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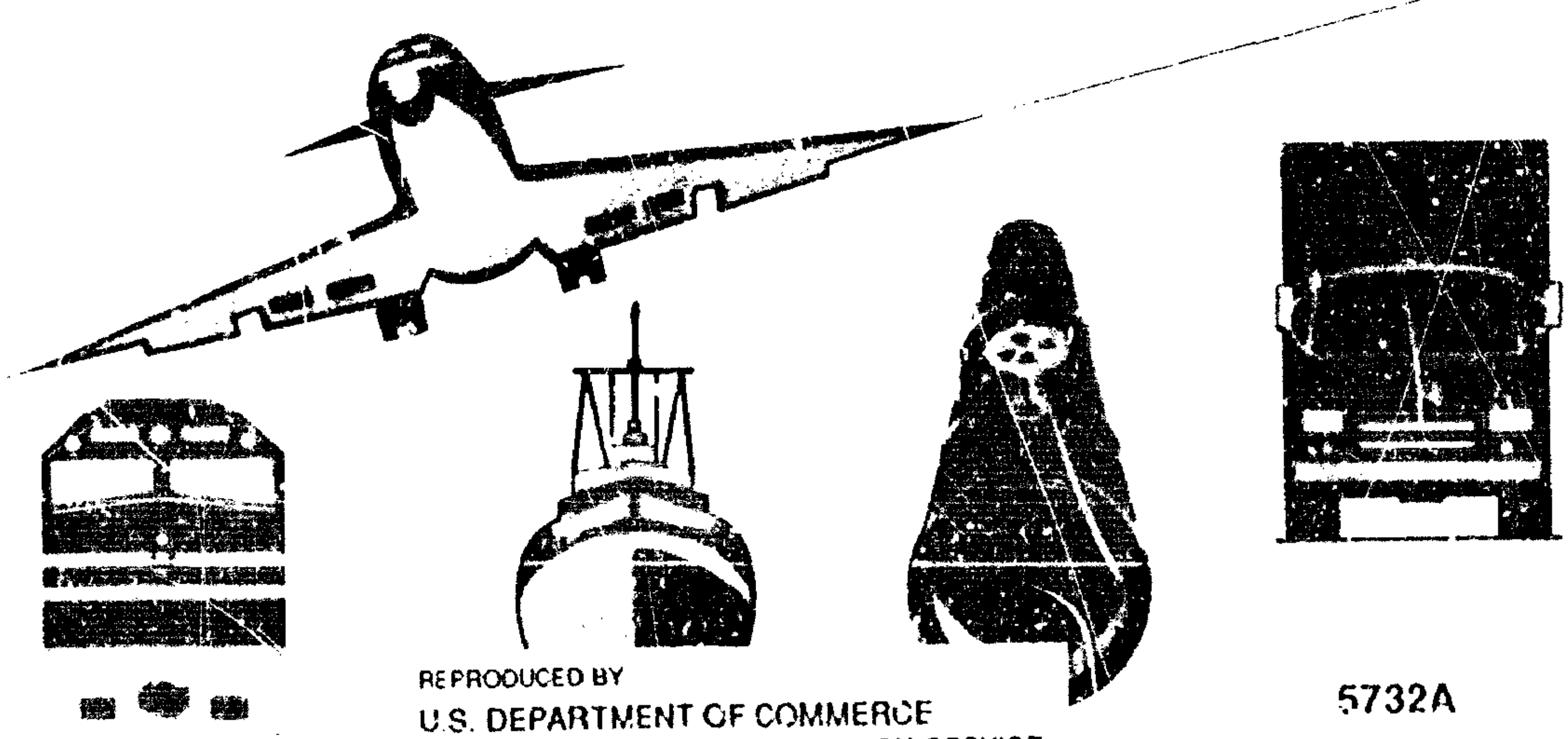
NTSB/AAR-93/02

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

TAKEOFF STALL IN ICING CONDITIONS
USAIR FLIGHT 405
FOKKER F-28, N485US
LAGUARDIA AIRPORT
FLUSHING, NEW YORK
MARCH 22, 1992



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Adopted: February 17, 1993
Notation 5732A

Abstract: This report explains the crash of USAir flight 405, a Fokker 28-4000, after an attempted takeoff from runway 13 at LaGuardia Airport, Flushing, New York, on March 22, 1992. The safety issues in the report focus on the weather, USAir's deicing procedures, industry airframe deicing practices, air traffic control aspects of the flight, USAir's takeoff and preflight procedures, and flightcrew qualifications and training. The airplane's impact with the ground, postaccident survivability, and crash/fire/rescue activities are also discussed. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration, the Port Authority of New York and New Jersey, the Department of Transportation, and the New York City Health and Hospitals Corporation.

CONTENTS

EXECUTIVE SUMMARY

On Sunday, March 22, 1992, about 2135 eastern standard time, a Fokker 28-4000 (F-28), N485US, operating as USAir flight 405, crashed during an attempted takeoff from runway 13 at LaGuardia Airport, Flushing, New York. Flight 405 was operating under Title 14, Code of Federal Regulations, Part 121, as a scheduled passenger flight from Jacksonville, Florida, to Cleveland, Ohio, with a stopover at LaGuardia Airport. There were 47 passengers, 2 flightcrew members and 2 cabincrew members on board. The captain, one of the cabincrew members, and 25 passengers received fatal injuries. The airplane was destroyed by impact forces and subsequent fire.

The National Transportation Safety Board determines that the probable causes of this accident were the failure of the airline industry and the Federal Aviation Administration to provide flightcrews with procedures, requirements, and criteria compatible with departure delays in conditions conducive to airframe icing and the decision by the flightcrew to take off without positive assurance that the airplane's wings were free of ice accumulation after 35 minutes of exposure to precipitation following deicing. The ice contamination on the wings resulted in an aerodynamic stall and loss of control after liftoff. Contributing to the cause of the accident were the inappropriate procedures used by, and inadequate coordination between, the flightcrew that led to a takeoff rotation at a lower than prescribed air speed.

The safety issues in this report focused on the weather affecting the flight, USAir's deicing procedures, industry airframe deicing practices, air traffic control aspects affecting the flight, USAir's takeoff and preflight procedures, and flightcrew qualifications and training. The dynamics of the airplane's impact with the ground, postaccident survivability, and crash/fire/rescue activities were also analyzed.

Safety recommendations concerning these issues were addressed to the Federal Aviation Administration, the Port Authority of New York and New Jersey, the Department of Transportation, and the New York City Health and Hospitals Corporation.

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1. FACTUAL INFORMATION

1.1 History of Flight

On Sunday, March 22, 1992, about 2135 eastern standard time, a Fokker 28-4000 (F-28), N485US, operating as USAir flight 405, crashed during an attempted takeoff from runway 13 at LaGuardia Airport, Flushing, New York. The airplane was operating under Title 14, Code of Federal Regulations (CFR), Part 121, as a scheduled passenger flight from Jacksonville, Florida, to Cleveland, Ohio, with a stopover at LaGuardia Airport. There were 47 passengers, 2 flightcrew members and 2 cabincrew members on board. The captain, one of the cabincrew members, and 25 passengers received fatal injuries. Impact forces and the subsequent fire destroyed the airplane. Instrument meteorological conditions prevailed at the time of the accident, and a thin layer of wet snow covered the runway.

The airplane's flightcrew and cabincrew were on the third day of a scheduled 4-day sequence. None of the previous flight segments involved landing at or taking off from LaGuardia. The crew began their activity on March 22, 1992, with flight 1257 from Tri-Cities, Tennessee, to Charlotte, North Carolina, at 1109.[1] Flight 1257 ended in Charlotte, at 1140. The flightcrew was then assigned to initiate flight 1863 to Jacksonville, Florida, in N485US, at 1445. Flight 1863, flown by the captain, arrived in Jacksonville at 1550. The next segment, flight 405, was scheduled to depart Jacksonville at 1635. Flight 405 was given a ground delay because of poor weather in the LaGuardia area and was further delayed in order to remove the baggage of a passenger who chose to deplane. Flight 405 departed

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[1] All times are eastern standard time (EST) based on the 24-hour clock.

Jacksonville at 1715 and was cleared into the LaGuardia area without significant additional delays. The first officer, who had flown the Tri-Cities-Charlotte leg, said that he accomplished an instrument landing system (ILS) approach to LaGuardia's runway 4 "to minimums" and initiated braking on the landing roll. Ramp congestion delayed taxiing to the parking gate. Although the first officer could not recall the inbound taxi route, he estimated a 10-minute wait on the ramp for a gate. The airplane was parked at Gate 1 at approximately 1949, 1 hour and 6 minutes behind schedule.

After the airplane was parked at Gate 1, the line mechanic who met the flight was advised by the captain that the aircraft was "good to go." The captain left the cockpit, without further comment or instructions, and the first officer prepared for the next leg to Cleveland that had originally been scheduled to depart at 1920. The first officer stated that they had not experienced any problems with the airplane. The first officer then went into the terminal for 3 to 5 minutes to use the rest room. The captain returned about 10 minutes after the first officer, and neither of them performed a walkaround inspection of the airplane, nor were they required to do so by USAir procedures. The first officer described the snowfall as "not heavy, no large flakes." He stated that the windshield heat was on low, snow was sliding off the airplane and that the airplane's nose had a watery layer as far as his arm could reach out the window. The first officer did not recall the presence of wind.

USAir deicing records show that the airplane was deiced with Type I fluid with a 50/50 water/glycol mixture, using two trucks.[2] After the deicing, about 2026, one of the trucks experienced mechanical problems and was immobilized behind the airplane, resulting in a pushback delay of about 20 minutes. The captain then requested a second deicing of the airplane. The airplane was pushed away from the gate to facilitate deicing by one deicing truck. USAir deicing records show that the second deicing was completed at approximately 2100. At 2105:37, the first officer contacted the LaGuardia ground controller and requested taxi clearance.[3] The airplane was cleared to taxi to runway 13. At 2107:12, the flightcrew switched to the LaGuardia ground sequence controller, which they continued to monitor until changing to the tower frequency at 2125:42.

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[2]Type I fluid is manufactured to military specification MIL-A-3243 or MIL-D-8243. The fluid must consist of at least 80 percent ethylene glycol or propylene glycol or 80 percent of a mixture of both. If diluted with 50 percent water, by weight, the fluid must have a freezing point no higher than -20 degrees Celsius.

[3]The times used in this section were taken from the cockpit voice recorder (CVR) recording. The transcript of this recording can be found in appendix D.

During the taxi and takeoff, the first officer was conducting the nonflying pilot duties. The before-takeoff checklist was completed during the taxi. The first officer recalled that they selected engine anti-ice for both engines during taxi. The captain announced that the flaps would remain up during taxi, and he placed an empty coffee cup on the flap handle as a reminder. The first officer stated that they had no visual or directional control problems, but that the captain announced they would use USAir's contaminated runway procedures that included the use of 18 degrees flaps. He stated that the captain then announced that they would use a reduced V_1 speed of 110 knots. The first officer said that he used the windshield wipers "a couple of times" and that he used the ice (wing) inspection light to examine the right wing "maybe 10 times, but at least 3." The first officer stated that the inspection light was on only during the time he was looking at the wing. He also stated that he looked at the wing, checking the upper surface for contamination, and the black strip on the leading edge for ice buildup. Further, he said that he did not see any contamination on the wing or on the black strip and therefore did not consider a third deicing. He said that he did not consider the snowfall heavy, and he did not recall any wind blowing the snow. The first officer stated that as they approached the number one spot for takeoff, they looked back at the wings several times. Near the time of the takeoff, he recalled saying, "Looks good to me, black strip is clear."

Northwest Airlines flight 517, a B-757, was deiced and taxied out around 2100. It was queued on taxiway A directly behind flight 405. The captain stated that he had a good view of the top of the F-28 wing, and that there was just enough snow on the fuselage to "fuzzy" the USAir printing but that the wings appeared to be clear. He believed that the snow had "all but stopped" and was more concerned about the amount of vehicular traffic, such as sweepers and plows, than he was about the snowfall.

Trump Shuttle flight 1541, a B-727, pushed back from its gate at 2125. The airplane had landed at 2045, and the second officer noted that they had "picked up a lot of snow quickly during my postlanding walkaround, but by the finish it seemed to be more rain." He stated that the snow was mostly sliding off all but the level surfaces and that it seemed to be sticking more to the side of the airplane that faced north. He estimated that by the time they had deiced, between 2110 and 2115, they had 1/4 inch or less accumulation of loose wet snow. They were holding No. 1 at taxiway CC when flight 405 taxied by for takeoff. He estimated that the wing tip of flight 405 passed within 50 feet of their airplane's nose. His position was quite a bit higher than the F-28 wing. He said that the wing was well lit by the reflection of light from the runway and aircraft. He described flight 405 as a "fairly clean airplane." He said that he could not comment on clear ice, but that the wings and fuselage were clear of snow. After flight 405 was holding in takeoff position, he observed the illumination of the inspection light, which was reflected on the wing, for about 1 minute. He commented to the other crewmembers that the light was "blinding him." He did not observe any spray during flight 405's takeoff roll, but he did see the fireball at 2135. He said that a landing flight was given a go-around at less than 300 feet inside the middle marker for runway 13.

The CVR recording revealed that flight 405 was cleared into the takeoff and hold position on runway 13 at 2133:50. The airplane was cleared for takeoff at 2134:51. About 2134:56.6, the CVR recorded a sound similar to the release of the parking brake, and, shortly thereafter, it recorded an increase in engine noise. At 2135:17.1, the captain and, shortly thereafter, the first officer made a callout of 80 knots, and, at 2135:25.4, the first officer made a V_1 callout. At 2135:26.2, the first officer made a V_R callout. (See figure 1). The specified takeoff speeds for the F-28 at the weight and configuration of flight 405 (66,000 pounds gross weight and an 18-degree flap setting) are 124 indicated air speed for V_1/V_R and 129 indicated air speed for V_2.

The first officer described the takeoff as normal through the rotation. He stated that no problem was evident with vibration, rate of acceleration, ambient noise, and directional control and that the takeoff was initiated with a smooth gradual rotation to 15 degrees at the normal rate of 3-degrees per second.

At 2135:28.4, approximately 2.2 seconds after the V_R callout, the CVR recorded a sound similar to nose strut extension. Approximately 4.8 seconds after nose strut extension, the sound of stick shaker began and continued until the end of the CVR recording. At 2135:33.4, the first stall warning beep was recorded, followed by five stall warning beeps starting 4.9 seconds later. At 2135:40.78, the sound of initial impact was recorded, and the recording ended at 2135:42.72.

The first officer recalled that the liftoff was normal but that he never called "positive rate." He was aware that the main landing gear came off the runway, but as they were "...about at ground effect[4] a pronounced buffet developed

[4]Ground effect is usually a beneficial influence on aircraft performance and occurs while an airplane is flying close to the ground. It results from a reduction in upwash, downwash, and wing tip vertices which provide a corresponding increase in lift and a decrease in induced drag. Reference: US Navy, *Aerodynamics for Naval Aviators*, Revised edition, January 19[illegible]5.

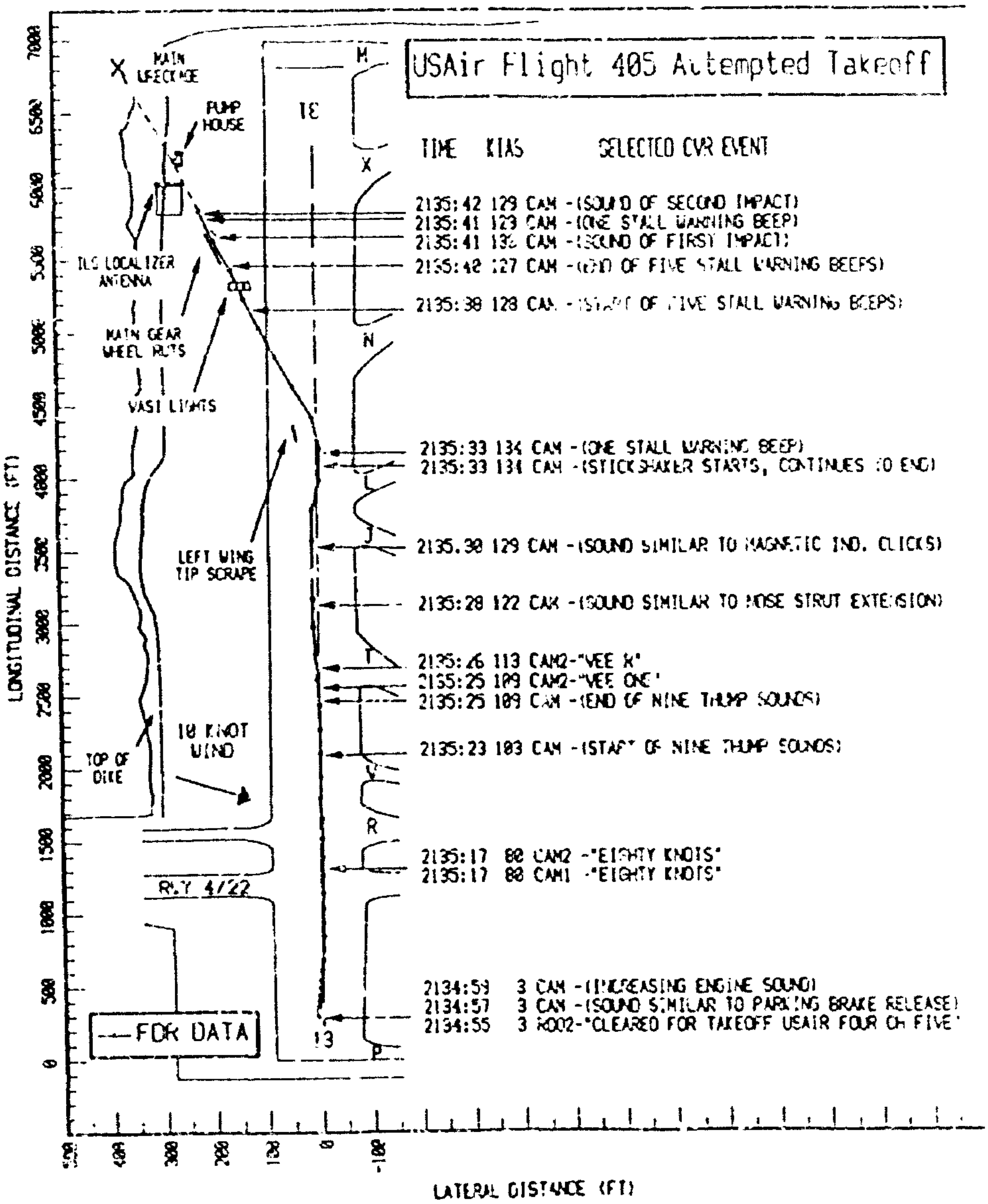

Figure 1.--Ground track and selected CVR sounds.

in the airframe." The first officer stated that they began rolling to the left, "just like we lost lift." He stated that as the captain leveled the wings, they headed toward the blackness over the water and that he joined the captain on the controls. The first officer said that they seemed to agree that the airplane was not going to fly and that their control inputs were in unison. He did not remember any aileron input, and there were no "heavy control inputs." They used right rudder to maneuver the airplane back toward the ground and avoid the water. They continued to try to hold the nose up to impact in a flat attitude. He said that there was at least one cycle of nose pitch oscillation accompanying the buffet. The first officer stated that he did not touch the power levers. The last thing he remembered was an orange and white building that disappeared under the nose. He recalled a flash, a jolt, a rumbling along the ground, and then a sudden stop.

The airplane came to rest partially inverted at the edge of Flushing Bay, and parts of the fuselage and cockpit were submerged in water. After the airplane came to rest, passengers stated that several small residual fires broke out on the water and on the wreckage debris. Aircraft rescue and fire fighters (ARFF) responded to the accident scene, extinguished the fires, and began rescue efforts. The accident occurred at 2135:43, during the hours of darkness, at 40 degrees 46 minutes and 23 seconds north latitude and 73 degrees 51 minutes and 29 seconds west longitude.

1.2 Injuries to Persons

Injuries	Flightcrew	Cabincrew	Passengers	Other	Total
Fatal	1	1	25	0	27
Serious	0	1	8	0	9
Minor	1	0	11	0	12
Records Not Received	0	0	3	0	3
Total	2	2	47	0	51

1.3 Damage to Airplane

The airplane was destroyed during the impact sequence and subsequent fires. The estimated value of the airplane was $13.12 million.

1.4 Other Damage

During the accident sequence, the airplane struck and destroyed two of three outermost visual approach slope indicator (VASI) boxes, an ILS localizer antenna structure, and a water pump house. The estimated cost to restore the VASI boxes and the ILS antenna structure was $431,988. Temporarily repairing the pump house cost $120,000, and replacing the pump house and the entire system would cost approximately $1 million.

1.5 Personnel Information

The two flightcrew members and two cabincrew members were properly qualified and certified for the flight. The captain and first officer did not have any record of previous aircraft accidents or violations of Federal Aviation Administration (FAA) regulations.

