents. It is quite odd now for the NTSB to assert that these same prior incidents disclosed an ice-induced "aileron hinge moment reversal" phenomenon to ATR and not to itself. It is doubly odd for the NTSB to make this assertion when it encouraged and participated in the Edwards AFB test program whose stated goal was to discover for the first time whether "freezing drizzle conditions could produce an aileron hinge moment divergence" (as the NTSB so-called the phenomenon in its comments on the Edwards AFB flight test plan).

What is most disturbing about the report's position on this point is that it obscures the safety concern disclosed in this accident that this flight crew was so oblivious to the icing conditions they encountered that they ignored the multiple warnings, instructions, and regulations they already had received regarding proper operations in such conditions. To suggest that a more specific warning about an "aileron hinge moment reversal phenomenon would have had any impact on this flight crew is not supportable by the NTSB's record of investigation.

2.7.2. ATR DISSEMINATION OF ICING INFORMATION

The BEA strongly disagrees with paragraph 1 of the report's Probable Cause Statement regarding ATR's alleged failure to "completely disclose to operators and incorporate in the ATR- 72 AFM and FCOM and training programs, adequate information concerning previously known effects of freezing drizzle and freezing rain conditions on the stability and control characteristics, autopilot and related operational procedures when the ATR-72 is operated in such conditions. " The NTSB's position in this regard completely ignores the critical factual information discussed in Sections 1.4.1 and 1.4.2, above which shows that ATR did provide specific warnings in respect to these issues. The BEA discusses its further comments regarding this issue below.

Despite the lack of identification by the NTSB, BEA, ATR, FAA, and DGAC, prior to the Roselawn accident of the freezing drizzle induced "aileron hinge moment reversal" phenomenon, the documents discussed in Sections 1.4.1 and 1,4.2 above clearly show that American Eagle/Simmons passed on to its flight crews these ATR warnings that, under icing conditions outside those specified in 14 CFR Part 25, Appendix C, the ATR-42/72 aircraft performance and control forces may be affected in such a way that autopilot self-disconnect and subsequent roll excursions could occur; that roll efficiency would nevertheless be maintained; and that recovery could be readily achieved by making firm aileron inputs to counter the roll excursions, and by applying basic stall recovery techniques.

Simmons own “restatement of company operations policies” (ref. Appendix 2) further provided :

a) “Large droplets of freezing rain impact much larger areas of aircraft components and will in time exceed the capability of most ice protection equipment”;

b) “Flight in freezing rain should be avoided where practical”;

c) “If icing or adverse weather is experienced, make a PIREP . . “;

d) “Freezing rain may form ice on an aircraft that is near the freezing level”;

e) “If freezing rain is encountered, you should exit the condition immediately. This diversion should consist of a turn towards better conditions and/or climb to a warmer altitude”;

f) “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;”

g) “However, our aircraft are not to be operated in known freezing rain or severe ice. If these conditions are experienced, the procedure is to exit these conditions immediately. ”

Flight 4184’s flight crew violated these “company operations policies” by not avoiding freezing precipitation conditions; by not making a PIREP; by not exiting the freezing precipitation conditions immediately, and most importantly, by not exercising crew vigilance in such conditions. To suggest that a more specific warning about a freezing drizzle induced “aileron hinge moment reversal” phenomenon, which was not known until after the Roselawn accident, would have had any impact at all on this flight crew, is not supported by the record.

Finally, when the Simmons "company operations policies" discussed above are combined with the multiple warnings, instructions, and regulations this flight crew had already been provided, as discussed by the BEA in Section 1.4.1 and 1.4.2 above, it is clear that ATR and the Operator Simmons had provided numerous warnings of the type the NTSB describes as missing, regarding the hazards of flight operations in icing conditions, including freezing precipitation conditions. Had these warnings not been ignored by the crew of Flight 4184, this accident would not have occurred.

2.7.3. ATR TRAINING FOR UNUSUAL ATTITUDES

ATR developed a Flight Simulator Data Package to enable simulation of aircraft behaviour cases of unusual attitudes.

This Data Package was contained in the Flight Safety International Simulators, in particular in Houston since early 1989.

The normal training syllabus includes demonstrations of recovery from unusual attitudes as early as the second training session. This demonstration consists of large longitudinal and lateral excursions approaching 60° bank angle without reaching the stall.

The BEA is concerned by the AMR Eagle's decision not to have taken advantage of this simulator capability until after this accident.

3. CONCLUSION

3.1. BEA FINDINGS

The BEA strongly believes that the following Findings are mandated by the facts of this accident. These Findings are fully supported by the previously cited factual references and analysis of the accident.

1. This accident occurred as a result of a prolonged operation of the aircraft in freezing drizzle/rain conditions well beyond the certification envelope for all aircraft.

2. Airworthiness Authorities and the aviation industry worldwide did not sufficiently recognize, prior to the Flight 4184 accident, freezing drizzle characteristics and their potential effect on aircraft performance and controllability.

3. Despite investigation of prior incidents involving icing conditions outside 14 CFR Part 25, Appendix C, by the NTSB, BEA, ATR, FAA and DGAC, these parties did not anticipate the mechanism of the ice-induced aileron hinge moment reversal that was involved in this accident and that was not discovered until the post-accident Edwards AFB testing program.

4. ATR properly analyzed and took appropriate and adequate measures in response to such prior icing related incidents.

5. The DGAC acted correctly and properly in its certifications of the different ATR model aircraft as the primary certification authority, and the FAA properly applied the Bilateral Airworthiness Agreement in its certifications of the aircraft.

6. The DGAC provided appropriate oversight of the continued airworthiness of the ATR-42 and ATR-72 aircraft and took all appropriate actions to assure the continued airworthiness of the aircraft in response to such prior icing related incidents.

7. The DGAC provided the FAA on a timely basis with all relevant airworthiness or safety of operation information developed from previous ATR icing incidents, including those in freezing rain, in full compliance with the BAA and ICAO Annex 8.

8. The FAA Indianapolis Ground Controller released Fight 4184 from a 42-minute ground hold despite having been informed by the Traffic Management Coordinator that conditions were such that the flight would likely be required to hold in the air before reaching its destination. The release of Flight 4184 under these conditions was contrary to the policy established in FAA Order 7110.65, Air Traffic Control, to reduce congestion in the air traffic system and to limit the duration of airborne holding.

9. American Eagle/Simmons' policy precluded the distribution of AIRMET Zulu Update 3 for icing and freezing level in the Flight Release for Flight 4184. This AIRMET was applicable to Flight 4184's route of flight from Indianapolis to Chicago, and stated that "light occasional moderate rime icing in cloud and in precipitation" could be expected. This AIRMET also provided information regarding the freezing level along Flight 4184's route of flight.

10. AMR Eagle/Simmons was adequately warned by ATR prior to the accident about the dangers of operating in freezing precipitation and understood the need to avoid such conditions.

11. AMR Eagle/Simmons, in turn, warned its flight crews prior to the accident about the dangers of operating in icing conditions, including freezing precipitation, and instructed its flight crews to avoid such conditions.

12. The flight crew of Flight 4184 had been expressly warned about the dangers of freezing precipitation and the necessity of crew vigilance.

13. Flight 4184's flight crew knew they were operating in icing conditions.

14. Proper monitoring of the outside air temperature, clouds, precipitation, and the ice accumulating on the aircraft by the crew of Flight 4184 would have informed them that they might be operating in a freezing precipitation environment.

15. Despite these warnings and instructions, and having entered known icing conditions, the flight crew of Flight 4184 had absolutely no discussions regarding: the nature and extent of the icing conditions they were encountering; the outside meteorological conditions; the need to request a clearance to an alternative altitude or route to remain clear of the known icing conditions; the operation of the aircraft's de-icing and anti-icing equipment.

16. Flight 4184's flight crew had ample opportunity to ask the ATC for a clearance to exit the icing conditions.

17. AMR Eagle/Simmons' company policies require that flight crews stay out of icing conditions when possible.

18. After the Mosinee incidents, ATR proposed to the FAA, through the DGAC, a revision to the ATR-42 FCOM and AFM which contained information on the effects of freezing rain conditions on aircraft stability and control characteristics and on the autopilot and set forth related operational procedures to be used when an aircraft inadvertently encounters such prohibited conditions. This proposal was not accepted by the FAA.

19. ATR provided Simmons and other operators with the identical information, applied to both the ATR-42 and ATR-72 aircraft, concerning the effects of freezing rain (understood by Simmons to include "freezing precipitation" in the AOM).

20. ATR provided specific warnings to Simmons and other operators, for their pilots, about the adverse characteristics of freezing rain and about roll events which could occur in such conditions and gave specific guidance for recovery from such events and, in addition, developed aircraft modifications seeking to reduce the possibility of such events occurring.

21. Simmons company policy had already provided ample instructions to the Flight Crews regarding the icing threat and the basic rules of behaviour to face such a situation.

22. The failure of Flight 4184's flight crew to follow these company policies and manual provisions and exit the known icing conditions led directly to this accident.

23. Despite the lack of anticipation by the NTSB, BEA, ATR, FAA and DGAC, prior to the accident, of the mechanism of the ice-induced aileron hinge moment reversal, Simmons/AMR Eagle and its flight crews had been warned that, under icing conditions outside those specified in 14 CFR Part 25. Appendix C the ATR 42/72 aircraft performance and controllability might be affected in such a way that auto-pilot self-disconnect and subsequent roll excursions could occur; that roll efficiency would nevertheless be maintained; that recovery could be achieved by making firm aileron inputs to counter the roll excursions and by applying basic stall recovery techniques. These were appropriate and adequate instructions to flight crews based on what was known from prior incidents.

24. ATR adopted appropriate and adequate changes to its flight crew training program and simulator data training package based on what was known from prior icing incidents.

25. Chicago ARTCC controllers were aware that light to moderate icing conditions were forecast for the area of LUCIT intersection at the time Flight 4184 was released from its ground hold.

26. Chicago ARTCC controllers had received PIREPs reporting icing conditions on the day of the accident and had been specifically briefed by their supervisor at the beginning of their shift that they must be aware of icing conditions and because "Icing Kills".

27. Chicago ARTCC controllers were aware that the weather conditions were deteriorating throughout the Chicago area before and during the time Flight 4184 was enroute from Indianapolis to Chicago. Therefore they could not have ignored the specific weather conditions at the Lucit holding pattern, at Flight Level 100.

28. If the Controller at Chicago ARTCC had received an icing PIREP from Flight 4184, immediate precautionary communication would have been made by ATC with the crew regarding exiting the icing area.

29. Flight 4184 was the only aircraft holding at LUCIT intersection, and multiple altitudes were available for diversion from the known icing conditions.

30. AMR Eagle/Simmons' company policy, Federal Aviation Regulations, and the Airman's Information Manual require that flight crews provide ATC with a PIREP of known icing conditions. However the crew of Flight 4184 did not to provide such a report of their known icing conditions.

31. Had the crew of Flight 4184 provided to ATC the mandatory PIREP of their known icing conditions, ATC would have provided them with a diversionary clearance so that they could have immediately exited the icing conditions. The flight crew's failure to provide a PIREP of their known icing conditions contributed to this accident.

32. FAA Order 711 0.65J, *Air Traffic Control,* requires ATC controllers to solicit PIREPS of "icing of light degree or greater" when such conditions exist or are forecast to exist in their area of jurisdiction. ATC did not solicit an icing PIREP from Flight 4184, that contributed to this accident.

33. ARTCC failed to report to the Air Traffic Control System Command Center (ATCSCC) and the Traffic Management Coordinator of the excessive holding time experienced by Flight 4184 as required.

34, The Sterile Cockpit Rule (as imposed by FAR 121.542 and Simmons/AMR Eagle's Flight Manual) requires the captain to impose the rule during any phase of a particular flight as deemed necessary. This rule should have been applied by the Captain of Flight 4184.

35. Flight 4184's holding in known icing conditions at 10,000 feet, in instrument conditions, awaiting momentary clearance to descend below 10,000 feet to commence an instrument approach into one of the world's busiest airports constituted a "critical phase of flight" within the meaning and intent of FAR Section 121.542.

36. The flight crew of Flight 4184 demonstrated a lack of involvement in primary duties and failed to exercise proper situational awareness as well as proper Cockpit Resource Managment. This directly contributed to the accident.

37. The Captain's lack of assertiveness and complete failure to integrate himself into the required flight activities left the entire operation of the aircraft to the First Officer.

38. AMR Eagle/Simmons' ATR42/72 Airplane Operating Manual (AOM) provides only for holding with the aircraft configured in the flap zero degree configuration. Flight 4184's flight crew's unauthorized use of the flap 15 configuration while holding at 175 knots in icing conditions created the critical ice ridge beyond the de-icing boots which ultimately led to the roll upset, and thereby directly contributed to the accident.

39. Post-accident flight tests at Edwards Air Force Base and in France confirmed that Flight 4184 was recoverable after the initial roll upset.

3.2. PROBABLE CAUSE

This accident was caused by a combination of factors, as reflected in the following BEA-proposed Probable Cause Statement :

> The Probable Cause of this accident is the loss of control of the aircraft by the flight crew, caused by the accretion of a ridge of ice aft of the de-icing boots, upstream of the ailerons, due to a prolonged operation of Flight 4184 in a freezing drizzle environment, well beyond the aircraft's certification envelope, close to VFE, and utilizing a 15 degree flap holding configuration not provided for by the Aircraft Operating Manuals, which led to a sudden roll upset following an unexpected Aileron Hinge Moment Reversal when the crew retracted the flaps during the descent.

The contributing factors to this highly unusual chain of events are :

1. The failure of the flight crew to comply with basic procedures, to exercise proper situational awareness, cockpit resource management, and sterile cockpit procedures, in a known icing environment, which prevented them from exiting these conditions prior to the ice-induced roll event, and their lack of appropriate control inputs to recover the aircraft when the event occurred ;

2. The insufficient recognition, by Airworthiness Authorities and the aviation industry worldwide, of freezing drizzle characteristics and their potential effect on aircraft performance and controllability ;

3. The failure of Western Airworthiness Authorities to ensure that aircraft icing certification conditions adequately account for the hazards that can result from flight in conditions outside 14 CFR Part 25, Appendix C, and to adequately account for such hazards in their published aircraft icing information;

4. The lack of anticipation by the Manufacturer as well as by Airworthiness and Investigative Authorities in Europe and in the USA, prior to the post accident Edwards AFB testing program, that the ice-induced Aileron Hinge moment reversal phenomenon could occur.

5. The ATC's improper release, control, and monitoring of Flight 4184.

4. RECOMMENDATIONS

The BEA notes with interest the disparity between the broad scope of the recommendations which the NTSB makes as a result of this accident and the selective focus of the NTSB's statements of its findings and proposed Probable Cause of this accident. Except as noted below, the BEA agrees with the NTSB recommendations.

4.1. FLIGHT CREW PERFORMANCE - STERILE COCKPIT

It is significant that the Report recommends that the FAA evaluate the need to make observance of the sterile cockpit rule mandatory for air carriers when their aircraft are holding in icing conditions regardless of altitude (4.2.8), and recommends that AMR Eagle "encourage" its captains to observe a sterile cockpit environment in icing conditions. These recommendations are in sharp contrast with the Report's incorrect "findings" that the gross distractions of this flight crew and the Captain's departure from the cockpit in known icing conditions "did not contribute to this accident". The BEA suggests that the NTSB recommend that the FAA take steps to emphasize that the sterile cockpit rule applies to all critical phases of flight, and that a critical phase of flight includes all operations in known icing conditions, regardless of altitude. This recommendation is consistent with the FAA's rationale behind the sterile cockpit rule.

4.2. PRE-FLIGHT AND IN-FLIGHT WEATHER INFORMATION

The report's nine recommendations regarding pre-flight and in flight weather information (4.11 - 4.16, 4.3, 4.2, and 4.3) seek to assure that pilots are provided, obtain, and consider all pertinent weather information both for in-flight and pre-flight planning purposes, and that further steps be taken to improve the quality of the information. The BEA agrees with these recommendations, but finds it surprising that the report makes no mention in its findings of the failure of, the Company to provide the flight crew of Flight 4184 with AIRMET information which specifically forecasted icing conditions along their route of flight, and the complete absence in the CVR transcript of any effort by the flight crew to update their weather information while enroute and during their hold.

4.3. PIREPS

The BEA suggests that the NTSB recommend that the FAA and American Eagle/Simmons take steps to enforce the Airman's Information Manual (AIM) requirement that flight crews "report icing conditions to ATC/FSS. " The BEA also suggests that the NTSB recommend that the FAA take steps to enforce FAA Order 7110.65, Air Traffic Control, which requires that ATC solicit PIREPS regarding "icing of light degree or greater. " The failure of the flight crew to provide a PIREP to ATC, and the failure of ATC to solicit a PIREP from the flight crew, and the critical effects of these failures in contributing to this accident are ignored by the report in its findings and recommendations. It is insufficient to simply suggest, as does report Recommendations 4.31 that the definition of PIREP information should be amended.

4.4. AIRCRAFT CERTIFICATION - FREEZING DRIZZLE/RAIN

The report's five recommendations regarding aircraft certification (4.17 - 4.21) properly call for more accurate determination of the parameters affecting ice accretion. However, if the recommendation to expand the icing certification envelope to include freezing drizzle/freezing rain conditions "as necessary" is meant to imply that the NTSB believes aircraft should now be certified for operations in these dangerous conditions where the risks to aircraft are still relatively unknown, instead of focusing on improved detecting and avoidance of these conditions, the interests of aviation safety are not being served. Regarding the report's recommendation for certification test programs and certification criteria, these issues are addressed in Recommendation 3 of the Special Certification Review Report of the FAA and DGAC. The BEA therefore suggests that this recommendation be adopted by the NTSB to replace the current recommendation on this subject.

4.5. CERTIFICATION AND CONTINUING AIRWORTHINESS UNDER THE BAA

The BEA believes that with respect to the report's three recommendations to the FAA regarding certification and monitoring of continued airworthiness of aircraft operating in the U.S. (4.25 to 4.27), the NTSB recognizes that the concern is not with the BAA itself, but instead with the procedures being used for the mutual exchange of significant incident, accident, and other airworthiness information pursuant to either the BAA or other formal or informal agreements between the FAA and DGAC. The BEA suggests that the report recommend that the NTSB and the FAA take steps to assure that all pertinent information from accident and incident investigations conducted by the NTSB or FAA involving a foreign manufactured aircraft, including all facts and analyses of incidents and accidents and other airworthiness information, is provided on a timely basis to the exporting country's airworthiness authority so that it can monitor and insure the continued airworthiness of aircraft certified by it as the primary certification authority.

4.6. ATR

The recommendation the report makes to ATR is written so as to imply that there is a “hinge moment reversal problem” with the aircraft that has not been resolved. The BEA disagrees with this implication. The actions taken as a result of the post-accident investigation and test program, including those addressed to flight crews and the modifications of the boots, addressed and resolved the issue. The BEA also does not believe that this issue is unique to ATR. Rather, it applies to all turboprop aircraft, as evidenced by the recent FAA proposed Airworthiness Directives on this subject, which apply to virtually every model of turboprop aircraft in the world. The BEA encourages the further work being done by ATR to consider redundant safety measures to protect against inadvertant encounters with icing conditions beyond Appendix C certification standards.

4.7. AMR EAGLE

Based on the lack of cockpit discipline, the BEA suggests that the report recommends that the FAA and AMR Eagle take all necessary steps to prevent the recurrence of such conduct. In this regard, AMR Eagle's operating and training procedures should be fully reviewed and corrected if necessary, so as to address such conduct.

The BEA agrees with the report recommendation that the FAA require air carriers to provide standardized training that adequately addresses recovery from unusual events and unusual attitudes (4.29). Based upon this accident, the BEA supports the report recommendation that AMR Eagle takes steps to immediately institute a training program to address these issues with its flight crews.

5. APPENDICES

APPENDIX 1 : **Letter DGAC to FAA Bruxelles (Mr. VAROLI) n°53296 dated 21 Mars 1989**

APPENDIX 2: **Memorandum SIMMONS Airlines - Loss of aircraft stability (N427MQ) January 23, 1989.**

APPENDIX 3: **STUDY OF METEOROLOGICAL INFORMATION AS CONTRIBUTION TO THE NTSB REPORT (April 15, 1996)**

APPENDIX 1

Letter DGAC to FAA Bruxelles (Mr. VAROLI)
dated 21 Mars 1989

MINISTERE DE L'EQUIPEMENT, DU LOGEMENT, DES TRANSPORTS ET DE LA M

DIRECTION GENERALE
DE L'AVIATION CIVILE

SERVICE DE LA FORMATION AERONAUTIQUE
ET DU CONTROLE TECHNIQUE

ED210389/EL210389

BUREAU CERTIFICATION

TEL 40.43.45.06

N/REF 53296 SFACT/TC

AFFAIRE SUIVIE PAR M. DORMOY

Paris, le 21 MARS 1989

Monsieur l'Administrateur
de la FEDERAL AVIATION ADMINISTRATION
American Embassy
27 Bd du Régent
B 1000 BRUXELLES
BELGIQUE
(ATN M. VAROLI)

Ref : 1. FAA facsimile letter RA/VK0969/89 dated March 14, 1989
2. DGAC facsimile letter, same subject, dated March 17, 1989
3. FAA facsimile letter, RA/vk/1027:89 same subject, dated March 20, 1989
4. FAA letter (from MR. M.C. BEARD) to RAI, dated May 26, 1988, freezing rain conditions
5. FAA AC 20.117.

Monsieur l'Administrateur,

Notre lettre référencée en (2) ci-dessus, a exprimé les commentaires de la DGAC sur le projet d'AD de la FAA pour l'ATR 42. La FAA a accepté d'étudier les propositions de solutions différentes que pourraient fournir la DGAC ou le constructeur de l'ATR, en vue d'arriver à une action commune en France et aux Etats-Unis.

La note jointe en annexe est ainsi proposée pour l'analyse de la FAA.

Les commentaires pour la NPRM sur l'AAS vous seront envoyés le 22 mars 1989.

Je vous prie d'agréer, Monsieur l'Administrateur, l'expression de ma considération distinguée.

P.J. : 1 note

Copies : FAA Washington M. BEARD
FAA Seattle M. LEROY Keith
M. Martenson (ANM 113)
M. CRACKEN (ANM 113)

L'Ingénieur en Chef de l'Armement
Chef du Bureau Certification des Aéronefs

P. LAPASSET

COURTESY TRANSLATION

Our reference (2) letter above expressed comments of DGAC regarding FAA's plans for AD actions for the ATR 42. FAA has agreed to consider the alternate proposals to be provided by the DGAC, in a view of a common US/French action, or by the ATR constructor. The following note is accordingly submitted for FAA consideration.

Comments on NPRM about AAS will be sent on 1989, march 22.

NOTE

Planned priority letter AD - restricting the use of the autopilot

1. As previously mentioned, the DGAC is concerned about the global crew workload increase that would result from systematically prohibiting the use of the autopilot in such a wide range of conditions as that of the FAA planned AD and the subsequent negative impact on flight safety.

The prime cause of the S/N 91 incident seems to us moreover to be a prolonged operation within freezing rain conditions, more than a inappropriate autopilot behaviour or an "unusual" airplane response. This would refer to an asssessment of likely airplane responses in freezing rain conditions which up to now are not envisaged by the requirements.

For these reasons and as far as the priority AD action is concerned, the DGAC will require to amend the Airplane Flight Manual for both :

a) - emphasizing the need to avoid continued flight in freezing rain conditions. This of course is based on the fact that such conditions are usually predictable, recognizable and avoidable. As mentioned in our previous facsimile letter, the ATR constructor has been requested to publish an appropriate background information, for helping the crews in the observance of this limitation.

b) - giving simple procedures for the cases where freezing rain conditions cannot be temporarily avoided or are inadvertently encountered. These procedures do include the prohibition of the use of the autopilot.

You will find enclosed in Attachments 1 and 2 respectively the proposals of AFM - Limitations Section change and of the relevant O.E.B. Your comments would be very much appreciated.

2. During the FAA/DGAC/ATR meeting held in Seattle on March 6, 1989, it has been shown that the incident most probably occurred as a consequence of asymmetrical ice buildups on the wing in front of the ailerons, after a prolonged flight in freezing rain.

The ATR constructor has very recently been led to investigate, as part of the development of the ATR 72 project, several options for its roll control. Among these configurations, the installation of vortex generators on the upper wing surface forward of the ailerons has proved to be efficient in correcting the local airflow disturbances coming from ice buildups on the leading edge. This improvement should be also worthwhile in the cases of asymmetric ice buildups or deposits. This device has no detrimental effect on the other roll control characteristics.

The constructor is therefore evaluating its effect on the ATR 42. Preliminary flight tests have shown very encouraging results. Additional flight testing are presently made with the French CEV. An evaluation could be made by the FAA flight test pilot at the same time in Toulouse.

... ...

This improvement could answer some concerns expressed by the FAA and by the DGAC following the S/N 91 incident. Should this investigation be shown satisfactory, the ATR constructor could complete a retrofit of the US ATR 42 fleet within a short period, of the order of three months.

This action has received a high priority level and is closely monitored by the DGAC.

ATTACHMENT 1

AFM CHANGE
LIMITATIONS SECTION

****

2.01.02 - KINDS OF OPERATION

add to the current paragraph

- Operation in freezing rain shall be avoided.

WARNING : Ice accretion due to freezing rain may result in asymmetrical wing lift and associated increased aileron forces necessary to maintain coordinated flight.

Should the aircraft enter into a freezing rain zone, the following procedure must be adhered to :

a - autopilot shall not be used

b - speed shall be increased in keeping with performance and prevailing weather conditions (turbulence), that is :

. flaps retracted : 180 kt minimum

. flaps extended : as close as possible to VFE for the airplane configuration.

c - excessive manoeuvering shall be avoided.

d - freezing rain conditions shall be left as soon as possible. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course.

A T T A C H M E N T 2

OPERATION ENGINEERING BULLETIN
- FREEZING RAIN -

****

SUBJECT : FREEZING RAIN

1 - Reason for issue

Inform the flight crew on :

- freezing rain phenomenon
- identification of freezing rain
- procedures to adopt in the event of flight through an area where freezing rain is present.

DRAFT

2 - Background information

a) General

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.

b) Freezing rain phenomenon

- Freezing rain conditions normally occur as a result of weather conditions wherein temperature increases with altitude (temperature inversion). Warm rain falls from or 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. Freezing rain water drops are known to exist up to about 1300 microns in diameter (instead of 5 to 50 microns for droplets).

- 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 in ice. To protect an aircraft from freezing rain of this type would require that the entire aircraft rather that just the leading edges, be equipped with de-icing and anti-icing equipments. This, traditionally, has been considered impractical.

- Ice accretion due to freezing rain may result in asymetric wing lift and associated increased aileron forces necessary to maintain coordinated flight.

c) Freezing rain localization

Freezing rain rarely occurs and is rarely encountered at high altitudes unless associated with large storm systems such as thunderstorms. It is normaly a low altitude weather phenomena and is mainly linked to the presence of a front (temperature ranging from - 6° to 0° C).

DRAFT

d) Freezing rain and certification

Advisory circular 20.117 states :

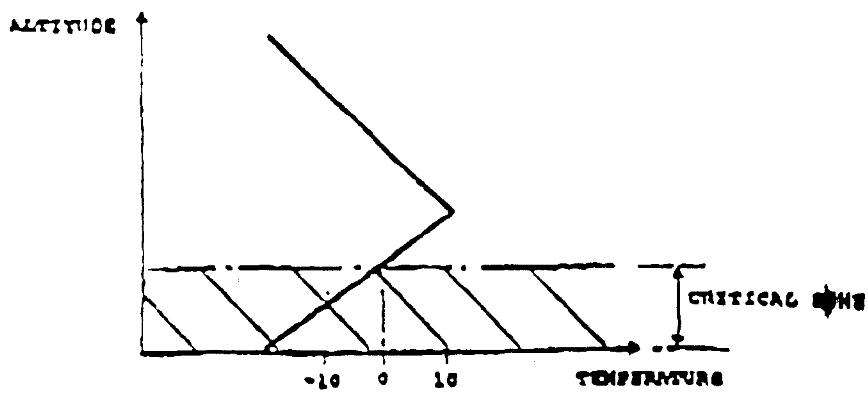
"It is emphasized that aircraft ice protection systems are designed basically to cope with supercooled cloud water environment (not freezing rain). Supercooled cloud water droplets have a median volumetric diameter (MVD) of 5 to 50 microns. Freezing rain MVD is as great as 1300 microns. Large drops of freezing rain impact much larger areas of aircraft components an will, in time, exceed the capability of most ice protection equipment. Flight in freezing rain should be avoided where practical".

e) 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.

    note : Temperature inversion is a zone where temperature increases with altitude.



* These conditions are <u>recognizable</u> :

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.

DRAFT

Note : Heavy rain is visually detectable (at night switch ON 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 it is :

- transparent and consequently more difficult to detect but gives an unusual shiny aspect to the covered surfaces.
- adhere to most of the surfaces of the aircraft which limits the effectiveness of the deicing boots to the leading edge surfaces.

Zones where freezing rain is likely to be encountered
<u>MUST BE AVOIDED</u>.

3 - Procedure

Nevertheless, should the aircraft enter in a freezing rain zone, the following pqrocedure must be applied.

a) Do not use Auto Pilot.

b) Increase speed in keeping with performance and prevailing weather conditions (turbulence)
flaps retracted : 180 kt minimum
flaps extended : as close as possible to VFE for aircraft configuration.

c) Avoid excessive manoeuvring.

d) Leave freezing rain conditions as soon as possible. This can usually be accomplished by climbing to a higher altitude into the positive temperature region or by altering course.

DRAFT

APPENDIX 2

MEMORANDUM SIMMONS AIRLINES
LOSS OF AIRCRAFT STABILITY (N427MQ)
JANUARY 23, 1989

SIMMONS AIRLINES

TO: All Flight Crewmembers

FROM: Dave Wiegand, Director of Flying DJW

RE: Loss of Aircraft Stability (N427MQ)

DATE: January 23, 1989

The following is a synopsis of events that occurred with N427MQ during the initial approach phase to CWA on Thursday December 22, 1989. The subsequent events following the incident will be presented along with a summation and recommendations.

INCIDENT

N427MQ, ATR-42, departed ORD as MQ Flight 4295. Departing ORD the load manifest lists a take-off weight of 34,051 pounds, which included a fuel load of 4000 pounds and 34 passengers.

The enroute flight to CWA was described by the crew as normal. The cruising altitude was 16,000 feet with a TAT of -25 oC. The crew was running level 3 ice protection systems because light rime ice was being experienced enroute. All aircraft systems were functioning normally. The Captain was the flying pilot and continued as the flying pilot, until the A/C was safely on the ground at CWA.

The descent and initial approach phase were conducted in controlled airspace under the control of MSP Center. The planned procedure was to receive radar vectors for a straight in approach to the ILS RWY 8 at CWA. The initial approach vectoring was done at an altitude of 6000 feet because of MSP Center radar coverage limitations in the CWA area. The crew reports that conditions at 6000 feet were IMC with a TAT of + 10 oC, in light precipitation. Level 2 anti-ice systems were selected ON. When the flight was located northwest of the outer marker and north of the localizer, they were given a final heading for the localizer intercept, a descent to 3000 feet and clearance for the ILS RWY 8 approach. Prior to passing the Outer marker, the Captain decided the vectors given from MSP Center were unsatisfactory, attributable to a strong southerly air flow experienced at their altitude. A request was made from MSP Center for clearance direct to AUW VOR and the ILS RWY 8 to CWA via their own navigation.

After the requested clearance was issued by MSP the flight proceeded directly to the AUW VOR at 3000 feet. After crossing the AUW VOR Flight 4295 proceeded to track outbound on the AUW VOR 237 o radial until intercepting the ICWA localizer outbound, to be followed by a published procedure turn and straight in ILS RWY 8 approach to CWA. The remainder of the flight, up to the point of the incident was conducted at 3000 feet. The aircraft was experiencing light precipitation until entering the procedure turn. Shortly before the incident the precipitation increased significantly. The autopilot was on, with the high bank mode selected.

The crew had initiated a turn toward the inbound procedure turn heading when they experienced an aircraft vibration, described as being similar to a prop imbalance. Immediately following the vibration, the auto pilot disconnected and the A/C rolled sharply to the left. At this point the flight crew implemented stall recovery procedures. The rapid response of the flight crew to the situation, enabled the aircraft to be controlled to less than 500 feet of altitude loss. After aircraft control was regained the flight proceeded safely and without further incident for a landing at CWA.

Following the incident, as the flight was being vectored for the final approach to CWA, the crew received an updated weather report on the field conditions at CWA. This update reported that freezing rain had just moved through the CWA area. The airport maintenance department was in the process of applying de-ice chemical to the runways. The airport was still open.

SUMMATION

The data obtained from the DFDR at the time of the incident shows the following:

- Temperature .... + 1o TAT
- Airspeed .... 151 Knots
- Flaps and gear .... Retracted
- Aircraft heading...... 295 Degrees
- Props................. 86%
- Torque................ 20% left and 30% right
- Auto pilot............ ON
- Stick Pusher.......... Not activated
- Maximum Bank Angle.... 65o
- Radar Altimeter....... 1145 AGL

The Aerospatiale analysis of the DFDR and CVR has established that:

1. The A/C was submitted to freezing rain

2. 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.

3. As a consequence the A/P was normally disconnected by its monitoring system.

4. 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. However, due to the accumulation of ice on the control surfaces the aircraft response was sluggish.

5. The rest of the flight was uneventful including the landing on an ice covered runway.

6. The ice collected on the aircraft surface was dissipated during the climb to 6000 feet following the incident recovery.

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.

The manufacturer wishes to recall the general recommendation of the FAA Advisory Circular AC 20-117 issued in December 1982. (A reprint may be found in the Simmons Airline Training Department, Winter Operations for Flight Crews Manual, issued in November of 1988.)

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 a 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.

(REF. Telex OCS/E 1/89)

RECOMMENDATIONS

The incident most probably occurred as a result of the effects of a significant accumulation of airframe ice degrading the aircraft's stability and control characteristics, such that the crew had to apply stall recovery techniques. It is important that crews continue to practice the safe procedures they currently utilize. Those procedures are outlined in a memo dated January 6, 1989 referencing Flight in Icing Conditions, generated by the Manager of Flight Standards. This memo is a restatement of company operations policies. For your convenience the contents of that memo are included on the attached pages.

Flight In Icing Conditions

The winter of 1989 is surpassing our expectations for severe weather. We are experiencing more adverse weather than in the previous couple of years and icing encounters appear to be more prevalent. Please review the following procedures pertaining to our winter operations.

REF. (Dispatch Into Forecast Severe Icing - G.O.M., 3-4-8, paragraph E)

Simmons Airlines aircraft will not be released or flown into known severe icing conditions. Positive confirmation that severe icing conditions do exist shall constitute two similar pilot reports in the same specific area.

The reports should be from the same type of aircraft which are operating along our planned route of flight.

If icing or adverse weather is experienced, make a PIREP so your fellow pilots may benefit from your experience. This is important if the weather is better or worse than forecast.

Aircraft may be flown into light or moderate icing conditions only when full de-icing and anti-icing equipment for wings, propellers, empennage, windshield and pitot-static systems are installed and operable.

The temperature range favorable for ice formation is generally 0 to -15 degrees Celsius. However, supercooled water droplets in liquid form at 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 phenomenon 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 towards better conditions and/or a climb to a 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 aid in the detection of ice.

The temperature ranges stated in the AFM for the SD3 is +6 degrees Celsius OAT and the FCOM for the ATR-42 is +7 degrees Celsius TAT. These are the minimum temperatures at which deice equipment must be turned on. If a pilot has reason to believe an encounter with icing is imminent, the systems should be turned on sooner.

The normal use of the pneumatic leading edge deicing system in the SD3 is to cycle the system after a sufficient amount of ice has formed on the leading edge. This will allow proper shedding of accumulated ice.

In the ATR-42 the Level 3 deice system must be operated as soon as, or before, ice develops. Again, if you have reason to believe that an icing encounter is imminent, select the system on.

For both aircraft, cycling the pneumatic deicing system during a period of what appears to be a wet or clean wing should not cause any bridging of ice or affect future deicing system cycles. However, it will provide a valuable aid in the detection of clear ice or freezing rain. The weather radar may also be useful when operating in visible moisture, near the freezing level. Use of weather radar may help identify areas of greater precipitation.

The Company Policy for dispatching both the SD3 and the ATR-42 into forecast icing conditions remains the same. An aircraft may be dispatched into forecast freezing rain.

However, our aircraft are not to be operated in known freezing rain or severe ice. If these conditions are experienced, the procedure is to exit these conditions immediately. If the conditions are reported or being experienced at the airport of intended landing, then to crew must evaluate their situation relative to remaining fuel, distance to your alternate, etc. With time allowing, coordinate your plan of action with Dispatch. Some of the obvious possibilities are; holding until conditions improve, diverting to the listed alternate, or diverting to an amended alternate.

If you have any question about our procedures, please call the Flight or Training Departments for further clarification. We prefer to discuss any questions you may have before a undesirable situation develops.

Thank you for you attention.

APPENDIX 3

STUDY OF METEOROLOGICAL INFORMATION AS A CONTRIBUTION TO THE NTSB REPORT (APRIL 15, 1996)

MINISTERE DE L'AMENAGEMENT DU TERRITOIRE , DE L'EQUIPEMENT ET DES TRANSPORTS
SECRETARIAT D'ETAT AUX TRANSPORTS

INSPECTION GENERALE DE L'AVIATION CIVILE
ET DE LA METEOROLOGIE

BUREAU ENQUÊTES-ACCIDENTS

Le Bourget, le 15 avril 1996

CAZ

ACCIDENT TO THE SIMMONS AIRLINES ATR 72

REGISTERED N401AM

(AMERICAN EAGLE FLIGHT 4184)

NEAR ROSELAWN (IN) ON OCTOBER 31,1994

STUDY OF METEOROLOGICAL INFORMATION

AS A CONTRIBUTION TO THE NTSB REPORT

Note: *The original French version of this study was issued on August 25, 1995. This is the corrected English version with revisions and updated data integrated from material subsequently supplied to the BEA by the NTSB.*

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SUMMARY

1. INTRODUCTION

The meteorological data and documents quoted and used in this study were provided to the BEA by the NTSB, in particular:

- general plotted and analysis altitude and ground charts;

- available data based on from radiosoundings;

- weather radar and satellite imagery;

- available ACARS data transmitted during the flight, relevant PIREPs and testimonies.

DFDR data from aircraft N401 AM and Chicago air traffic control radar data[1] (altitude and coordinates) are used to determine the atmospheric structure in the flight environment, from the descent from 16000 feet to the holding pattern at 10000 feet, then during descent towards 8000 feet and finally, during the uncontrolled descent down to 5000 feet.

The CVR and ATC records are used to provide cross-correlation with the DFDR data, with the results of calculations and with certain information and procedures drawn from the ATR 72 FCOM.

Information related to results of models and simulations generated by research centers or universities commissioned by the NTSB are quoted to allow comparison. Neither analysis nor detailed critical study of this research has been undertaken by the BEA.

Weather forecasts and available meteorological information (flight release to the crew, information at disposal of ATC) are not dealt with in this study.

The objective of this report is to establish a reconstitution of the atmospheric conditions prevailing in the holding pattern on October 31, 1994 between 21 h 00 and 22 h 00 UTC[2].

2. GENERAL SITUATION BETWEEN 18h00 AND 22h00

2.1- Situation at Altitude

At 500 hPa (see appendix 1), a low pressure belt was located to the north of 50 °N (over Canada), extended by a thalweg (trough) over Minnesota (MN), Wisconsin (WI), Iowa (IA) and Illinois (IL)

[1] Radar data and trajectography relative to the part of the flight in the holding pattern were not provided in full to the BEA until February **1996.**

[2] Time in this report is Universal Time Coordinated (UTC). Central standard time (CST), which is local time, corresponds to UTC minus six hours.

At 700 hPa and 850 hPa, (see regional charts in appendix 2) the same low pressure belt existed. The thalweg concerned Michigan (MI), Wisconsin and Illinois at 700 hPa, and Wisconsin, Michigan, Illinois, Indiana (IN) and Ohio (OH) at 850 hPa.

On the Indianapolis (IN) - Chicago (IL) route, winds and temperatures evaluated at the corresponding altitudes were :

-500 hPa (5600 to 5500 m) :230° / 50-60 kt to 210° /40-50 kt, -17 to -20 °C;

-700 hPa (2970 to 2930 m) :220° / 40 kt to 160° /20 kt, 0 to -6 °C;

- 850 hPa (1400 to 1380 m) : 210°/35 kt backing to 050° /20 kt, +7 to 0 °C.

2.2- Surface Situation

Regional surface analyses at 1800 h, 2000 h, 2100 h and 2200 h are attached in appendix 3.

A large area of low pressure covered the United States to the east of the Mississippi. The minimum centered 1004 hPa to the east of Saint-Louis was slowly deepening (1000 hPa at 2000 h, deepening to 998 hPa at 2200 h), while moving to ENE.

At 2200 h, the low was centered slightly to the west of Terre-Haute (WSW of Indianapolis). A complex system was associated with this depression:

- a main disturbance moving ENE of the warm front was moving very slowly to the north; it extended from Lafayette to Fort-Wayne (IN) and to Cleveland (OH) between 2100-2200 h; the cold front extended from Nashville (TN) to Indianapolis and Lafayette (IN) at 2200 h;

- a secondary cold front located along the Mississippi, Ohio and Wabash rivers at 2200 h;

- an air mass limit, as an occlusion, separating the wet air ahead of the warm front from the polar dry and cold air; at 2200 h, it was located to the NE of Illinois and was passing over Michigan and the south of Ontario; its western part was backing to the south, due to northerly air flow, and its eastern part extended to the north or north-west.

2.3- Synoptic meteorological conditions

In the warm disturbance area, near the warm front (air temperature T = 12 to 15 °C and dew point Td = 11 to 14 °C), there was mist with stratus (St) and stratocumulus (Se) under altocumulus (Ac) and altostratus (As). Some rainfall or scattered showers were noticed.

The main cold front was not very active. It formed the limit between the preceding air (warm sector) at 15-18 °C (Td), with wind blowing from south to SSW gusting up to 25 kt, and the following air at 10-12 °C (Td).

The secondary cold front formed the limit with unstable cold air (Td = 4 to 7 °C), characterized by several cloud layers with generalized rainfall or rainshowers and many stratus layers.

Above the areas located to the north of the warm front (Td= 5 to 7 °C), the sky was overcast by stratocumulus and altocumulus - altostratus with frequent drizzle and rainfalls, and near the occlusion, rain and showers. It must be pointed out that precipitation was general and much more intense to the north of the front than in the immediate vicinity. LUCIT **intersection and the associated holding pattern, which N401AM was flying in, was in this area.**

To the north of the occlusion, and northwards of the Great Lakes and Wisconsin, the sky gradually became clear. The air mass temperature dropped from between 2 and 5 °C (Td), to the north of the precipitation area, to between -2 and -4 °C (Td) in the clear sky area.

3. ATMOSPHERIC STRUCTURE

3.1- Radiosoundings at 0000 h

The radiosounding launch time was around 2300 h, thus one hour after the time of the ATR 72 accident (see diagrams in appendix 4).

The Peoria (IL) sounding took place in wet arid cold air following the secondary cold front. In addition to the marked instability of the low layers, below 950 hPa (saturated pseudoadiabatic temperature **Θ'w** = 3 °C), it was characterized by a relatively stable wet air mass between 900 and 500 hPa. The **Θ'w** reached 8 to 13°C between 750 and 450 hPa. The wind was blowing from north to NNE from ground to 650 hPa, with a speed of 20 to 30 kt. Between 940 and 820 hPa, its speed was 50 to 55 kt, and it gradually weakened down to 10 kt at 680 hPa. Above, it backed west, then south-west 20 to 30 kt at 500 hPa.

According to the Pontiac (MI) radiosounding, in stable wet cold air prior to the warm front, the air mass had a **Θ'w** of 7 °C from surface up to 860 hPa; it was topped by a temperature inversion of 3 °C, due to the warm front surface (slope of 1.3 %). Above, the wet and stable air mass temperature increased up to 16 °C **(Θ'w)** at 550 hPa. The wind was ENE to ESE 15 to 25 kt from the ground to 830 hPa. It veered SSE to SSW, reaching 30 kt at 700 hPa; then it stayed SW 35 to 45 kt until 450 hPa.

Dayton station (IN) was located in the warm area. In the lower layers, the air mass temperature **(Θ'w)** was 15-16 °C from ground to 850 hPa. Drying appeared up to 600 hPa, this being the evolution of the subsidence inversion existing at 1200 h above 650 hPa, at the limit with the air mass at 16 °C. The light southern wind turned to SSW at 900 hPa, its force increasing with altitude, from 30 to 65 kt at 500 hPa.

On the north - west of Lake Michigan, Green Bay station was in the polar cold air forward of the north of the occlusion, at the edge of the area of the disturbance. The atmospheric structure was characterized by a **Θ'w** of 3 °C between ground and 800 hPa, then 6 to 8 °C up to 570 hPa. The wind was steady NNE 10 to 20 kt from surface to 650 hPa; it then turned E to SE 10 to 15 kt and veered to S to SSW above 500 hPa, with an increase in speed of 20 up to 35 kt.

3.2- ACARS Measures

ACARS messages from six United Airlines flights, transmitted between 20 h 30 and 00 h have been studied and analyzed. These aircraft were flying to the north and much more to the east or to the west than N401 AM, especially during the holding pattern phase at LUCIT intersection.

These flights were leaving from or going to Chicago (see navigation map and diagrams related to ACARS messages in appendices 5 and 6) :

- UAL 128, ORD - MIA : climbing at 20 h 32, approaching Kankakee (IKK) at 20 h 42 (420 hPa);

- UAL 176, SFO - ORD : moving away from Dubuque(DBQ) at 20 h 54 (415 hPa), on final at 21 h 15;

- UAL1046, IAH - ORD: crossing Bradford (BDF) at 21h 40 (400 hPa), on final at 22 h 02;

- UAL 379, ORD - OAK : climbing at 22 h 35, cross-wise to Rockford (RFD) at 22 h 45 (425 hPa);

- UAL 793, SJU - ORD : towards Knox (OXI) at 23 h 21 (425 hPa), on approach at 23 h 44 (750 hPa);

- UAL 708, ORD - BOS : climbing at 23 h 42, en route towards Keeler (ELX) at 23 h 51 (425 hPa).

Taking into account the general weather situation, with specific reference to the atmospheric structures based on radiosoundings, these flights took place in the active disturbance area:

- the air mass crossed by the flights on the routes BDF - ORD, ORD - RFD and ORD - ELX was the same as that of the Peoria sounding at 0000 h, and the structures were very similar. However, the NNE to NE wind 30 to 45 kt up to 750 hPa veered SE at 700 hPa, increasing from 20 up to 40-50 kt above 550 hPa;

- the atmospheric structure on the route DBQ - ORD was in an intermediate position between the Green Bay and Peoria soundings : the NNE to NE wind speed was not more than 35 kt from ground to 750 hPa; then it weakened, veering SSW 20 kt at 550 hPa, increasing up to 50 kt between 450 and 400 hPa;

- the start of flight ORD - IKK took place in cold air; then the structure became similar to the one encountered by flight OX1 - ORD above 720 hPa; the winds were quite similar and are comparable to those measured during the Dayton sounding above 650 hPa.

3.3- Atmospheric structure based on N401AM DFDR data

The static air temperatures (SAT), calculated from the total air temperature (TAT) measurements (see diagram in appendix 7) between 21 h 12 (540 hPa) and 21 h 58 (850 hPa) give a structure which can be superimposed over that of the Pontiac sounding from 850 to 670 hPa and 570 to 540 hPa. Between these two altitudes, it is characterized by a θ'w of 14 °C constant up to 600 hPa and by an inversion of 1.5 °C with a thickness of 250 m.

In the atmospheric layer centered on 700 hPa, where the aircraft was flying between 21 h 18 and 21 h 57 (during the approach to LUCIT intersection, then in the holding pattern), the temperatures varied between -2 and -4 °C. None of the available information could lead us to question the reliability of the temperature probe and recorded values, nor the calculation method based on the diagrams of the ATR 72 FCOM. The temperature values did not vary suddenly, but rather through consistent stages, doubtless linked to the state of the atmosphere : wet air (outside of clouds), saturated air (in clouds), saturated air with precipitation.

At 10000 ft, the data used to calculate the wind are those provided by the air trajectory and by the ATC radar trajectography. Various calculations made with time periods of between 9 and 60 seconds give an average wind of 210°140 kt.

3.4- Satellite imagery analysis

The various satellite images taken between 20 h 30 and 22 h 00 (see appendices 8 to 10) show cloud cover whirling around the low pressure area centered above Illinois. They also show the warm sector and the secondary cold front, the northern part of which was in the whirling cloud cover.

In the warm sector, the thermal analysis shows that the temperatures at the tops of the clouds varied between -15 and -10 °C (4500 to 4000 m) and reached -3 to +3 °C (3000 m to 1000-1500 m) locally.

The thermal gradient provides an interesting indication on the warm frontal limit : a significant extension in altitude of cloud layers up to 9000 m (-40°C).

In the holding pattern, N401AM initially flew in an area where the temperature at the tops of the highest cloud layer varied between -25 and -35 °C (7000 -8000 m), then at about -20 °C (6000 m) for the 15 last minutes. This finding is at variance with the conclusions drawn by American scientists, who deduced temperatures of only -15°C at the tops of the clouds.

3.5- Radar echo analysis

The precipitation echoes (drizzle, rain, mixed rain and snow) are obtained by the reflection of a signal from drops of water in the atmosphere. Reflection from crystals (ice, dry snow) is significantly weaker than from water droplets or drops.

Ground weather radar equipment in use is of centimetric type, with a wave length of between 3 and 10 cm, and more generally of between 3 and 5 cm. With this kind of radar, reflection from drops or "wet" crystals with a size of at least 100 µm becomes possible. In comparison, millimetric radars have a lower reflective threshold: about 20 µm (cloud droplets).

Airborne radar equipment has the same characteristics and the reflectivity of precipitation echoes is expressed on a four-level scale, depending on precipitation intensity (reference ATR FCOM and Pilot Handbook PRIMUS 800 Color Digital Weather Radar) :

- level 0, black: no detectable cloud (intensity of less than 1 mm/h corresponding to a reflectivity of less than 23 dBz).

- level 1, green: normal cloud, corresponding to light echoes (intensity of 1 to 4 mm/h corresponding to a reflectivity of between 23 and 33 dBz).

- level 2, yellow: dense cloud, corresponding to moderate to strong echoes (between 4 and 12 mm/h corresponding to a reflectivity of between 33 and 40 dBz).

- level 3, red : severe storm, corresponding to very strong echoes (intensity more than 12 mm/h corresponding to a reflectivity of more than 40 dBz).

Aircraft N401AM was equipped with the Honeywell PRIMUS 800 weather radar (wave length 3.2 cm). During the section of the flight in the holding pattern, whenever the radar was functioning in WX position, precipitation echoes were detected, appearing in green, or at a higher value, on the EHSI screen.

Thus the more common meteorological radars (wave length of between 3 and 5 cm) detect drops of atmospheric phenomena classified as drizzle (diameter of 50 to 500 µm) or rain (diameter > 500 pm). Reflectivity, expressed in dBz, depends on drop size and mean concentration, hence also on the liquid water content.