The captain, age 44, held an airline transport pilot (ATP) certificate with type ratings in the F-28, DC-9, EMB-110, DHC-7 and B-737. He also had an airplane multiengine land rating with commercial privileges for the DC-6, and an airplane single-engine land rating. He held a flight engineer certificate with a rating for turbojet-powered aircraft and also an expired flight instructor certificate issued on July 2, 1981. At the time of the accident, company records indicate that he had accumulated approximately 9,820 total flying hours, of which 2,200 hours were in the F-28. A total of 1,400 hours of F-28 time was as captain. He was issued a first class medical certificate with no limitations on November 19, 1991. He completed his last proficiency check on January 9, 1992. He received his last recurrent training on December 17, 1991, and completed an annual 9-hour home study course on winterization, passing the winterization closed book examination on November 25, 1991.

The captain was hired as an F-28 first officer by Piedmont Airlines on May 20, 1985, and served in that capacity until he was reassigned as a B-737-200 first officer on September 15, 1986. He upgraded to captain of the F-28 and received his initial type rating on January 7, 1989. He subsequently bid captain on the B-737-200 and received a type rating on February 13, 1990. During a cutback in flight operations, he was reassigned as a captain on the F-28. He received requalification training in the F-28 on January 20 and 21, 1991, and completed the proficiency check on January 22, 1991.

The first officer, age 30, was hired by Piedmont Airlines on July 19, 1989. He held an ATP certificate with ratings for airplane multiengine land and commercial privileges for airplane single-engine land. At the time of the accident, company records indicate that he had accumulated approximately 4,507 total flying hours, of which 29 hours were in the F-28. This F-28 flying time was his only piloting experience in transport-category turbojet aircraft. He held a flight engineer certificate with ratings for turbojet-powered aircraft and an expired instructor certificate issued on August 16, 1987. He also held an FAA license for nonfederal control towers with a rating for Beaver County Airport that was issued on September 25, 1981. On March 11, 1992, he received a first class medical certificate with no limitations.

The first officer was hired as a B-727 second officer and served in that capacity until he was furloughed on August 1, 1991. He was recalled on November 21, 1991, as a B-727 second officer. His last proficiency check as a second officer was accomplished on December 5, 1991. His last recurrent training was received on November 26, 1991, while he was still a second officer. He was reassigned as an F-28 first officer on February 1, 1992, and completed that initial training with a proficiency check on February 22, 1992. He received the F-28 airplane portion of his proficiency check on February 23, 1992. His last line check was accomplished during his initial operating experience (IOE) on February 29, 1992. He completed the annual winterization home study course and passed the examination on November 21, 1991.

1.5.1 72-Hour Summary--Flightcrew Activity

The summary of flightcrew activity in the 72 hours prior to the accident is based on the itinerary submitted by the first officer, his interview with investigators 3 days after the accident, and USAir crew pairing information. The first officer and the captain were paired for March 20, 21, and 22; therefore, the captain's 72-hour history would closely match that of the first officer.

The first officer stated that he and the captain departed Charlotte for Roanoke about 1350 on March 20 and that the captain was flying the airplane. The flightcrew flew four more legs, in which they alternated flying duties as they did for the entire trip. They landed at Dulles International Airport, near Washington, D. C., at 2137, arrived at the hotel at 2200, and slept for approximately 7 hours.

On Saturday, March 21, the flightcrew departed the hotel about 0645 for Dulles. The airplane was deiced twice and then flew to Charlotte, arriving at approximately 0920. The next leg was to Mobile, Alabama, where the flightcrew ate lunch together. At 1450, they departed Mobile and, at 1609, arrived in Charlotte, where they changed airplanes for a flight to Bristol, Tennessee. Although visual flight conditions existed in the Bristol area, the flightcrew performed a category-II approach in order to verify the operation of equipment.

The flightcrew arrived at the hotel in Bristol at approximately 1930. The captain and first officer dined together at a local restaurant and consumed some beer. They met one of the flight attendants at the same restaurant. According to the first officer, he drank three beers, the last of which was by 2130. Both he and the captain left the restaurant 30 minutes after the flight attendant had departed, returning to the hotel at around 2315. The first officer said that he slept from approximately midnight to 0930.

All members of the crew departed the hotel together, arriving at the airport in Bristol at approximately 1000 on March 22. They departed Bristol at 1109 and arrived in Charlotte at 1140. Using the first officer's car, the captain and first officer proceeded to a restaurant, where they ate lunch, and returned to the airport at 1330.

The first officer performed the preflight duties, and, at 1446, they departed with the captain flying the airplane. They arrived in Jacksonville, Florida, at 1550, and departed for LaGuardia at 1715, with the first officer flying the airplane. At 1949, they arrived at LaGuardia Airport after flying an ILS approach because the published weather reported visibility at the runway's minimum range.

1.6 Airplane Information

USAir flight 405 was a Fokker 28 series 4000 (F-28) airplane manufactured in the Netherlands. Its original type certificate was approved by the Civil Aviation Authority of the Netherlands. The FAA accepted the certification of the airplane under the Bilateral Airworthiness Agreement.

The F-28 is a two-engine, medium-range airplane designed for transporting as many as 85 passengers and 479 cubic feet of cargo. The F-28 has moderately swept wings and no leading edge high lift devices, engines mounted on the sides of the rear fuselage, and a T-tail. The airplane is powered by two

Rolls-Royce Spey Mk 555-15P turbofans and each is designed to provide 9,900 pounds of takeoff thrust. The engines are not fitted with thrust reversers.

The airplane, registered in the United States as N485US, Serial No. 11235, was delivered to Piedmont Airlines on August 19, 1986, and was acquired by USAir in the merger of the airlines on August 5, 1989. At the time of the accident, the airplane had accrued 12,462 hours and 16,280 cycles.

The left engine, Serial No. 9252, was installed on the airplane on December 9, 1990. At the time of the accident, the engine had operated a total of 24,491 hours, and 2,882 hours since the last shop visit.

The right engine, Serial No. 9763, was installed on the airplane on April 18, 1991. At the time of the accident, the engine had operated a total of 13,204 hours, and 2,014 hours since the last shop visit.

The airplane's center of gravity at takeoff was calculated to have been 21.0 percent of mean aerodynamic chord. The airplane's gross takeoff weight for this flight was calculated at 66,295 pounds, and the airplane's maximum allowable takeoff weight was 73,000 pounds. Both values were within limits for the flight.

The maintenance records of N485US were examined at the USAir maintenance facility in Pittsburgh, Pennsylvania. The records indicated that the airplane had been inspected and maintained in accordance with the General Maintenance Program as defined in USAir's Operations Specifications and in accordance with its FAA-approved Aircraft and Powerplant Reliability Programs.

The review of the maintenance records revealed no discrepancies that were relevant to the circumstances of the accident. The records indicated that all required inspections and maintenance actions had been accomplished within the times specified. The airplane logs carried 20 controlled open items, none of which were considered noteworthy with respect to the accident flight.

The cockpit was of the standard captain and first officer configuration. The cabin was configured into two sections. (See figure 2). The first class section had a forward-facing double occupancy seat unit on the left side labeled 1A, C and one forward-facing double occupancy seat unit on the right side labeled 1D, F, for a total of four seats.

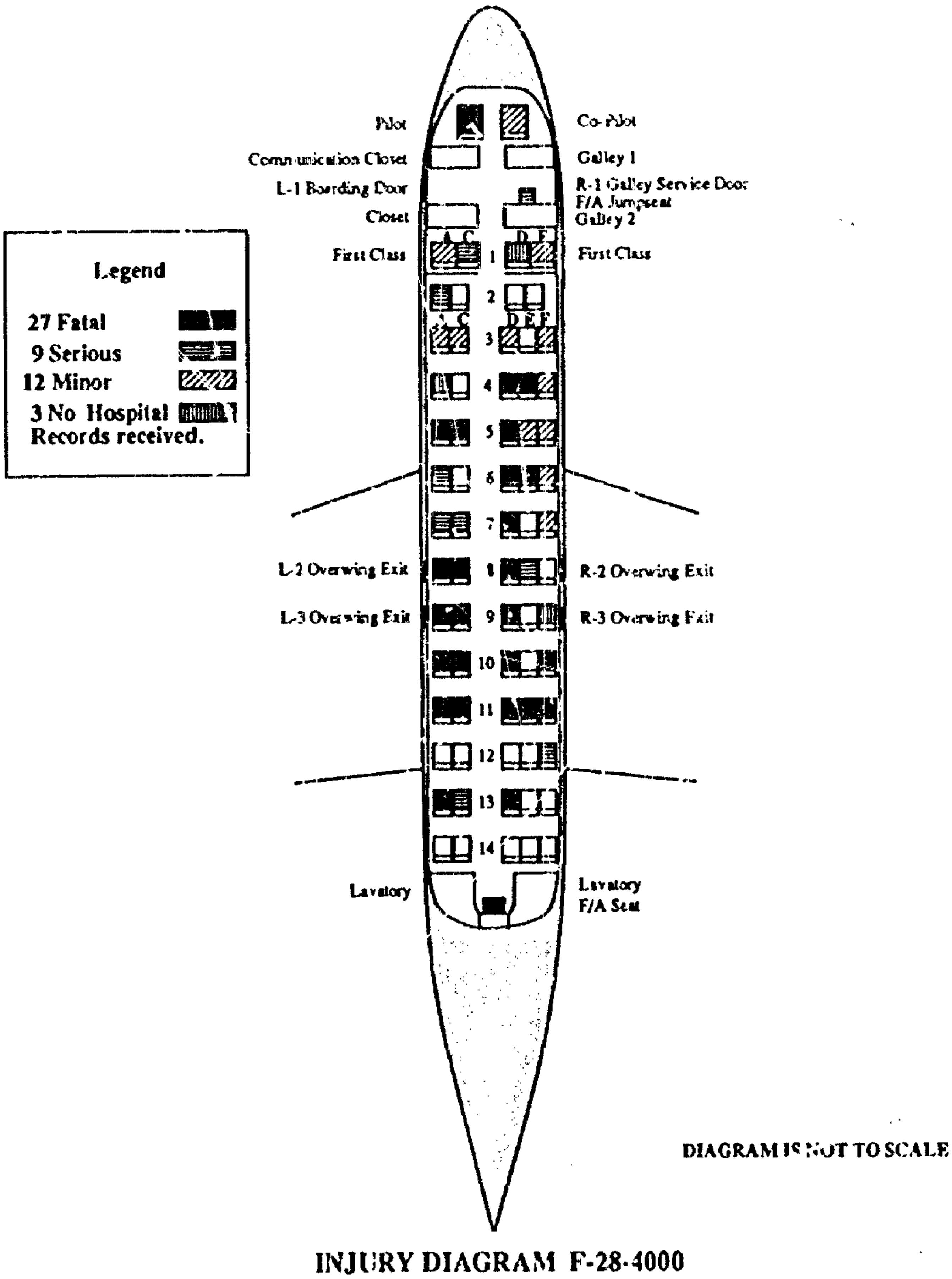

Figure 2.--Cabin diagram and injury information.

The coach cabin was configured with 13 rows of forward-facing double occupancy seat units on the left side of the cabin labeled 2A, C through 14A, C and one forward-facing double occupancy seat unit labeled 2D, F followed by 12 rows of forward-facing triple occupancy seats units on the right labeled 3D, E, F through 14D, E, F. There were 64 seats in the coach section. There were two cabincrew jumpseat locations in the cabin that were single units and forward facing. One cabincrew seat was in the right front of the airplane between Galley 1 and Galley 2. The second cabincrew seat was in the rear of the fuselage between the left and right lavatories.

1.7 Meteorological Information

1.7.1 Surface Observations and Forecast

The weather observations and forecast for LaGuardia on March 22, 1992, up to and after the time of the accident were as follows:

> 2050 - Indefinite ceiling 700 feet sky obscured, visibility 3/4 mile light snow and fog, temperature 31 degrees F, dew point 30 degrees F, winds 070 degrees at 13 knots, altimeter setting 29.67 inches of Hg, runway 04 visual range 6,000 feet plus, drifting snow, wet snow, snow increasing 1 inch in the past hour/2 inches since last synoptic observation (1900)/4 inches on the ground.

> 2145 - Indefinite ceiling 700 feet sky obscured, visibility 3/4 mile light snow and fog, temperature 32 degrees F, dew point 31 degrees F, winds 060 degrees at 13 knots, altimeter setting 29.66 inches of Hg, runway 04 visual range 6,000 feet plus, surface visibility 7/8 mile, drifting snow, wet snow.

The terminal forecast for the LaGuardia area valid beginning at 2000 called for:

> A ceiling of 500 feet overcast, visibility 3/4 mile with light snow and fog, winds 070 degrees at 10 knots; occasional ceiling 300 obscured, visibility 1/2 mile with moderate snow and fog; chance ceiling 1,100 feet overcast, visibility 2 miles with light snow and fog.

1.7.2 Port Authority Temperature Sensors

A temperature sensor, operated by the Port Authority of New York and New Jersey, was near the intersection of runways 13/31 and 04/22. Data obtained from this sensor indicated a temperature of 29 degrees F at 2018. Successive readings of 29 degrees F were reported until 2135 when a readout of 30 degrees was recorded. The Port Authority calibrates its meteorological equipment yearly.

1.7.3 Automatic Terminal Information Service (ATIS)

Information "Lima" was broadcast at 2000; information "Mike" was broadcast at 2100; and information "November" was broadcast at 2124.

At the time of the accident, information November was the most current ATIS transmission available to flightcrews and was as follows:

> LaGuardia Airport information November, zero one five zero Zulu weather: indefinite ceiling, seven hundred, sky obscured, three quarters of a mile, light snow and fog. Temperature three one, dew point three zero. Wind one zero zero at one two, altimeter two niner six seven. ILS DME approach in use. Land runway one three, depart runway one three. Braking action advisories in effect. Runway 4/22 closed for snow removal. SNOTAM: Runway 13/31 plowed forty foot either side of centerline. Thin layer of wet snow on surface runway has been sanded. Advise on initial contact that you have November.

> Information Mike was as follows:

> This is LaGuardia Airport information Mike, zero one five zero Zulu: indefinite ceiling, seven hundred, sky obscured. Visibility three quarters of a mile, light snow, fog. Temperature three one, dew point three zero. Wind one zero zero at one two, altimeter two niner six seven. ILS Approach in use. Landing runway four, departing runway one three. Braking action advisories are in effect. LaGuardia tower TCA available on frequency one two six point zero five. NOTAM: all taxiways have a thin covering of wet snow up to one eighth of an inch. Centerline lights obscured. Runway 4/22 has a thin covering of wet snow. Runway has been

treated with urea[5] and has been sanded. On initial contact advise that you have information Mike.

Information Lima was current when the flightcrew of USAir 405 confirmed the predeparture clearance with the clearance delivery controller at 1955. Information "Lima" was as follows:

> LaGuardia Airport information Lima, zero zero five zero Zulu weather: indefinite ceiling, five hundred sky obscured, one half mile, snow and fog. Temperature three zero, dew point three zero. ILS approach in use. Land runway four, depart runway one three. Braking action advisories in effect. LaGuardia SNOTAM: all taxiways have a thin covering of wet snow up to one eighth of an inch. Centerline light obscured. Runway 4/22 has a thin covering of wet snow. Runway has been treated with urea and has been sanded. Runway 13/31 has thin layer of wet snow. Runway has been treated with urea and has been sanded. Advise on initial contact that you have Lima.

1.7.4 Precipitation Amount

The LaGuardia weather observer measured 1 inch of snow (a water equivalent of 0.11 inch) between 1900 and 2000, 0.5 inch snow (a water equivalent of 0.09 inch) between 2000 and 2100, and 0.4 inch of snow (a water equivalent of 0.06 inch) between 2100 and 2140. He characterized the snow as wet.

1.8 Aids to Navigation

Navigational aids were not used by the flightcrew during the accident sequence.

1.9 Communications

No equipment-related communications difficulties were reported between air traffic control facilities and the flightcrew involved in this accident.

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[5] A chemical applied to the runway surface to melt ice and snow.

1.10 Aerodrome Information

LaGuardia Airport serves the New York and New Jersey metropolitan area and is 4 miles east of New York City, in Flushing, New York, at 40 degrees 46.38 minutes north latitude and 73 degrees 52.23 minutes west longitude. Two-thirds of the airport is surrounded by water. Flushing Bay surrounds the departure end of runway 13, and Bowery Bay surrounds the departure end of runway 31. The airport's official elevation is 22 feet above mean sea level (msl). The airport is owned by the City of New York and is operated by the Port Authority of New York and New Jersey as a public use airport. It is serviced by an FAA air traffic control tower and is classified as an index D[6] airport for ARFF capabilities.

LaGuardia Airport has two operational runways that are designated 4/22 and 13/31. Runway 13, the accident runway, is 7,000 feet long by 150 feet wide. The surface is asphalt, except for the first 900 feet, which is grooved concrete on an elevated deck with saw-cut transverse grooves 1 1/2 inches apart and 1/4 inch wide and deep. Runway 13's elevation decreases from 13 feet msl at the threshold to 7 feet msl at the runway 31 threshold. Runway 13 has a medium intensity approach lighting system with runway alignment indicator lights, a four-box VASI on the left side, runway identifier lights, and is marked with precision instrument runway markings. Runway 13/31 has dual parallel taxiways running its full length. Runway 4/22 is 7,000 feet long by 150 feet wide and crosses runway 13/31 between 1,000 and 1,300 feet from the runway 13 approach end.

The most recent FAA annual airport certification inspection prior to the accident was conducted on September 3 and 4, 1991. Discrepancies were noted at the time of the inspection and were corrected and cleared by October 29, 1991.

1.10.1 LaGuardia Snow and Ice Control Plan

At the time of the accident, LaGuardia had an FAA-approved snow and ice control plan as required by 14 CFR 139.313. The airport duty manager/snow coordinator stated that runway 13/31 had been plowed, sanded, and treated with urea just prior to the accident. The LaGuardia operations log indicated that at 1900, the following Notice to Airmen (NOTAM) was issued: "R/W 13/31 has a thin

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[6]An index D airport has five or more average daily departures of air carrier airplanes that are at least 159 feet long but less than 200 feet long and has fewer than five average daily scheduled departures of air carrier airplanes that are longer than 200 feet. An index D airport is required to have three crash, fire and rescue vehicles and to have available 500 pounds of dry chemical or Halon 1211 agents or 450 pounds of dry chemical agent plus 4,100 gallons of water.

covering of wet snow. R/W has been sanded and treated with urea." At 1930, the log showed that runway 13/31 had been plowed 20 feet on each side of the centerline and that snow removal crews were "...waiting for additional passes. [because the] Tower [was] rolling a few departures." The airport duty manager also stated that work continued on runway 13/31 until 2115 when "nil" braking was reported by an airplane that landed on runway 4. Runway 4/22 was closed, and the snow removal equipment was moved from runway 13/31 to work on runway 4/22. At that time, he reported to airport operations that conditions on runway 13/31 were identical to those described in NOTAM 03/015, which stated: "R/W 4-22 plowed 40 feet each side of CL [centerline]. Surface has thin layer of wet snow. R/W sanded."

The FAA Lead Airport Safety and Certification Specialist stated that while he was walking on runway 13/31, about 90 minutes after the accident, he observed that the center of the runway was covered with 1/4 inch to 1 inch of slush and that the snow was slightly deeper along the runway edges.

1.10.2 Type II Anti-icing Fluid Restrictions

On October 30, 1990, the airport manager issued to all tenants Airport Manager's Bulletin No. 90-29, "Type II Glycol Aircraft Deicer," that restricted the use of Type II anti-icing fluid "to overnight/lengthy ground type operations...." and required that Type II fluid be removed from aircraft prior to departure from their gates. The bulletin further stated that the restrictions would remain in effect until additional test information was received from the FAA regarding the effects of Type II anti-icing fluid on runway friction.

On April 21, 1992, the Manager of Airport Technology, FAA Technical Center, Atlantic City, New Jersey, advised that the center had conducted tests using Type II anti-icing fluid on runway surfaces that were contaminated with varying degrees of rubber deposits. The preliminary conclusions indicated some degradation of runway friction. He added, however, that tests were continuing. On the same day, the supervisor of the airport's aeronautical services stated that although the use of Type II anti-icing fluid was permitted at John F. Kennedy International Airport (JFK), its use was being restricted at LaGuardia until additional guidance was received from the FAA because of the belief that the shorter runways and the deck areas made runway friction a more critical factor for the safety of aircraft. In May, 1992, an airport staff engineer further advised that the airport did not use separate runways for landings and takeoffs, which was the paramount reason for the Type II restriction.

The manager of aeronautical services at JFK confirmed that a number of international air carriers had been using Type II anti-icing fluid at JFK for about 2 years and that neither he nor the operations staff had noted any degradation in runway friction. Also, an official at Logan International Airport, Boston, Massachusetts, reported no observations of runway degradation after the use of Type II anti-icing fluid at Logan. This airport has two runways that are more than 10,000 feet long.

1.10.2.1 LaGuardia Airplane Deicing Operations

At the time of the accident, air carriers deiced their own airplanes on apron areas around their terminals.