Measurements from the doppler radar of Lockport (KLOT) between 21 h 30 and 22 h 00, at a variety of elevations (0. 5°, 1.5°, 2.4° and 3 .4°) showed a general extension of the echoes towards NNE as well as an increase in their reflectivity. The holding pattern was situated at the edge of the extended area at the time period under consideration (see appendices 11 to 13).

These elevations correspond respectively to the following average altitudes, vertical to the holding pattern: 4600,9400, 13700 and 18700 ft.

3.5.1- Determination of the wind

A wind field was calculated, by scientists commissioned by the NTSB, on the basis of data provided by the Lockport radar (about 40 NM of the hold) within a 22 NM radius. The profile of the wind calculated between 21 h 45 and 21 h 55 was similar to that established with the measurements taken by flight BDF - ORD. Lockport station was in cold air and the S to SSW flow existed only above 700 hPa (about 10000 feet).

The evolution of the precipitation echoes was examined by the BEA in order to determine direction and speed of the noticeable echoes vertical to the holding pattern. The profile thus obtained was superimposable on the profile obtained from Dayton radiosounding measurements, in the warm sector. **At the level of the holding pattern, this calculation confirms those made by the BEA, using the airborne and ATC radar trajectories of the aircraft: 200 to 210° /40 kt.**

3.5.2 -Reflectivity of the echoes corresponding to N401AM movements

The acceptable reflectivity threshold in operational conditions is 5 dBz. In France this threshold is extended to a minimum of 15 dBz so that the results obtained are completely reliable (in terms of potential precipitation quantity and intensity)

Echoes related to the 0.5° elevation of the radar were not considered, except during the final descent; they corresponded to a mean altitude of 4600 ft (1400 m) in the holding pattern.

The major successive passages through the known precipitation areas are as follows (see appendix 14) :

- at about 21 h 24-21 h 25, turning right at LUCIT intersection : 15-20 dBz at 1.5°;

- between 21 h 25 and 21 h 29, turning right and initiation of outbound leg: 5 to 15, briefly 20 dBz at 1.5°, and intermittently 5 to 10 dBz at 2.4° and 3.4°;

- from 21 h 33 to 21 h 35, in right turn after LUCIT intersection :5 to 15 dBz at 1.5°;

- between 21 h 37 and 21 h 39 mn 30 s, in southern turn to return to the intersection :5 to 10 dBz at 1.5°;

- between 21 h 40 and 21 h 45, on the northern part of the circuit : 10 to 15 dBz rapidly increasing to 15-20 dBz (25 dBz around LUCIT intersection) at 1.5°, and 15 dBz at 2.4° around LUCIT;

- between 21h 46 and 21 h 48, on southern part of the circuit :5 to 15 dBz at 1.5° and 0-15 dBz at 2.4°;

- from 21 h 51 to 21 h 55, end of inbound leg, then turning South and on outbound :10-15 dBz, briefly 20 dBz at 1.5°, and 5 to 10 dBz at 2.4° and 3.4°;

- **between 21 h 55 and 21 h 58, end of outbound leg, then turning in descent and accident sequence : 15-20 dBz quickly increasing up to 30 dBz at 0.5° and 1.5° (possibly 35 dBz at 1.5°) and 15-20 dBz at 2.4°.**

3.6- Ground Reports and Measurements

The ground meteorological observation closest to the site was performed at Lowell airfield, at about 3 NM from LUCIT intersection, 30 mn or so after the accident:

· wind : SW / 20 kt with gusts,
- significant weather: light drizzle,
- clouds : BKN 1400 ft, OVC 3000 ft.

Between the time the aircraft entered the holding pattern (21 h 24) and the time of the accident (21 h 58) a total of 2..5 mm of precipitation was measured at Demotte (between 21 h 45 and 22 h 00). Demotte is situated NNE at a distance of 9 NM from the site of the accident and 6 NM to the east of LUCIT intersection.

At Demotte, a witness testified that he heard the accident at about 22 h 00. At that time he was driving his car and affirmed that weather conditions were bad with heavy rain and strong wind.

3.7- Crew reports

Several PIREPs were transmitted by United Airlines crews to Chicago ATC between 21 h and 22 h 30. **No real time PIREPs transmissions seem to have been made by the controllers to inform other crews in flight.**

These PIREPs indicate light to moderate icing: rime and/or glaze at various flight levels :

- above FL 120 in the warm sector;
- at 6000 ft and above in the preceding cold air, near Lake Michigan;

-0 °C at 4000 ft with freezing rain at 22 h 01 above Pontiac (IL) VOR, in cold air in the low area.

An airline Captain's report communicated some accurate information concerning the period between 22 h 10 and 22 h 40: descending from 14000 ft to HALIE intersection (26 NM NNE of the site) at 2000 ft on approach to Chicago, continuous icing (rime), with rapid accretion reaching 1.3 to 2 cm on the probe. **The Captain also revealed the detection of green echoes on the airborne weather radar.**

Information about conditions closest to the accident site were provided by two B727[3] crews in flight near LUCIT at the time of the accident, who indicated that, in the cloud layers they were flying in, rain and even heavy rain and some sleet were occurring. The icing layer extended between 15000 and 5000 ft according to one of them and, according to the second one, whilst descending, it started at 14000 feet and was prevalent down as far as 6000 feet.

3.8- Results from numerical model used by the NTSB

The results of the numerical model NCAR-MM5 valid at 0000 h vertical to the accident site established a parallel structure, 1 °C lower than the one determined with the DFDR between 850 and 720 hPa, then 2 to 30 lower up to 660 hPa; the difference became less than 1 °C from 660 to 600 hPa and suddenly increased above, reaching 3 to 4 °C (see NCAR-MM5 diagram in appendix 7).

[3] These two B 727's were reported in CVR and radiocommmications transcriptions as KIWI AIR 17, which was the source of the TCAS warning about one minute before the accident, and KIWI AIR 24, which had crossed LUCIT intersection at a 10 NM distance to the east at about 22 h 10.

This result was very much like the thermal profile obtained with the ACARS data of flight ORD - IKK from 750 to 700 hPa; above, it was very close to the values obtained on the other routes, essentially between 600 and 500 hPa, except for the DBQ - ORD route.

Results concerning the calculated wind were very similar to the values measured during the sounding realized at Pontiac at 0000 h or to ACARS measurements performed three hours earlier on route ORD - IKK (with an error margin of 10 to 15 kt below 750 hPa).

There is also an analogy between the winds calculated with the NCAR-MM5 model and the data provided by the radar of Winchester (IL), near Jacksonville (north of Saint-Louis), though in cold air and too far from LUCIT in order to apply them to the accident site.

At altitude, the structure (temperatures and winds) calculated with the numerical models, whose results were used by the NTSB, cannot be considered to be a reference. Indeed, the BEA calculated the various trajectories on the basis of the data from American models and wind profiles, and these show significant variations with those of this study. The trajectory calculated by the BEA corresponds more exactly to those based on the ATC radar tracks (see appendices 15 and 16).

On the ground, the results obtained with the NCAR-MM5 model also seemed to be far removed from reality, as expressed on the charts, if we consider such parameters as time, position, values at the center of the minimum and pressure gradient. Real data existed, however, and accurate weather charts could have been plotted and drawn in order to generate more accurate analyses , as the BEA did (see appendices 2 and 3).

4. INTERPRETATION OF THE RESULTS

4.1- Analysis of the situation at altitude

The atmospheric structure between 800 and 600 hPa, cm-responding to an altitude of 2000 to 4200 m (6700 to 14000 ft), between parallels 36 and 42 °N and meridians 82 and 92 °W is now considered.

Three discontinuities related to three conflicting air masses can be noted:

- the warm sector, to the east of 88 °W and to the south of 41 °N, where the strong SSW to SW current prevailed at every altitude, with a speed of 25 to 30 kt from 900 hPa and reaching 60 kt at 600 hPa; according to the analysis at 700 hPa, this sector was characterized by a light thermal gradient in the warm advection extending as far as Kankakee (IL) and Pontiac (MI) with temperatures of- 1 to -2 °C;

- in the following cold air, to the west of 88 °W meridian, the thermal gradient was strong: the temperature value -5 °C could be found near Lockport (KLOT) with a calculated thermal wind of SE / 50 kt; this zone was the center of the depression and was linked to a thermal minimum of about -12 °C or so which tended to deepen the thalweg southwards;

- in the air ahead, to the north of41 °N parallel and to the east of 88 °W meridian, the E to NE wind, from ground up to 850 hPa, veered SE to S 20 to 30 kt to turn SSW above 700 hPa, the speed increasing to 45 kt ; the thermal gradient was light and temperature at 700 hPa downed from -2 °C to -6 °C to the north-west, from LUCIT intersection toward Chicago-O'Hare airport.

4.2- Analysis of the atmospheric structure above the LUCIT intersection holding pattern

Ground conditions corresponded to the ones ahead of the warm front (ground trace).

At altitude, air mass heating had begun to develop from the passage over Lafayette, in the warm sector, despite the fact that the mean structure was the same as that of the Pontiac sounding. Conversely, the wind flow seemed to be similar to that at the Dayton sounding at all levels and to that at the Pontiac sounding above 700 hPa.

Towards 600 hPa (about 4000 m), the temperature inversion was typical of the top of cloud layer in latent instability (Ac - As) liable to develop up to 500 hPa, if the false isothermal layer representing the interpolation between two measures recorded to the north of Kankakee during flight ORD - OAK was taken into account.

Between 765 and 685 hPa (2700 -3200 m), the quasi-isothermal layer at 2 °C with a thickness of about 400 m indicated a fluctuation at the level of the cloud tops (mean top and maximum top). In this layer, no significant wind flow discontinuity appeared and even less wind shear, in contrast to assertions made by some scientists whose results on weather conditions were used by the NTSB. Indeed a clue was visible on the satellite imagery, the Kelvin-Helmoltz waves which are characteristic of wind shear phenomena: the altitude of these Kelvin-Helmoltz waves was determined on the imagery by using the temperature of the associated cloud layer, between -13 °C and -16 °C, corresponding to an altitude of 5000 to 5700 m, or 17000 to 19000 feet (7000 to 9000 feet above the altitude at which aircraft N401AM was flying in the holding pattern!).

The intensity of the precipitation echoes in terms of reflectivity generally varies between 5 and 15 dBz, briefly 20 dBz. After 21 h 50, the maximum reached 25 dBz at the various elevations : at the level of the holding pattern, two kinds of drops may have existed together, those relative to the precipitation within the cloud under study and those falling from a cloud above, also inducing enlargement of drops by coalescence. **This is also a point of disagreement with some of the conclusions drawn by the NTSB, since there is no mention of the precipitation (rain or drizzle, freezing drizzle, or mixed rain and snow, even sleet) which originated from the upper cloud layer and which was detected on the KLOT radar (2.4° elevation) and which was confirmed by the determination of cloud layers from satellite imagery and radiosoundings or ACARS, consistent with the testimonies of the two Boeing 727 flightcrews.**

The examination of the radar images showed there was no bright band (clue admitted as a melted snow area at temperature close to 0 °C) between 0. 5° and 2.4° elevations in the warm area and its limits, as defined above (§ 4.1). This leads to the idea that most of water droplets or drops above isotherm 0 °C (about 2200 m) in this area were supercooled. Some PIREPs, even though they related to areas at some distance from the site, seem to confirm this fact.

Regarding reflectivity, precipitation was still considered to be light, sometimes moderate.

4.3- Reconstitution of the conditions in the honding pattern

Between 21 h 15 and 21 h 57, the ATR 72 was flying in the layer 685-725 hPa (about 12000-9000 ft). The study results, detailed in the previous paragraphs, and their interpretation leads to the discovery of a certain number of characteristics of this layer.

4.3.1- Cloud conditions

The flight took place at the edge of a stable cloud layer whose mean top was at 2750 m and the maximum top at 3200 m. Turbulence did not exist or was very light, certainly limited to the maximum level of the tops, possibly associated with an effect of the strong wind whose laminarity was disturbed by the proximity of the warm frontal surface (wind shift).

A more unstable layer was located just above, adjoining the previous one (top 4300 m), reaching 5500 m at the level of the warm sector. **After 21 h 50 these layers thickened noticeably, while the rainy area linked to the depression was moving to NE, this being revealed by the intensification of the precipitation echoes detected on the Lockport weather radar. This confirms the detection of supercooled rain and drizzle drops as precipitation.**

4. 3.2- Conditions of temperature and liquid water content

The precipitation detected on the Lockport weather radar was partly generated by the cloud layers located above 3000 m and played a role in the enlargement of water droplets and drops contained in the layer in which N401 AM was flying, where temperatures varied between -2 and -4 °C (SAT). This can be directly linked to the water vapor and liquid water contents through the air mass mixing ratio (saturating or not), depending on the aircraft location in time and space (holding pattern legs) :

- outside the cloud layer (humid air);

- in the cloud layer, without precipitation (saturated air);

- in the cloud layer, with precipitation (saturated air with increasing liquid water content).

In fact, on the basis of adiabatic theory, a decrease in temperature from -2 to -4 °C at approximately 3000 m (10,000 ft) would induce a global increase in cloud liquid water content (LWC) of 0.7 g/kg dry air, which corresponds to 0.65 g/m3 , without taking into account the extra liquid water due to the precipitation falling from the layers above. In this case, temperature variations must be correlated to the corresponding areas traversed.

4.3.3- Icing conditions

Calculation of the time spent by the ATR 72 in precipitation leads to a cumulative time of almost 24 minutes, out of a total time of more than 30 minutes in such conditions in the holding pattern, with Static Air Temperature varying between -2 and -4 °C (Total Air Temperature between +1.5 and +3.5 °C). This duration is based on precipitation echoes detected on the weather radar in the area of the holding pattern of the aircraft, which means, by deduction, drop size diameters detected of about 100µm or more (see appendices 11 to 14).

Between 21 h 24 and 21 h 29 and then from 21 h 33 to 21 h 35, the aircraft was flying intermittently and briefly in low to moderate precipitation (15-20 dBz). SAT varied between -2.5 and -4 °C (LWC = 0.45 g/m3) and TAT between +1.5 and +2.8 °C. **The crew, who had activated the airframe de-icing at 21 h 16 mn 32 s (DFDR time) switched it off at 21 h 23 mn 22s (DFDR time), and although the NP had remained at 86% since take off (during climb, cruise, initiation of the descent phase), they reduced it to 77% at 21 h 24 mn 13 s (DFDR time, steady state). At 21 h 33 mn 56 s a caution alert single chime was recorded on the CVR which was not acknowledged by the crew.**

Between 21 h 37 and 2 1h 39 mn 30 s, the plane passed through a light precipitation area (5 to 15 dBz); then, from 21 h 40 to 21 h 45, precipitation became moderate (15-20 to 25 dBz), and precipitation was also falling from upper layers. Temperatures varied between -2.5 and -4 °C (LWC = 0.45 g/m3) and TAT between +1.8 and +2.2 °C. **In that interval a caution alert single chime sounded, which can be considered to be the aural warning from the ice accretion detector (21 h 41 mn 07 s, CVR time[4]); the crew immediately activated the airframe de-icing and modified PRPM, increasing NP from 77% to 86%.**

At 21 h 48, the aircraft left an area of generally light precipitation (5 to 15 dBz), including precipitation from an upper layer; SAT varied between -2.3 and -3.2 °C (LWC = 0.27 g/m3), TAT by +1.8 and +2.5 °C. **At 21 h 48 mn 43 s, one of the pilots remarked "I'm showing some ice now".**

At 21 h 55 mn 42 s, the First Officer said "we still got ice", getting no answer from the Captain. The ATR had been flying under precipitation becoming moderate for more than four minutes (10 to 20 dBz) with SAT between -2.6 °C and -3.5 °C (LWC = 0.27 g/m3) and TAT between **+1.2 °C** and **+2.2 °C.**

From 21 h 56 until 21 h 58, the plane was descending, from 10000 feet to about 9000 feet, in moderate precipitation (20 to 30 dBz). SAT varied between -1.2 and -3.5 °C (LWC = 0.5 g/m3) and TAT between +2.8 and +4.5 °C.

4. 3. 4- Ice accretion

The aim of this paragraph is not to discuss the size of water drops and droplets in clouds or in precipitation. The radar echoes considered are precipitation echoes; the minimum diameter for drop detection being about 100 pm.

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[4] CVR transcription starts at 21h27 mn 59s

Using parameters set out in this study (liquid precipitation, air temperature, liquid water content), it is possible to try to make a simple ice accretion calculation, using the " Lucas Aerospace " diagram : accretion per minute in relation to liquid water content, The values calculated are provided for information only and are no more than a rough estimate. **Ice accretions (rime or glaze) would have reached 1 to 2 mm/mn, which overall represents a thickness of between 35 and 65 mm during the time spent in the holding pattern for more than 30 minutes, independently of freezing drizzle or freezing rain falling in the layer or from a layer above for almost 24 minutes..**

AS an example, in the layer or for the different major phases described above, the following rough values **were** obtained (regardless of drop size or water runoff capacity and liquid precipitation):

-between 21 h 24 and 21 h 35: thickness of 10 to 12mm;

-between 21 h 37 and 21 h 45 : ll to 13mm;

-between 21 h 46 and 21 h 48 :2 mm;

-between 21 h 51 and 21 h 55 : 4mm;

-between 21 h 55 and 21 h 58 : 4 to 6 mm.

No calculation or information could lead to a conclusion as to the possible shape of ice accreted on the wing, nor regarding an ice ridge behind the de-icing boots. **However, we can assume, considering the size of the drops (100 µm or more), the temperature of about -2 °C and the aircraft configuration (flaps at 15°, leading to AOA reduction through 0°) that water drop impacts occurred both aft of the upper wing leading edges and that, due to a deficiency in heat transfer, significant water run-back could have occurred aft of the de-icing boots. These observations mainly relate to the time from 21 h 37 to 21 h 45 (including the AAS warning time) and between 21 h 51 and 21 h 58 (last minutes before the accident).**

5. CONCLUSION

The icing conditions in which the ATR 72 N401AM was flying do not appear to be exceptional in terms of meteorological conditions, considering the results highlighted by the present study. The conditions were light to moderate icing, since the flight was taking place in a stable cloud layer at negative temperatures, close to 0 °C . **These moderate icing conditions, conducive to ice accretion, were seriously aggravated by liquid precipitation (supercooled drops of rain or drizzle) generated in this layer or originating in an upper layer.** This explanation can be considered to be typical of a meteorological forecast lacking in detail, such as the AIRMET broadcast's summary concern with icing conditions. **The excessive duration of the flight in such conditions, with no recorded comments (as shown by the CVR transcript) on the severity of the icing, nor any upon the procedures to be applied in the conditions, seems incomprehensible on the part of the flightcrew.**

Another major element is the domain of aircraft certification in icing conditions. The reference is Appendix C of FAR - JAR 25 regulation : which sets the certification limits. This regulation does not consider the existence of supercooled droplets or drops having a diameter over 40 µm in continuous maximum atmospheric icing conditions, with a liquid water content over 0.8 g/m3 in the cloud layer, nor the case of freezing drizzle or freezing rain.

Thus the study points up the following five findings:

1. **According to the content of the flight release, the crew was aware of the existence of light to moderate icing on the Indianapolis - Chicago route at the levels at which they were flying.**

2. **In an available AIRMET, valid before and for the flight, rainfall was forecast at the altitude of flight N401AM, with negative air temperatures.**

3. **Precipitation was detectable on the airborne radar on WX position.**

4. **The flight in the holding pattern lasted over 30 minutes in a cloudy atmosphere with liquid precipitation and at a SAT varying between -2 and -4 °C. This was in complete contradiction with the limits specified in the certification and operational procedures.**

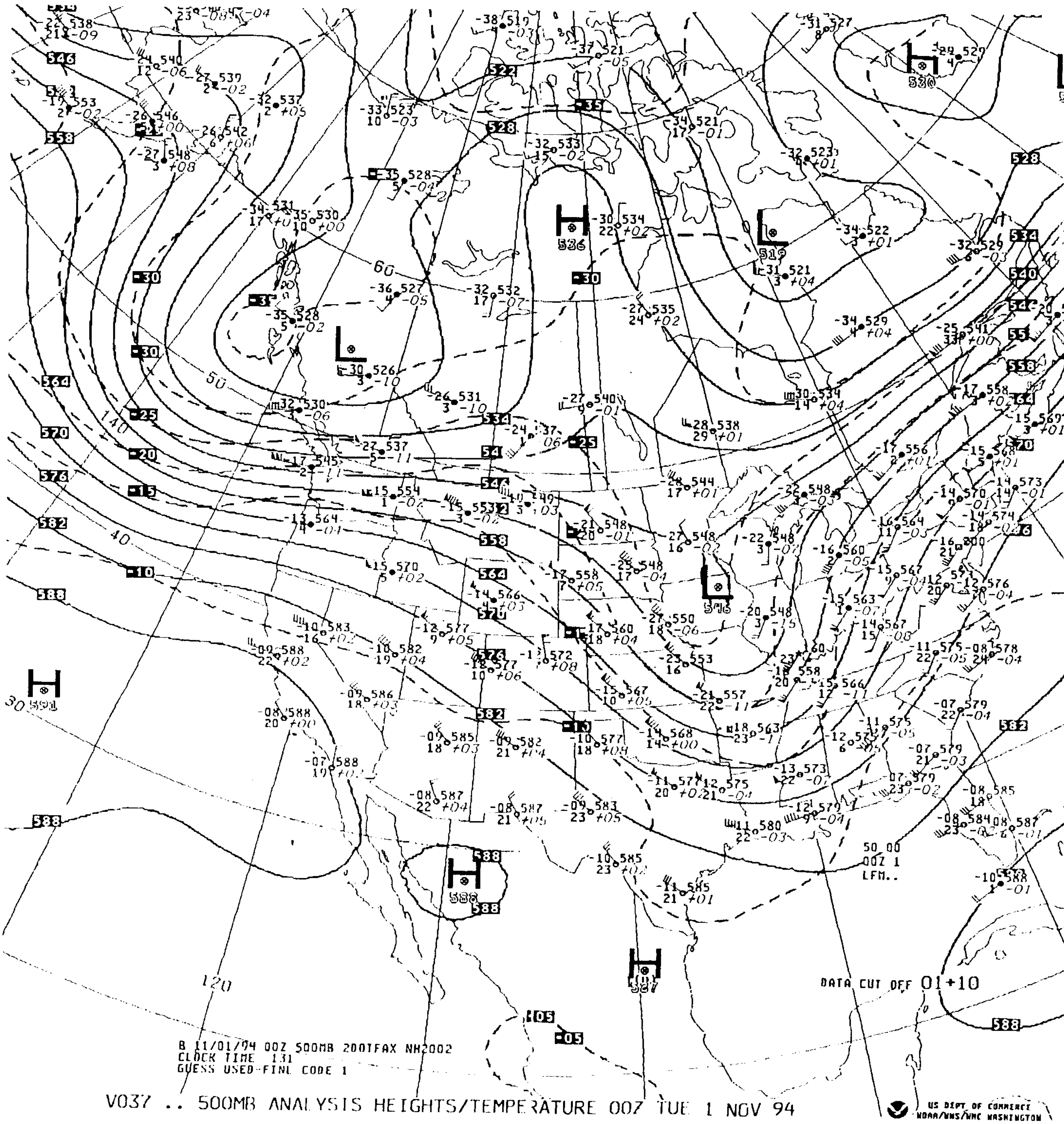
5. **Procedures relative to flights in icing conditions, specifically those related to the surveillance of environment, Static Air Temperature, ice indicators and detectors, as well as some visual cues, were not respected by the flightcrew. In addition, standard procedures relating to propeller speed adjustment and anti-icing and de-icing system activation in icing conditions were not properly applied.**

In conclusion, overall crew vigilance and awareness did not correspond to the basic rules to be applied on such a flight, occurring in icing conditions conducive to ice accretion.

APPENDICES

1. Weather Chart at 500 hPa
2. Weather Charts at 700 and 850 hPa
3. Ground Weather Charts between 18 h 00 and 22 h 00
4. Radiosoundings Diagrams at 00 h 00
5. Chicago Area Navigation Chart with six Aircraft Routes added (ACCARS data)
6. ACCARS Data Diagrams
7. N401 AM DFDR Data Diagram
8. Visible Spectrum Satellite imagery
9. Infra-red Spectrum Satellite Imagery
10. General Satellite and Radar Pictures
11. Radar Imagery at 0.5° elevation at 21 h 54 and 22 h 00 (UTC)
12. Radar Imagery at 1.5° elevation between 21 h 30 and 22 h 00 (UTC)
13. Radar Imagery at 2.4° elevation between 21 h 30 and 22 h 00 (UTC)
14. Precipitation Echoes in the Holding Pattern
15. Comparison between the BEA Computing and Radar Track.
16. Comparison between BEA Computing and Results provided by the NTSB.