1.10.3 Runway Safety Area

FAA Advisory Circular (AC) 150/5300-13, Table 3-1, recommends that any object within a safety area be frangible.[7] The ILS localizer ground plane antenna and the pump house, which were east of runway 13/31, were outside the 500-foot runway safety area, which is 250 feet from either side of the runway centerline.

1.10.4 Air Traffic Control (ATC)

On the night of the accident, from 1900 to 2000, the Engineered Performance Standards (EPS)[8] allowed 58 aircraft per hour (29 arrivals and 29 departures) and were based on arrivals for runway 4 and departures for runway 13. The EPS limit was imposed because of a ceiling of 0 to 200 feet and a runway visual range (RVR) of 600 to 2,400 feet. There were 36 arrivals and 22 departures scheduled according to the Official Airline Guide (OAG). There were actually 24 arrivals and 15 departures.

From 2000 to 2100, the EPS allowed for 58 aircraft per hour (29 arrivals and 29 departures). There were 25 arrivals and 28 departures scheduled according to the OAG. However, there were 15 arrivals and 29 departures.

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[7]A safety area is a designated area abutting the edges of a runway or taxiway intended to reduce the risk of damage to aircraft inadvertently leaving the runway or taxiway. (Title 14, CFR 139.3).

[8]A mathematically derived runway capacity standard. EPSs are calculated for each airport on an individual basis and reflect that airport's aircraft mix, operating procedures, runway layout, and specific weather conditions.

From 2100 to 2200, the EPS category changed to arrivals and departures for runway 13, because runway 4 was closed, reducing the arrivals and departures per hour to 50 aircraft. There were 36 arrivals and 22 departures scheduled during this hour. From 2100 until the accident at 2135, there were 11 arrivals and 14 departures. An F-28, which was USAir flight 1900, was the last airplane to land on runway 13 prior to the takeoff of USAir flight 405. At 2134:31, the flightcrew of flight 1900 reported to the local controller that their airplane was clear of the runway. Approximately 20 seconds later, flight 405 was cleared for takeoff.

On the day of the accident, at approximately 1400, the FAA's Central Flow Control implemented a ground delay program at the airport for scheduled arrivals. The manager of Central Flow Control stated that because the forecast weather did not materialize for the New York area until much later than forecast, the ground delay program was postponed and later reinstituted. The flow control process restricted aircraft inbound to LaGuardia by delaying ground departures at other airports. Additional ground stops were instituted at adjacent air traffic control centers, and elongated in-trail spacing and airborne holding were used for LaGuardia-bound aircraft.

1.10.5 Ground Delay Reporting

Immediately prior to the accident, 15-minute ground delays were reported. Such delays are reported only in multiples of 15-minute increments at FAA ATC towers. A tower annotates the time that a pilot calls for clearance to taxi from the gate for takeoff and also annotates the takeoff time. A "15-minute" delay is not reported at LaGuardia until a "23-minute" difference exists between the two times. This 23 minutes is the sum of the 15 minutes plus the average time that it takes for an aircraft to taxi from the gate to the departing runway. At LaGuardia, that average taxi time from Gate 1 was determined to be 8 minutes. Therefore, no delay is reported until 23 minutes after the time an aircraft has called for clearance to taxi for takeoff. From 23 minutes to 37 minutes past the initial call for taxi clearance, the flight is categorized as having a "15-minute" delay. From 38 minutes to 53 minutes, a "30-minute" delay is said to exist. The LaGuardia tower had logged flight 405's call for taxi clearance as 2106 and logged the departure time as 2135. Although 29 minutes had elapsed from the call for taxi to the time of takeoff, the flight was within the reported "15-minute" ground delay category.

1.10.6 Gate Hold Procedures

According to the tower's Operational Position Standards dated June 1, 1990, there are no "Gate Hold" procedures at LaGuardia Airport. However, the tower's Letter to Airmen No. 91-7, "LaGuardia Airport Departure Delay Procedures," dated June 15, 1991, are applicable to all fixed-wing aircraft operating at LaGuardia Airport and are to be implemented whenever departure delays exceed or are expected to exceed 15 minutes.

This local departure delay procedure states that clearance delivery will advise of known delays and/or "Expect Departure Clearance Times" when clearances are issued. Pilots may remain at the gate or go to a "delay absorbing area" that includes ramps, hardstands, taxiways or gates. The letter advises that if the flightcrew elects to remain at the gate, the departure sequence cannot be guaranteed. The flightcrew is responsible for advising the ground or local controller if the airplane will be taxiing on partial power or needing to restart an engine. Ground control frequency or the assigned air traffic control frequency must be monitored at all times.

The Assistant Air Traffic Manager, LaGuardia Airport tower, testified that:

> At LaGuardia there are no gate hold procedures, because we cannot give a sequence, a departure sequence, at the time of initial callup....We cannot guarantee that sequence at LaGuardia because of the physical limitations of the ground space there...to give guaranteed departure times, you would have to drastically limit the amount of aircraft coming in and out of LaGuardia.

At the public hearing, Air Traffic Bulletin No. 92-1, dated January 1992, was discussed. It stated that under adverse icing conditions, the air traffic control team can help by ensuring that aircraft take off in a reasonable amount of time by using efficient traffic management procedures, and that aircraft should be sequenced from gates after they complete the deicing process to enhance the safety factor under extreme weather conditions. The Assistant Air Traffic Manager also testified that before the accident, the LaGuardia tower was unaware of this bulletin but that if the tower had been made aware of the bulletin, the procedures on the night of the accident would not have been any different. He stated that they would not have initiated gate hold procedures because such procedures do not exist at LaGuardia.

Most airports have gate hold procedures. Airports such as JFK, Newark, White Plains, Philadelphia, Boston, and Providence were affected by precipitation on the night of the accident. All of them had gate hold procedures except Providence. As of the adoption date of this report, the Providence tower was in the process of formulating gate hold procedures.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The airplane was equipped with a Fairchild Model A-100 CVR, Serial No. 53857. The recording consists of three channels of good quality audio information. One channel contains the cockpit area microphone audio information. The other two channels contain information from the flightcrew's radio and the airplane's public address system. A fourth CVR channel contains no usable audio information. The recording began at 2104:42, shortly after the airplane was blocked out of USAir's Gate 1, and continued uninterrupted until 2135:42.72, when electrical power was lost during the crash sequence.

The CVR recording, which was examined on a spectrum analyzer, was used to determine the speed of the fan sections of the engines [N_1] during the takeoff roll. The frequency signatures of the engines stabilized at approximately 101 percent N_1 during most of the takeoff roll until about 5 seconds before the end of the recording. During the last 5 seconds, the engine signatures began a slow decrease from about 101 percent N_1 to 97 percent N_1 at the end of the recording. During the takeoff roll, no deviations above or below the stabilized signatures were noted.

During the takeoff roll from 2135:22.72 to 2135:24.72, the area microphone channel recorded sounds that were identified as the airplane's nose wheel running over the embedded centerline runway lights. The airplane's ground speed was calculated for this 2-second period by using the time and distance between runway lights. The ground speed increased from 98.6 knots (at the start of the noise) to a maximum of 108 knots at 2135:23.88.

Shortly after the first officer's call "Vee R," two sounds were heard on the area microphone channel of the CVR. A CVR recording of a normal takeoff was obtained from a similar USAir F-28 to compare with the accident recording. The sound at 2135:28.4 on the accident recording was similar to the sound of the nose strut extending during rotation on the test flight. The sound at 2135:30.56

was similar to the sound of the lift dumper magnetic indicators on the instrument panel switching from "armed" to "in" on the test flight.

1.11.2 Flight Data Recorder

A Fairchild digital flight data recorder (FDR), model F800, Part No. 17M900-274, Serial No. 154, was removed from the airplane and examined at the Safety Board's laboratory.

The FDR was not damaged by impact. However, the internal electronic components and tape recording medium were coated with water and jet fuel. The recording medium was removed, washed, and dried. The quality of the recording was good, and data from flight 405, as well as the five preceding takeoffs, were recovered.

This model FDR records pressure altitude, air speed, heading, normal acceleration, and microphone keying data. Each data parameter is sampled and recorded 1 time per second, except for pressure altitude, which is sampled and recorded 2 times per second; and normal acceleration, which is sampled 10 times per second, with the peak value of each 1/2 second recorded in the following 1/2 second.

In general, at low roll and pitch angles, normal acceleration is approximately equal to the acceleration in the vertical plane of flight (up or down). On the runway, the normal acceleration is about 1 G.[9] For takeoff, the normal acceleration increases above 1 G as the airplane lifts off. The normal acceleration increases to 1.15 to 1.2 G as the airplane transitions to climbing flight. Once the transition to flight is accomplished, the normal acceleration returns to a near 1 G value (about .96 G for a 15-degree pitch attitude). Usually, a rise in normal acceleration above 1 G shows the approximate point at which liftoff occurs. However, for flight 405, because of the noise present in the altitude data, the liftoff point is not clear.

Rotation of the airplane during takeoff changes the airflow patterns across the static air pressure ports, resulting in a high static pressure measurement referred to as the static position error. This error is transient and is associated with the angle of attack (AOA) in ground effect. Recorded FDR air speed and altitude

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[9]A nondimensional measure of acceleration comparing the actual acceleration to the acceleration of the earth's gravity.

values are generally low during this time, and liftoff occurs near the bottom of the "dip" routinely recorded for altitude. However, because of the noise present in the altitude data from the accident flight, the liftoff point is not clear. The indicated air speed, magnetic heading, and microphone keying information taken from the FDR were normal.

The ground track of the airplane was determined using FDR data on indicated air speed, magnetic heading, and time. The altitudes that the airplane reached were assumed to be negligible in these calculations. Microphone keying information was used to establish a time correlation between the CVR and FDR recordings. Normal acceleration data from the FDR are shown in Figure 3. Altitude data, recorded in 30-foot increments, are shown in Figure 4. The ground track and selected CVR sounds are shown in Figure 1.

1.12 Wreckage and Impact Information

The main wreckage came to rest to the left side of runway 13, partially inverted at the edge of Flushing Bay. Parts of the fuselage and cockpit were submerged in the water. (See figure 5). The initial ground contact scrape marks from the airplane were approximately 4,250 feet from the threshold of runway 13 and about 36 feet left of the runway centerline and ranged from 5 feet to 65 feet long. Aluminum particles and paint chips were found on these scrape marks. About 200 feet farther along the runway, plexiglass lens cover pieces were found that matched the plexiglass from the left wing tip. There were no other impact marks found on the runway that could be associated with the airplane. The elevation of the accident site was 6.7 feet msl.

Two of the three outermost VASI boxes, which were about 65 feet from the edge of the runway and 5,316 feet from the threshold, were destroyed. Black rubber transfer marks were found on the boxes.

A pair of wheel ruts 8 inches wide, about 200 feet long, was on the wet ground 5,469 feet from the threshold and 100 feet to the left of the runway's edge. Another pair of wheel ruts was nearly parallel to the first pair.

The lateral distance between the first and second pair of wheel ruts was about 16 feet, oriented about 10 degrees left of the runway's centerline. The F-28's main gear wheels are 16 1/2 feet apart.

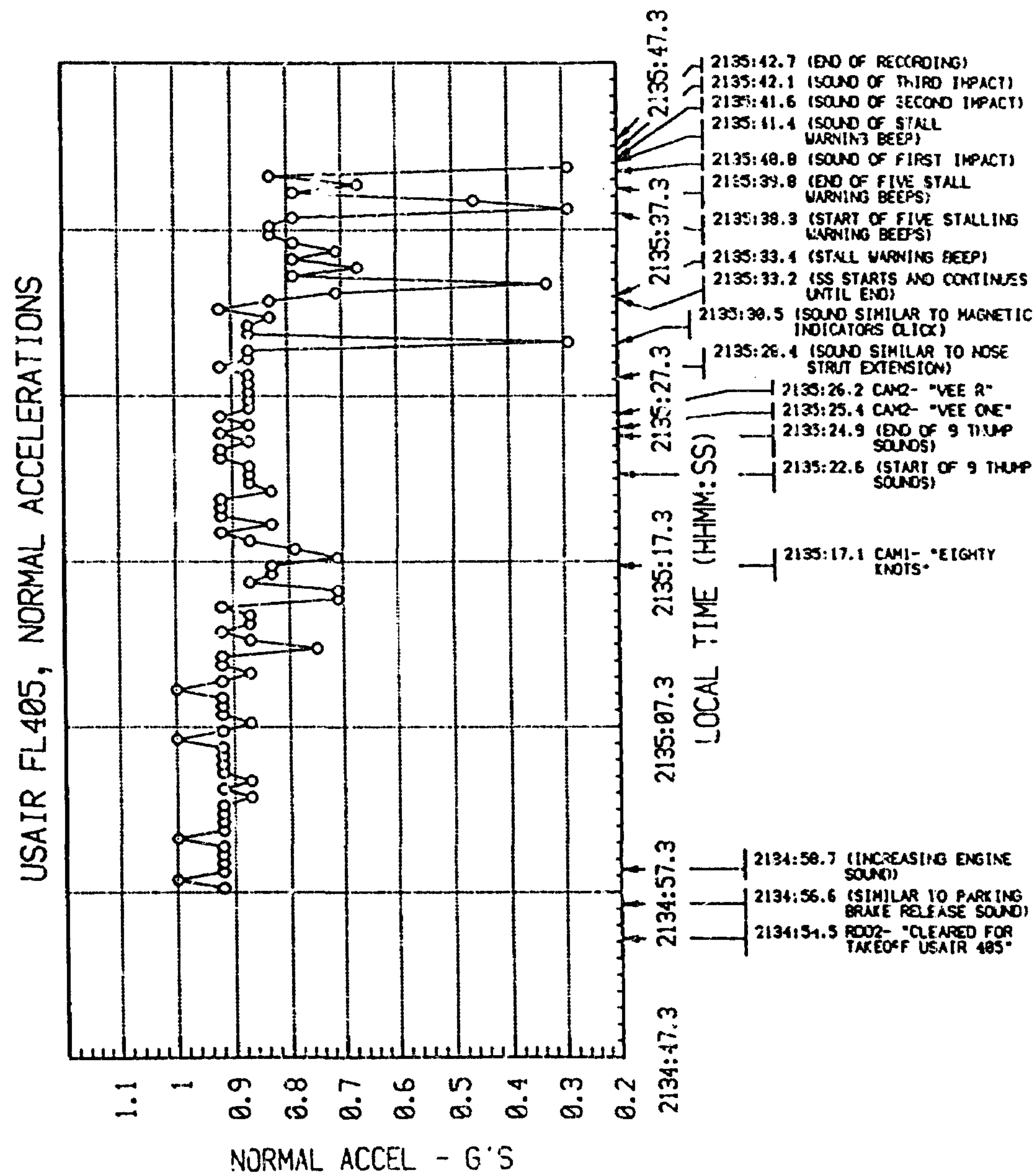

Figure 3.--Normal acceleration data.

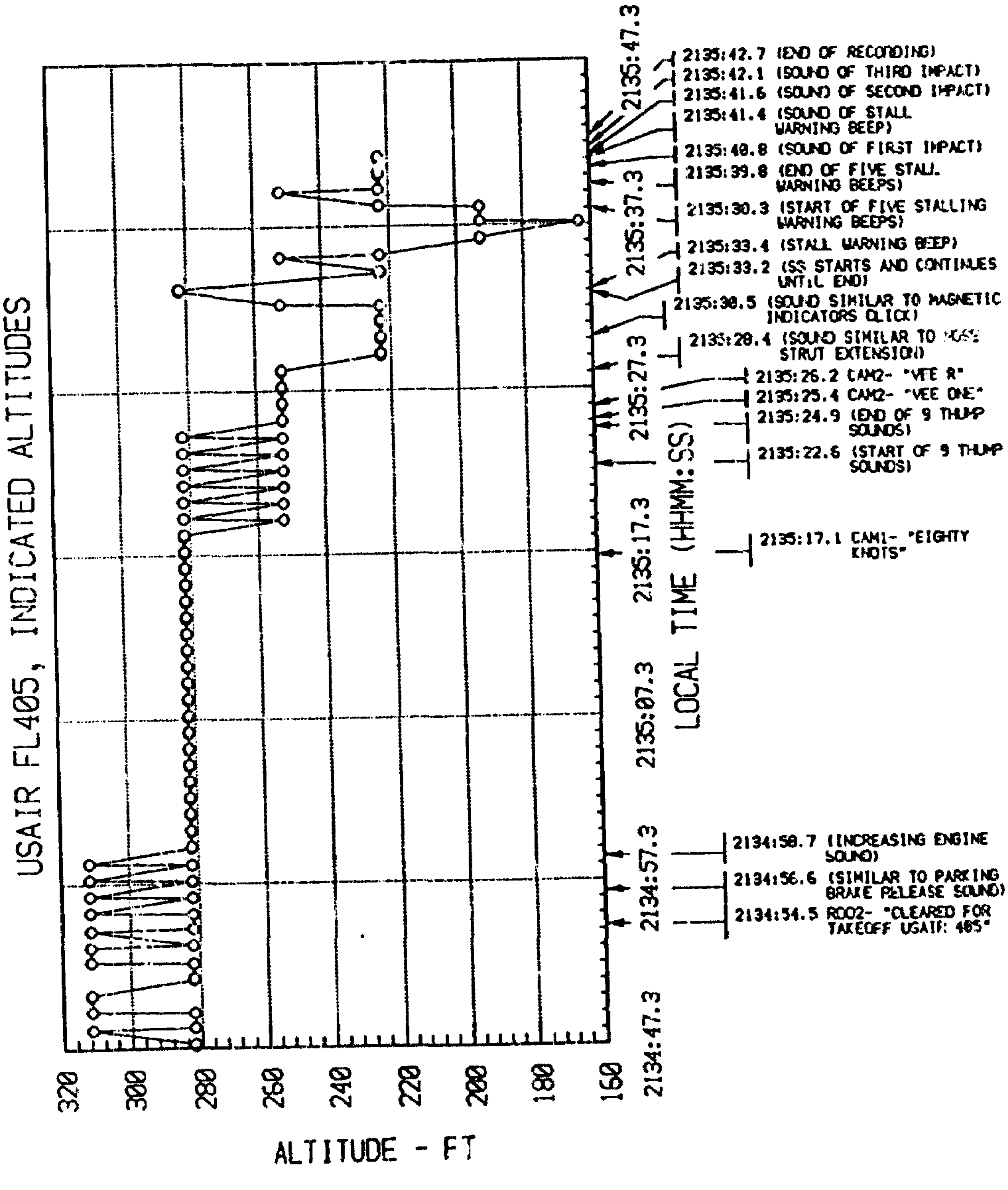

Figure 4.--Altitude data.

Figure 5.--Main wreckage of USAir flight 405.

An ILS localizer antenna structure, which was about 200 feet long, was supported by 18 metal beams, beginning 5,810 feet to 6,027 feet from the runway threshold. Fourteen beams were in a row parallel to the runway and 200 feet from the runway's left edge. The remaining four beams formed a square at the end of the structure. The last four beams, which were 6-inch "I" beams about 6,011 feet from the threshold, were damaged. Pieces of leading edge skin were embedded in the "I" beams and surrounding structure. An examination of the hole and rivet pattern on the leading edge structure indicated that the pieces were from the left wing leading edge. The first 14 beams were dislodged from their concrete bases. Small pieces of left wing structure were found between the first and last localizer "I" beams. There was no indication of fire damage to these parts.

A dike running parallel to and about 200 feet from the left edge of the runway was found scorched at a point 6,030 feet from the threshold. Fire damage and fuel on the ground were observed in this area. A water pump house 6,148 feet from the threshold was destroyed by the airplane impact and subsequent fire. A section of the aft cargo door and structure containing the door's lower hinge was found in the pump house and exhibited fire damage. Many pieces of the left wing were found around the pump house. The remaining wall behind the pump house was also damaged by the airplane's impact. Part of the wing center section was excavated from the pump house debris. Airplane structure found between the pump house and the main wreckage was damaged by fire.

A 2-foot section of the left wing tip was found 250 feet from the edge of the runway and 5,860 feet from the threshold on the Flushing Bay side of the dike, near the water.

The first right wing piece (the inboard flap) found along the wreckage path was 6,295 feet from the threshold and about 165 feet left of the runway's edge. Most of the right wing remained with the main wreckage. A 12-foot section of the left wing showing fire and impact damage was 6,765 feet from the threshold and about 195 feet from the runway's edge. Most of the remaining wreckage was found over the dike and in the water, about 6,820 feet from the threshold and about 295 feet left of the runway's edge.

The airplane was partially reconstructed, and all critical airplane structures were accounted for.

1.12.1 Airframe Damage

The fuselage separated primarily into four sections during the impact sequence. The first section, from the nose to just aft of the fourth passenger window, came to rest upside down and partially submerged in Flushing Bay. The captain's windshield was intact but sustained impact damage. The captain's aft window had no damage. The first officer's windshield had minor scratches. The first officer's sliding window was closed and undamaged and the side window was scratched. There was no evidence of bird feathers or foreign objects on or near the cockpit windows.

The left side and bottom of the forward section was crushed by impact forces. A hole was in the fuselage skin to the left of the pilot's seat. The left main entrance door was found in the closed position and had no external damage. The left side fuselage skin exhibited sooting. The right side of the forward fuselage section sustained minor damage near the roof, which exhibited compression wrinkles. The right side fuselage skin exhibited sooting. The right side service/emergency door was not found.

A second section of the fuselage, from just aft of the fourth passenger window to the eleventh passenger window, was found floating in the water. The floor and corresponding bottom structure was torn and showed fire damage, and part of the floor structure was found attached to the first section. The roof and left side structure showed compression buckling and contained soot.

The third section of the fuselage, from the eleventh passenger window to approximately the aft bulkhead, was found submerged in the water. The left fuselage skin and the crown were destroyed by fire. A portion of the fuselage skin was intact on the right side. There was fire damage to the aft section. The left wing attachment structure to the fuselage, comprised of "Z" section stringers, exhibited extensive upward and slightly aft bending. There was no indication of fire damage in this area. A short section of the right wing, about 3 feet long, remained attached to the fuselage. The fuselage around the right wing attachment was fire damaged, and the soot pattern indicated the direction of fire from bottom to top. Both emergency exit doors on the right side were missing. The right aft cargo compartment was fire damaged, and the right aft lower fuselage had impact damage with buckling and twisting of the skin. The crush was from outboard to inboard, tearing the stringers and the skin attached to them.

The fourth section of the fuselage, the empennage, was found at the main wreckage site resting on the left horizontal stabilizer. The tail cone was not damaged. The vertical stabilizer and the rudder assembly remained attached to the empennage. The left side of the vertical stabilizer and the rudder showed fire damage. The upper skin and the frame supporting the vertical stabilizer skin were burned. The leading edge of the vertical stabilizer exhibited fire damage. The right side of the vertical stabilizer showed fire damage near the root area and soot deposits on the remaining surface. The left horizontal stabilizer was bent upwards and exhibited impact damage along the leading edge. The top and bottom portions of the skin, near the front spar around the leading edge, were crushed and bent aft. The leading edge of the left horizontal stabilizer, near the root, showed impact damage along the span. Sooting from forward to aft was observed on the upper and lower surfaces. The right horizontal stabilizer was not damaged. Sooting was observed on the lower surface in a random direction and forward to aft on the upper surface.

1.12.1.1 Wing Leading Edge Damage

The entire leading edge of the left wing was damaged, and five impact strikes were evident. Three of these strike areas were 6 to 7 inches wide and penetrated the leading edge to the front spar. The front spar was bent aft at the location of the strike areas. Fire damage was observed from the leading edge to the trailing edge near the area of the strikes. The distance between the outboard and the mid-strike areas along the wing span was 75 inches, and between the mid-strike and the inboard areas was 82 inches. The remaining two impact strikes were 2 inches wide and penetrated close to the front spar. No contamination or corrosion was found on the leading edge of the left wing, and no gap existed between the base of the stall fence and the leading edge of the wing.

The leading edge of the right wing exhibited impact damage at around 15 feet and 25 feet, respectively, from the fuselage centerline. Wood was found embedded in the skin in these areas. No evidence of corrosion on the leading edge was observed, and no gap existed between the base of the stall fence and the leading edge of the wing.

1.12.1.2 Speedbrake Damage

There are two speedbrakes on an F-28; one on each side of the tail of the airplane. The right speed brake exhibited impact and fire damage. The top skin of both the right and left speed brakes were burned. There were no skid marks or scratches on the bottom of the speed brakes. Both right and left speed brakes exhibited impact damage that corresponded to the brakes in the closed position.

1.12.2 Systems Damage

The landing gear were damaged and were found in the down and locked position. All the flap tracks carried witness marks from the rollers that were in the middle of the roller travel range. The actuator screw threads were counted from the carriage to the ends of the actuator jackscrews. On another F-28 the equivalent jackscrew extension measured 18 degrees of flap deflection.

The elevator and rudder were found in the neutral position. The rudder trim jackscrew was in the mid-range. Pitch trim in the F-28 is controlled by an adjustable stabilizer. The stabilizer position was found at 0 to -1 (airplane nose up). Both aileron actuator extensions corresponded with full trailing edge up deflections. However, the continuity of the airplane's lateral control system had been lost during the crash sequence.

Both cockpit high pressure fuel valve levers were in the forward limits of travel beyond the detents. The fuel shutoff valves were in the "ON" position and both crossfeed valves were closed. All four boost pump switches were in the "ON" position, and the three unburned pumps contained fuel. The cockpit fuel indicators showed 7,100 pounds in the left fuel tanks and 7,600 pounds in the right fuel tanks.

The dual hydraulic system quantity gauges in the cockpit showed zero. All selector switches at the aft end of the console were in the forward "ON" position, and hydraulic system selector switches to the right of the radar display were raised to the normal position.

The engine pressure ratio gauges were found set at a thrust index value of 1.74 and 1.75, and the wing and tail anti-ice valves were found closed. The seals on the wing anti-ice system were examined, and no definitive indications of leakage of the engine bleed air were found. Preimpact engine, wing, and tail anti-ice switch positions could not be established because of the effects of rescue and escape activities and the movement of the inverted cockpit containing water and debris that covered the overhead switch panels.

Cockpit switches for the engine anti-ice valves were found in the "OFF" position immediately after the cockpit was drained of water. An inspection of an engine anti-ice switch revealed that the switch position could be altered easily by the application of slight pressure. The switch style had been changed when the airplane was operated by Piedmont Airlines. After the accident, USAir issued an Engineering Order to install switches that would lock into each selected position.

1.12.3 Engine Damage

The left engine separated from the fuselage and came to rest off the left side of the runway. The right engine remained with the aft fuselage and was submerged in the water for several hours.

The engines were examined on scene and were subsequently disassembled for complete examination at the manufacturer's repair facility in Canada, under the direction of a Safety Board investigator. Rotational-type damage was present in both engines. In the left engine, both the low pressure and high pressure compressors had blades that were broken and bent opposite to the direction of rotation, and molten metal impingement in the high pressure turbine was observed. In the right engine, the high pressure compressor had curled blade tips, nicked and torn blade and vane leading edges, and blades that were bent opposite to the direction of rotation. The fuel flow regulators and other accessories from both engines could not be tested because of major impact damage and water contamination.

1.12.3.1 Inlet Anti-Ice Valves

The engine anti-ice valves are operated by engine bleed air as directed by a solenoid-operated pilot valve. If electrical power is lost when the valves are open, the air is ported to the "close" side of the valve, and the valve closes. If air pressure is lost, the valve will retain the last commanded position. The valves do not move freely without power.

The inlet anti-ice valves from both engines were examined at the Safety Board's Materials Laboratory in Washington, D.C. The two valves from the right engine contained a large amount of ash and other debris, and they were cleaned with a mild detergent solution. Tap water flowed through the valves from both the right and left engines in the normal airflow direction. The outer air shell assembly of each valve was removed to determine valve position. One valve from the right engine was fully open. The other valve from the right engine was open approximately 0.25 inch. Both valves from the left engine were open approximately 0.125 inch. Full open position, engine anti-ice "ON," for this valve is 0.50 inch.

1.13 Medical and Pathological Information

Of the 27 occupants who died, 8 of them sustained minor injuries and died as a result of drowning, 7 sustained serious injuries and died as a result of drowning, 9 died as a result of blunt force trauma, 1 died as a result of smoke inhalation/burns, 1 died from burns, and 1 survived for several hours but subsequently died at the hospital with cervical spine injuries.

Some of the 24 survivors sustained injuries that consisted of fractures of the lower extremities, ribs and arms, first, second, and third degree burns to heads, hands, arms and legs, as well as multiple contusions, abrasions, and lacerations.

Federal regulations require Part 121 air carriers to have a drug testing program to prevent illegal drug use in the work place. According to the regulations, urine is collected for drug analysis; and alcohol is not one of the drugs identified in the testing procedure. Further, urine that is collected under this authority and procedure may not be used for any purpose that is not covered in 49 CFR Part 40, "Procedures for Transportation Work Place Drug Testing Program." These procedures are essentially the drug testing guidelines developed by the Department of Health and Human Services for federal employee drug-free work place programs, which require tests of urine for the following five drugs or drug classes: opiates, amphetamines, cocaine, PCP, and marijuana.

Toxicological testing of urine and blood samples of the deceased captain was completed by the Civil Aeromedical Institute, Oklahoma City, Oklahoma. The samples tested negative for carboxyhemoglobin, cyanide, ethanol and drugs.

Voluntary blood and urine samples from the first officer were requested by the Safety Board, and this request was denied. A urine sample was collected from the first officer and tested for drugs under the Department of Transportation (DOT) regulations (14 CFR 121.457). The urine sample was negative for the five drug types.

On December 5, 1989, the Safety Board issued Safety Recommendations I-89-4 through -12 asking the DOT to develop uniform regulations for the comprehensive testing of employees in safety-sensitive transportation positions for the presence of alcohol and drugs postaccident or postincident. These recommendations addressed such issues as the need for timely specimen collection, collecting blood as well as urine, including additional drugs beyond the five drug classes specified in the Department of Health and Human Services' guidelines, and a zero alcohol level. After considerable communication between the Safety Board and the DOT on these recommendations, and following the enactment of the Omnibus Transportation Employee Testing Act of 1991, on December 15, 1992, the DOT issued Notices of Proposed Rulemaking (NPRMs) that address some of the issues that were addressed in the Safety Board's 1989 recommendations. The Safety Board is currently evaluating the NPRMs and will provide comments to the DOT.

1.14 Fire

No evidence of preimpact fire was found. Several surviving passengers reported fires in the forward left and aft portions of the airplane after the initial impact. Many small fires were reported, including some on the water, after the airplane came to rest. ARFF personnel stated that when they initially observed the main wreckage site, the entire fuselage appeared to be on fire.

1.15 Survival Aspects

1.15.1 Interior Damage and Occupant Injuries

1.15.1.1 The Cockpit

The cockpit instrument panels were in place and submerged in the water. The floor on the left side of the cockpit and the captain's seat pedestal were displaced upward approximately 3 inches. The captain's rudder pedals were displaced upward to about 11 inches from the lower edge of his instrument panel. The captain's sliding window (R2) could not be unlocked because of impact damage to the left side of the nose area.

1.15.1.2 The Passengers and Seats

The airplane was equipped with 28 double and triple occupancy seats, 14 on each side of the center aisle for a total of 68 passenger seats; 28 seats were on the left side of the cabin and 40 were on the right side. Nineteen of the 28 seats had separated from the cabin floor and were scattered throughout the wreckage, and 6 of them were fire damaged. The remaining nine seats were not recovered. Of these 19 seats, 10 were from the right side of the cabin and 9 were from the left side. Only one first class seat unit at row 1D, F remained partially attached to the floor following the water recovery of the airplane. Seats that were near the front of the cabin sustained less damage than those in the rear.

Prior to impact, passengers did not assume the brace position. When the airplane came to rest, many of the passengers in the forward portion of the cabin were upside down, while others, who were upright, were submerged in water over their heads. Some passengers tried to move from their seats while their seatbelts were still buckled, and other passengers had difficulty locating and releasing their seatbelt buckles because of disorientation. Following the accident, passengers reported fires in the forward left and aft portions of the airplane, including many small fires on the water. Passengers stated that they escaped through large holes in the cabin. The lead flight attendant and first officer escaped through a hole in the cabin floor near the flight attendant's position. Several passengers reported assisting others out of the cabin and into the knee-deep water. Many of them walked in the water to the dike, climbed up the wall and over an embankment, and slid down a steep hill to the runway. Others were assisted out of the water by ground personnel. Fatally injured passengers were between rows 4 and 11, near the overwing exits, and at row 13. (See figure 2).

1.15.2 Passenger Safety Briefing Card

The examination of the passenger safety briefing cards found in the airplane showed two types of galley service doors (R-1). However, only one door is installed on a particular F-28 model at any one time. The examination also showed that the safety card did not show how to operate either of the two types of galley service doors in the emergency mode if the normal operating mode failed. In addition, the overwing briefing card depicts a plastic cover over the release handle and an opening in the cover to permit the cover's removal. Examination of another F-28 revealed that the opening in the plastic cover is shielded by thin plastic that has to be broken before a person can place his or her fingers into the cover to remove it.

1.15.3 ARFF Activities

1.15.3.1 Notification

The tower cab coordinator on duty at the time of the accident stated that he saw flames and a fireball emanating from the crash site. He listened to the emergency conference line for about 2 seconds and announced "Code 44"[10] twice. He thought no one was on the line to hear him, and he advised the supervisor that he was not getting a response. He told the supervisor to go to the brown telephone, which was the hot line to the police garage. The controller returned to the emergency conference line and repeated "Code 44," received a faint response, and gave the accident location as "Runway 13 and taxiway November." He then hung up the telephone and activated the pull box (Box 37) alarm.

The incident commander of the Port Authority of New York and New Jersey Police stated that while he was working in his office at the police emergency garage, he heard both the crash alarm and the pull box alarm sound at around 2134 to which he and the ARFF vehicles responded.

On August 13, 1991, 9 months prior to the accident, control tower personnel submitted an Unsatisfactory Condition Report (UCR) stating that the "crash phone" was unacceptable because it was "impossible to hear responses due to the poor quality of the phone lines." The reply that was attached to the UCR stated that the Port Authority of New York and New Jersey had taken steps to correct the system but that no estimated "date for replacement was available." In the meantime, a backup telephone was used.

1.15.3.2 Fire Fighting

The initial response of the Port Authority of New York and the New Jersey Police consisted of four ARFF vehicles, carrying about 7,400 gallons of extinguishing agent. Three of these vehicles were primary crash trucks (required to meet 14 CFR 139 Index D criteria) and the other was a reserve truck. Seven ARFF personnel responded in these vehicles. The ARFF vehicles responded immediately upon hearing the "Call 44" alarm and communicated with the tower on ground control frequency while en route to the crash site. Additional police/ARFF officers responded in sector cars from various points in and around the terminal area.

ARFF personnel reported that snow and fog hampered their visibility during the response. As a result, vehicle speeds were reduced, and the airplane was not visible to them. The ARFF crew chief, in truck 1, reported that they arrived in the area about 4 minutes after the notification and that truck 1 began to apply

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[10] "Code 44" is referring to "Call 44" that is defined in the LaGuardia Airport Certification Manual, page 17-9, as: "An actual or impending crash. Major aircraft accident or fire. Aircraft in dire emergency. Full response as indicated in the aircraft emergency plan will go into effect."

extinguishing agent to the burning pump house. At that time the airplane was not visible to them; however, he observed people on top of the dike. After extinguishing most of the fire in the pump house, which he estimated took about 30 seconds and one-half of the extinguishing agent aboard truck 1, he dismounted, donned his self-contained breathing apparatus, and climbed the dike where he observed the burning fuselage in the water. ARFF personnel used the crash truck turrets to apply extinguishing agent over the dike to the burning fuselage. Since the turret operators, who were inside the trucks, could not see the fuselage, fire fighters proceeded to the top of the dike to direct the aiming of the turrets with hand signals.

ARFF personnel and New York City Fire Department (NYCFD) fire fighters used hand lines to attack the fuselage fire. The incident commander estimated that the fire was under control in 10 minutes. He also stated that the lack of an emergency medical service (EMS) representative in the command post created difficulties in coordinating EMS activities.

1.15.3.3 Water Rescue

The Port Authority and the New Jersey Police Department have two rescue boats: a 19-foot "Boston Whaler" powered by a 70-horsepower outboard motor, and a 25-foot "Boston Whaler" powered by two 150 horsepower outboard motors. At the time of the accident, the 25-foot boat was on a trailer, parked near the police emergency garage. Construction of a boat lift was underway but had not yet been completed. The incident commander's chronological report confirmed that the 19-foot boat responded at 2151. Command post logs show that the 25-foot boat was launched at 0100. In addition, two New York Police Department (NYPD) boats, one Nassau County Police Department boat, and seven U.S. Coast Guard boats participated in the emergency response.

The first divers to enter the water were officers from the NYPD Harbor Scuba Team. They estimated that they entered the water at 2220 and did not find any passengers alive in the water or inside the airplane.

1.15.3.4 Medical Response

At 2146, the first New York City EMS unit, which was an automobile with an EMS lieutenant on board, arrived at the airport's Guard Post 3 staging area. The unit was held there until it was escorted by some NYCFD fire trucks to the crash site at 2151. The EMS lieutenant stated that the first EMS ambulance units, which included two advanced life support ambulances, two basic life support ambulances, and one mobile emergency room, arrived at the crash site at 2155. The EMS lieutenant stated that he established a triage area on the paved surface of runway 13/31 opposite the crash site. The lieutenant also stated that he placed 12 survivors into response vehicles and a pickup truck for transport to hospitals. He assigned triage functions to paramedics/emergency medical technicians and implemented triage tagging. An additional triage area was established at the Trump Terminal. Six injured passengers were transported by a van from the Trump Terminal to the EMS staging area at the intersection of the Grand Central Expressway and Ditmar Boulevard for subsequent transportation to hospitals. The lieutenant stated that buses to shelter and transport the uninjured survivors arrived about 2 hours after these activities took place. He transferred the command of triage activities to an assistant chief of EMS. The lieutenant stated that all of the injured passengers were removed from triage areas within 1 hour and 10 minutes from the time he was notified. A total of 52 people, including rescuers and the deceased, were transported to hospitals, and 50 persons were handled at the runway 13/31 triage area. Three passengers refused treatment. The EMS lieutenant reported that no attempts were made to resuscitate victims who appeared drowned and/or lacked vital signs because he believed that such victims could not be revived after succumbing in cold salt water.

The lieutenant estimated that 15 ambulances responded to the accident site, all of which were used to transport the injured to hospitals, and that 40 additional ambulances were available at the staging area but were not needed.

1.16 Tests and Research

1.16.1 Effects of Airframe Contamination on Airplane Performance

A number of flight tests, simulator studies, and resultant publications have addressed the significant effects on aerodynamic performance that may result from icing on an airplane's wing upper surface or leading edges during takeoff. Wind tunnel and flight tests have shown that minute amounts of ice or other contamination on the leading edges or upper surfaces can cause a significant reduction in the stall AOA.[11] The tests showed that such contamination can reduce wing lift as much as 30 percent and increase drag by as much as 40 percent. Further, uneven contamination across the leading edge can result in wing drop or

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[11]B. L. G. Ljungstrom: "Wind Tunnel Investigation of Simulated Hoar Frost on a Two-Dimensional Wing Section With and Without High Lift Devices," FFA-AU-902, April 1972, *Wingtips* magazine No. 14, December 1989.

roll as the stall develops unevenly across the wing. Upper wing surface contamination reduces boundary layer control and induces separation and disruption of airflow over the wing, thereby reducing lift.

It was stated in a paper published by Douglas Aircraft Company "The Effect of Wing Ice Contamination on Essential Flight Characteristics" that, "As the amount of contamination increases, the airplane becomes increasingly unstable, eventually stalling without stick shaker activation at speeds normally scheduled for takeoff."[12]

At the FAA-sponsored "International Icing Conference on Airplane Ground Deicing," held on May 28 and 29, 1992, Working Group I, Aircraft Design Considerations, had many conclusions and recommendations on the subject of ice and frost contamination on wings. The following is a partial list of Group I's consensus items:

- Wing upper surface contamination of ice, snow or frost causes significant increases in stall speeds and reductions in rate-of-climb capability.

- Wing contamination decreases the stall AOA (angle of attack) resulting in loss of artificial stall warning for some aircraft.

- At small wing contamination roughness, hard wings (no leading edge devices) show a larger percentage of lift losses than wings with leading edge devices and may operate with reduced stall speed margins. However, these differences are not significant enough to allow operation with wing contamination for any class of airplanes.

Recommendations:

- Strict attention needs to be focused on ensuring that critical aircraft surfaces are free of contamination of ice, frost and snow.

- Keep it clean.

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[12]Douglas Aircraft Company, paper No. 8501, April 29, 1991.

- Airframe manufacturers should continue to review effects of wing contamination for hard wings and to recommend appropriate performance adjustments.

1.16.2 Aerodynamic Effects of Deicing/Anti-icing Fluids

Type I and Type II fluids are used to negate the effects of ice contamination on airplane structures.[13] Type I fluids are used for "deicing." Deicing fluid removes ice from the surfaces of the airplane but does not prevent refreezing. Type II fluids are used for "anti-icing" an airplane. Anti-icing fluid provides protection against refreezing for a period known as the effective holdover time. Type II fluids have been used primarily in Europe for many years with a good safety record. The majority of the airplane operators in the United States rely upon Type I fluids for protection. Type II fluids were not available at LaGuardia Airport. The accident airplane was deiced with Type I fluid approximately 35 minutes before the attempted takeoff.