APPENDIX 1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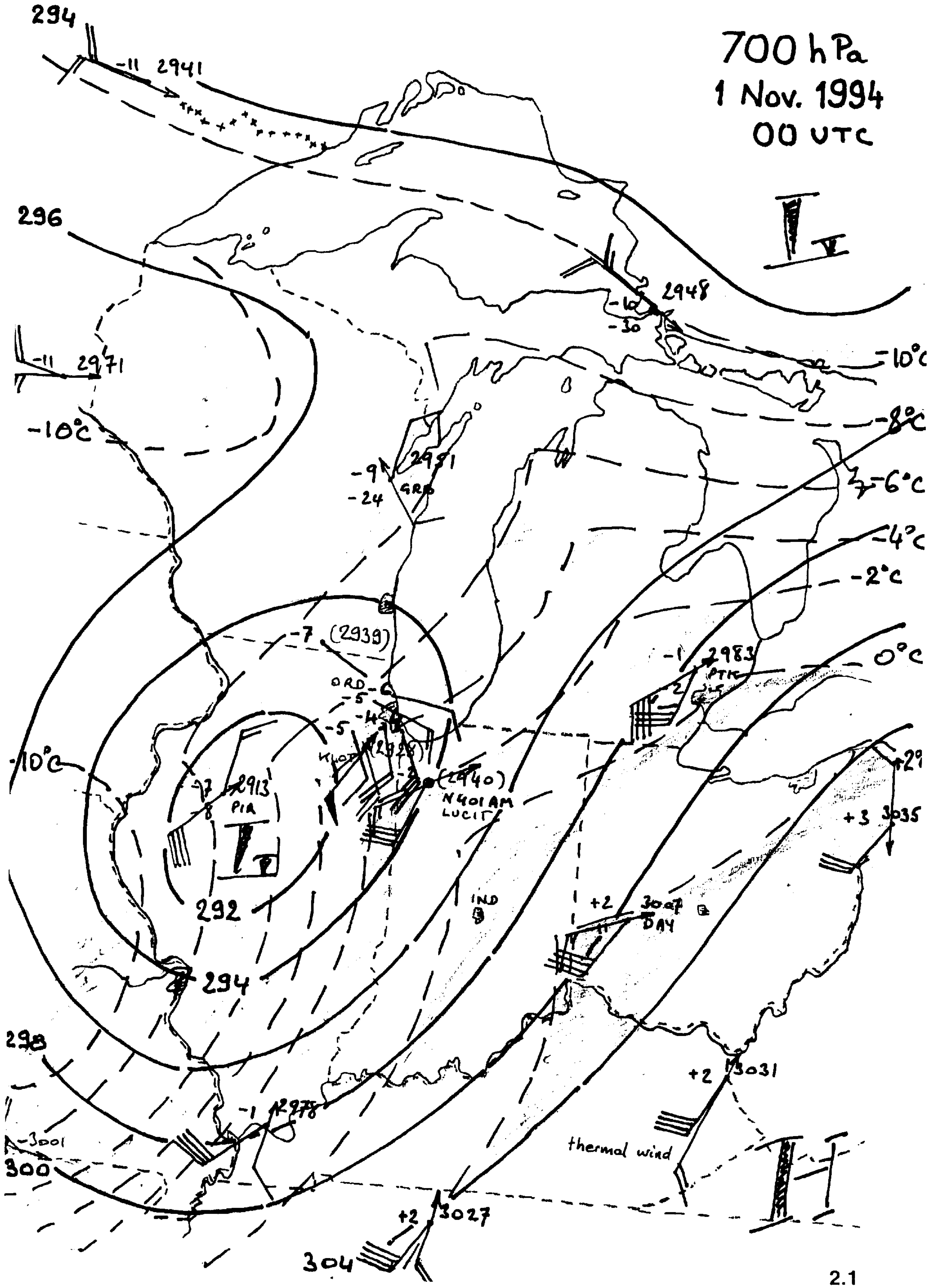
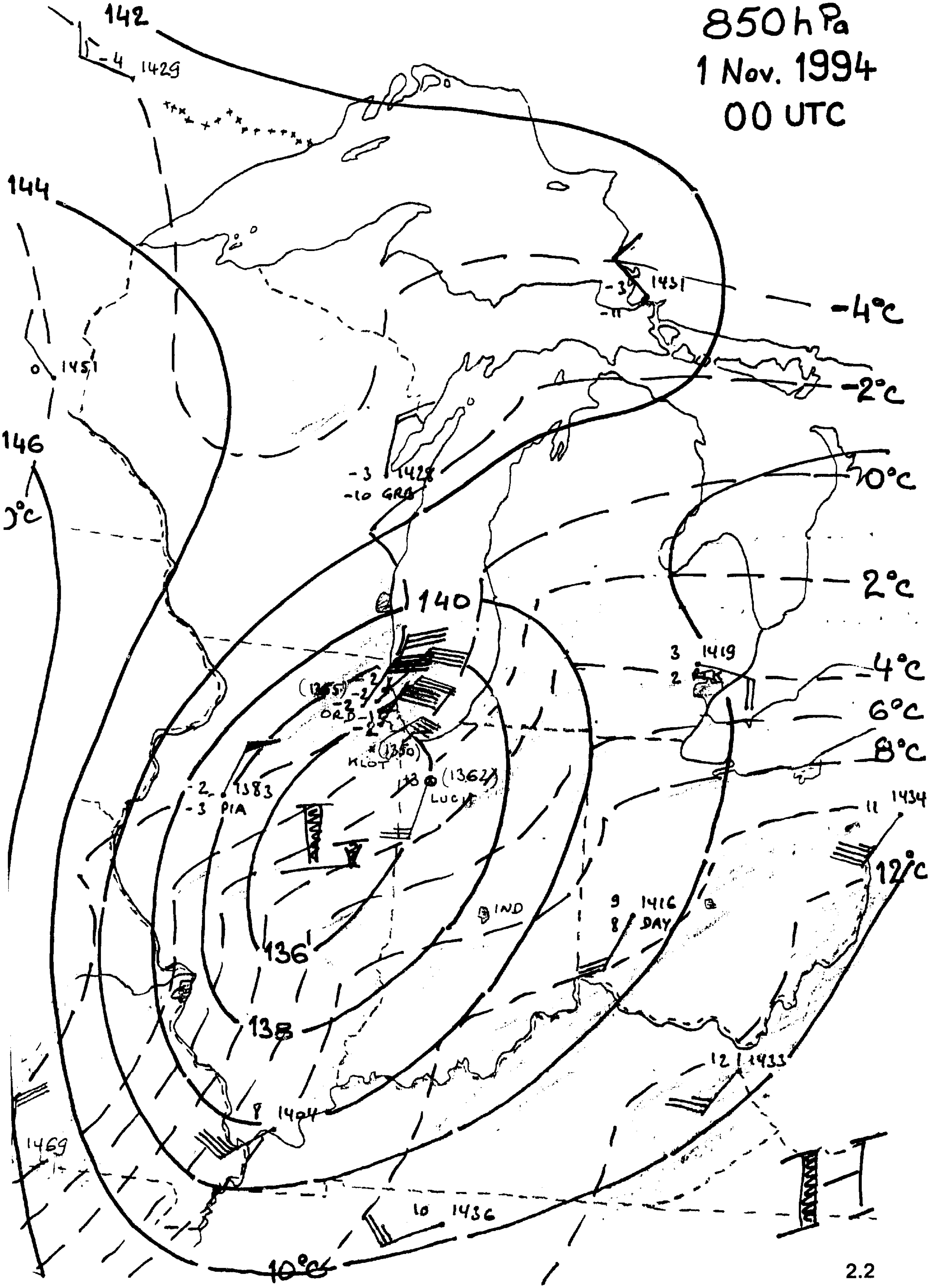
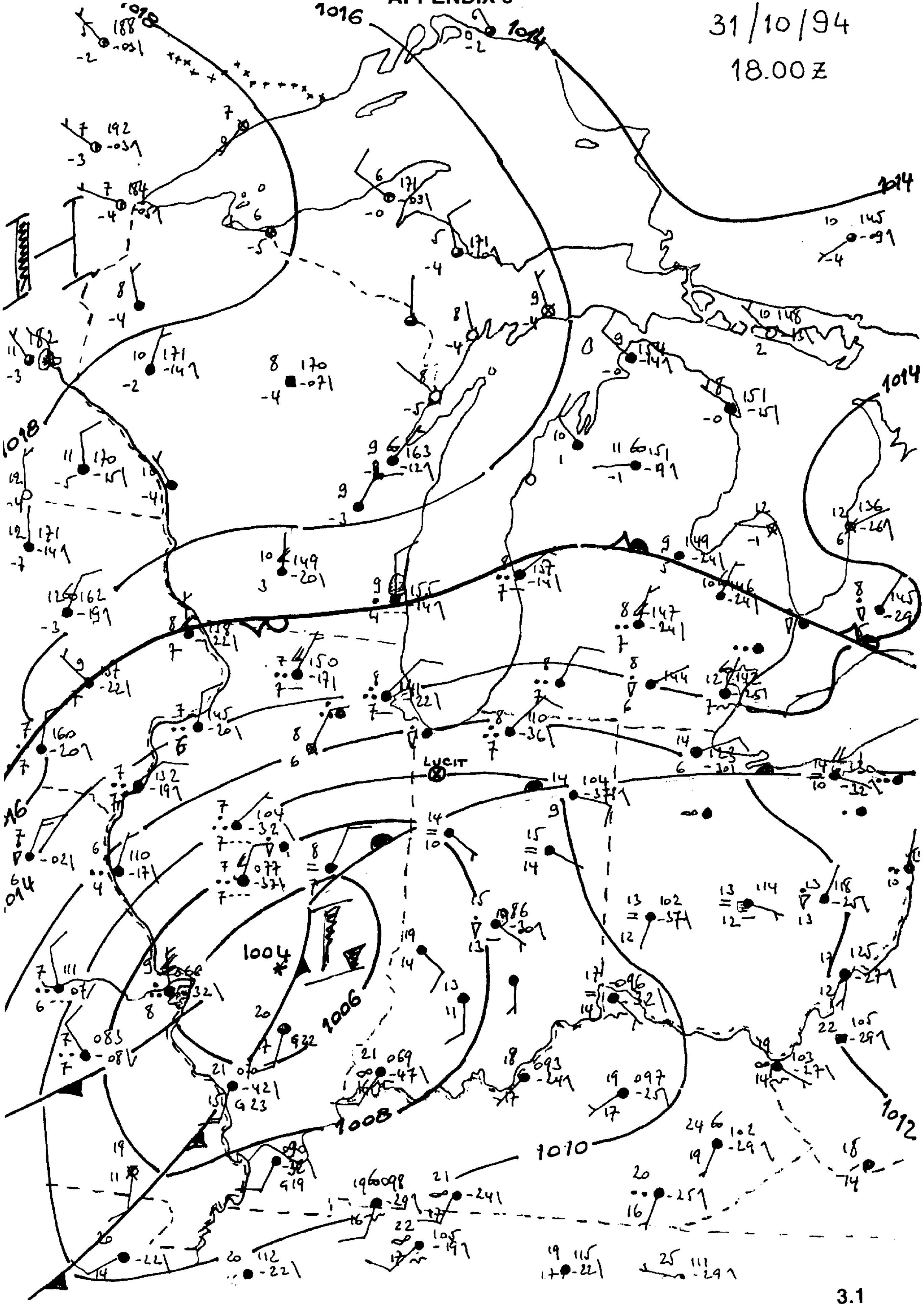
GUESS USED-FINL CODE 1
DATA CUT OFF 01+10
V037 .. 500MB ANALYSIS HEIGHTS/TEMPERATURE 00Z TUE 1 NOV 94
US DEPT OF COMMERCE
NOAA/NWS/NMC WASHINGTON


700 hPa
1 Nov. 1994
00 UTC
294
2941
296
2971
-10°C
2948
-10°C
-8°C
-6°C
-4°C
-2°C
0°C
2951
GRB
(2939)
ORD
2983
PTK
KLOT
(2940)
N401AM
LUCIT
2913
PIA
292
294
IND
3027
DAY
3035
298
2978
3031
-3001
300
thermal wind
3027
304


850 hPa
1 Nov. 1994
00 UTC
142
144
146
140
138
136
-4°C
-2°C
0°C
2°C
4°C
6°C
8°C
12°C
10°C
1429
1451
1431
1428
GRB
1419
1383
PIA
ORD
KLOT
(1350)
(1362)
LUCK
IND
1416
DAY
1434
1433
1404
1469
1436

APPENDIX 3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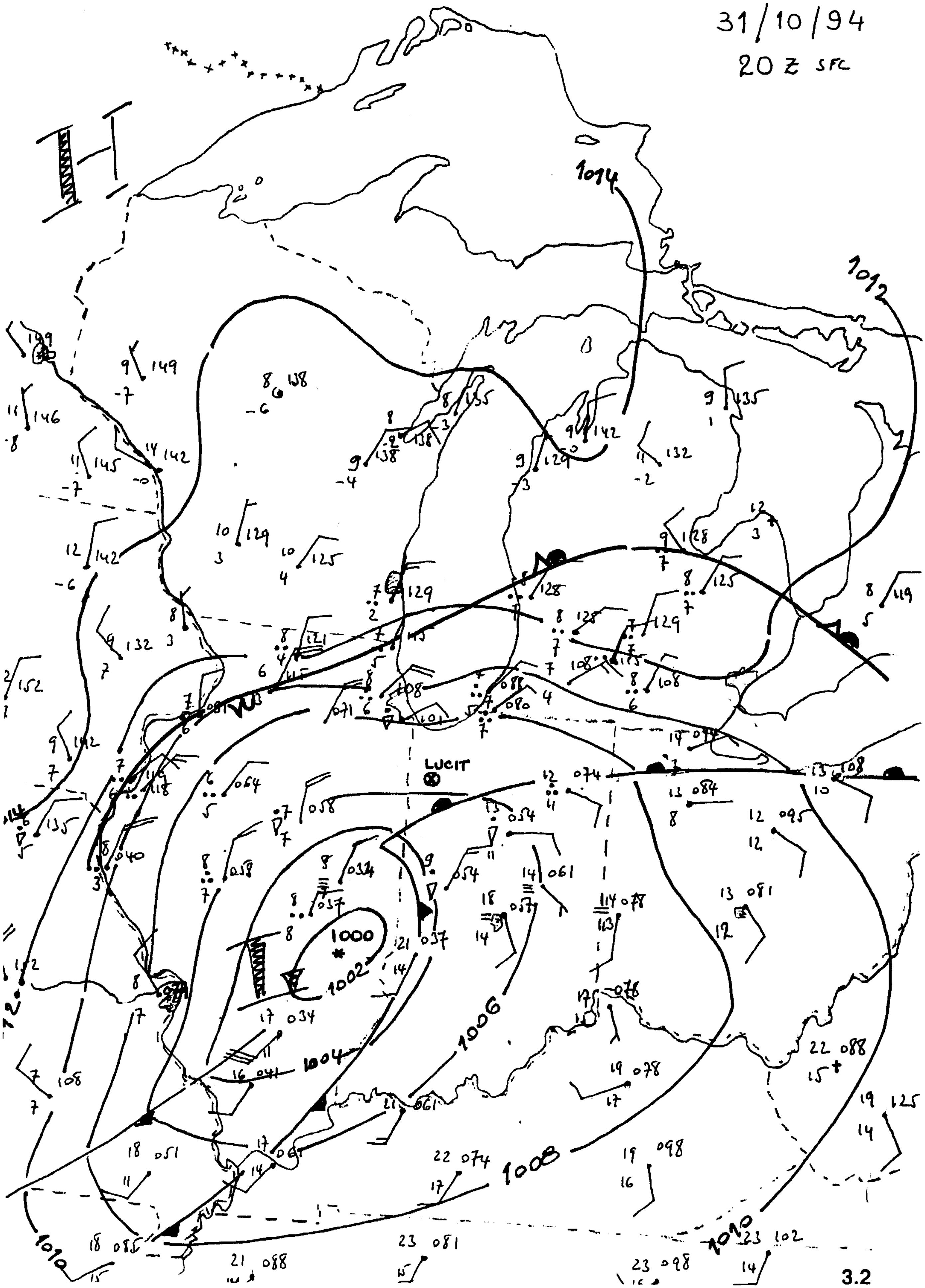
18.00Z
1016
1014
1018
1014
1004
1006
1008
1010
1012
LUCIT



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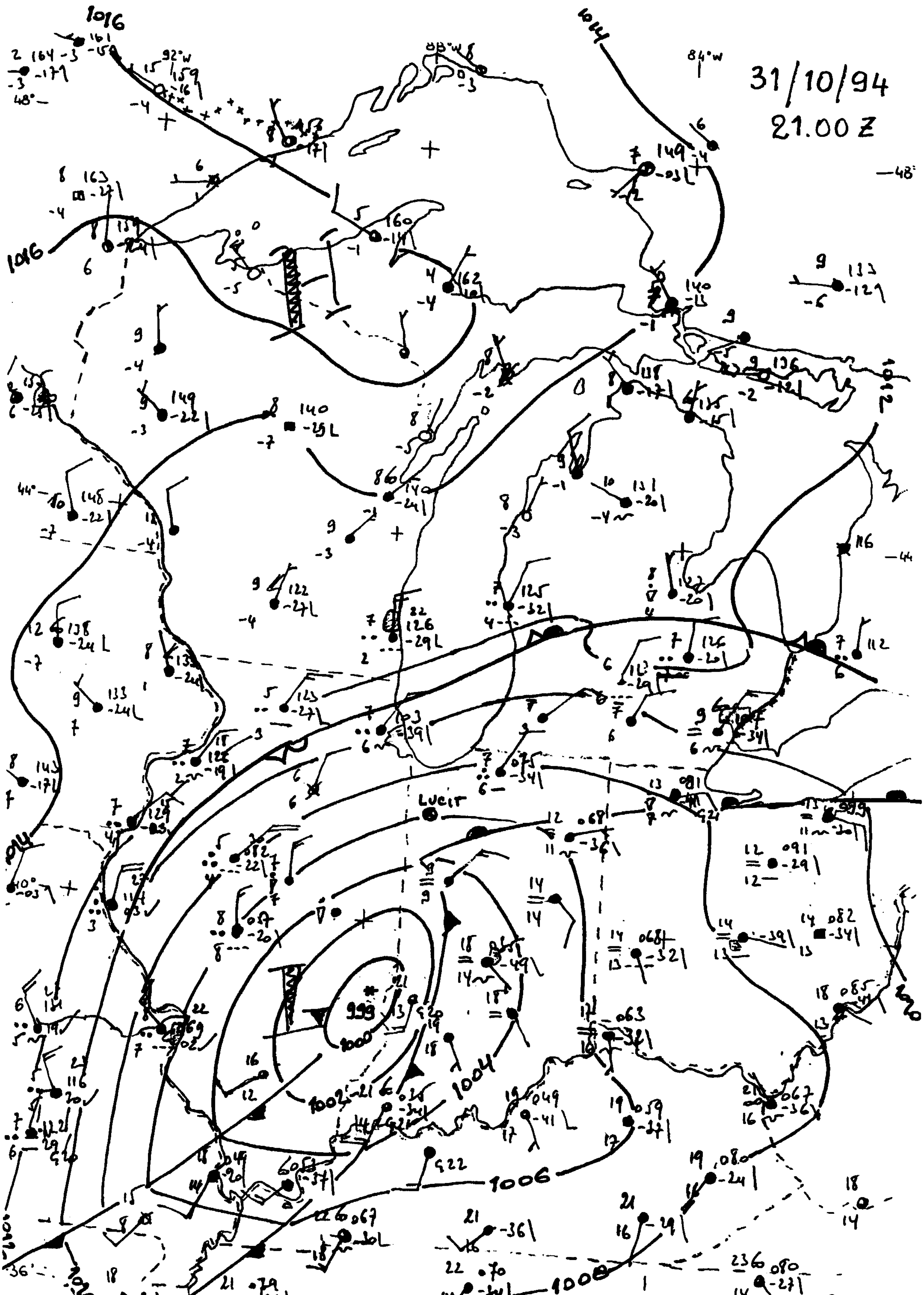
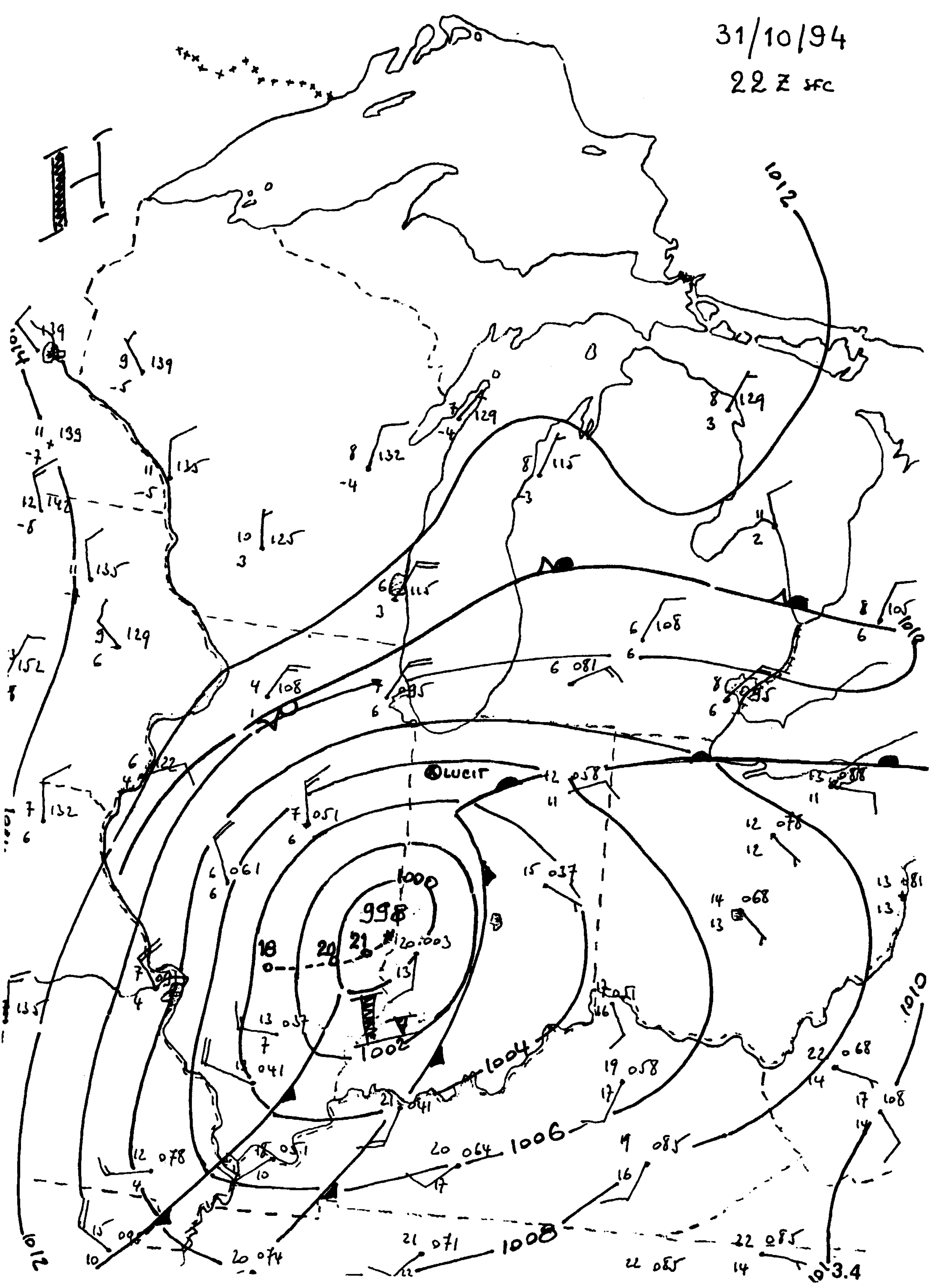
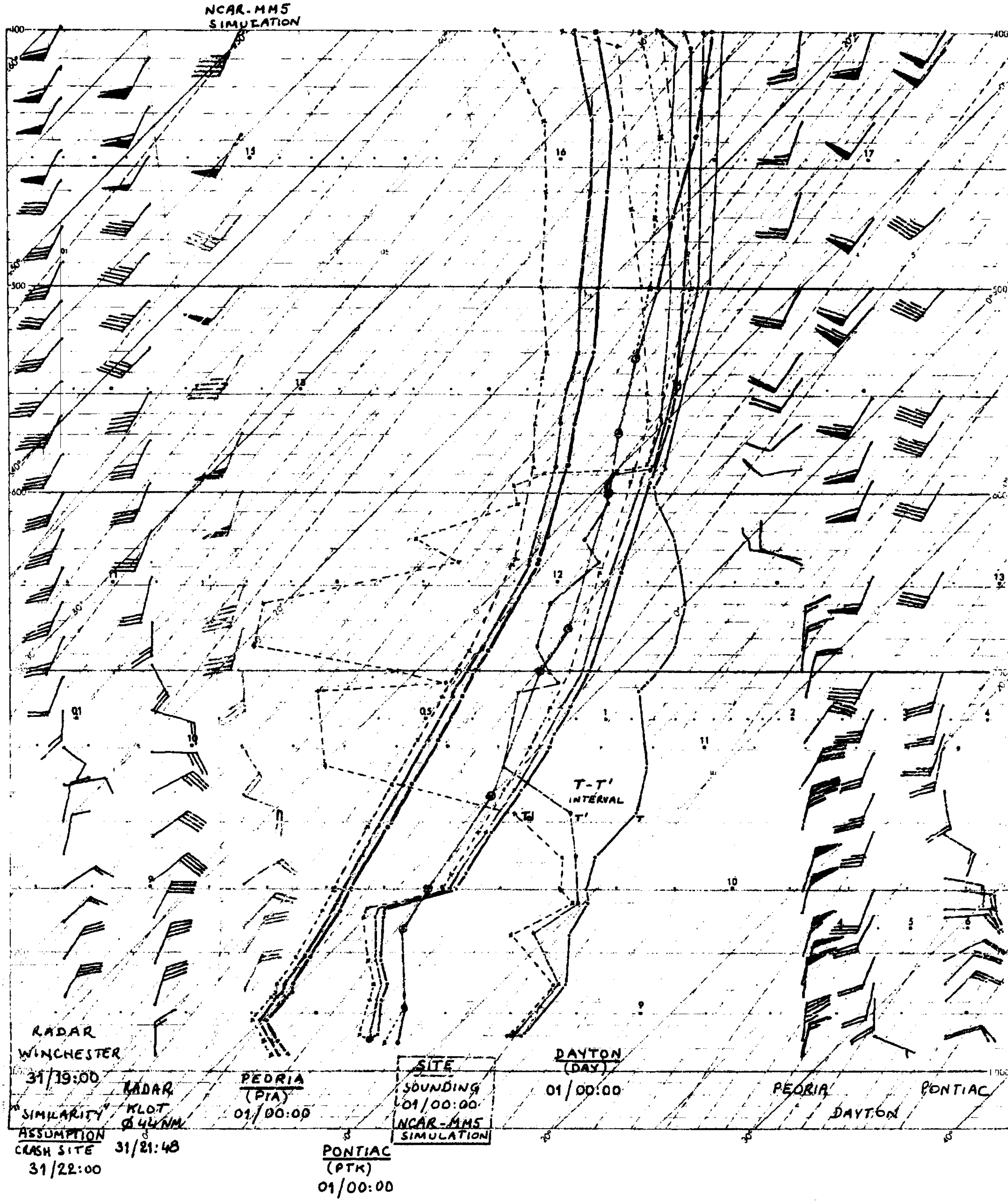