Flight tests have shown that both Type I and Type II deicing/anti-icing fluids do flow off the wings of a treated airplane in significant amounts during the initial takeoff ground run.[14] However, the residual fluid is sufficient to cause a temporary decrease in lift and an increase in drag during rotation and initial climbout. These effects are more significant at lower ambient temperatures. It is generally agreed that the aerodynamic effects of the newest generation of Type II fluids are minimal and impose no greater aerodynamic effects than Type I fluids. However, these aerodynamic effects were deemed significant enough by Boeing to recommend performance adjustments on two early models of B-737 airplanes. For all other Boeing models, the manufacturer believes that there are sufficient performance margins available to offset the effects of the fluids. Fokker has studied the effects of deicing/anti-icing fluids on the Fokker 100 airplane and concluded that "no performance corrections need be applied when the aircraft is correctly deiced and anti-iced prior to take-off."[15] Fokker personnel stated that this conclusion is also applicable to the F-28 airplane.

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[13] Type II fluid can be operationally defined as fluid containing a minimum glycol content of 50 percent (with 45-50 percent water plus thickeners and inhibitors) and/or meets the AEA Type II specification.

[14] L. J. Runyan, T. A. Zierten, E. G. Hill and J. K. Murakami: Joint Boeing/AEA/NASA flight and wind tunnel evaluations of aircraft ground deicing/anti-icing fluids, presented to AEA Deicing/Anti-icing Task Force, 13 July, 1988, Hamburg, West Germany

[15] According to the December 1989 issue of Fokker's *Wingtips* publication.

Working Group I also had many conclusions on the subject of deicing/anti-icing fluids. The following is a partial list of the group's consensus items:

- o Not all the fluid flows off the wing prior to liftoff.
- o The remaining fluid residual (roughness) generally results in measurable lift losses and drag increases.
- o The fluid effects vary with the flowoff characteristics of each fluid, ambient temperature, dilution, model configuration, and exposure to precipitation.
- o The aerodynamic effects of the fluids rapidly dissipate after liftoff.
- o In general, reduced thrust procedures for takeoff (assumed temperature method) are acceptable when deicing/anti-icing fluids are used - provided the runway is clean of snow or slush. However, the airframe manufacturers may require thrust margins for specific aircraft models.
- o Airframe manufacturers may make additional recommendations based on the fluid effects on specific aircraft models.

1.16.3 Effect of Wing Contamination on Takeoff Characteristics of the F-28 Mk4000

At the request of the Safety Board, a parametric study of the takeoff characteristics of the F-28 aircraft was conducted by Fokker's Aerodynamic and Aeroelasticity Department, using parameters specified by the Safety Board. The study consisted of 14 test cases that investigated the effects of pilot technique and ice contamination on the wing's upper surface. The simulation test results are summarized in appendix E.

The complex analytical simulation of F-28 Mk4000 performance was based on nonlinear equations of motion. The characteristics of the engines and landing gear were also modeled. The aerodynamic model was based on wind tunnel measurements and included, where applicable, the effect of wing contamination on lift, drag, and pitching moment. Post-stall data were included to allow path simulations in which the AOA exceeded the stall AOA in free flight and in ground effect.

The results of the Fokker study quantified the effect of varying rotation speed, rotation rate, and the target pitch attitude for initial climb with both a clean wing and a wing with ice contamination on the upper surface.

An addendum to this study provided additional F-28 dynamic simulations in which flight control inputs were modified until an approximate match was made with the events and times derived from the accident airplane's CVR. There were no reasonable scenarios wherein the sounds coincident with takeoff rotation and the activation of stall warning devices could be replicated when the simulation was conducted with an airplane having a clean wing. When the aerodynamic performance was degraded by wing contamination, the simulation showed a reasonable approximation of the events as they were recorded on the CVR.

1.16.4 View of Right Wing From First Officer's Seat

On April 1, 1992, Safety Board invesrigators and other parties to the investigation convened at Newark International Airport for the purpose of observing the F-28 wings at night from the first officer's seat before and after deicing.

The sliding cockpit window was opened fully, allowing an unobstructed view of the right wing. When an investigator leaned his head out of the window, the wing's leading edge rivets and about the outer 80 percent of the wing's leading edge were visible. The black strip used by flightcrews to determine wing ice contamination accumulated in flight was visible, and it appeared flat black in contrast to other reflections on the leading edge. The ice light, which is for in-flight detection of leading edge contamination, shone on the ground and reflected light upward onto the wing. This light made little or no difference with regard to helping investigators observe the upper wing surface.

The first officer's sliding window was then closed. About 60 percent of the outer wing was visible when it was observed through both the sliding window and the window behind it. With the sliding window closed, it was difficult to see details or any parts of the wing, such as rivets. When attempts were made to observe the black strip, it could only be seen through the scratched window behind the sliding window, and it was difficult to see details of the wing. The flat black strip was visible but distorted by the window glass.

The airplane was then deiced, and the sliding cockpit window was opened fully, allowing an unobstructed view of the right wing. When the investigator leaned his head out of the window, the wing's leading edge rivets and about the outer 80 percent of the wing's leading edge were visible, appearing wet and glossy.

With the window closed following deicing, the team agreed that it would be difficult to distinguish between wetness and clear ice on the leading edge. The group agreed that if the outboard 60 percent of the wing were covered with snow, the snow could be seen.

1.17 Additional Information

1.17.1 USAir Cold Weather Operations Guidance

The Cold Weather Operations section of USAir's F-28 Pilot's Handbook included the following guidance, in part:

> GENERAL
>
> During a normal takeoff, the angle-of-attack reaches approximately 9 degrees at rotation. Thin layers of ice resulting from frost or freezing fog cause a certain sandpaper roughness of the wing and tail surfaces. This roughness may cause air-flow separation at angles-of-attack below 9 degrees resulting in control problems, wing drop or even a complete stall shortly after rotation.
>
> EXTERIOR SAFETY INSPECTION
>
> Although removal of surface snow, ice or frost is normally a maintenance function, the flight crew should be alert during preflight preparation to inspect areas where surface snow or frost could change or affect normal system operations. Supplemental preflight checks should include the following: SURFACE - CHECK FREE OF FROST, ICE AND SNOW.

BEFORE TAKEOFF

It is the captain's responsibility to exercise caution prior to takeoff. If the elapsed time since deicing exceeds 20 minutes, careful examination of the surfaces should be conducted to determine the extent of accumulation and to assure that the takeoff can be made safely and in compliance with existing FARs.

TAKEOFF

The recommended rotation rate is approximately 3 degrees per second. At light gross weights and cold temperatures, this rate will result in an initial climb speed above $V_2 + 20$. Initial climb speeds up to $V_2 + 20$ will not significantly affect the climb profile.

NOTE: Smooth rotation rates are essential in avoiding possible pitchup and roll-off characteristics that may be encountered when airfoil contamination is likely.

If pitchup and/or roll-off is encountered after liftoff, use aileron, rudder and elevators as required to maintain desired flightpath. Smooth, continuous flight control inputs should be used to avoid over-controlling.

1.17.2 FAA Deicing Regulations

For many years, the FAA has conducted research on aircraft icing characterization, protection concepts, and deicing/anti-icing fluids. The agency has disseminated advisory circulars, bulletins, memoranda, articles and notices related to winter operations in an effort to ensure that this information is dispersed and integrated into the appropriate aviation systems.

The following Federal Aviation Regulations (FARs) on pilot and operator responsibility for aircraft operation in icing conditions became effective in 1950: FAR Part 91.3, Responsibility and Authority of the Pilot in Command; FAR Part 121.629, Operation in Icing Conditions; FAR Part 91.527, Operating in Icing Conditions; and FAR Part 135.227, Icing Conditions: Operating Limitations. In 1982, prompted by the Air Florida accident investigation, the FAA published Advisory Circular (AC) 20-117, Hazards Following Ground Deicing and Ground

Operations in Conditions Conducive to Aircraft Icing.[16] AC 20-117 emphasizes the "clean aircraft concept," stressing that even minute amounts of frost, ice or snow on particular aircraft surfaces can cause degradation of aircraft performance and changes in aircraft flight characteristics. Since the AC was originally published, as many as 10 icing-related accidents, including USAir flight 405, have occurred. Prior to January 1, 1992, the FAA had not mandated any specific regulations on airframe icing detection, prevention and deicing.

The Safety Board has issued 39 safety recommendations that address airframe ice accumulation, engine ice accumulation, ground icing and deicing, and the detection of weather conducive to icing conditions. (See appendix F). Twenty of these safety recommendations were prompted by five airplane accidents that occurred during takeoff.[17] In these five accidents, the Safety Board found that the surface of the airplane's wings had accumulated some ice contamination, degrading the airplane's aerodynamic performance. These recommendations address topics that include informing operators about the characteristics of deicing/anti-icing fluids; informing flightcrews about the potential for ice formation after deicing; reviewing information that air carrier operators provide to flightcrews on runway contamination and engine anti-ice during ground operations; requiring flightcrew inspections before takeoff if takeoff is delayed after deicing; emphasizing to air carrier maintenance departments the importance of maintaining ground support equipment; and requiring air carrier training programs to cover the effect of wing leading edge contamination on aerodynamic performance.

Numerous Safety Board recommendations have been made for the issuance of airworthiness directives (ADs) or air carrier operations bulletins (ACOBs) that direct specific procedures for aircraft having characteristics that make them more susceptible to icing problems. In response to a Safety Board recommendation, the FAA issued AD 92-03-01, AD 92-03-02, and ACOB 03-92-1. These rules were directed solely at the flightcrews of DC-9-10 series aircraft and

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[16] Aircraft Accident Report--"Air Florida, Inc., Boeing 737-222, N62AF, Collision with 14th Street Bridge, Near Washington National Airport, Washington, D.C., January 13, 1982" (NTSB/AAR-82/08)

[17] Aircraft Accident Report--"Ozark Airlines, Inc., McDonnell Douglas DC-9-15, N974Z, Sioux City Airport, Sioux City, Iowa, December 27, 1968." (NTSB/AAR-70/20)

NTSB Field Investigation--"Trans World Airlines Flight 505, McDonnell Douglas DC-9-10, Newark International Airport, Newark, New Jersey, November 27, 1978."

NTSB Field Investigation--"Airborne Express, Flight 125, McDonnell Douglas DC-9-15, Philadelphia International Airport, Philadelphia, Pennsylvania, February 5, 1985."

Aircraft Accident Report--"Continental Airlines, Flight 1713, McDonnell Douglas DC-9-14, Stapleton International Airport, Denver, Colorado, November 15, 1987." (NTSB/AAR-88/09)

Aircraft Accident Report--"Ryan International Airlines, Flight 590, McDonnell Douglas DC-9-15, Cleveland-Hopkins International Airport, Cleveland, Ohio, February 17, 1991." (NTSB/AAR-91/09) state that a visual check and a physical (hands-on) check of the leading edges and upper wing surfaces must be made to verify that the wings are clear of contamination prior to takeoff. To date, no other airplane models have been singled out for special procedures by the FAA. However, the Safety Board had recommended that the need for such precautions be reviewed for other transport airplanes that did not have leading edge devices.

Based, in part, on the results of the FAA-conducted International Conference on Airplane Ground Deicing, the FAA proposed on July 21, 1992, that each U.S airline must have an FAA-approved ground deicing plan in place for the winter season by November 1, 1992. The FAA is encouraging airline, airport, and air traffic control officials to develop deicing plans jointly for specific snowbelt airports. The proposal applies solely to large civil jet aircraft operating under FAR Part 121. The proposal also requires that the airlines limit the length of time that an airplane can be exposed to snow or freezing rain before it is inspected or deiced and that they train pilots and other personnel to detect wing ice. The FAA is also encouraging the airlines to switch from the use of Type I deicing fluid to Type II.

The FAA has changed operational procedures for controlling the flow of aircraft on the ground to reduce the length of time aircraft must wait in line for takeoff after being deiced. The FAA has also said that it will ask the Society of Automotive Engineers (SAE) to convert its ad hoc committee on ground deicing to a permanent committee. SAE charts show the amount of time that an airplane can be exposed to icing conditions after the application of Type I or Type II fluids before the fluid becomes effective. (See appendix G). In addition, the FAA has stated that it will make available Airport Improvement Program funds to help finance the construction of deicing pads on taxiways to further reduce the time between deicing and takeoff.

On September 23, 1992, the FAA published the "Deicing Interim Final Rule." The rule relates to such topics as Holdover Times; Type I and Type II Fluids; Pretakeoff Contamination Check; Inspections for Specific Airplane Types by Airworthiness Directive; the Takeoff Decision; Training; Airport/ATC Roles; Cost; Environmental Analysis; and Federalism Implications.

2. ANALYSIS

Strange as it may seem, a very light coating of snow or ice, light enough to be hardly visible, will have a tremendous effect on reducing the performance of a modern airplane. Although this was known in Canada for many years, only in the last three years has this danger been recognized here. It occurs only when the ship is on the ground, and makes take-off dangerous. To avoid this danger the airlines cover the wings with tarpaulins, or they make certain that all ice is off before the airplane is allowed to depart.

Jerome Lede..., M.E.[18]
April 20 ...

2.1 General

The airplane was certified, equipped, and maintained in accordance with FAA regulations and company procedures. The weight and balance were within the prescribed limits for the takeoff.

The captain and first officer were certified and qualified for their respective positions in accordance with company standards and Federal regulations. The CVR evidence and the first officer's statements indicate that the captain was controlling the airplane and the first officer was performing the nonflying pilot duties during the takeoff.

There is no evidence that the flightcrew had adverse medical histories. The toxicological specimens obtained from the captain during the autopsy were negative for alcohol and drugs. The first officer's urine sample was negative for the presence of the five drugs tested for under DOT regulations. However, tests for the presence of alcohol or drugs, other than the five tested for under DOT regulations, were not conducted because the first officer declined to submit blood samples for toxicological examination.

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[18] From "Safety in the Operation of Air Transportation," a lecture under the James Jackson Cabot Professorship of Air Traffic Regulation and Air Transportation at Norwich University. Mr. Lederer started his career in 1926 as an aeronautical engineer for the U.S. Airmail Service. Among his considerable contributions to aviation safety, he evaluated risks for aviation insurance underwriters; served as Director of Safety, Civil Aeronautics Board; founded the Flight Safety Foundation; and served as Director of Safety, National Aeronautics and Space Administration.

The Safety Board determined that the fire fighting and water rescue response were efficient under the circumstances and contributed to the survivability of many of the airplane occupants.

There was no evidence that general life habits or recent events adversely affected the flightcrew performance. Analysis of fatigue factors indicated that while both the captain and first officer had put in a long day and that this was 3 and 1/2 days into a 4-day trip, they were both well-rested. Additionally, experimental studies[19] indicate that crews perform better in terms of problem solving and general crew coordination at the end of a multiple day trip than at the beginning.

Examination of the wreckage and maintenance records revealed no evidence of preimpact failure or malfunction of the airplane structure or systems.

The CVR sound spectrum study, crew testimony, and postaccident examination of the engines indicate that both engines accelerated normally at the start of takeoff, and operated normally until initial impact. The one fully open engine anti-ice valve and the three partially open engine anti-ice valves indicate that the engine anti-ice had been properly selected "ON" for both engines for takeoff.

At the time of the accident, LaGuardia Airport was in instrument meteorological conditions due to an indefinite ceiling, 700 feet vertical visibility, and 3/4-mile prevailing visibility in light snow and fog. Although such conditions had been reported at LaGuardia since 2050, the Safety Board determined that the surface condition of runway 13/31 was acceptable for safe operations since the coefficient of friction and the depth of the wet snow were within acceptable operating limits. Plowing and sanding of the runways had been appropriately conducted and were continuing as needed. In addition, NOTAMs[20] had been transmitted, or were currently being transmitted, that accurately described runway surface conditions at the time of the accident.

The PIREP reporting a "nil" braking action on runway 4/22 resulted in the immediate and appropriate closure of that runway. This resulted in increased delays and a longer holdover time for flight 405 after it had been deiced at the gate. However, the Safety Board believes that the closure of runway 4/22 was an

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[19]Foushee, H.C., Lauber, J.K., Baetge, M.M. and Acomb, D.B., 1986. Crew Factors in Flight Operations III: The Operational Significance of Exposure to Short-Haul Air Transport Operations. NASA Technical Memorandum 88322, NASA-Ames Research Center, Moffett Field, California.

[20]Notice to Airmen.

operational necessity to ensure the safety of operations on that runway. This factor did contribute to the delays encountered by departing airplanes.

The evidence gathered from the CVR and the FDR, as well as the statements of the first officer and passengers, revealed that after liftoff, the airplane could not transition to a positive climb angle. This situation indicated that the aerodynamic lift-producing capability of the wings was degraded. There are numerous possible reasons for a loss of aerodynamic efficiency, such as an improper wing configuration, deployment of speedbrakes, and contamination or roughness of airfoil surfaces.

There was no evidence that wing leading edge paint roughness or erosion/corrosion existed that could have degraded the airplane's performance. The fire patterns and damage to the speedbrakes showed that the speedbrakes were stowed before and during the accident sequence.

The continuity of the airplane's flight control systems was examined and revealed no failure prior to impact. The six flap actuator jackscrews confirmed that the flaps were set at 18 degrees, the proper configuration for takeoff from a contaminated runway. The wing and tail bleed air systems, including their seals, were intact, and the systems were found shut off. Therefore, the evidence indicates that there was no bleed air leakage that would have contributed to a loss of lift during the takeoff attempt.

The evidence did not support improper wing configuration, airframe or system defects, or deployment of the speedbrakes as reasons for the loss of aerodynamic efficiency. Consequently, the analysis of this accident focused on the following: the weather affecting the flight; USAir's deicing procedures; industry airframe deicing practices; air traffic control aspects affecting the flight; USAir's takeoff and preflight procedures; and flightcrew qualifications and training. The dynamics of the airplane's impact with the ground, postaccident survivability, and crash/fire/rescue activities were also analyzed.

2.2 Prevailing Weather Conditions

The Terminal Forecast for LaGuardia Airport, prepared by the National Weather Service (NWS), did not need to be updated at the time of the accident. The temperature recorded at the airport was below freezing, and wet snow was falling continuously for several hours prior to the accident. Therefore, flight 405 was exposed to conditions that were conducive to airframe icing.

2.3 Flight Performance of USAir Flight 405

Aircraft headings and indicated air speeds obtained from the FDR were used to develop a time history of the airplane's ground track from the beginning of takeoff to the impact. Further, the acceleration during the takeoff, as derived from the air speed data, was compared with the expected acceleration, as calculated by the manufacturer. The comparison of accelerations showed that the takeoff ground roll of flight 405 was normal. While ice contamination increases the drag produced by the wing, this effect is not significant below the air speeds and high AOA associated with liftoff and initial climb. During flight 405's takeoff ground roll, wing AOA was near zero, and the air speed was relatively low. The ground roll performance exhibited by the airplane was normal as would be expected with or without ice contamination on the wings.

The Safety Board's evaluation of simulation data provided by Fokker for the conditions of the accident takeoff showed that the airplane without wing contamination would lift off about 2 seconds after the start of rotation, assuming an average 3-degrees-per-second rotation rate. During the 2 seconds, the airplane would accelerate about 7 knots. Thus, with the start of the rotation at a pitch attitude of -1 degree and a proper speed of 124 knots, the airplane would lift off as it reached 131 knots when the pitch attitude was about 5 degrees. The simulation data showed that the AOA would reach a peak of about 9 degrees as the airplane transitioned to the initial climb. With a stall AOA of 12 degrees in ground effect, the airplane, without wing contamination, would have at least a 3 degree-AOA stall margin during the transition to climb. This margin would increase as the airplane accelerated and established a climb.

Two distinctive sounds were recorded on the CVR shortly after the V_R call. The correlation with FDR data showed that the first sound occurred as the airplane passed 122 knots, and the second occurred 2.2 seconds later. A comparison of these sounds with sounds recorded during a normal takeoff of other F-28 airplanes disclosed that the first sound was similar to the extension of a nose wheel strut and the second sound was similar to the magnetic clicks in the lift dumper indicator on the instrument panel that occur coincident with the extension of the main landing gear struts. The Safety Board used the timing of these events to analyze the speed at which the captain of flight 405 started to rotate the airplane and the rate of rotation to the takeoff pitch attitude.

The simulation conducted by Fokker showed that during a normal rotation the nose strut extension occurs about 0.7 second after the captain initiates rotation through the control column. Thus, the Safety Board concluded that the captain initiated a takeoff rotation when the airplane reached about 119 knots, about 5 knots lower than the proper rotation speed. The timing between the nose gear strut extension and the main gear strut extension indicated that the rotation rate was about 2.5 degrees per second, a rate that was in accordance with USAir procedures. The Safety Board's analysis showed that, with the rotation at a 5 knot slower speed, 119 knots, compared with 124 knots, the airplane would lift off at about 128 knots with an AOA of about 5.5 degrees. Under these conditions, the AOA probably exceeded 9 degrees as the airplane transitioned to a normal climb. According to Fokker wind tunnel data, a wing upper surface roughness caused by particles of only 1-2 mm diameter (0.4-0.8 inch), at a density of about one particle per square centimeter, can cause lift losses on the F-28 wing of about 22 and 33 percent, in ground effect and free air, respectively. When the aerodynamic characteristics of the wing were degraded during the simulations to a level consistent with the performance attained during previously conducted contaminated wing tests, the stall AOA in ground effect was reduced from 12 degrees to 9 degrees. Thus, it is probable that, during the transition to climb immediately after liftoff, the airplane reached an AOA beyond the stall AOA with significant loss of both lift and lateral control effectiveness. The abrupt roll that occurred during the takeoff of flight 405 is consistent with this analysis. The replication of events in the Fokker F-28 simulator confirmed that, with a contaminated wing, AOAs as high as 12 degrees, well into the stall regime, were reached even when the pilot initiated rotation at the proper speed to a target pitch attitude of 15 degrees at a rate of 3 degrees per second.

The following is from a Fokker document[21] on the effect of wing ice contamination on the F-28 wing:

> With frost roughness present on the wing upper surface the characteristic of slow stall progression towards the wing tip is lost and uncontrollable roll may develop at angle of incidence (attack) as low as 10 degrees...The drag of the clean wing is such that the aircraft is capable of climbing away at the required climb angle at V_2 with one engine inoperative. In the case of a contaminated wing the drag may, however, be doubled due to a wing stall which occurs at an angle of incidence (attack) only slightly greater than that for

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[21] Fokker Report L-28-222 "Note on the Aircraft Characteristics as Affected by Frost, Ice or Freezing Rain Deposits on Wings," dated December 16, 1969.

stick shaker operation. Consequently, acceleration is lost even with all engines operating at T.O. power.

Most wings are designed so that the inboard sections will stall before the outboard sections. This design ensures that roll control can be maintained through use of the ailerons on the outboard wing sections. However, the variable distribution of ice particles and shorter chord length on the outboard sections of the wing usually create an irregular stall distribution across the wing. A premature stall of the outboard sections usually occurs first, with a resultant loss of lateral control. A significant nose-up pitching moment would also be expected in swept wing aircraft when the outboard wing sections stall. However, the sweep angle of the F-28 wing is only 16 degrees, and wind tunnel tests conducted by Fokker indicate that a nose-down pitching moment can occur following a contaminated wing stall.

In any event, it was apparent from the evidence that after liftoff, the airplane could not transition to a positive climb angle during the 11 seconds that it was airborne before striking the dike. The maximum air speed recorded by the FDR during the 11 second flight was 134 knots, stick shaker activated at this time, and air speed then decreased and varied between 130 and 128 knots for the remainder of the flight. According to the Fokker simulation data, at this speed, the airplane should have been able to sustain a load factor of 1.5 G at the stick shaker threshold AOA which would still have provided about a 3-degree AOA stall margin. The single "beep" of the aural stall warning immediately after stick shaker activation indicates that the airplane momentarily attained an even higher AOA, between 12.5 and 15 degrees. However, the signal was not continuous, and for 5 seconds the airplane was apparently at an AOA less than that at which lift, with a clean wing, normally begins to decay and drag increases rapidly. That the airplane was unable to attain this normal flight performance is considered by the Safety Board to be conclusive evidence that the normal aerodynamic lift capability characteristic of the wing was significantly degraded by an accumulation of frozen contaminant.

2.4 Deicing Fluid Holdover Time and Ice Accumulation

The Safety Board found that the airplane had been properly cleared of ice and snow during the two deicing procedures at the gate. However, approximately 35 minutes elapsed between the second time that the airplane was deiced and the initiation of takeoff during which the airplane was exposed to continuing precipitation in below freezing temperatures.

An objective determination of the amount of ice that could have formed on the wings and empennage surfaces of the airplane after it was deiced requires analysis of numerous variables and assumptions. First, an estimation must be made of the length of time that the deicing fluid was effective. Although extensive research has been performed in ground deicing technology, the calculation of the effective holdover time of the deicing fluid is complicated by more than 30 variables that may influence the effectiveness of the deicing solution. Some of the more important variables after application include the influence of precipitation, deicing fluid thickness, strength, and temperature, aircraft skin and ambient temperature, wind (actual wind or apparent wind due to taxiing), residual moisture on airframe surfaces, and the conditions of the ramp, taxiways, and runways.[22] In addition, it has been shown that ice will not necessarily form at a uniform level across the wing, since ice accretion on a wing may start earlier at certain locations than at others. Moreover, after the effective holdover time has been exceeded, the amount of precipitation accumulation on the airplane must be determined for the remaining time interval before takeoff.

Although the weather observatory at LaGuardia is about 3/4 of a mile from the gate area, the assumption was made that the rate of snowfall at the airplane location was consistent with that near the observatory. Other factors, such as aircraft skin temperature, shape and slope of the airplane surface, wind direction, and speed may also affect the accumulation of snow or ice on the airplane.

The average amount of time calculated to deice/anti-ice an airplane was investigated. Based on past accident investigations, 12 minutes was the average time necessary to deice/anti-ice a large airplane using two deice/anti-ice trucks. It could take longer if there is a considerable accumulation of ice, the airplane is large, such as a Boeing 747, and if only one truck is used. For smaller airplanes, deicing could take less than 12 minutes using two trucks.

Aircraft exposure time must be calculated from the time that deicing begins rather than when it is completed. The FAA NPRM in the Federal Register of July 23, 1992, states that "Holdover time begins when aircraft ground deicing/anti-icing commences and expires when the deicing/anti-icing fluid applied to the aircraft wings...loses its effectiveness."

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[22]FAA AC 20-117, "Hazards Following Ground Deicing and Ground Operations in Conditions Conducive to Aircraft Icing," December 17, 1982.

FAA AC 20-117 contains a simplified formula that gives a gross estimate of the length of time that a deicing fluid would be effective. However, according to the FAA, the formula tends to overestimate the holdover time at temperatures near freezing. To compensate for this limitation, the FAA introduced a correction factor of 0.5 into the formula.

Meteorological variables involved in the calculation include the precipitation rate and ambient air temperature. The precipitation rate of 0.09 inch water equivalent per hour was calculated from the weather observatory snowfall data. In addition, the lowest temperature of 29 degrees F, recorded by the Port Authority thermistor, was used for the calculations.

The following table shows holdover times calculated using the formula given in AC 20-117 and the 0.5 correction factor for a range of Type I fluid thickness values using the precipitation rate and temperature values cited in the preceding paragraph. The thickness of the Type I fluid applied to the accident airplane is unknown.

Type I

Fluid Thickness (mm)	Holdover Time-- (Minutes)
0.020	4.55
0.025	5.67
0.030	6.83
0.035	7.96
0.040	9.10
0.045	10.24
0.050	**11.37**
0.055	12.51
0.060	13.65
0.065	14.79
0.070	15.92
0.075	17.06
0.080	18.20

NOTE: According to the FAA, a typical thickness for Type I fluid is 0.05 mm.

Temperatures greater than 29 degrees F would have increased the effective time of the deicing fluid. Conversely, a greater rate of precipitation accumulation would have had the effect of reducing the holdover time of flight 405.

The Safety Board believes that given the numerous variables and complexity of the problem, the specific amount of ice that accumulated on the aerodynamic surfaces of the airplane during the taxi phase is indeterminable. However, the Safety Board also believes that some contamination occurred in the 35 minutes following the second deicing and that this accumulation led to the control difficulty shortly after rotation.

2.5 Flightcrew Performance - Takeoff Procedure and Stall Recovery

The Safety Board views the evidence as conclusive that the primary factor in this accident was the reduced performance of the wing due to ice contamination. Therefore, the Safety Board evaluated the extent to which the decisions of, and procedures used by, the flightcrew could have contributed to the accident.

After arriving at the USAir gate following the landing at LaGuardia, both the captain and the first officer departed the airplane for short periods, and both of them were aware that the weather conditions were conducive to the accumulation of frozen precipitation on the wings. Upon returning to the airplane, neither of them performed a walkaround inspection or took any special actions to check the condition of the wing leading edge and upper surface. However, the airplane was subsequently deiced and the wing condition was purportedly checked by ground personnel which obviated the need for the crew to depart the airplane a second time for an external inspection. That the captain requested a second deicing after about a 20-minute delay indicated his concern about the continuing exposure to precipitation; the request was prudent and in accordance with USAir guidance. Following the second deicing, the flightcrew was most likely satisfied that the airplane was free of adhering contamination.

The flightcrew was not aware of the exact delay that they would encounter before takeoff and their decision to leave the gate was reasonable. After taxiing, when it became evident that they would be delayed for a prolonged period, conversations between the crew showed that they were aware of and probably concerned about the risk of reaccumulating frozen contamination on the wing. Their awareness of this risk should have been heightened by the need to use the windshield wipers intermittently in combination with the freezing outside air temperature. When it became apparent that the delay would exceed 20 minutes, USAir guidance prescribes a careful examination of the airplane's surfaces. The first officer stated after the accident, and passengers confirmed, that he had turned on the wing inspection light to view the wing on several occasions. However, the only related comment recorded on the CVR was nearly 30 minutes after departing the gate and about 5 minutes before takeoff when the first officer said "looks pretty good to me from what I can see." The observation was made through the closed cockpit window. The Safety Board believes that even with the wing inspection light, the observation of a wing from a 30- to 40-foot distance, through a window that was probably wet from precipitation, does not constitute a careful examination.

The USAir guidance and information that was disseminated to flightcrews should have been sufficient to alert the flightcrew to the risk of attempting a takeoff while uncertain of the wing condition. The Safety Board recognizes the dilemma of flightcrews under these circumstances; for example, to return to the gate only to be confronted with further delay or flight cancellation, or to proceed with takeoff and accept the risk involved. Thus, the Safety Board strongly supports the actions taken since this accident to provide more specific criteria for wing deicing and inspection to reduce flightcrew decision making responsibilities. Nonetheless, even before these actions, the Safety Board believes that the flightcrew of flight 405 should have taken more positive steps to assure a contamination-free wing, such as entering the cabin to look at the wing from a closer range. Although the Safety Board acknowledges that the detection of minimal amounts of contamination, sufficient to cause aerodynamic performance problems, is difficult and may not be possible without a tactile inspection, an observation from the cabin would have improved the chance of seeing some contamination and might have prompted the flightcrew to return to the gate. The Safety Board believes that the flightcrew's failure to take such precautions and the decision to attempt the takeoff while unsure of wing cleanliness led to this accident and is a cause of it. Further, the Safety Board believes that the lack of definitive criteria provided to flightcrews by the FAA and the airline industry[23] at the time of this accident regarding the effective holdover time of Type I fluid and the difficulty of detecting minimal amounts of contamination is also causal.

Having made the decision to proceed with takeoff, the flightcrew should have made certain that their takeoff procedures afforded the maximum safety

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[23]For the purposes of this report, "airline industry" includes government and industry organizations responsible for and capable of studying the problems associated with aircraft icing hazards, and disseminating information to flightcrews about these problems, and for developing technology and requirements to minimize such hazards.

margins. Guidance[24] disseminated to USAir F-28 flightcrews in November 1991 specified the particular sensitivity of the nonslatted F-28 wing to the aerodynamic effects of wing contamination and discussed the use of conservative takeoff speeds and takeoff rotation rates.

While preparing for takeoff, the captain noted that he would use 110 knots as the V_1 decision speed. For flight 405, the specified V_1 speed would have been 124 knots. The USAir procedure prescribes that the nonflying pilot call out V_1 5 knots below the specified speed so that an engine failure at V_1 would result in a "go" decision, and the Safety Board believes that this procedure is acceptable. However, reducing V_1 to 110 knots was not authorized for this takeoff. There was no discussion between the captain and first officer about the reduced V_1 selection. During the public hearing, the first officer could not explain why the captain chose 110 knots for V_1. It is assumed that the captain was concerned about the airplane's stopping ability on the runway since he made a reference to the difficulty of stopping on a "short runway going that fast...."

Because V_1 speed is only significant in the context of a rejected takeoff or the continuation of a takeoff following the failure of an engine, the captain's selection of a reduced V_1 of 110 knots was not in and of itself a factor in the accident. However, the selection of a low V_1 speed led the first officer to call V_R prematurely. The first officer stated that, because V_1 and V_R are normally the same speed, he inadvertently followed his normal procedure of calling V_R immediately after V_1.

The correlation of CVR and FDR data shows that the V_R call made by the first officer occurred at around 113 knots, approximately 11 knots below the correct rotation speed of 124 knots. The first officer noted that notwithstanding the premature V_R call, the captain did not rotate the airplane for liftoff until the appropriate speed. However, the analysis of the sounds associated with nose gear strut extension disclosed that the captain began the takeoff rotation 5 knots below the proper V_R speed. The reason for the captain's early takeoff rotation cannot be determined. However, because the air speed indicator bug was properly set for a V_R of 124 knots, the Safety Board believes that the captain may have been reacting, in a somewhat delayed manner, to the first officer's early V_R callout without crosschecking his own air speed indicator.

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[24]Memorandum written by an Empire Airlines captain in 1984, issued by the USAir F-28 flight manager.

As a result of the early rotation, the airplane lifted off prematurely and at an AOA about 0.5 degrees higher than it would have otherwise. During a normal takeoff with an uncontaminated wing, the 0.5 degree increase in AOA would have been insignificant. However, with the performance of the wing degraded by contamination, this increment in AOA may have been the difference between a successful transition to climb and an immediate stall resulting in the accident. Thus, while beginning the takeoff rotation early is not appropriate for normal operation, it is significantly inappropriate and hazardous when there is a possibility of wing contamination.

The Safety Board's analysis showed that during a takeoff with rotation initiated at 124 knots, the airplane could achieve a peak AOA of about 9 degrees, the AOA at which stall could occur in the presence of contamination. Thus, any existing AOA stall margin would have been minimal at best. However, with the early rotation, it is evident that an AOA beyond the stall AOA was reached almost immediately after liftoff.

Although the Safety Board cannot determine that a successful takeoff could have been accomplished with proper takeoff rotation procedures, the Board concludes that the early initiation of takeoff rotation eliminated that possibility and thus contributed to the accident.

The first officer stated that following the stick shaker and control problems, both he and the captain knew that the airplane was not going to fly and that the focus of their efforts was to stay over land and remain upright. Other than initially applying rudder, there were no corrective actions taken by the flightcrew. They used the yoke to "hold on" to the airplane. The Safety Board cannot determine whether any actions could have been taken by the flightcrew that would have resulted in a different type of impact and possibly reduced the severity of the accident. Based on evidence obtained from FDR data, the Safety Board concludes that seconds after liftoff, the airplane was in a stall regime from which recovery was not possible.

2.6 USAir Procedures/Guidance

2.6.1 Deicing

At the time of this accident, USAir was using Type I glycol-based fluid for deicing airplanes. As with many other domestic air carriers, USAir had not equipped any of its facilities to dispense the Type II fluids to provide extended anti-ice protection to its aircraft. The Safety Board believes that USAir's procedures met airline standards and were consistent with most of the industry. The groundcrews believed that visual inspections were sufficient for determining the presence of airplane surface contamination. Groundcrews interviewed by Safety Board investigators were very conscientious; however, they, like the individuals that trained them, were unaware of the need for tactile inspections under certain conditions. Nonetheless, the Safety Board believes that flight 405 was probably free of frozen contaminants when it left the gate.

2.6.2 Guidance to Flightcrews

USAir flightcrews received materials and training concerning winter operations consistent with, and in some cases, exceeding industry standards. The initial F-28 ground school emphasized the critical nature of the F-28 hard wing. The bimonthly publication *Flightcrew View* provided reference material on many subjects for the flightcrews and was part of their recurrent training program. The September-October 1991 issue contained information on winterization procedures, including AC 20-117. The USAir pilots were also given an examination that included questions about the effects of frost and ice and pilot responsibilities during their recurrent training. Additionally, an excellent perspective of the contamination problem was offered in a memorandum written by an Empire Airlines[25] captain in 1984, and issued by the USAir F-28 Flight Manager in November 1991. The captain points out:

> Contamination - Frost accumulations of as little as 1/16 of an inch, like medium to course grit sandpaper, on the wing leading edge can increase stall speeds by 30 percent (right in the vicinity of V_1, V_R). Uneven contamination across the leading edge will result in wing drop or roll off as the stall develops across the wing....Ice or frost accumulations can appear on leading edges during taxi out or takeoff roll - a de-icing beforehand even on a clean wing may prevent such accretion.

The captain further wrote that leading edge lift devices recover lift loss due to light ice accumulations. He cautioned that pilots must not get a false sense of security when preceding B-727s successfully take off, especially when their own airplanes are not equipped with leading edge lift devices.

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[25] Empire Airlines was a regional commuter airline based out of Utica, New York, operating F-28s. It merged with Piedmont Airlines, which subsequently merged with USAir Inc.

Finally, the captain pointed out:

When wing contamination is suspected despite earlier preventative measures, rotation rates must not be excessive and takeoff speeds may be increased up to 10 knots (increased V_R speeds of up to 10 knots have limited effect on aircraft performance profiles - but speeds in excess of 10 knots adversely effect performance rates). Available field length must be accounted for in the decision to rotate slower than 3^o per second and to target higher takeoff speeds.

This, in effect, is a more conservative approach to the Fokker "unwritten" technique used by company pilots when contamination may be present after deicing. During the field phase of the Safety Board's investigation, a Fokker test pilot said that he routinely added a margin to V_R. However, Fokker did not publish such a procedure. The increased V_R is also the focus of Safety Board Safety Recommendation A-91-127. Although the recommendation was directed specifically to the DC-9-10 series airplane, it has similar application for all swept-wing airplanes without leading edge devices. Some adjustment in takeoff technique is needed, if there is a possibility that contamination has accumulated on the airframe after deicing.

Throughout the investigation of this accident, many pilots acknowledged the fact that the F-28, which has no leading edge devices on its wings, was sensitive to contamination. They also generally acknowledged that, "if necessary, I would examine the wing from the cabin." However, they universally believed that they could detect any significant contamination from the cockpit. The USAir Vice President of Flight Operations testified that he believed the crew had as good a view from the cockpit as they would from the cabin window. This opinion was maintained with great confidence, even when such descriptions as 1/16 inch or less were posed as possible contamination. The Safety Board believes that this apparent "universal" overconfidence is evidence that flightcrews did not attach enough significance to the company's directive about conducting a careful examination of the wings after 20 minutes in weather conditions conducive to accumulations of ice. Flight 405's flightcrew actions to accomplish a "...careful examination of the surfaces...to determine the extent of accumulation and to assure that the takeoff can be made safely...." were to turn on the in-flight wing ice inspection light, and look through the closed cockpit window. This gave them a distant view of the outer 1/2 to 2/3 of the wing leading edge, but not the wing root, or much of the upper surfaces of the wing. The Safety Board believes that a careful examination of the wings should involve some type of exterior inspection allowing for a close examination or tactile inspection if the holdover time has been exceeded. The Safety Board also believes that until more advanced technology is used to detect ice accretion on wings, an additional deicing/anti-icing is the only way to ensure that the wings are free of contamination prior to takeoff. Further, the Safety Board recommends that the FAA require all operators to use training aids that will illustrate to the flightcrew what contamination looks like and feels like on a wing, and the amount of contamination that could be detected under different light conditions.

Most pilots operating at LaGuardia during the time of the accident stated that they were checking other airplanes around their airplanes for snow/ice accumulation and were basing the decision to take off on the successful takeoffs of preceding airplanes exposed to the same weather. Yet, pilots have no means of knowing such critical details as the arrival/descent profile, ground time, gate exposure, deicing time, deicing fluid mix, and temperature of these airplanes. In short, the time history of other airplanes may be entirely different, and thus such comparisons are not valid. Moreover, the distances and lighting conditions make it virtually impossible to detect the minute amounts of contamination that can adversely affect safe flight. The Safety Board believes that the flightcrew of flight 405, as well as flightcrews of other airlines operating at the same time, did not have sufficient appreciation for the consequences that minute amounts of ice have on aircraft performance, notwithstanding the company training and literature on the subject.

While the reference to a 9-degree AOA reached during takeoff in the GENERAL section of the USAir F-28 Pilot's Handbook is accurate, the handbook fails to adequately stress its significance. The various forms of manufacturer literature, published since the manufacture of the F-28,[26] identify liftoff at 8-degrees AOA, stick shaker at 12 degrees, and stall at 15-degrees AOA. Aerodynamic data from Fokker studies show that sandpaper-like contamination on the wing disrupts the normal stall progression toward the wing tip, and an uncontrollable wing roll may develop as low as 10-degrees AOA. The loss of control can occur before stick shaker activation, and the pilot would not be aware that a stall is approaching until lateral control is lost.

A note in the Pilot's Handbook implies that a smooth rotation would prevent pitchup and rolloff when contamination is present, and that smooth

[26] The first-production F-28 flew on 21 May 1968.

continuous aileron, rudder, and elevator inputs would correct the problem. In fact, if there is contamination, a 3-degrees-per-second rotation rate can place the airplane into a stall regime at liftoff. The contamination-induced spanwise airflow negates the aileron effectiveness, and rudder input aggravates the stall. Although the elevator is still effective, the pilot has no altitude to trade for air speed. The only remedy for the pilot is to avoid over-rotation and to arrest the pitch attitude before a wing stall occurs and control is lost.

The Fokker, Empire Airlines, and Piedmont Airlines manuals, from which the USAir manual evolved, described an initial rotation attitude of 10 degrees. The intention is that smooth rotation to 10 degrees will establish a proper liftoff attitude, and, as the airplane accelerates through V_2, the pilot may continue the rotation up to a maximum of 15 degrees.