31/10/94
21.00 Z
1016
1014
1012
1010
1008
1006
1004
1002
1000
999

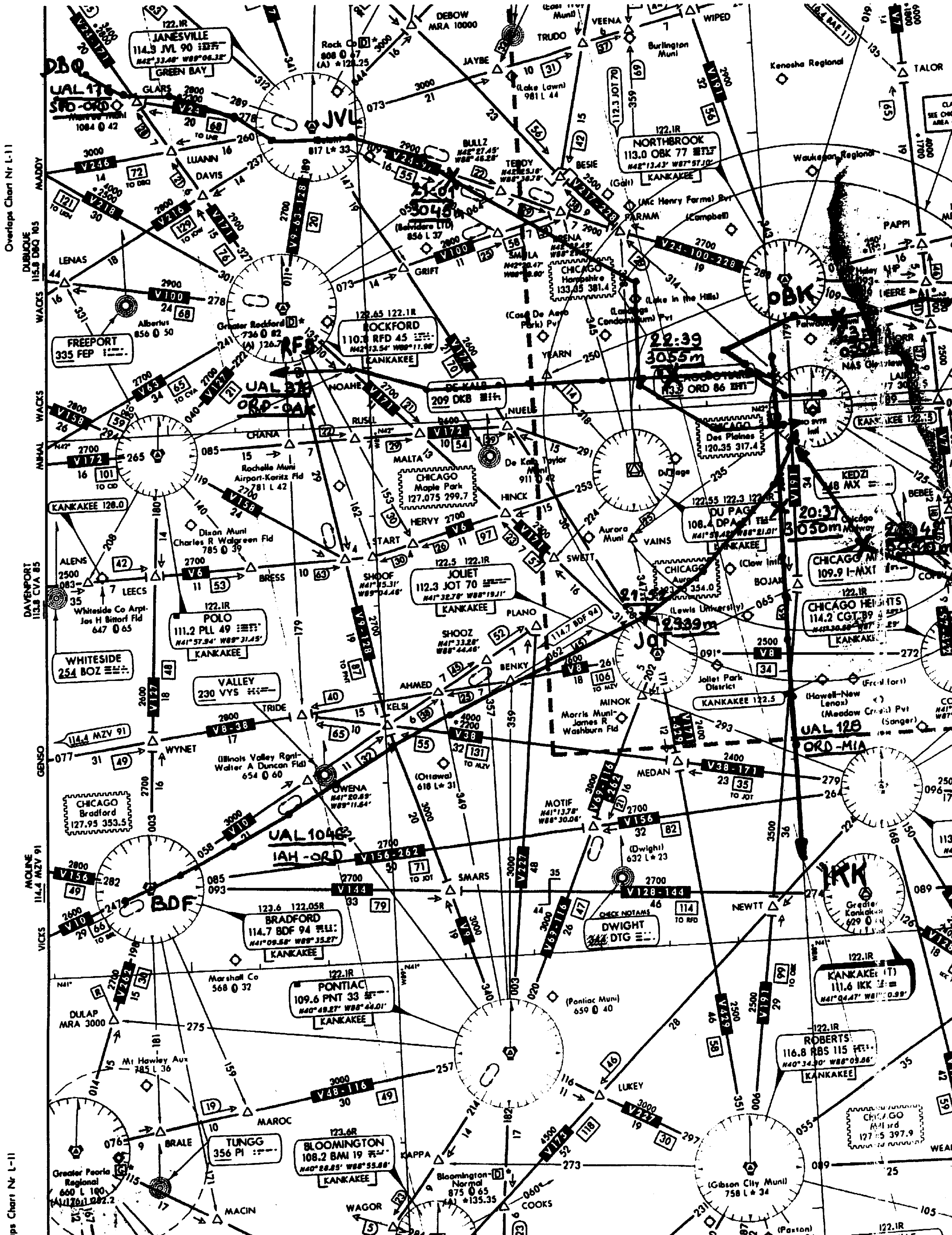
3.3


31/10/94
22Z sfc
H
LUCIT
998
1000
1002
1004
1006
1008
1010
1012

APPENDIX 4


NCAR-MM5
SIMULATION
T-T'
INTERVAL
T'
T
RADAR
WINCHESTER
31/19:00
"SIMILARITY"
ASSUMPTION
CRASH SITE
31/22:00
RADAR
KLOT
Ø44NM
31/21:48
PEDRIA
(PIA)
01/00:00
PONTIAC
(PTK)
01/00:00
SITE
SOUNDING
01/00:00
NCAR-MM5
SIMULATION
DAYTON
(DAY)
01/00:00
PEORIA
DAYTON
PONTIAC

APPENDIX 5 -I



Overlaps Chart Nr L-11
JANESVILLE
114.3 JVL 90
GREEN BAY
DBQ
UAL 178
SFO-ORD
JVL
ROCKFORD
110.8 RFD 45
KANKAKEE
FREEPORT
335 FEP
DE KALB
209 DKB
UAL 378
ORD-OAK
RFD
NORTHBROOK
113.0 OBK 77
OBK
CHICAGO
Des Plaines
120.35 317.4
DU PAGE
JOLIET
112.3 JOT 70
JOT
CHICAGO HEIGHTS
114.2 CGT
POLO
111.2 PLL 49
WHITESIDE
254 BOZ
VALLEY
230 VYS
KANKAKEE 128.0
CHICAGO
Maple Park
127.075 299.7
CHICAGO
Bradford
127.95 353.5
UAL 1046
IAH-ORD
BRADFORD
114.7 BDF 94
BDF
PONTIAC
109.6 PNT 33
DWIGHT
DTG
UAL 128
ORD-MIA
IKK
KANKAKEE
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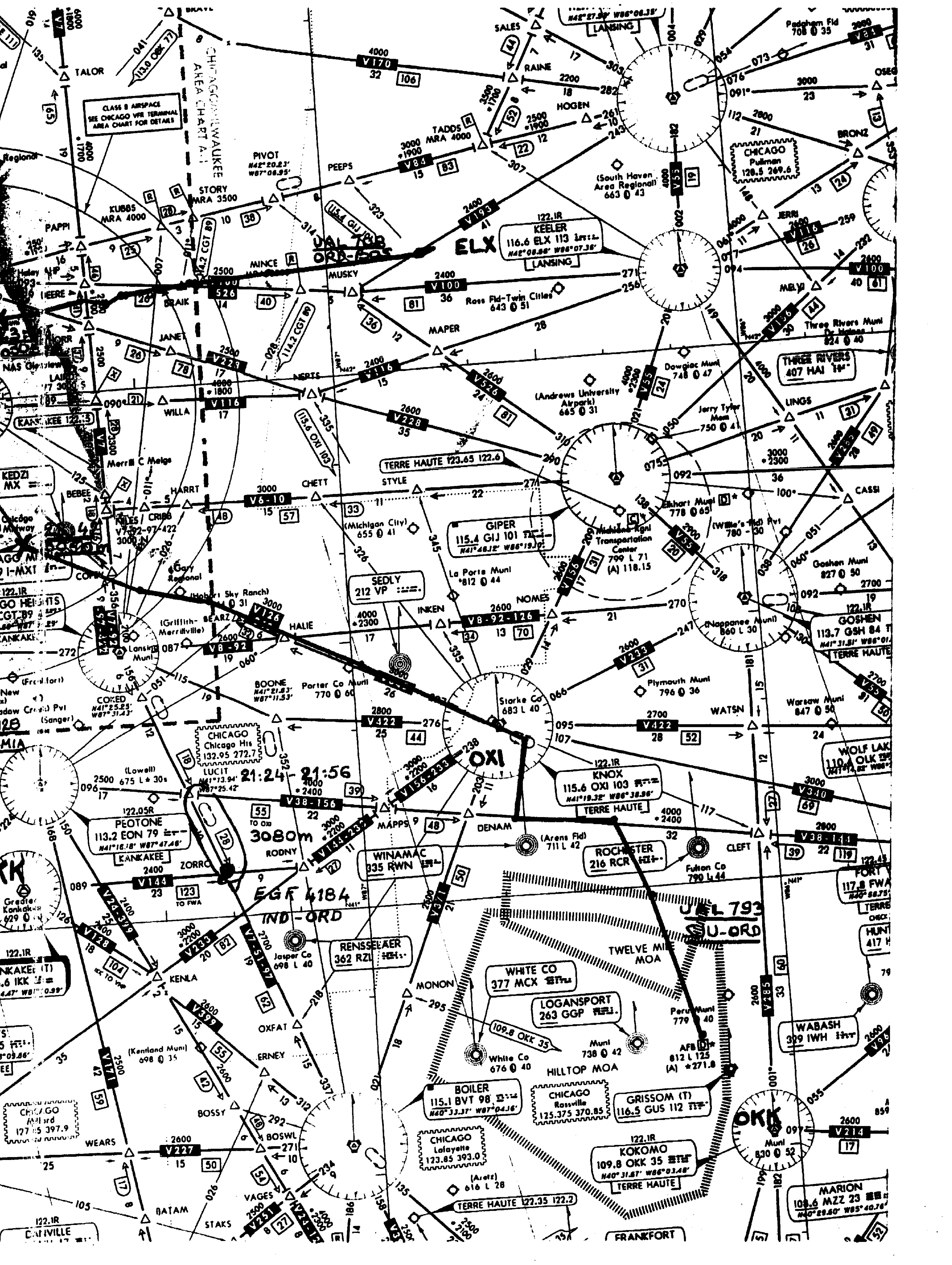
BLOOMINGTON
108.2 BMI 19
Overlaps Chart Nr L-11

APPENDIX 5-2



CHICAGO/MILWAUKEE AREA CHART A-1
CLASS B AIRSPACE SEE CHICAGO VFR TERMINAL AREA CHART FOR DETAILS
TALOR
SALES
RAINE
HOGEN
TADDS MRA 4000
PIVOT
PEEPS
STORY MRA 3500
KUBBS MRA 4000
PAPPI
MINCE
MUSKY
UAL 708 ORD-BOS
KEELER 116.6 ELX 113
LANSING
ELX
Ross Fld-Twin Cities 643 51
MAPER
(South Haven Area Regional) 663 43
CHICAGO Pullman 128.5 269.6
JERRI
BRONZ
MELVI
Three Rivers Muni
THREE RIVERS 407 HAI
Dowagiac Muni 748 47
(Andrews University Airpark) 665 31
Jerry Tyler Mem 750 41
LINGS
CASSI
JANET
NERTS
WILLA
KANKAKEE 122.3
Merrill C Meigs
KEDZI
HARRT
CHETT
STYLE
TERRE HAUTE 123.65 122.6
BEBEE
NILES / CRIBB
(Michigan City) 655 41
GIPER 115.4 GIJ 101
Elkhart Muni 778 63
Michiana Rgnl Transportation Center 799 L 71 (A) 118.15
(Willie's Fld) Pvt 780 30
Goshen Muni 827 50
GOSHEN 113.7 GSH 84
TERRE HAUTE
SEDLY 212 VP
La Porte Muni 812 44
Gary Regional
(Hobart Sky Ranch)
BEARZ
HALIE
INKEN
NOMES
(Nappanee Muni) 860 L 30
(Griffith-Merrillville)
Lansing Muni
(Frankfort)
BOONE
Porter Co Muni 770 60
Plymouth Muni 796 36
Starke Co 683 L 40
WATSN
Warsaw Muni 847 50
WOLF LAKE 110.4 OLK
CHICAGO Chicago Hts 132.95 272.7
LUCIT
21:24 - 21:56
OXI
KNOX 115.6 OXI 103
TERRE HAUTE
(Lowell) 2500 675 L 30s
PEOTONE 113.2 EON 79
KANKAKEE
3080m
RODNY
MAPPS
DENAM
(Arens Fld) 711 L 42
ROCHESTER 216 RCR
Fulton Co 790 L 44
CLEFT
FORT 117.8 FWA
ZORRO
WINAMAC 335 RWN
EGF 4184 IND-ORD
UAL 793 SDU-ORD
Greater Kankakee 629
RENSSELAER 362 RZL
Jasper Co 698 L 40
TWELVE MILE MOA
KENLA
WHITE CO 377 MCX
MONON
LOGANSPORT 263 GGP
Peru Muni 779 40
WABASH 339 IWH
OXFAT
109.8 OKK 35
(Kentland Muni) 698 35
ERNEY
White Co 676 40
Muni 738 42
HILLTOP MOA
AFB 812 L 125 (A) 271.8
BOILER 115.1 BVT 98
CHICAGO Rossville 125.375 370.85
GRISSOM (T) 116.5 GUS 112
OKK
CHICAGO Milford 127.35 397.9
BOSSY
BOSWL
CHICAGO Lafayette 123.85 393.0
KOKOMO 109.8 OKK 35
TERRE HAUTE
Muni 830 52
WEARS
(Aretz) 616 L 28
VAGES
BATAM
STAKS
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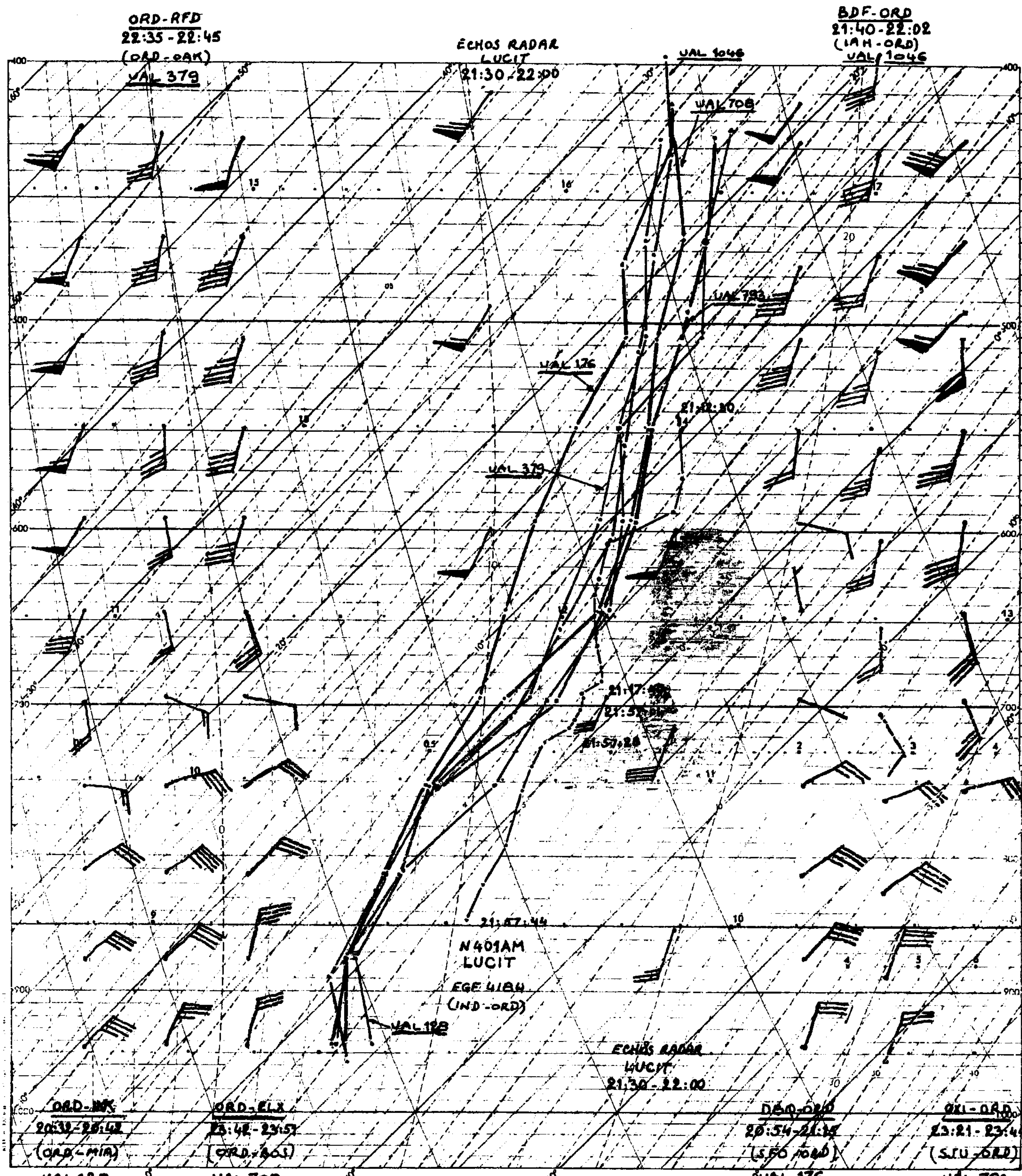
MARION 108.6 MZZ 23
DANVILLE
FRANKFORT

APPENDIX 6



ORD-RFD
22:35-22:45
(ORD-OAK)
UAL 379
ECHOS RADAR
LUCIT
21:30-22:00
UAL 1046
BDF-ORD
21:40-22:02
(IAH-ORD)
UAL 1046
UAL 708
UAL 793
UAL 176
UAL 379
21:57:44
N401AM
LUCIT
EGF 4184
(IND-ORD)
UAL 128
ECHOS RADAR
LUCIT
21:30-22:00
(ORD-MIA)
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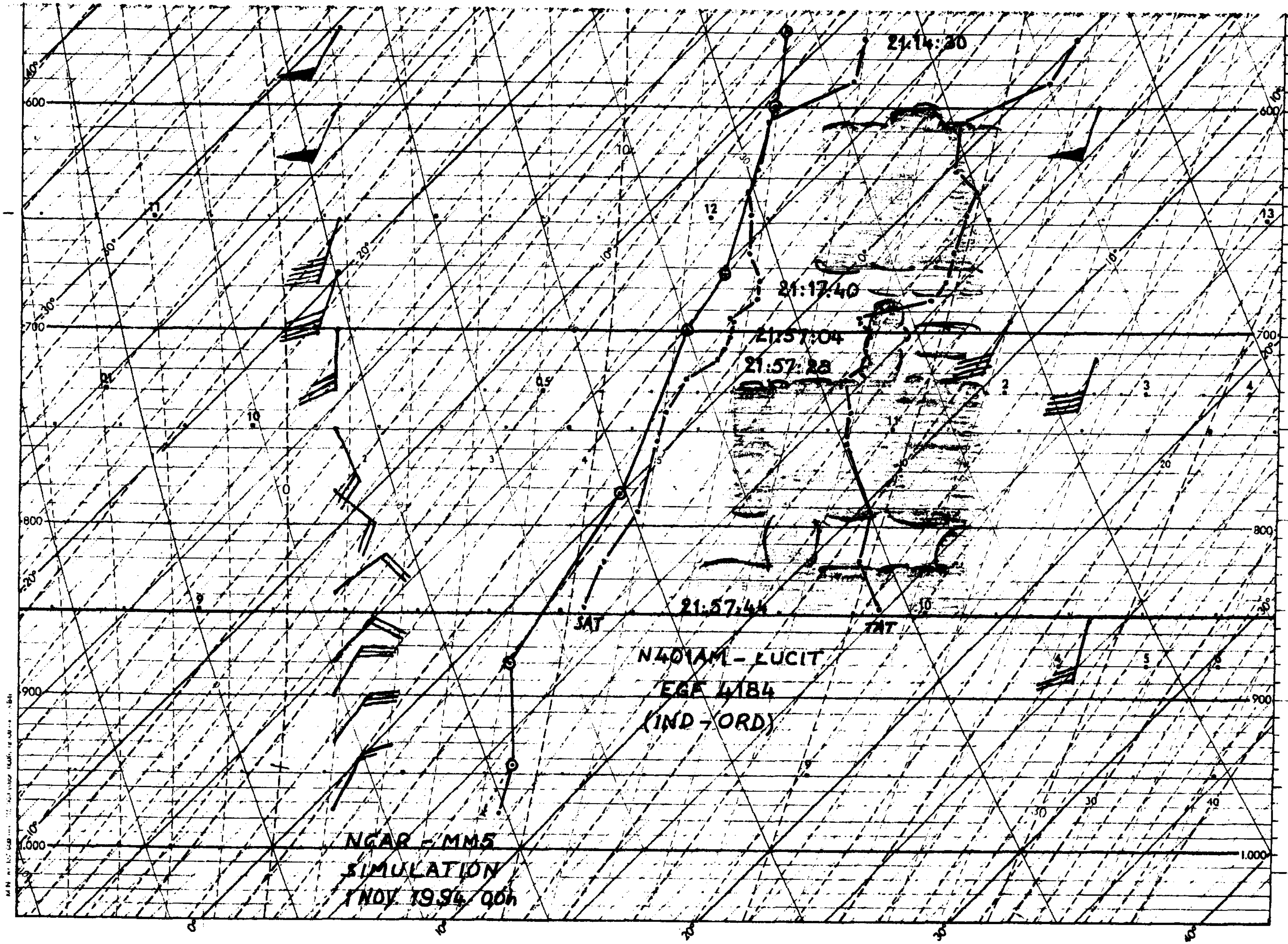
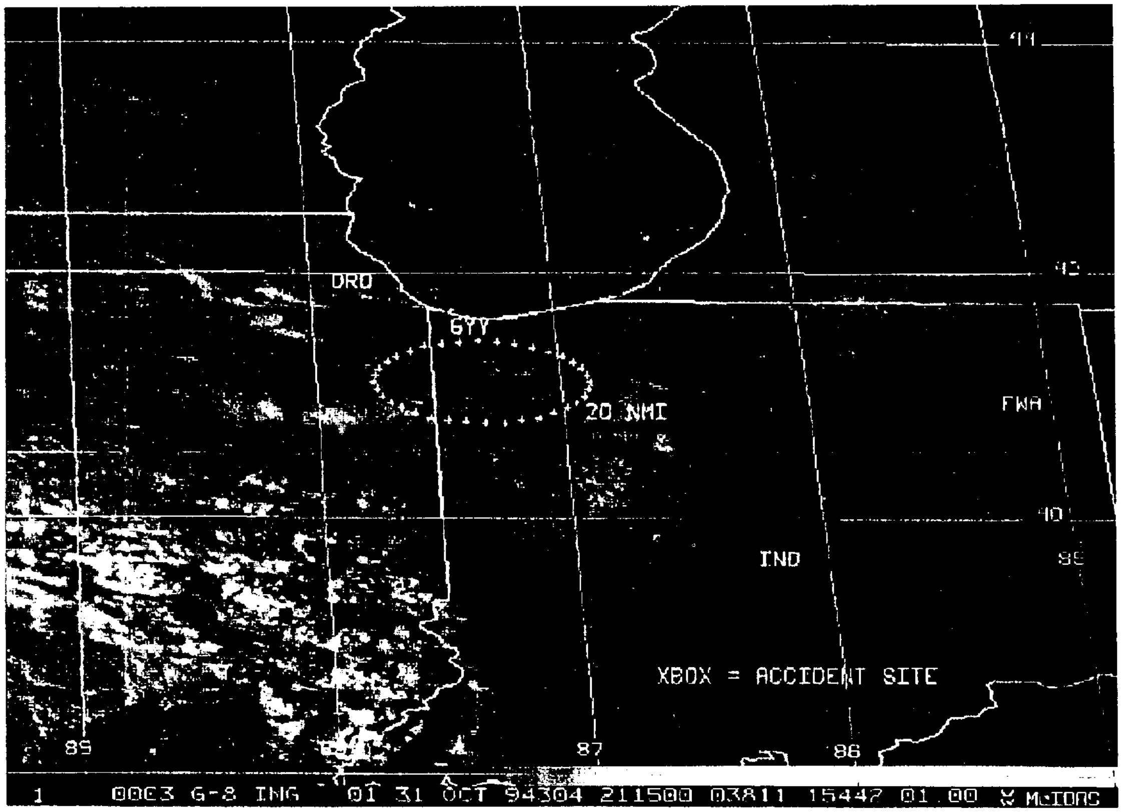
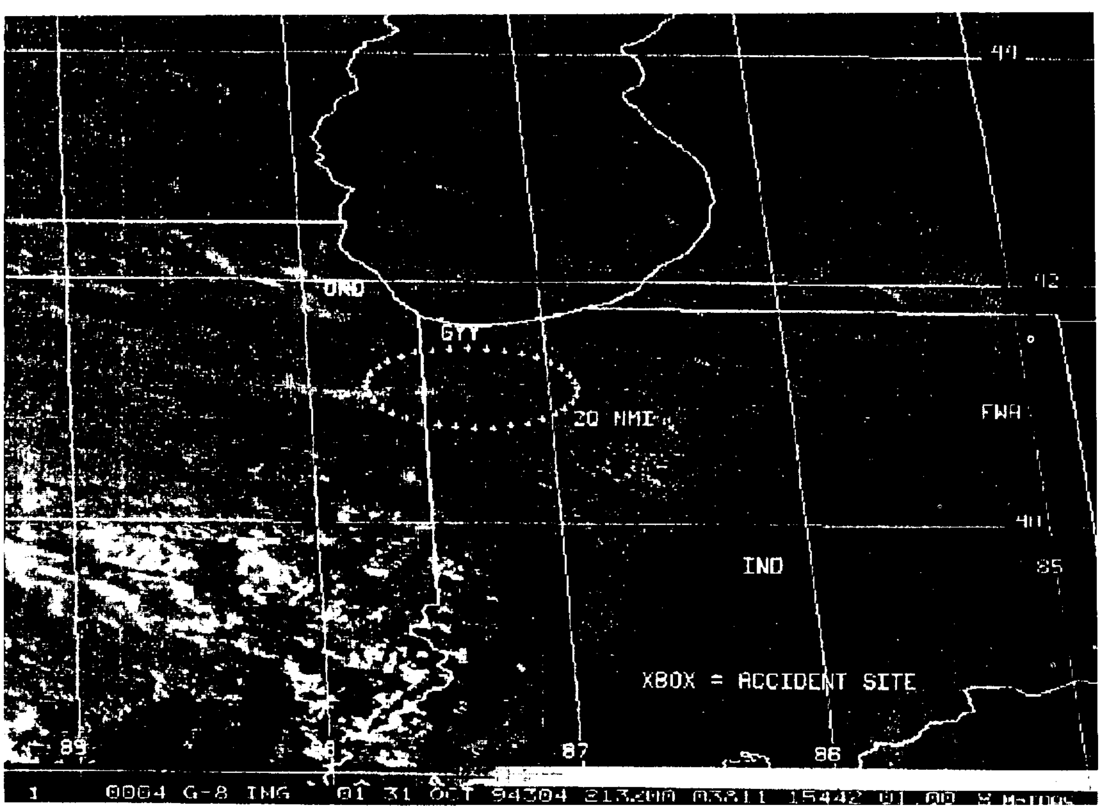
UAL 708
UAL 176
OXI-ORD
23:21-23:44
(SJU-ORD)
UAL 793