Under normal operating conditions (excluding high-density altitudes and engine problems) V_2 is reached before liftoff, and the rotation can be, for all practical purposes, a continuous maneuver to 12-15 degrees. The Safety Board believes that USAir's elimination of the reference to an attitude of 10 degrees creates the practice by line pilots of rotating directly to 15 degrees without crosschecking air speed. A total reliance on a smooth 3-degrees per-second-rotation rate is induced, and there is little emphasis placed on the air speed achieved, until the rotation maneuver is complete. At this point in the takeoff, the manual suggests that V_2+20 will be exceeded (under light weights and cold temperatures), and that the excess speed will not affect the climb profile.

2.7 Simulation of Optimal Takeoff Procedures

The data obtained from the simulated takeoff maneuvers conducted at Fokker were examined to determine if changes in F-28 operating procedures could yield a successful takeoff with ice adhering to the wings. The results of the maneuvers are shown in appendix E.

Assuming the normal USAir procedure, with ice adhering to the wings, if the rotation speed is increased by 10 knots, the peak AOA decreases approximately 3 degrees from 12 degrees to 9 degrees. However, there may be problems with routinely increasing rotation speed because of runway length requirements. If a relatively slow rotation rate of 2-degrees per second is used, the peak AOA decreases from 12 degrees to 8 degrees. However, the pilot cannot be expected to control rotation rate this precisely, so that a change in the recommended rotation rate alone may not be adequate.

The simulation data, with ice adhering to the wings, show that when target pitch attitude is decreased from 15 degrees to 10 degrees, the peak AOA decreases approximately 5 degrees, from 12 degrees to 7 degrees. Therefore, a lower pitch attitude is the most effective way to limit wing AOA during the takeoff maneuver--more effective than a slower rotation rate, or increasing rotation speed. Further, pitch attitude is easily targeted on the attitude indicator and is a primary means of control used by the pilot to achieve the desired performance from the airplane. If the target attitude is 10 degrees, the rotation rate is less significant.

The engine-out procedures for the F-28 Mk4000 recommend that a 10-degree pitch attitude be targeted for a climbout at V_2 to satisfy the airworthiness requirements on takeoff performance. Therefore, with both engines operating, it seems likely that the F-28 can satisfy climb requirements with an initial target pitch attitude below 15 degrees. Further rotation to 15 degrees of pitch would occur after the airplane has successfully climbed out of ground effect. Such a change in operating procedures would give the F-28 an increased safety margin before wing stall during the takeoff maneuver. Flight dynamics calculations by Fokker show that this alternate takeoff method (using a 10-degree rather than a 15-degree target pitch attitude) was also successful for simulated F-100 takeoffs with ice contamination on the wings. The Safety Board believes that the FAA should require Fokker to study the effect of establishing a lower target pitch attitude on takeoff for the F-28 and F-100 airplanes, and change its recommended operating procedures if necessary.

The primary concern should be how to structure the takeoff maneuver to prevent pilots from stalling the airplane, especially when the airplane has just lifted off and is still in ground effect. Although a slow rotation rate, or overspeed procedure will also reduce wing AOA, simulation data for the F-28 show that lowering pitch attitude provides a sufficient reduction in AOA during the takeoff maneuver without imposing associated runway length or takeoff weight performance penalties.

2.8 Actions to Reduce Contaminated Wing Takeoff Hazard

2.8.1 FAA/Industry Conference

The crash of USAir flight 405 further prompted an industry-wide interest in the problems of operating aircraft in adverse weather conditions, such as freezing precipitation. The FAA initiated an intense effort to improve the safety of winter flight operations. To better understand ground deicing/anti-icing issues and to develop and implement feasible and effective safety improvements, the FAA sponsored the International Conference on Airplane Ground Deicing on May 28 and 29, 1992, in Reston, Virginia.[27] More than 800 participants discussed the problems posed by aircraft icing and examined possible solutions. The conference produced suggestions for corrective actions that were taken before the 1992/1993 winter season and also offered possible long-term improvements to existing systems. The focus of the conference was on carrier-operated, turbine-powered airplanes with more than 30 passenger seats.

From recommendations made by the working groups at the conference, on July 23, 1992, the FAA published a Notice of Proposed Rulemaking (NPRM) that would establish requirements for Part 121 certificate holders to develop an FAA-approved ground deicing/anti-icing program and to comply with that program any time such conditions as frost, ice, or snow could adhere to the aircraft's wings, control surfaces, propellers, engine inlets, and other critical surfaces. If an air carrier does not want to have an icing program, they are given the option of performing a mandatory exterior icing check at least 5 minutes prior to takeoff for all flights, whether or not the airplanes were deiced/anti-iced prior to takeoff, when weather conditions are such that frost, ice, or snow could adhere to an airplane's critical surfaces. On September 29, 1992, an Interim Final Rule was published and became effective on November 1, 1992.

In addition to the air carrier deicing programs required by rulemaking, the FAA is addressing the corollary issues relating to airport and air traffic control. Specifically, the actions being taken concern the reduction of the time that an airplane will be exposed to freezing conditions after having been deiced and the clearance for takeoff. This involves a reduction in ATC delays and, where practical, the implementation of offgate deicing facilities closer to the departure runways.

2.8.2 Reducing ATC Delays

It is axiomatic that the same weather conditions that prescribe the need to expedite an airplane's clearance for takeoff following a deicing operation are often the conditions most likely to lead to reduced airport capacity and thus increased ATC delays. The FAA has acknowledged the need to address this

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27 A summary of the conference was published by the FAA Flight Standards Service, Washington, DC 20591, in a document entitled "Report of the FAA International Conference on Airplane Ground Deicing."

problem by reviewing ATC and airport procedures, such as gate hold and flow control.

According to testimony, a departure delay is not initially reported by ATC until there is an actual delay of 15 minutes. The 15-minute delay does not include the addition of a "best case" (average) taxi time--which is inherent within the ATC system. For LaGuardia's runway 13, the best case taxi time, from a gate to the takeoff end of the runway, is 8 minutes. Therefore, flightcrews preparing for departure on runway 13 can experience a ground time delay for as long as 23 minutes without an awareness that they will be delayed for takeoff. If they encounter further delays, ATC will report delays in 15-minute increments.

Because delays are reported in 15-minute increments, a departure delay is listed as a "15-minute delay" even after 37 minutes has elapsed. Not until 38 minutes has elapsed between the time an airplane taxis and the time that it takes off will a 30-minute delay be reported by ATC.

If delays were reported based on lesser time intervals, flightcrews and airline dispatchers would benefit because a trend toward increasing delays would be more easily identifiable and would provide a more realistic basis for flightcrews to make assessments. Further, if dispatchers and flightcrews were able to anticipate the time to taxi from the ramp to the runway, they would understand that a 5-minute reported delay would mean approximately 13 minutes of elapsed time between the time the airplane requests taxi clearance and the time that the pilot expects to begin takeoff.

It should also be recognized that in a snowstorm, the average (best case) taxi times are often inappropriate. Flight 405 took about 20 minutes to taxi from the gate to the area of the departure runway before it entered a line of departing aircraft. The total time from completion of its deicing until takeoff was about 35 minutes, rather than the 15 minutes reported by ATC, primarily because of traffic congestion. To account for decreased taxiing speeds in snow, decreased visibility, and the need to communicate position to ground control, additional time should be added to the average taxi time that would subsequently be added to the reported departure delays. However, to reduce these times and guarantee a reasonably timely taxi time to initiation of the takeoff, gate hold procedures would have to be instituted so that actual taxi time is not prolonged because of other traffic. The Safety Board believes that gate holds should be initiated as soon as deicing operations begin, not after delays have exceeded 15 minutes, as in the current ATC definition of gate hold.

The Safety Board believes that the FAA should review its procedures for reporting taxi delays during conditions conducive to airframe icing at all airports and that it should report such delays in smaller increments to provide more realistic and useful reports. This procedure should be implemented at all airports that cannot provide departure runway deicing to allow immediate takeoff after completion of deicing.

2.8.3 Deicing and Anti-icing Fluids

The Use of Type I and Type II Fluids.--There are a number of views on the potential uses of Type I and II fluids. The use of Type I fluid raises concerns because its holdover time is shorter than the holdover time for Type II fluid under certain conditions. Both fluids are under scrutiny for their environmental impacts, and it is uncertain if Type II fluid diminishes the runway coefficient of friction since the fluid rolls off the airplane during the takeoff roll. Also, the use of either type fluid may result in a temporary degradation in the airplane's aerodynamic performance, a reduced stall margin, and an increase in drag.

The FAA reported in its Deicing rule dated September 2, 1992:

> With respect to the potential environmental effects of both type fluids, as the Environmental Assessment discusses, because of their low volatilities, low ecotoxicities, low toxicity to humans, and biodegradability, no impacts are expected over those already experienced for deicing/anti-icing operations carried out under the current regulations.

The Safety Board supports the FAA and its statement made in the Deicing Interim Final Rule:

> Each specific certificate holder determines the type of fluids used in its operations. As stated in the NPRM and in this preamble, each type fluid has its benefits and intended usage. All the information presently available to the FAA indicates that there is no availability problem associated with Type II Fluids and that their use continues to grow in Europe and Canada.

However, the Safety Board believes that no wide-body aircraft can be deiced with Type I fluid at a gate, taxi, and take off, before the recommended

SAE/ISO holdover time has expired when weather conditions are as follows: freezing fog below 32 degrees F, steady snow, freezing rain, or rain on cold-soaked[28] wings. Also, the Safety Board believes that Type II fluids may not provide adequate protection against the reformation of frozen contaminants when an airplane is anti-iced at a gate and the weather condition is freezing rain or when a mixture of less than 100 percent fluid concentration is used when rain is accruing on a cold-soaked wing.

It should be noted, that in freezing precipitation, large aircraft cannot be fully deiced before the first areas treated with a Type I fluid begin accumulating ice again.

Runway Hazards of Type II Fluid.--The Safety Board did not survey any other airports to determine if others would prohibit the use of Type II deicing fluids as did LaGuardia at the time of this accident. However, it is likely that the question has not arisen at many of the airports, including those in the snow belt, because the use of Type II fluid in the United States has been a relatively recent practice and is still not a common one. It is the decision of each air carrier (the airport tenant) whether to upgrade the equipment to dispense the Type II fluid. It is an expensive program, and several carriers are not using Type II fluid and have not requested its use from the airport managers. If LaGuardia's policy had been different, USAir might not have used Type II fluid, especially because USAir was not using Type II fluid elsewhere in its system at the time of the accident.

Consequently, the Safety Board finds that the restrictions placed on the use of Type II deicing fluid at LaGuardia as a result of Airport Manager's Bulletin 90-29 played no part in the causal factors of this accident. However, the Port Authority's concern over the potential for Type II fluid to diminish the runway coefficient of friction is valid, especially at LaGuardia, where the comparatively shorter runways, over-water decks, and the mixed traffic, such as landings and takeoffs on the same runway, make runway friction especially critical.

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[28]"Cold Soaking" is a term used to indicate that an object has been in a cold temperature long enough for its temperature to drop to or near the ambient temperature. A cold-soaked wing is a wing containing fuel that has usually been cooled while the airplane is flying at a high altitude. Upon landing, the wing structure warms faster than the fuel in the wing. When an airplane has landed with cold-soaked fuel in the wing tanks, and the fuel in the tanks contacts the skin of the wing, moisture from the air could deposit on the surface in the form of frost.

The Safety Board urges the FAA to continue its research into the effects of deicing fluid runoff on runway friction and publish appropriate guidelines for airport operators.

Offgate Deicing/Anti-icing.[29]--Deicing airplanes at a shared facility near the departure runway would reduce the elapsed time between deicing/anti-icing and takeoff roll, thus reducing the risk of accumulating additional ice/snow contamination on the critical airplane surfaces. Therefore, the Safety Board believes that the FAA should encourage selected airports to provide space and/or facilities for offgate deicing as close to departure points as practicable and safe.

The Safety Board acknowledges that each airport is geographically, topographically, and operationally unique. Because the matter of responsibility and accountability for conducting airplane deicing at the runway ends can be complex, airports in the United States are often administered and organized differently; and such efforts require cooperation between competing airlines, the airport managers, and the FAA ATC facilities. Nevertheless, the Safety Board believes that at each airport the FAA identifies as likely to experience icing conditions regularly and with sufficient volumes of traffic, a deicing working group should be established, and maintained, and should meet regularly, especially before and during snow and ice seasons. These working groups should, at a minimum, include representatives from tenant air carriers, fixed-base operators, FAA air traffic and airport safety and certification specialists, and airport management.

The Safety Board believes that the FAA should require that each certificate holder, operating under Title 14 CFR Part 139, whose airport is determined likely to experience icing conditions regularly, establish and submit to the FAA for approval a deicing plan that includes, at a minimum, the membership of the airport deicing working group; the location(s), equipment, and procedures to be used for gate deicing and offgate deicing; description(s) of gate-hold parameters and procedures; and delineation of responsibilities for the deicing of airplanes at the gate or offgate, as applicable.

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[29]For the purpose of this report, offgate deicing/anti-icing is defined as the elimination of ice/snow contamination on airplane fuselage, airfoil and engine surfaces, using Type I or Type II fluids, applied to airplane surfaces by fixed or mobile equipment at an airport location away from the terminal/gate areas and as close to the departure runway as is safely practicable, in order to reduce the elapsed time between commencement of deicing/anti-icing and takeoff roll.

2.8.4 Pretakeoff Inspections of Airplane Wings

The most positive assurance that an airplane is safe for takeoff in weather conditions conducive to the formation of frozen contaminants on the wing is a close inspection of the wing leading edge and upper surface immediately before takeoff. Federal Aviation Regulations require that the wing be clean; however, the investigation of past accidents has disclosed the difficulty involved with flightcrews determining whether wings are clean. The industry acknowledges that it is nearly impossible to determine by observation whether a wing is wet or has a thin film of ice. While a very thin film of ice or frost will degrade the aerodynamic performance of any airplane, the Safety Board believes that the aerodynamic characteristics, as well as the accident record, indicate a need for special attention to be given to transport jet airplanes that do not have leading edge devices for lift enhancement during takeoff.

The following is a general description of the effect of leading edge high lift devices, such as slats:[30]

> An important (or predominant) limitation of lift to be obtained in wings, is flow separation from the leading edge. Means of preventing or postponing such separation are, the use of leading-edge slots or slats, camber or the deflection of nose flaps, and boundary-layer control (blowing or by suction).
>
> These devices are used to increase the maximum lift and/or to prevent stalling from the wing tips, thus preserving lateral (aileron) control. All types of leading-edge lift-increasing devices function by increasing the angle of attack where stall takes place. They thus control separation, while lift (circulation) is basically controlled by the position of the trailing edge (by angle of attack, with or without a flap).

Like the F-28, the DC-9-10-series airplane has a fixed leading edge wing. Douglas Aircraft Company has found that the fixed leading edge wing is more susceptible to lift degradation due to ice, frost, or snow than a similar wing

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[30] From *Fluid Dynamic Lift*, by Dr. Sighard F. Hoerner and Henry V. Borst, 1975. Library of Congress Catalog Card Number 75-17441.

with extended leading edge slats. The following description of this finding is from an article published by Douglas Aircraft Company:[31]

> These [wing roughness] effects are particularly important for early transport aircraft having no leading edge devices. Extension of the leading edge devices of more advanced aircraft will generally recover most of the stall speed degradation resulting from the low levels of roughness cited here.

Although the low levels of roughness cited by Douglas are generally less than the roughness level expected to cause an accident, possible aerodynamic degradation is especially critical during takeoff since the AOA margin from stall is less than at any other regular phase of flight.

Fokker relates a different conclusion on the aerodynamic effects of icing on slatted and nonslatted wings. Citing a wind tunnel investigation[32] conducted by the Aeronautical Research Institute of Sweden (FFA), Fokker states:[33]

> Test results from this investigation have been used here to compare the effects of leading edge and/or trailing edge flap deflection on the aerodynamics of a contaminated wing section....The test results clearly demonstrated that between slatted and non-slatted wing configurations, there is no difference in aerodynamic degradation due to hoar frost roughness.

There is obviously a disagreement within the industry over the percentage degradation of lift due to upper wing surface contamination between slatted and nonslatted wings. However, there are no state-of-the-art wind tunnel results available to resolve this question. The Safety Board believes that the FAA, in conjunction with the National Aeronautics and Space Administration (NASA), should establish a wind tunnel and/or flight test program to study the aerodynamic degradation of both nonslatted and slatted airplane wings containing upper surface contamination.

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[31]From *DC Flight Approach*, "Wing Surface Roughness - Cause and Effect," January, 1979, published by Douglas Aircraft Company.

[32]B.L.G. Ljungstrom, "Wind Tunnel Investigation of Simulated Hoar Frost on a Two-Dimensional Wing Section With and Without High Lift Devices," FFA-AU-901, April, 1972.

[33]*Wingtips*, page 6, December, 1989.

Nonetheless, the critical factor in ice contamination is how close the takeoff maneuver gets the wing to its stall AOA. In this case, the fixed leading edge wing apparently has less margin of safety than the slatted wing, even if it is assumed that the percentage lift loss due to ice contamination is the same for both wings. During the takeoff maneuver, it takes longer to rotate the slatted airplane to a stall attitude so that the slatted airplane has time to climb and accelerate. Because airplanes with leading edge slats normally stall at a higher AOA, the risk of an AOA overshoot into the stall region is lower than it is for a fixed leading edge airplane. The combination of more altitude, higher speed, and enhanced roll control increases the likelihood of a successful takeoff when the upper surface of a slatted wing is contaminated with a minimal amount of ice. Further, airworthiness requirements are based on a safe climb speed (V_2) that is at least 20-percent above the stalling speed. Because the slatted wing creates lift over a broader range of AOA, a 20-percent margin in speed provides a slightly larger AOA margin before wing stall, typically a 1.5- to 2.0-degree greater margin between the AOA at V_2 and the stall AOA.

Although further study of aerodynamic stall margins and climb requirements is needed, decreasing the peak AOA during the takeoff maneuver would provide an enhanced level of safety for nonslatted airplanes taking off in icing conditions. There are far fewer nonslatted airplanes operating under 14 CFR Part 121, but they have experienced almost all of the takeoff accidents attributed to wing upper surface ice contamination. Because of the critical nature of the takeoff maneuver in icing conditions, the Safety Board believes that the FAA, in conjunction with NASA, should establish a joint government/manufacturer task force to study methods to improve the AOA safety margin during the takeoff transition to initial climb.

The FAA has a concern about the effects of advising pilots that nonslatted airplanes are more sensitive to wing ice contamination. It is believed that if nonslatted wings are singled out, pilots will feel that a minute amount of ice is acceptable on slatted wing airplanes. The Safety Board agrees that operations with wing contamination should not be allowed or encouraged for any class of airplane. However, the icing accident record is worse for nonslatted airplanes, and differences in aerodynamic stall margins during the takeoff maneuver could explain the disparity in the accident record. Therefore, until research is completed, the Safety Board supports the requirement for a tactile or external close visual inspection of the wings of nonslatted airplanes immediately before takeoff when anti-icing holdover time has been exceeded.

2.8.5 New Technology for the Detection of Contamination

The Safety Board has reiterated throughout this report the difficulties that flightcrews have in detecting contaminants on the wings of airplanes through visual inspection. To obviate the necessity of relying on visual perception or exterior tactile inspections to determine if the wings are clear of ice, snow, or frost, today's technology is being incorporated into equipment designed to detect contaminants on airplane surfaces and to present indications of unsafe conditions to ground personnel or flightcrews. Current concepts include electro-optical line-of-sight sensing extending into the infrared region or other techniques, such as measuring the changes in frequency and amplitude of vibrating piezo element diaphragms placed on the wing surface to detect contamination. The Safety Board believes that this technology is promising and will detect the presence of ice, snow, or frost on airplane surfaces.

2.9 Survivability

2.9.1 Passenger Safety Briefing Card

The passenger safety briefing card did not show or describe how to operate the galley service door or the main boarding door in their emergency modes, which must be used when the doors fail to operate normally, as required by 14 CFR 121.571(4)(b)(1).

The briefing card showed a plastic cover over the release handle for an overwing exit and an opening in the cover to permit its removal; in actuality, the opening is covered by thin plastic that must be broken before the cover can be removed. The airplane's exit markings were in accordance with 14 CFR 25.811. Although none of the exits were used in this accident because survivors evacuated through openings in the fuselage, passengers must be provided adequate information so that they can open emergency exits. The Safety Board is concerned that FAA surveillance did not identify the inaccurate and incomplete information shown on the passenger safety briefing cards.

2.9.2 Runway Area Obstructions

The Safety Board is concerned about the location of nonfrangible obstructions in the vicinity of runway 13/31 that significantly contributed to the severity of damage. The locations of the dike, the ILS localizer ground plane antenna, and the pump house met the current FAA criteria for frangibility since both structures and the dike were just outside the 500-foot runway safety area. However, AC 150/5300-13, Airport Design, Appendix 8, par. 4 states: "The ROFA (Runway Object Free Area) is a result of an agreement that a minimum 400-foot (120 m) separation from runway centerline is required for equipment shelters, other than localizer equipment shelters. Also, ICAO Annex 14, AERODROMES, Volume I Aerodrome Design and Operations, 8.6.1. states: "Unless its function requires it to be there for air navigation purposes, no equipment or installation shall be: a) on a runway strip,[34] a runway end safety area, a taxiway strip or within the distances specified in Table 3-1, column 11, if it would endanger an aircraft...."