APPENDIX 7


21:14:30
21:17:40
21:57:04
21:57:28
21:57:44
SAT
TAT
N401AM - LUCIT
EGF 4184
(IND - ORD)
NCAR - MM5
SIMULATION
1 NOV 1994 00h
600
700
800
900
1,000
0°
10°
20°
30°
40°

APPENDIX 8


44
ORD
42
GYY
20 NMI
FWA
40
IND
85
XBOX = ACCIDENT SITE
89
87
86
1 0063 G-8 IMG 01 31 OCT 94304 211500 03811 15442 01.00 McIDAS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ORD
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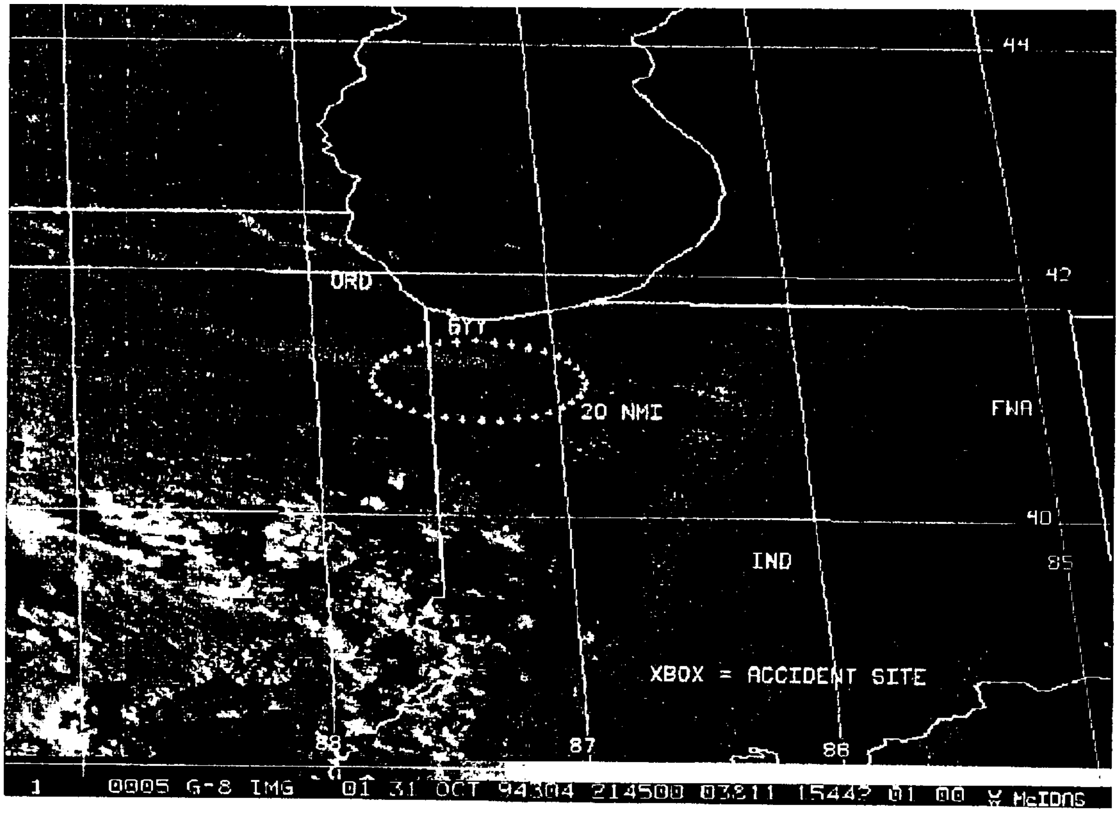
44
42
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85
ORD
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87
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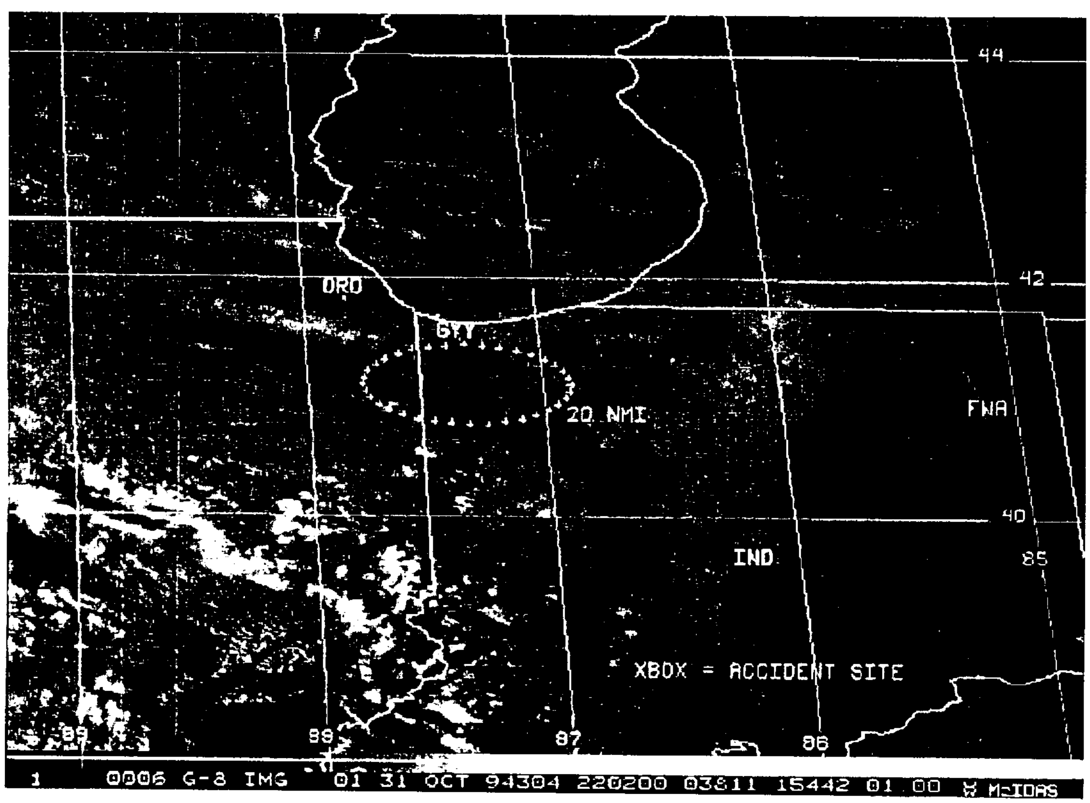
44
42
40
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ORD
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20 NMI
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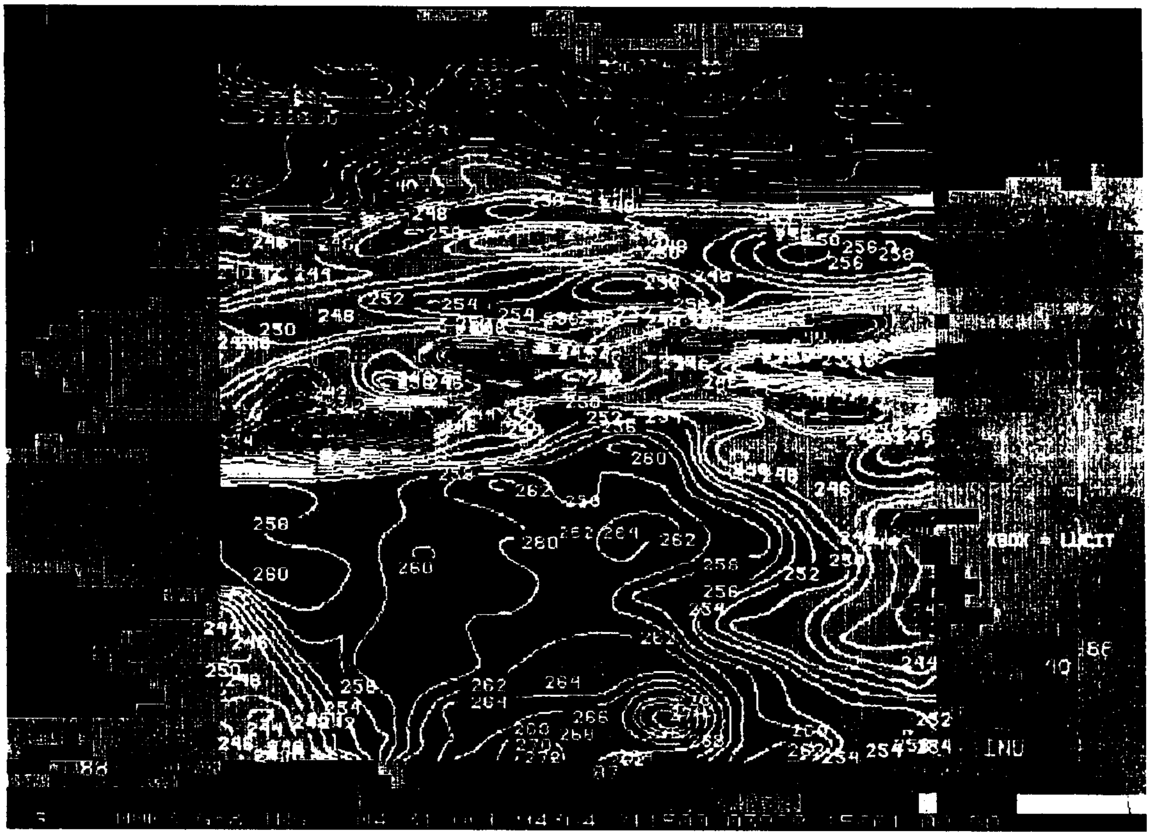
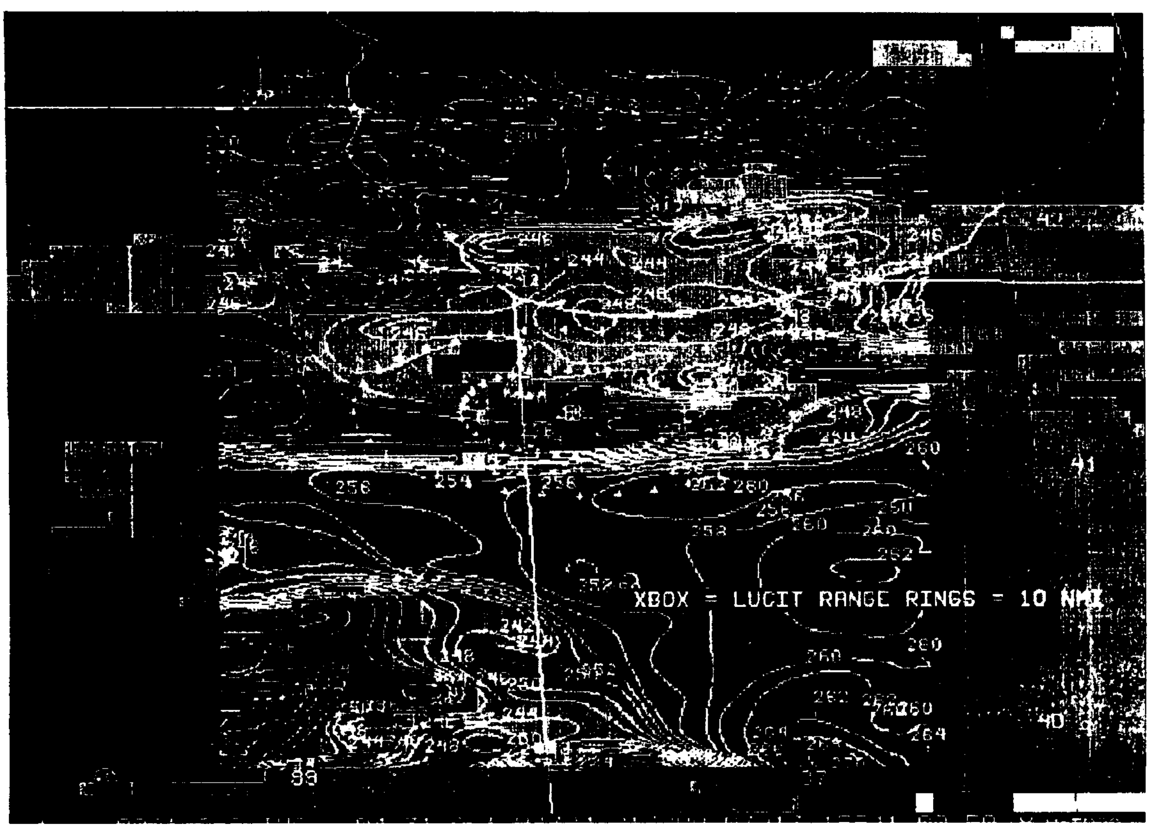
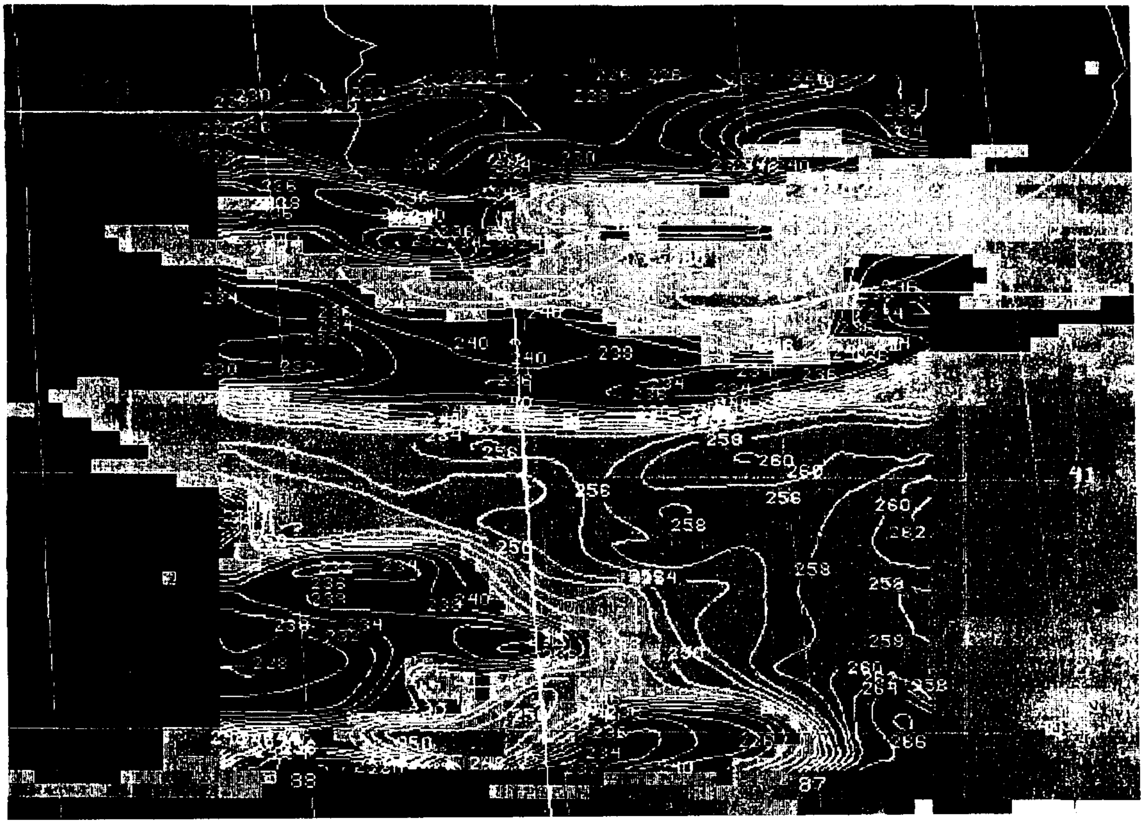
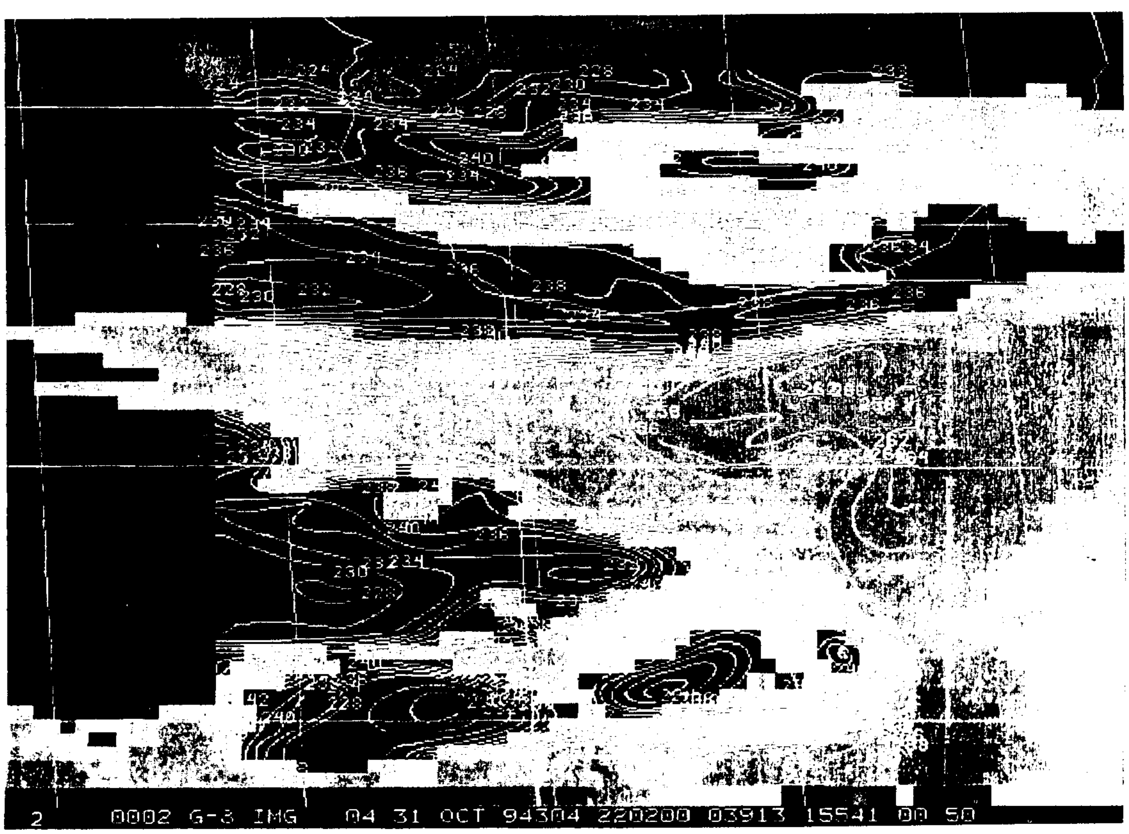
APPENDIX 9

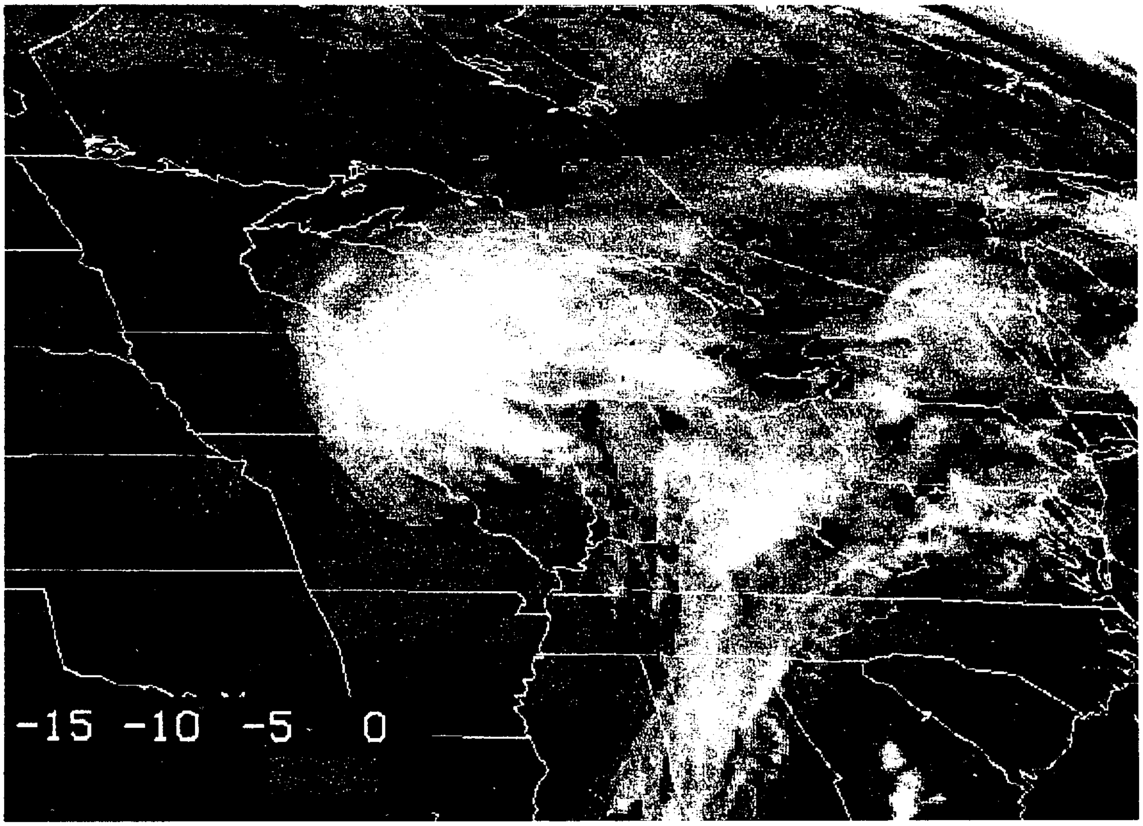


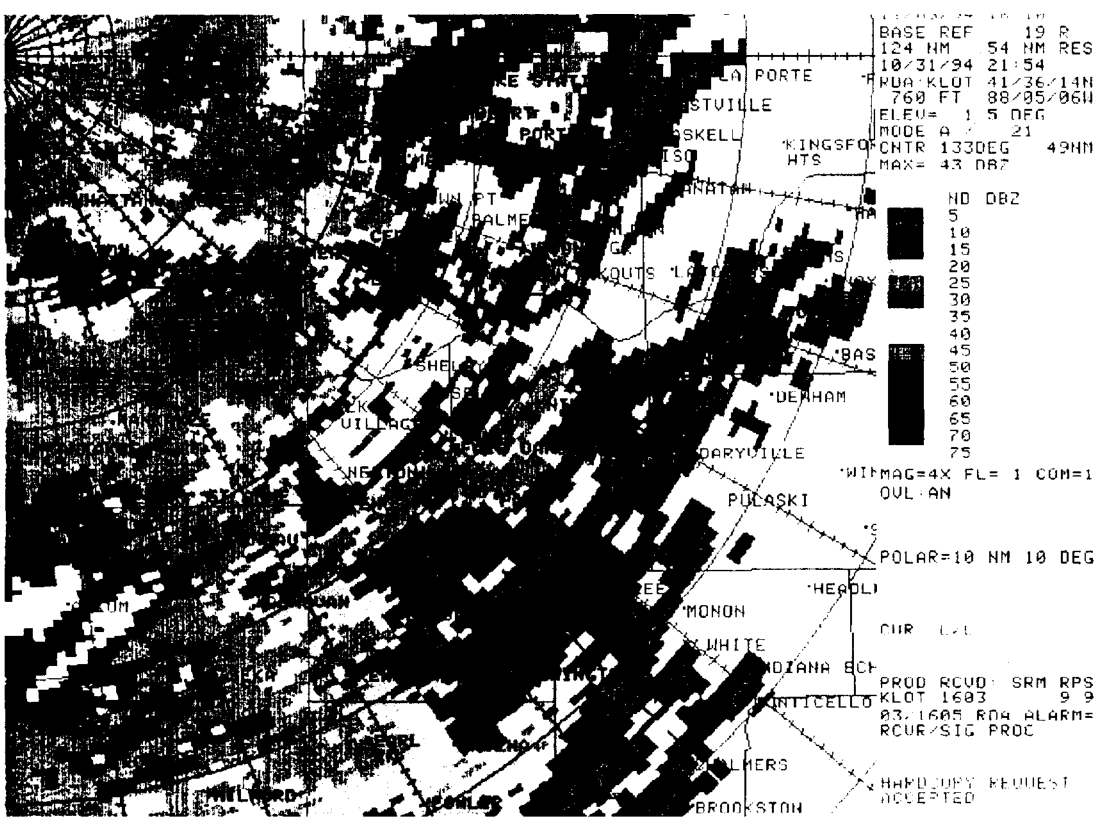




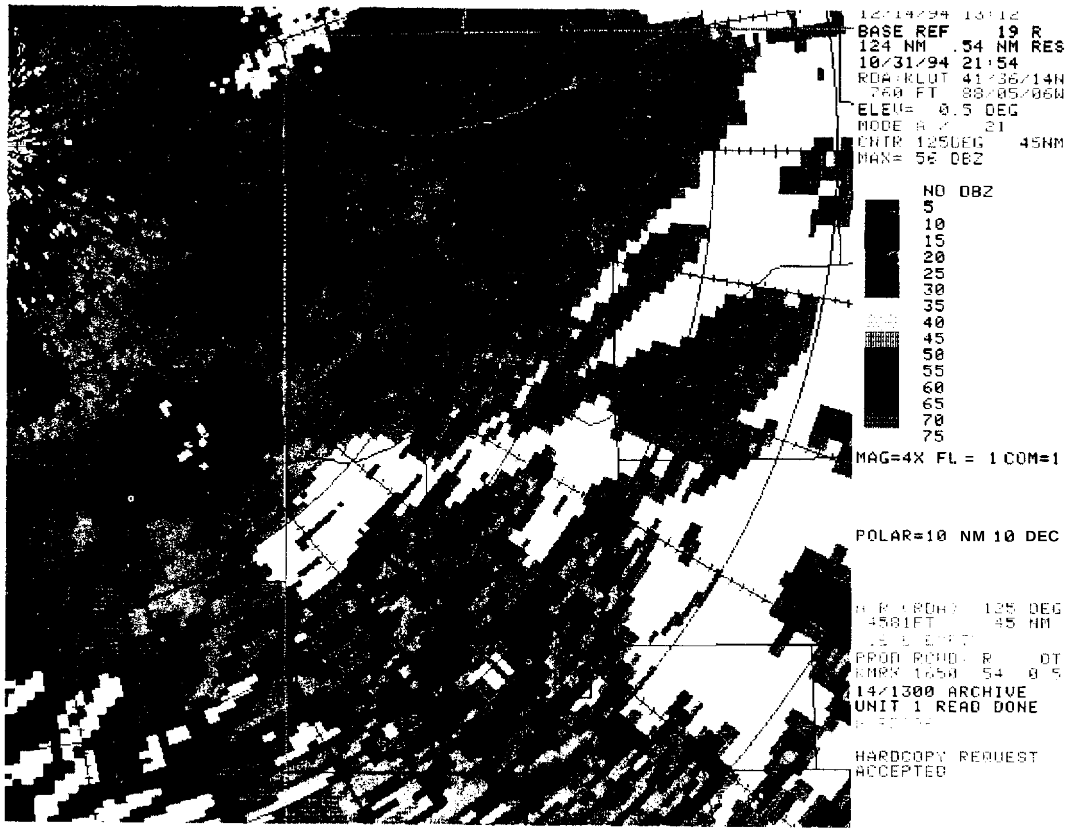

2 0002 G-8 IMG 04 31 OCT 94304 220200 03913 15541 00 50

APPENDIX 10

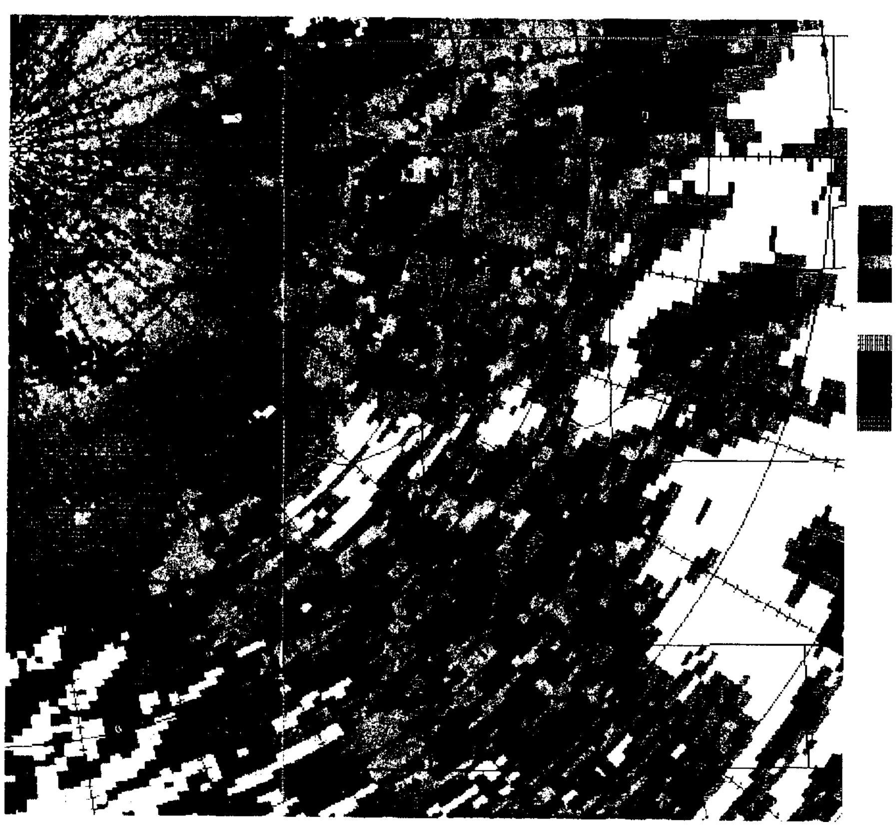

-15 -10 -5 0


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 133DEG 49NM
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
OVL:AN
POLAR=10 NM 10 DEG
PROD RCVD: SRM RPS
KLOT 1603 9 9
03/1605 RDA ALARM=
RCVR/SIG PROC
LA PORTE
KINGSFO
HTS
DENHAM
PULASKI
MONON
WHITE
MONTICELLO
BROOKSTON

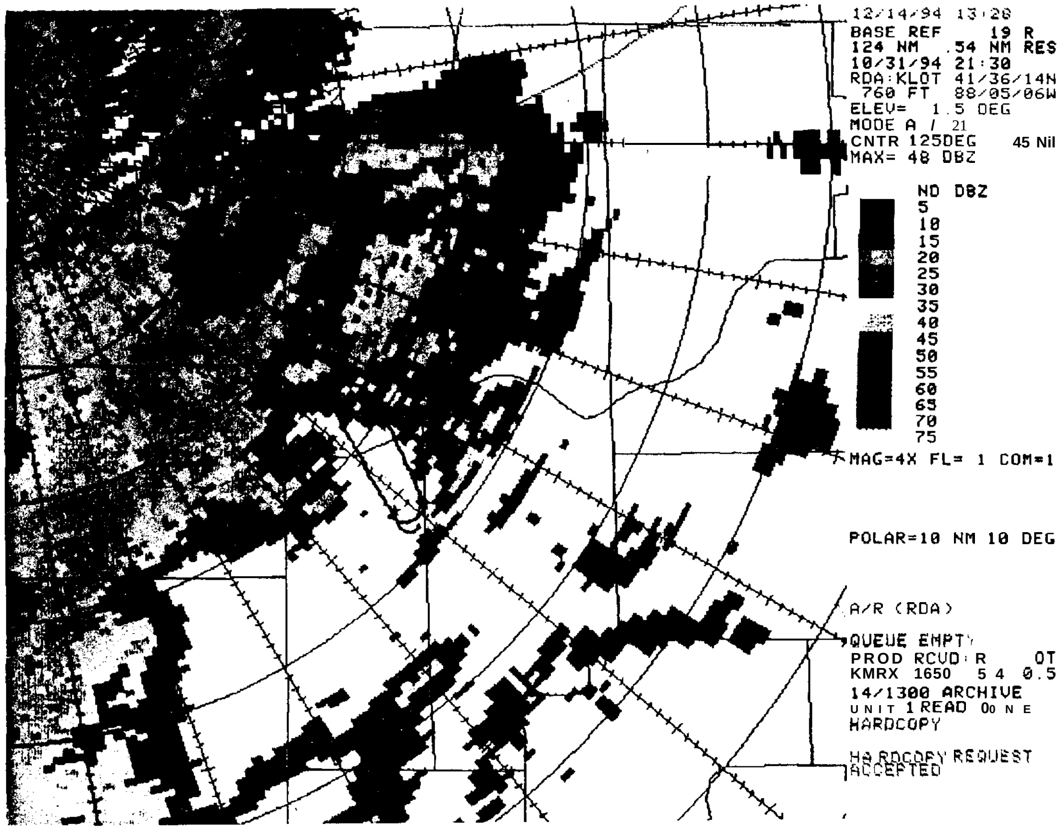
APPENDIX 11

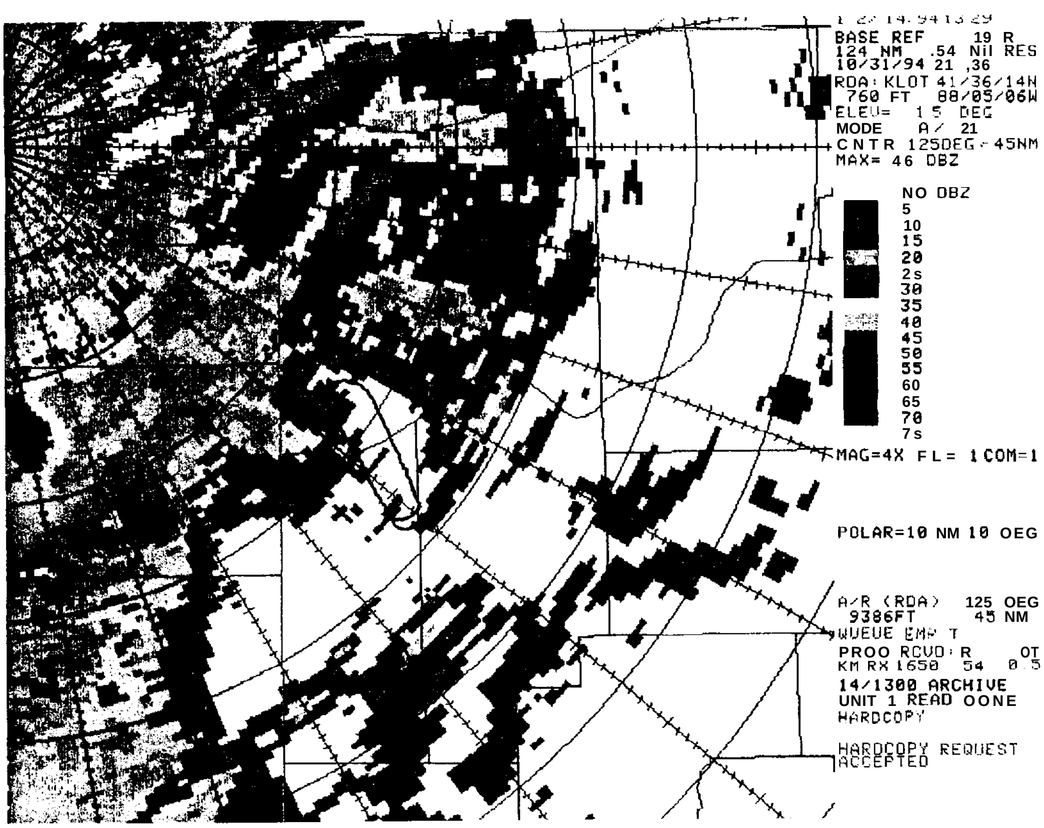


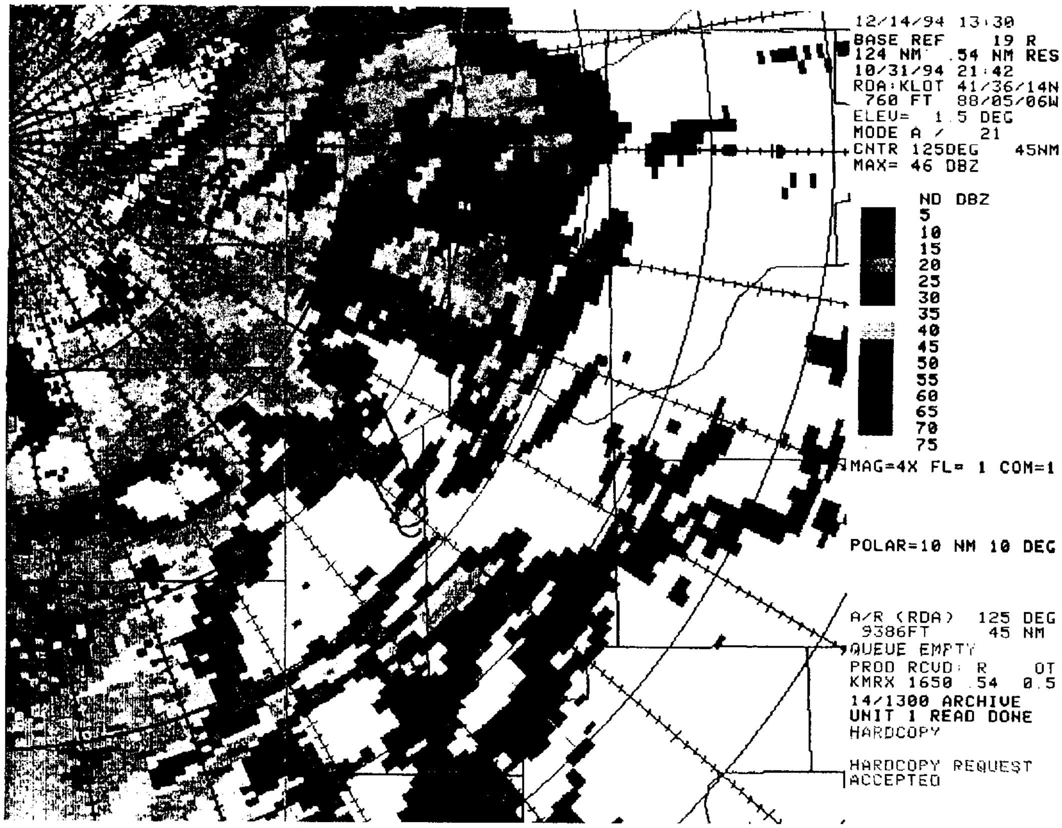
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:54
RDA:KLUT 41/36/14N
760 FT 88/05/06W
ELEV= 0.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 56 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL = 1 COM=1
POLAR=10 NM 10 DEC
125 DEG
4581FT 45 NM
PROD RCVD: R DT
KMRX 1650 54 0 5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

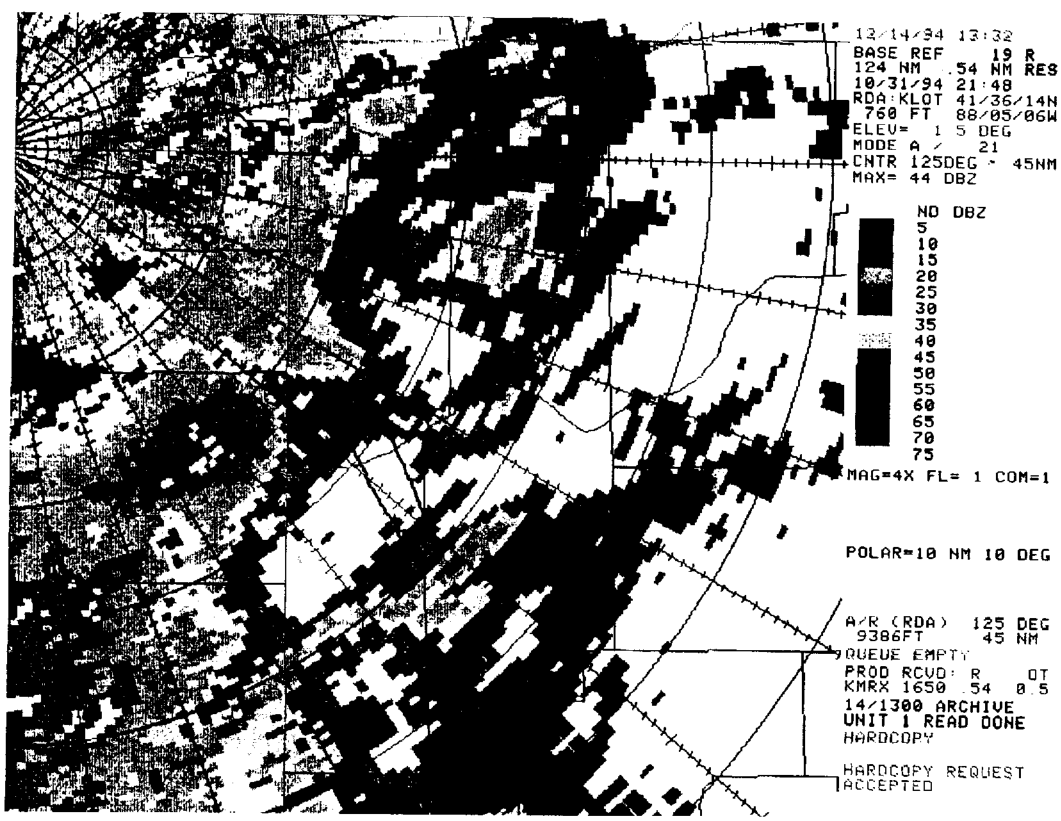


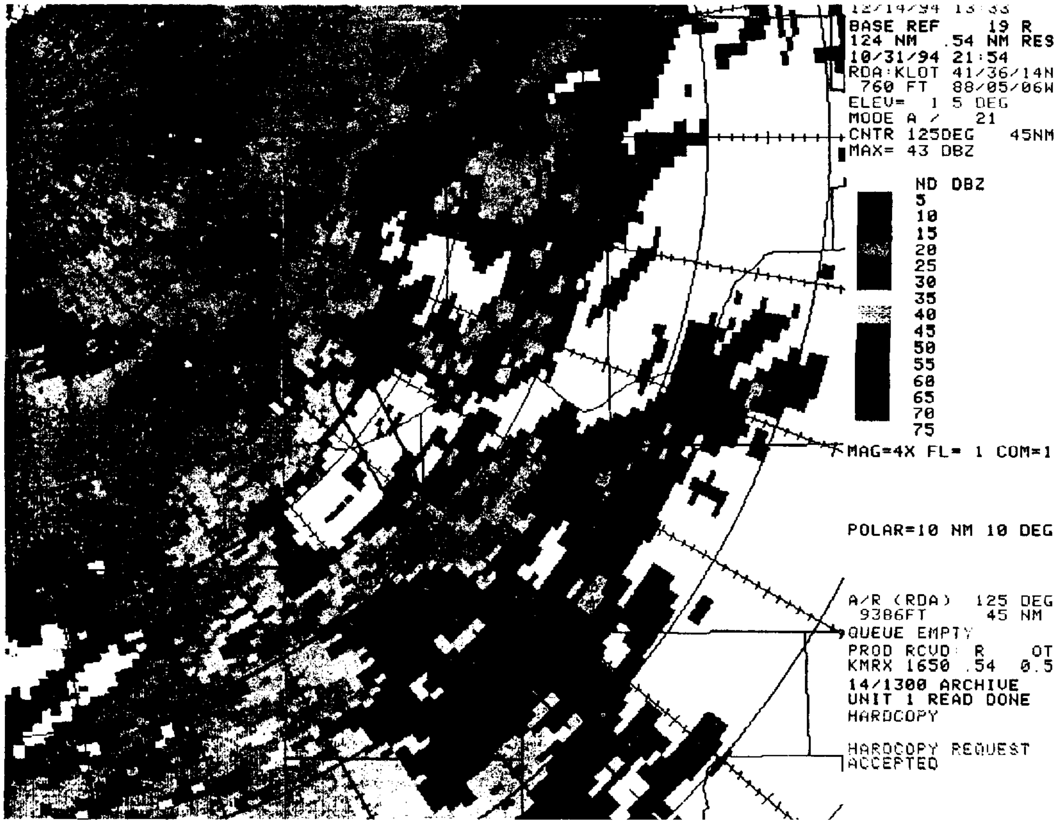
APPENDIX 12


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 45 Nil
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 5 4 0.5
14/1300 ARCHIVE
UNIT 1 READ 00 N E
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

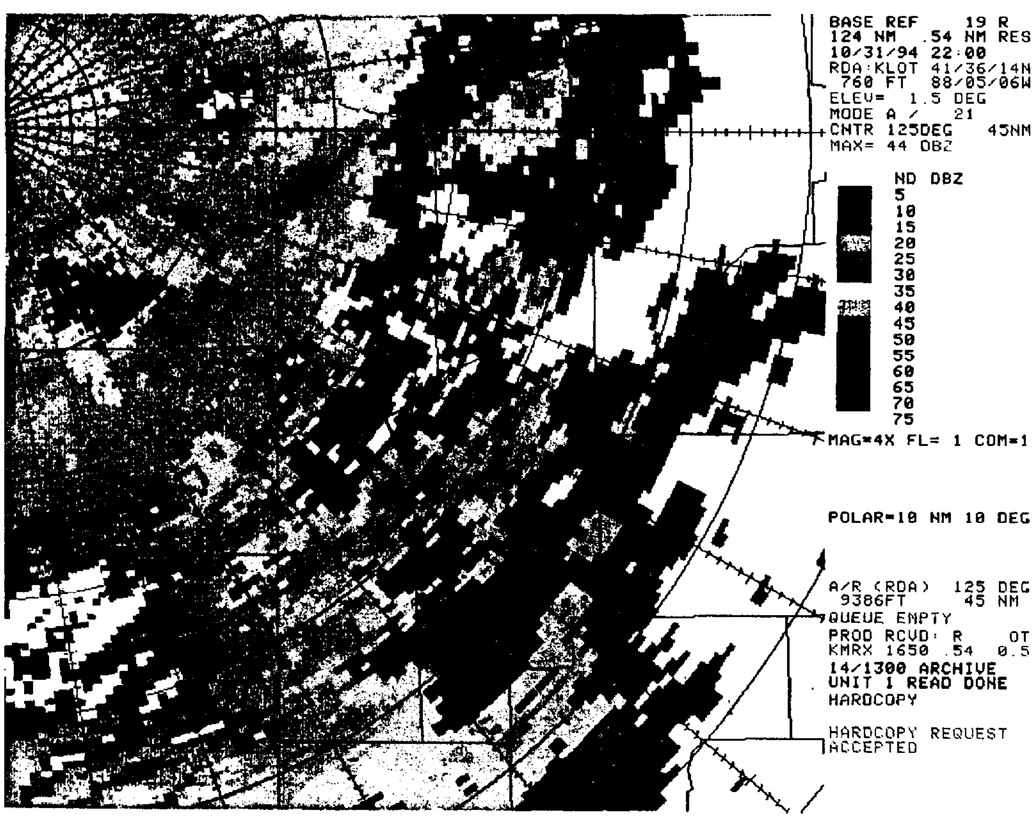

BASE REF 19 R
124 NM .54 Nil RES
10/31/94 21 ,36
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A/ 21
CNTR 125DEG-45NM
MAX= 46 DBZ
NO DBZ
5
10
15
20
2s
30
35
40
45
50
55
60
65
70
7s
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 OEG
A/R (RDA) 125 OEG
9386FT 45 NM
WUEUE EMP T
PROO RCVD:R OT
KM RX 1650 54 0 5
14/1300 ARCHIVE
UNIT 1 READ OONE
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

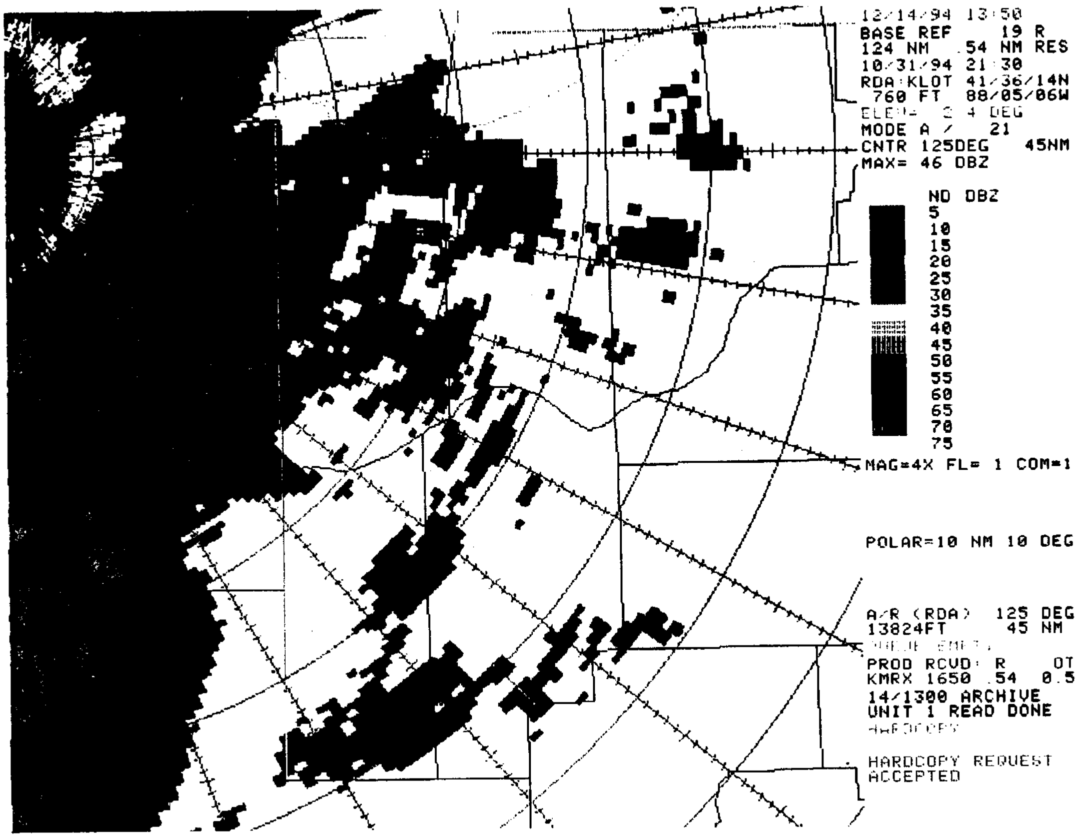

12/14/94 13:32
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:48
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 44 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

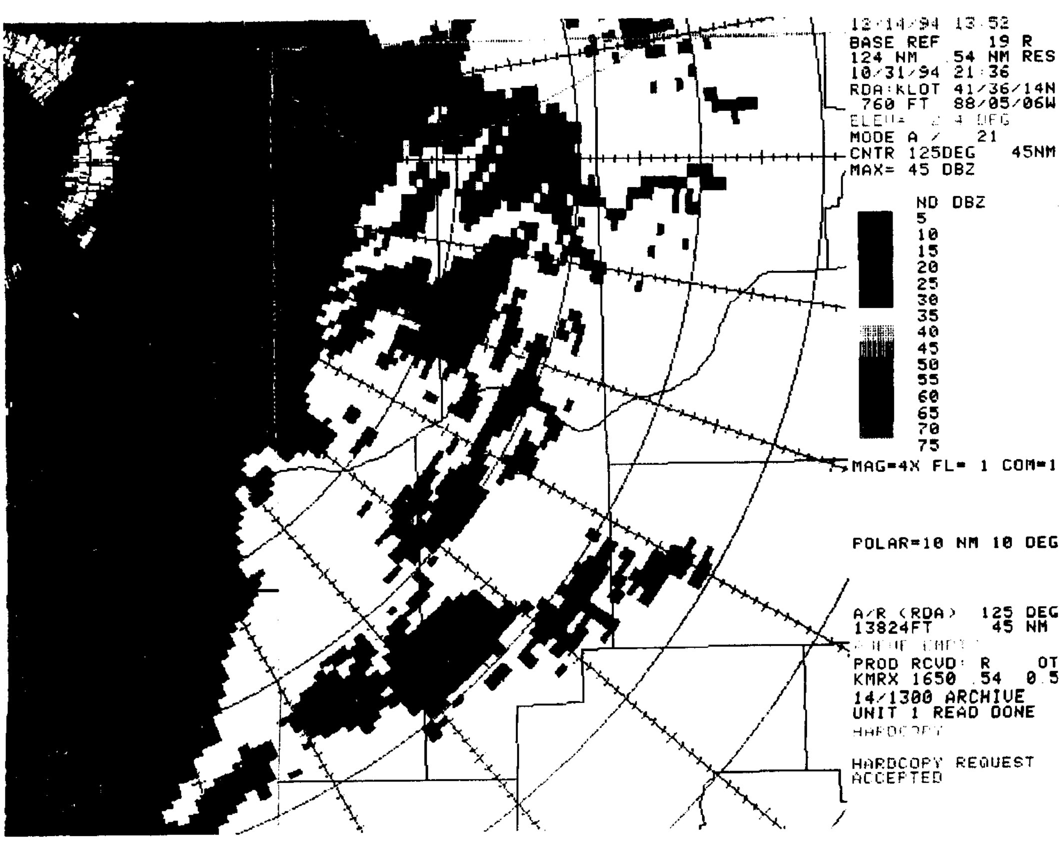


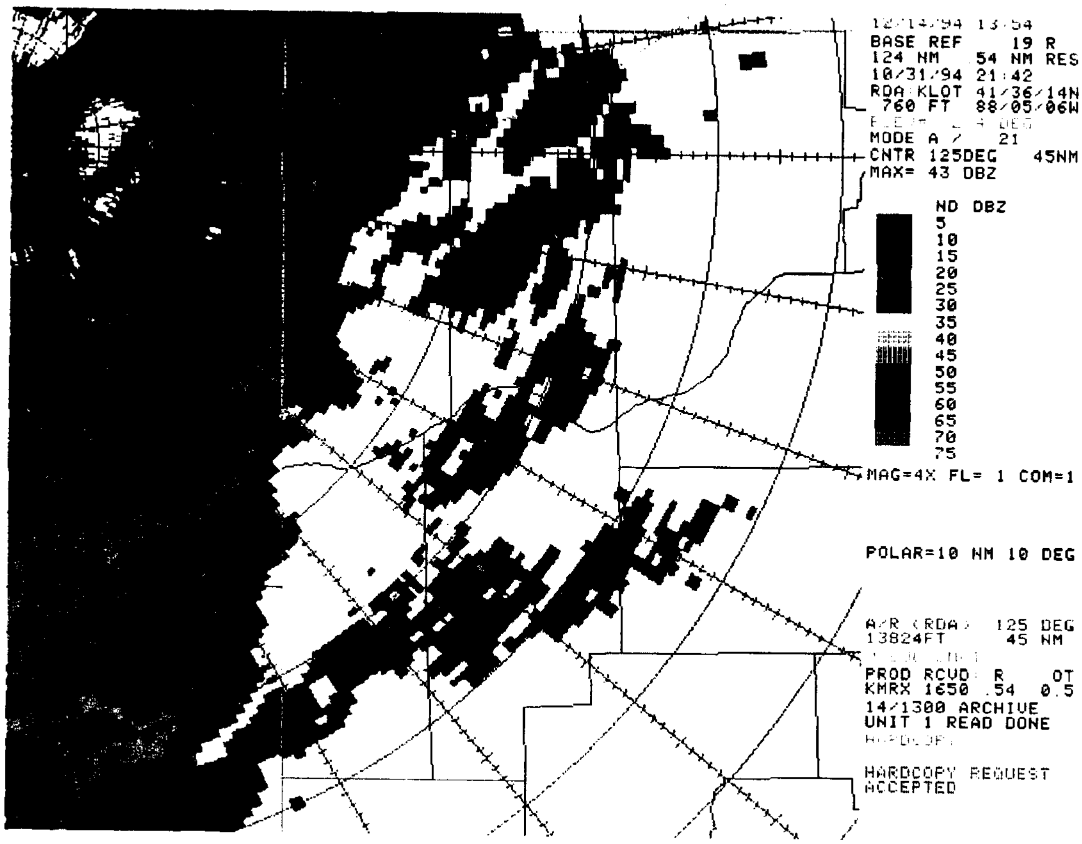
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:54
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 43 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

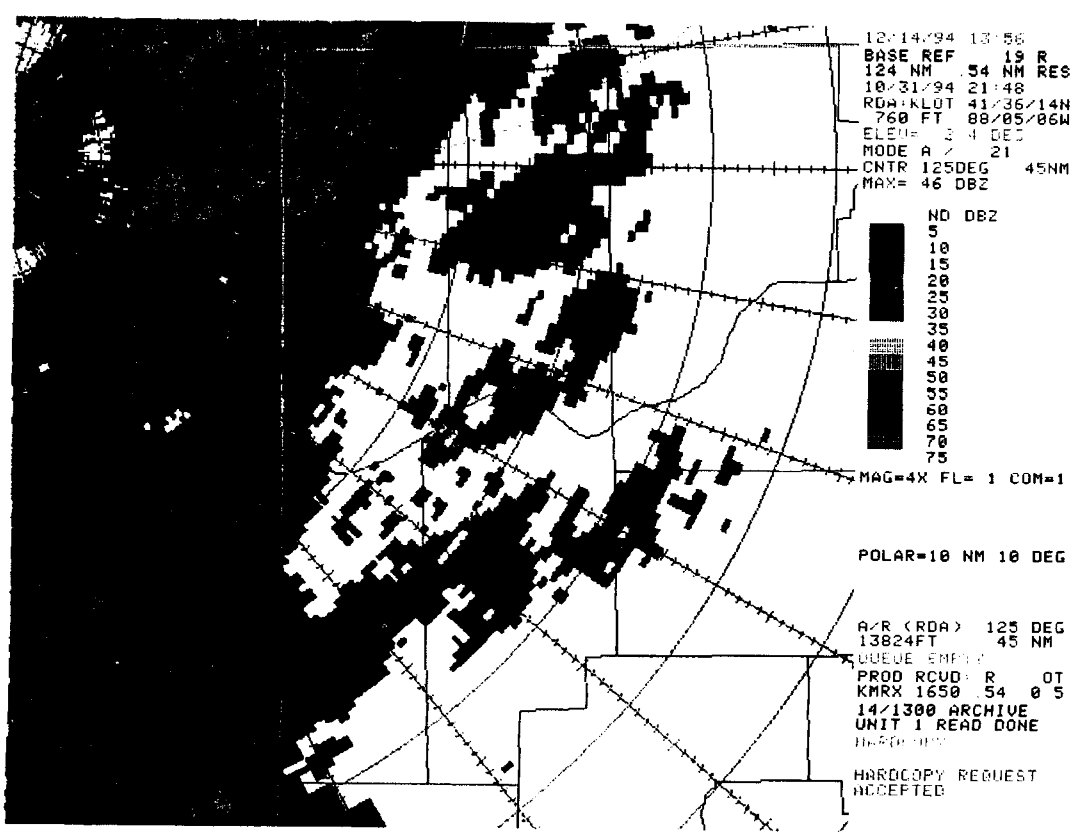


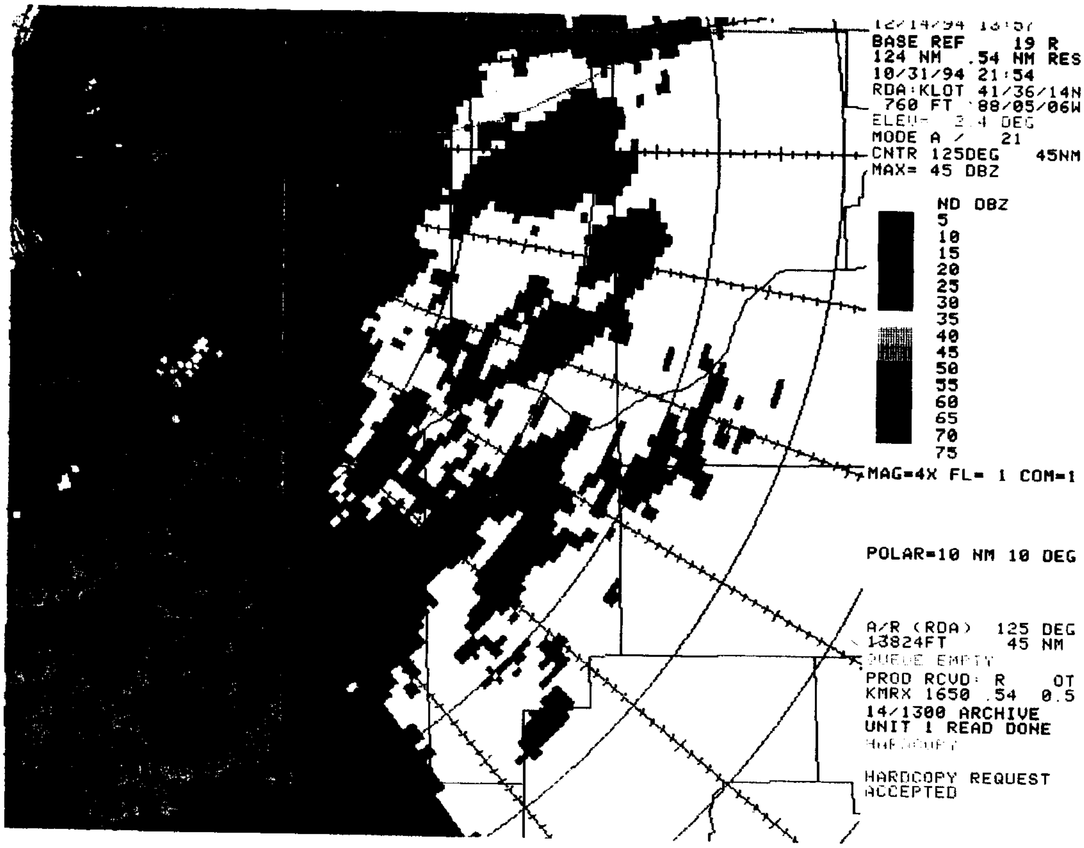
BASE REF 19 R
124 NM .54 NM RES
10/31/94 22:00
RDA:KLOT 41/36/14N
760 FT 88/05/06W
ELEV= 1.5 DEG
MODE A / 21
CNTR 125DEG 45NM
MAX= 44 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
9386FT 45 NM
QUEUE EMPTY
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY
HARDCOPY REQUEST
ACCEPTED

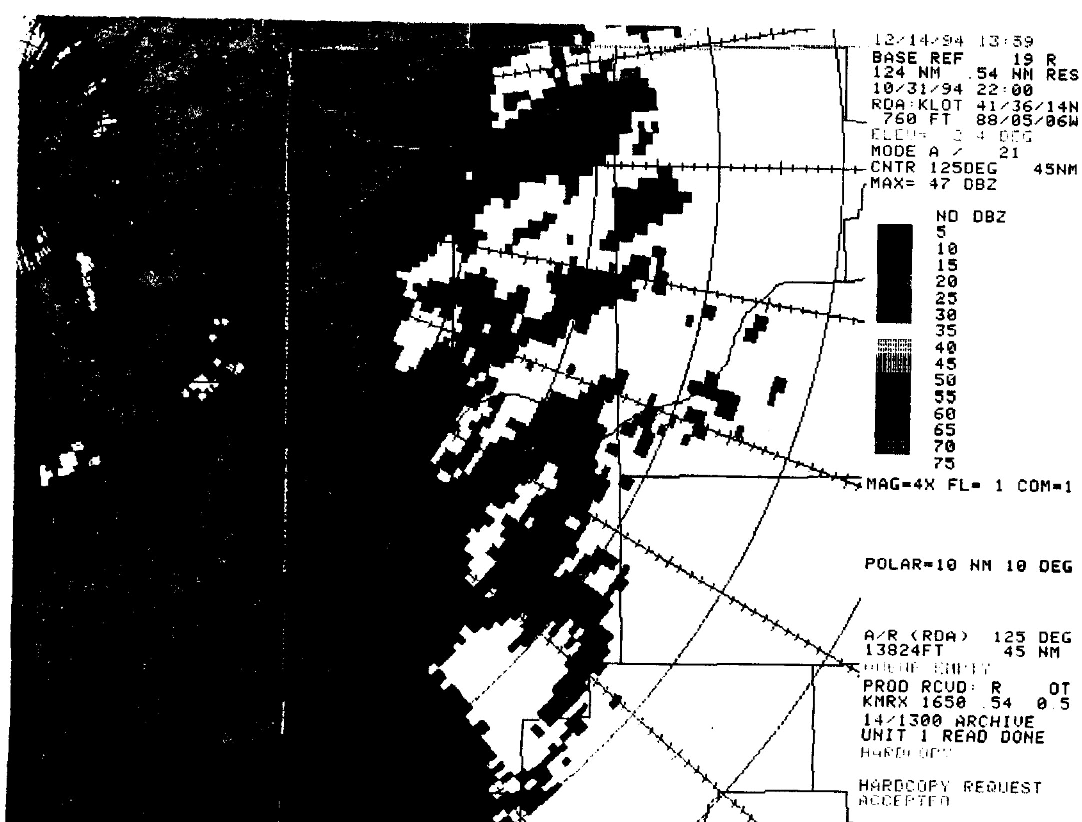

12/14/94 13:50
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:30
RDA:KLOT 41/36/14N
760 FT 88/05/06W
MODE A / 21
CNTR 125DEG 45NM
MAX= 46 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED


12/14/94 13:52
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:36
RDA:KLOT 41/36/14N
760 FT 88/05/06W
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
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

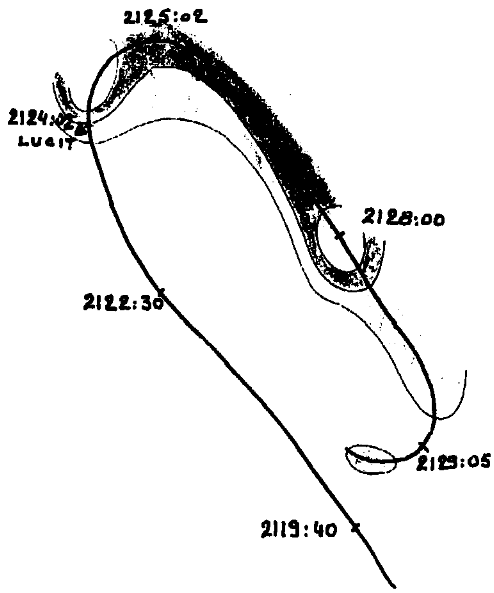

12/14/94 13:54
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:42
RDA:KLOT 41/36/14N
760 FT 88/05/06W
MODE A / 21
CNTR 125DEG 45NM
MAX= 43 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

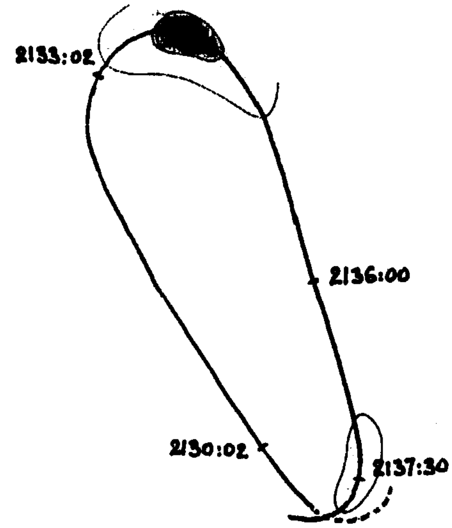

12/14/94 13:56
BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:48
RDA:KLOT 41/36/14N
760 FT 88/05/06W
MODE A / 21
CNTR 125DEG 45NM
MAX= 46 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0 5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

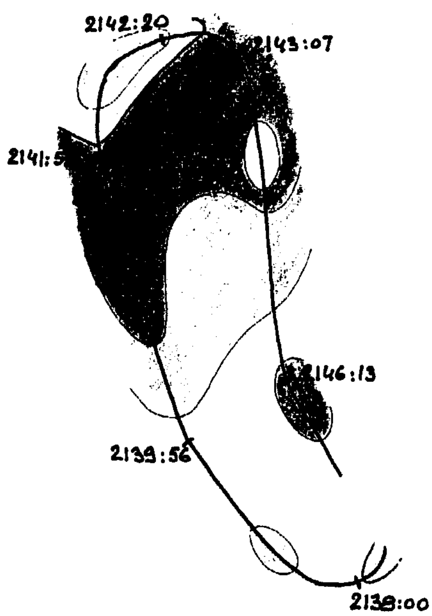

BASE REF 19 R
124 NM .54 NM RES
10/31/94 21:54
RDA:KLOT 41/36/14N
760 FT 88/05/06W
MODE A / 21
CNTR 125DEG 45NM
MAX= 45 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

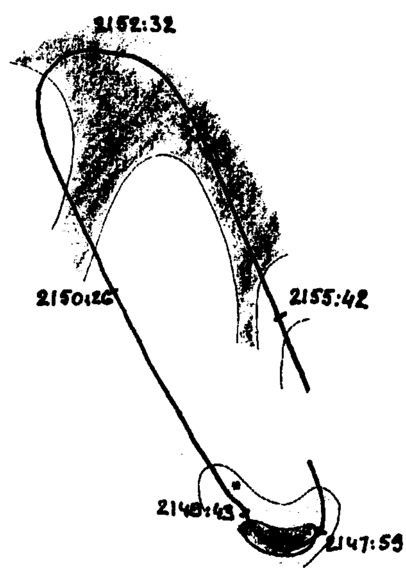

12/14/94 13:59
BASE REF 19 R
124 NM .54 NM RES
10/31/94 22:00
RDA:KLOT 41/36/14N
760 FT 88/05/06W
MODE A / 21
CNTR 125DEG 45NM
MAX= 47 DBZ
ND DBZ
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
MAG=4X FL= 1 COM=1
POLAR=10 NM 10 DEG
A/R (RDA) 125 DEG
13824FT 45 NM
PROD RCVD: R OT
KMRX 1650 .54 0.5
14/1300 ARCHIVE
UNIT 1 READ DONE
HARDCOPY REQUEST
ACCEPTED

APPENDIX 14



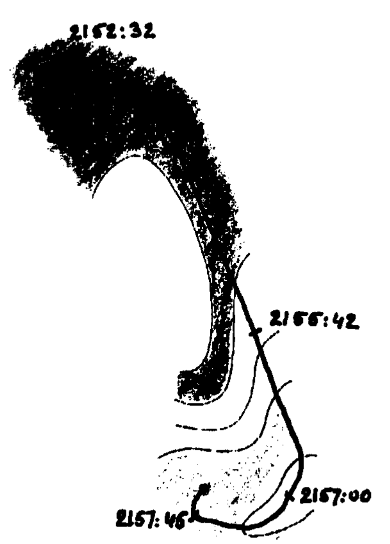






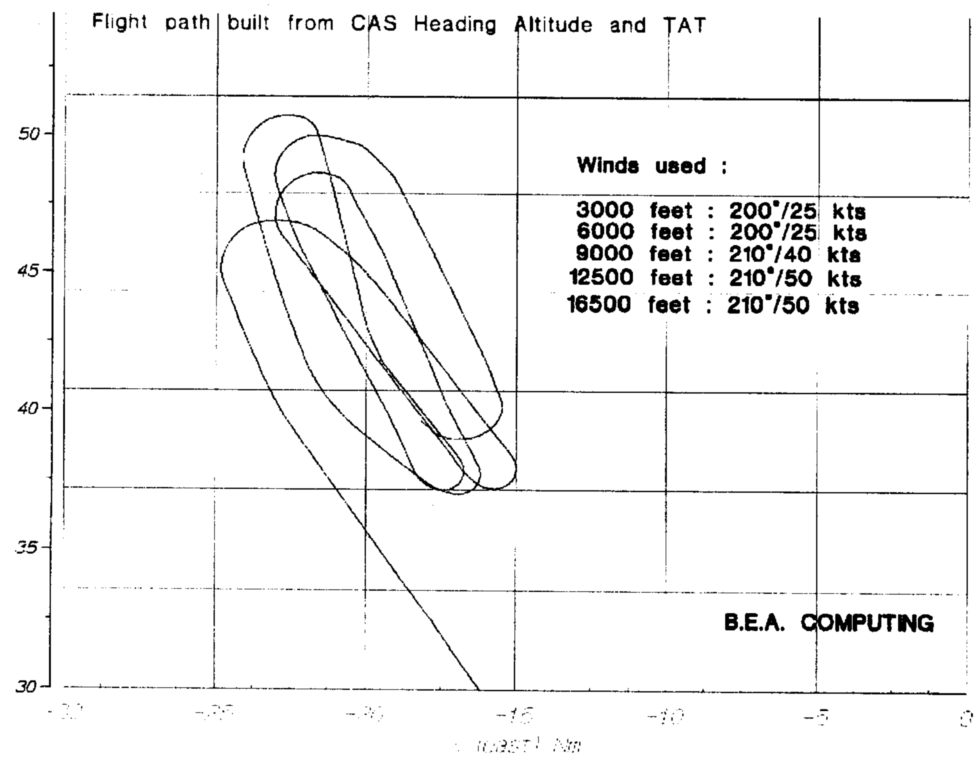
PRECIPITATION ECHOES
IN THE HOLDING PATTERN
(WEATHER RADAR REFLECTIVITIES)

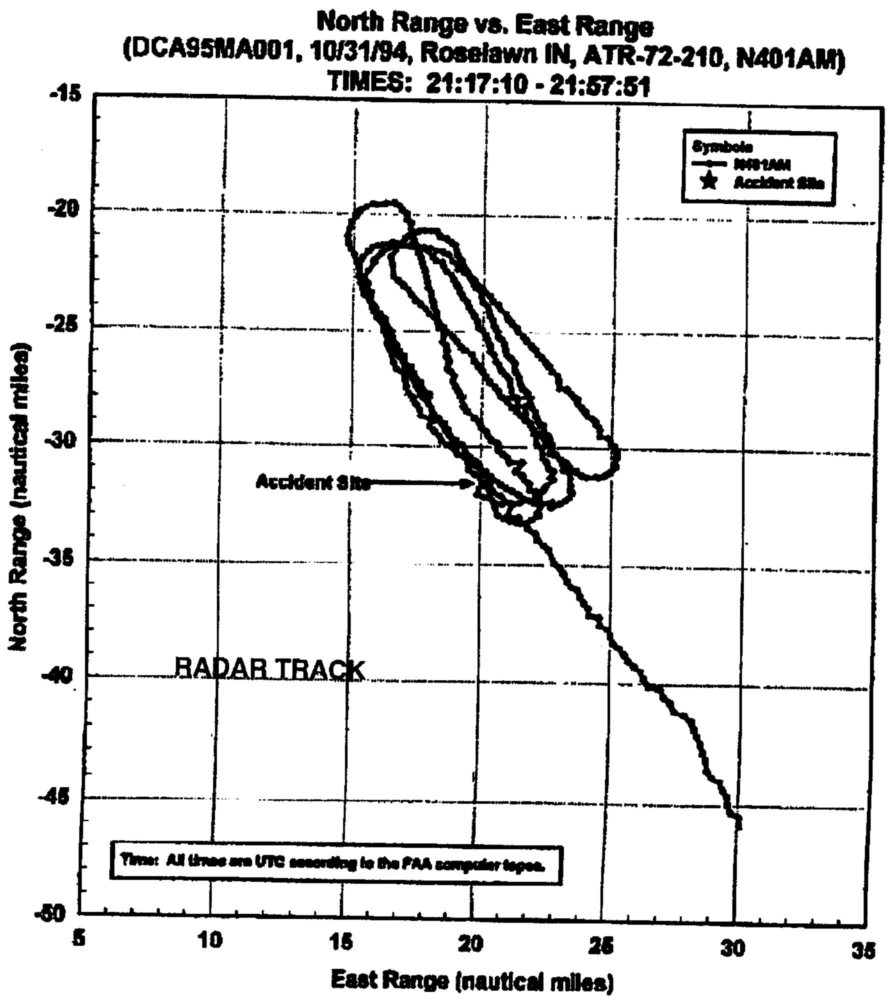
- 10 dBz
- 15 dBz
- 20 dBz
- 25 dBz
- 30 dBz
- 35 dBz



APPENDIX 15

COMPARISON BETWEEN B.E.A. COMPUTING AND RADAR TRACK





APPENDIX 16

COMPARISON BETWEEN
BEA COMPUTING AND RESULTS PROVIDED BY THE NTSB