Although the localizer ground plane antenna, pump house, and dike did not meet the criteria of AC 150/5300-13, Appendix 8 or the ICAO 8.6.1., the Safety Board understands the difficulties that LaGuardia faces in that regard, since the airport is physically restrained by size, location, and water boundaries.

The Port Authority Assistant Director of Aviation testified that the pump house, which was destroyed in the accident, was to be replaced by a newer underground pump house, which was not technically feasible at the time of the construction of the original pump house(s). The Safety Board is pleased that the Port Authority took this initiative to further improve the safety of the environment around runway 13/31. The Safety Board urges the Port Authority to continue this initiative and replace the two other pump houses, which are adjacent to runway 13/31, with buried installations.

Replacement of the FAA ILS localizer ground plane antenna has already been accomplished; however, the Safety Board found that the antenna is of a similar nonfrangible design as the original. The FAA General Engineer, Office of Airport Safety and Standards, testified that because of the unique location and design of the antenna, it was not technically feasible to make it frangible. The Safety Board urges the FAA to conduct research on the frangibility of the antenna and to replace the current ILS localizer ground plane antenna with one that can function properly and is a less hazardous obstruction.

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[34]From 3.3.3. "A strip including a precision approach runway shall, wherever practicable, extend laterally to a distance of at least: - 150 m (approximately 411 feet) where the code number is 3 or 4."

2.10 Airport Rescue and Fire Fighting Effectiveness

2.10.1 Communications

The Safety Board concludes that the difficulties the ATC controller experienced with the emergency conference line did not delay or hinder the emergency response because ARFF personnel heard the controller's first transmission. However, the Safety Board believes that a potential for a breakdown in communications exists until the deficiencies in the system are corrected. The Port Authority should expedite the replacement of the emergency telephone system.

2.10.2 Medical Response

The Safety Board believes that factors contributing to the delay in transporting the eight passengers and one cabin crewmember who sustained serious injuries included the following: poor weather/road conditions; confusion in locating and treating a number of victims who had been transported by airline personnel to various locations around the airport; and the EMS failure to maintain continuous and close communication with the Incident Commander at the command post during triage operations.

The Safety Board understands that during mass casualty incidents, the on-site treatment of victims by EMS personnel places first priority on medically stabilizing the injured prior to transporting them. However, seriously injured passengers were still arriving at area hospitals at 0015. Following the accident, sufficient resources were available to have stabilized and transported the injured more expeditiously. The Safety Board encourages the New York City Health and Hospitals Corporation and the Emergency Medical Service to review, in depth, and in concert with other New York City emergency response agencies, their response to the crash of USAir flight 405. The Safety Board believes that these services should continue to seek ways to improve coordination and to reduce the time required to transport injured persons to hospitals from LaGuardia Airport.

The Safety Board also noted that victims who were removed from the water during the initial stages of the emergency response, and who lacked visible vital signs, such as pulse, and respiration, were categorized as deceased and that no attempts were made to resuscitate them. The Safety Board does not dispute this judgment because a basic principle of triage is to treat victims having the most life-threatening injuries first with available medical resources and to utilize limited medical personnel in a manner that will provide maximum effectiveness. However, the Safety Board is also aware that in recent years a number of victims of cold water near drowning have been successfully resuscitated. They survived after periods of time under water, including sea water, as long as one hour or more. In view of these facts, the Safety Board believes that all emergency response organizations should review their emergency plans to include contingencies for applying cardiopulmonary resuscitation (CPR) techniques as soon as a sufficient number of trained personnel arrive to perform CPR, even during mass casualty/triage incidents, regardless of whether vital signs are present, especially if cold-water immersion/near drowning is involved and where traumatic injuries do not indicate death.

3. CONCLUSIONS

3.1 Findings

1. The flight and cabincrews were properly certificated and qualified for the flight.

2. The airplane was certificated, equipped, and maintained in accordance with Federal regulations and approved procedures.

3. There was no evidence of preexisting airplane structural, systems, or engine faults that contributed to the loss of control.

4. There was no evidence that the flightcrew had adverse medical histories. The first officer's statements indicated that both his general life habits and recent events and those of the captain did not adversely affect their performance.

5. Between 2100 and 2135, approximately 0.35 inch (8.89 millimeters) of wet snow fell at LaGuardia that contained a water equivalent of about 0.05 inch (1.27 millimeters).

6. At the time of the accident, USAir did not require a specific exterior inspection for ice contamination of F-28 aircraft during periods of freezing precipitation.

7. The airplane was deiced two times using Type I deicing fluid, and before leaving the gate, and the wings were properly clear of contamination.

8. In the 35 minutes between the second deicing and takeoff, during precipitation and freezing temperatures, the airplane accumulated ice on its lifting surfaces.

9. The delay and taxi time of 35 minutes exceeded the Type I deicing fluid's published safe holdover time, which for the existing conditions was calculated to be about 11 minutes.

10. The captain did not use a USAir-approved V_1 speed.

11. The first officer called V_R 11 knots early, and the captain rotated about 5 knots early. His rotation rate was about 2.5 degrees per second.

12. The airplane accelerated normally during the takeoff roll. After liftoff and before transitioning to the initial climb, the wing stalled before the stall warning system activated.

13. Lateral instability was caused by an irregular stall progression across the wing that led to an abrupt left roll and wing tip strike that further reduced the ability to climb.

14. The airplane experienced a wing lift deficiency because of ice contamination.

15. The initiation of rotation for takeoff at a speed about 5 knots below the prescribed speed resulted in a higher peak AOA at liftoff and, with the wing contamination, eliminated any AOA stall margin that might have existed with a normal rotation.

16. According to wind tunnel studies conducted by the manufacturer, a wing upper surface roughness consisting of particles only 1-2 mm diameter (0.04-0.08 inch), at a density of about one particle per square centimeter, can cause lift losses on the F-28 wing of about 22 and 33 percent, in ground effect and free air, respectively.

17. The first officer observed the wing from the cockpit and stated that he checked the black strip for ice accumulation. The black strip was intended to aid in detection of in-flight leading edge ice and, because of its location on the leading edge, is not effective for detecting upper surface ice.

18. At night, flightcrews cannot visually detect minute amounts of ice on the part of the wing that is visible from the cockpit windows. This part of the wing is 30 to 40 feet from the cockpit. Flightcrews also may not be able to detect such contamination from the cabin windows.

19. Runway 13/31 was not significantly contaminated, and runway conditions were properly reported at LaGuardia on the night of the accident.

20. Accident history shows that nonslatted, turbojet, transport-category airplanes have been involved in a disproportionate number of takeoff accidents where undetected upper wing ice contamination has been cited as the probable cause or sole contributing factor.

21. No specific injury pattern could be identified in the cabin to explain why some passengers survived the accident and others did not.

22. Passengers who sustained minor injuries and injuries that were not life threatening most likely drowned as a result of confusion, disorientation or entrapment or a combination of these factors.

23. At the time of the accident, procedures for opening emergency door exits were inaccurately and incompletely displayed on USAir's F-28 passenger safety briefing cards, but they did not contribute to the fatalities in the accident.

24. The locations of the dike, pump house, and ILS localizer ground plane antenna were within current FAA guidelines; however, the locations did not meet ICAO Annex 14 criteria.

25. The overall emergency response was effective and contributed to the survivability of the airplane's occupants; however, the response by the emergency medical services personnel was inadequately coordinated, and the ambulance response times to the hospitals were excessive.

26. The difficulties that the air traffic controller experienced with the emergency telephone system did not hinder or delay the ARFF response.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable causes of this accident were the failure of the airline industry and the Federal Aviation Administration to provide flightcrews with procedures, requirements, and criteria compatible with departure delays in conditions conducive to airframe icing and the decision by the flightcrew to take off without positive assurance that the airplane's wings were free of ice accumulation after 35 minutes of exposure to precipitation following deicing. The ice contamination on the wings resulted in an aerodynamic stall and loss of control after liftoff. Contributing to the cause of the accident were the inappropriate procedures used by, and inadequate coordination between, the flightcrew that led to a takeoff rotation at a lower than prescribed air speed.

4. RECOMMENDATIONS

As a result of this investigation, the National Transportation Safety Board makes the following recommendations:

--to the Federal Aviation Administration:

If gate holds are required to limit deicing fluid holdover time, encourage air traffic control (ATC) to initiate the gate holds as soon as a deicing operation begins rather than after delays have exceeded 15 minutes, as in the current air traffic control definition of gate hold. (Class II, Priority Action) (A-93-19)

Where deicing operations are conducted away from the departure runway, report taxi delays in conditions conducive to airframe icing in increments that are less than 15 minutes to provide more realistic and useful reports to dispatchers and flightcrews. (Class II, Priority Action) (A-93-20)

Require that flight crewmembers and appropriate ground personnel responsible for the inspection of transport-category airplanes for wing contamination receive specific periodic training that will illustrate what contamination looks like and feels like on a wing and the amount of contamination that is detectable under different light conditions. (Class II, Priority Action) (A-93-21)

Study the effects on performance of swept-wing turbojet airplanes when specific amounts of air speed are added to the computed rotation speed (delayed rotation) during takeoffs when wing contamination is possible. (Class II, Priority Action) (A-93-22)

Require Fokker to determine how takeoff performance and stall margin would be affected by using a lower initial target pitch attitude on F-28 and F-100 airplanes in the event that undetected upper wing ice contamination is present, and change the normal operating procedures if takeoff performance requirements can be met while the stall margin is improved. (Class II, Priority Action) (A-93-23)

In conjunction with the National Aeronautics and Space Administration, establish a wind tunnel or flight test program to study the aerodynamic degradation of both nonslatted and slatted airplane wings that have upper surface contamination. The study should be sufficient to define lift, drag and pitching moment changes related to ice contamination. (Class II, Priority Action) (A-93-24)

In conjunction with the National Aeronautics and Space Administration, determine the differences, if any, in effects on takeoff performance and stall margin when upper wing ice contamination is present on slatted and nonslatted airplanes; include consideration of operational and aerodynamic factors that may explain the disproportionate number of takeoff icing accidents of nonslatted airplanes. (Class II, Priority Action) (A-93-25)

Require airlines to establish a way to inform flightcrews of the type of fluid and mixture used, the current moisture accumulation rate, and the available holdover time. (Class II, Priority Action) (A-93-26)

Thoroughly research the effects of Type II fluids on runway surface friction coefficients to ensure that its use does not degrade airplane traction and braking beyond safe limits, and publish guidelines for the use of Type II fluids by airport operators. (Class II, Priority Action) (A-93-27)

Require that all airports, which might experience freezing conditions and that are certified under Title 14 CFR Part 139, establish deicing plans for approval. (Class II, Priority Action) (A-93-28)

Study the feasibility of building a frangible ILS antenna array for LaGuardia Airport. (Class II, Priority Action) (A-93-29)

Review Fokker 28-4000 passenger safety briefing cards to ensure that they clearly and accurately depict the operation of the two types of forward cabin doors in both their normal and emergency modes and that they describe clearly and accurately how to remove the overwing emergency exit handle cover. (Class II, Priority Action) (A-93-30)

--to the Port Authority of New York and New Jersey:

Expedite the replacement of the emergency telephone system between the air traffic control tower and ARFF units at LaGuardia Airport. (Class II, Priority Action) (A-93-31)

Modify or replace all pump houses adjacent to runway 13/31 so that they are not obstructions to airplanes. (Class II, Priority Action) (A-93-32)

--to the Department of Transportation, in cooperation with the Federal Emergency Management Agency, the National Fire Protection Association, and the American Association of Airport Executives:

Recommend a review of emergency plans to include contingencies for applying cardiopulmonary resuscitation (CPR) techniques as soon as a sufficient number of trained personnel arrive at a mass casualty/triage incident. Emphasis should be placed on attempting CPR regardless of whether vital signs are present, especially when cold water immersion/near drowning is involved and where traumatic injuries may not indicate death. (Class II, Priority Action) (A-93-33)

--to the New York City Health and Hospitals Corporation:

Review and evaluate, in concert with other New York City emergency response agencies, the emergency medical response to the crash of USAir flight 405 in order to improve agency coordination efforts and to reduce transportation times of injured persons from LaGuardia Airport to area hospitals. (Class II, Priority Action) (A-93-34)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

Carl W. Vogt
Chairman

Susan Coughlin
Vice Chairman

John K. Lauber
Member

John Hammerschmidt
Member

Christopher A. Hart
Member

February 17, 1993

5. APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. Investigation

The National Transportation Safety Board was notified of the accident around 2150 on March 22, 1992. An investigation team was dispatched from Washington, D.C., early the next morning and arrived at LGA shortly thereafter. Investigative groups were formed on the scene for operations, human performance, air traffic control, meteorology, structures/maintenance records, systems, powerplant, and survival factors. Groups were later formed for airplane performance and readout of the CVR and FDR in Washington, D.C. Safety Board Member John Lauber accompanied the investigative team.

Parties to the investigation included USAir Inc., Fokker Aircraft, the Air Line Pilots Association, International Association of Machinists, Association of Flight Attendants, National Air Traffic Controllers Association, Port Authority of New York and New Jersey, and the Federal Aviation Administration.

2. Public Hearing

A public hearing on this accident was held in Flushing, New York, from June 22 through June 25, 1992. Member John Lauber was the presiding officer of that hearing.

APPENDIX B

PERSONNEL INFORMATION

The Captain

The captain, age 44, held an airline transport pilot (ATP) certificate with type ratings in the F-28, DC-9, EMB-110, DHC-7 and B-737. He also earned an airplane multiengine land rating with commercial privileges for the DC-6, and an airplane single-engine land rating. He held a flight engineer certificate with a rating for turbojet-powered aircraft and also an expired flight instructor certificate issued on July 2, 1981. At the time of the accident, company records indicate that he had accumulated approximately 9,820 total flying hours, of which 2,200 hours were in the F-28. A total of 1,400 hours of F-28 time was as captain. He was issued a first-class medical certificate with no limitations on November 19, 1991. He completed his last proficiency check on January 9, 1992. He received his last recurrent training on December 17, 1991, and completed an annual 9-hour home study course on winterization, passing the winterization closed book examination on November 25, 1991.

The captain was hired as an F-28 first officer by Piedmont Airlines on May 20, 1985, and served in that capacity until he was reassigned as a B-737-200 first officer on September 15, 1986. He upgraded to the F-28 and received his initial type rating on January 7, 1989. He subsequently bid captain on the B-737-200 and received a type rating on February 13, 1990. During a cutback in flight operations, he was reassigned as a captain on the F-28. He received a requalification training in the F-28 on January 20 and 21, 1991, and completed the proficiency check on January 22, 1991.

The First Officer

The first officer, age 30, was hired by Piedmont Airlines on July 19, 1989. He held an ATP certificate with ratings for airplane multiengine land and commercial privileges for airplane single-engine land. At the time of the accident, company records indicate that he had accumulated approximately 4,507 total flying hours, of which 29 hours were in the F-28. He held a flight engineer certificate with ratings for turbojet-powered aircraft and an expired instructor certificate issued on August 16, 1987. He also held an FAA license for non-Federal control towers with a rating for Beaver County Airport that was issued on

September 25, 1981. He received a first class medical certificate with no limitations on March 11, 1992.

The first officer was hired as a B-727 second officer and served in that capacity until he was furloughed on August 1, 1991. He was recalled on November 21, 1991, as a B-727 second officer. His last proficiency check as a second officer was accomplished on December 5, 1991. His last recurrent training was received on November 26, 1991, while he was still a second officer. He was reassigned as an F-28 first officer on February 1, 1992, and completed that initial training with a proficiency check on February 22, 1992. He received the F-28 airplane portion of his proficiency check on February 23, 1992. His last line check was accomplished during his initial operating experience (IOE) on February 29, 1992. He completed the annual winterization home study course and passed the examination on November 21, 1991.

APPENDIX C

AIRPLANE INFORMATION

USAir flight 405 was a Fokker 28 series 4000 (F-28-4000) airplane manufactured in the Netherlands. Its original type certificate was approved by the Civil Aviation Authority of the Netherlands. The FAA accepted the certification of the airplane under the Bilateral Airworthiness Agreement.

The F-28-4000 is a two-engine medium-range airplane designed for transporting as many as 85 passengers and 479 cubic feet of cargo. The F-28-4000 has moderately swept wings and no leading edge high lift devices, engines mounted on the sides of the rear fuselage, and a T-tail. The airplane is powered by two Rolls-Royce RB 183-2 Spey Mk 555-15P turbofans and each is designed to provide 9,900 pounds of takeoff thrust. The engines are not fitted with thrust reversers.

The airplane, registered in the United States as N485US, Serial No. 11235, was delivered to Piedmont Airlines on August 19, 1986, and was acquired by USAir in the merger of the airlines on August 5, 1989. At the time of the accident, the airplane had accrued 12,462 hours and 16,280 cycles.

The left engine, Serial No. 9252, was installed on the airplane on December 9, 1990. At the time of the accident, the engine had operated a total of 24,491 hours, and 2,882 hours since the last shop visit.

The right engine, Serial No. 9763, was installed on the airplane on April 18, 1991. At the time of the accident the engine had operated a total of 13,204 hours, and 2,014 hours since the last shop visit.

The airplane's center of gravity at takeoff was calculated to have been 21.0 percent of mean aerodynamic chord. The airplane's gross weight for this flight was calculated at 66,295 pounds. Both values were within limits for the flight.

The maintenance records of N485US were examined at the USAir maintenance facility in Pittsburgh, Pennsylvania. The records indicated that the airplane had been inspected and maintained in accordance with the General Maintenance Program as defined in USAir's Operations Specifications and in accordance with its FAA-approved Aircraft and Powerplant Reliability Programs.

The review of the maintenance records revealed no discrepancies that were relevant to the circumstances of the accident. The records indicated that all required inspections and maintenance actions had been accomplished within the times specified. The airplane logs carried 20 controlled open items, none of which were considered noteworthy with respect to the accident flight.

APPENDIX D

COCKPIT VOICE RECORDER TRANSCRIPT

TRANSCRIPT OF A FAIRCHILD MODEL A-100 COCKPIT VOICE RECORDER S/N 53857 WHICH WAS REMOVED FROM A USAIR AIRLINES, INC., FOKKER AIRCRAFT CO. F-28-4000, WHICH WAS INVOLVED IN A TAKEOFF ACCIDENT ON MARCH 22, 1992 AT LAGUARDIA INTERNATIONAL AIRPORT, FLUSHING, NEW YORK.

RDO	Radio transmission from accident aircraft
CAM	Cockpit Area Microphone sound or source
PA	Aircraft Public Address sound or source
-1	Voice identified as Captain
-2	Voice identified as First Officer
-?	Voice unidentified
TWR	Laguardia Local Controller (tower)
GND-1	LaGuardia Ground Controller
GND-2	LaGuardia Ground Sequence Controller
UNK	Unknown source
*	Unintelligible word
@	Nonpertinent word
#	Expletive deleted
%	Break in continuity
()	Questionable text
(())	Editorial insertion
-	Pause

Notes: All times are expressed in eastern standard time. Only radio transmissions involving the accident aircraft were transcribed.

INTRA-COCKPIT COMMUNICATION TIME & SOURCE	INTRA-COCKPIT COMMUNICATION CONTENT	AIR-GROUND COMMUNICATION TIME & SOURCE	AIR-GROUND COMMUNICATION CONTENT
2104 42	start of recording.		
2104 46	start of transcript.		
2105:06 CAM-1	there he goes.		
2105:07 CAM-2	okay.		
		2105:37 RDO-2	and ground USAir four oh five's ready to taxi.
		2106:18 GND-1	USAir four oh five turn left on the inner and ah hold short of echo.
		2106:22 RDO-2	left inner hold short echo USAir four oh five.
		2106:24 GND-1	USAir four oh five left turn on the inner hold short of echo. ground on one two one point eight five.
2106.25 CAM-2	left inner hold short of echo.		
2106:28 CAM-1	okay.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
		2106:29 RDO-2	ground on twenty one eighty five USAir four oh five.
2106:34 CAM-2	left on the inner hold short of echo. ground twenty one **.		
2106:48 CAM-2	left on the inner to hold short of echo.		
2106:52 CAM-1	yeah that's where everybody else is here.		
2106:53 CAM-2	yeah.		
2107:12	((flight switched to ground2 frequency))		
2107:27 CAM-?	((sound of person stretching))		
2107:38 CAM-1	I'm off.		
2107:40 PA-1	folks we are in line for takeoff and I see about ta about seven airplanes ahead ahead of us so ah it's not goin' to be about another eight or nine minutes before it's our turn to go. so thank you for *.		

INTRA-COCKPIT COMMUNICATION

TIME & SOURCE	CONTENT
2108:04 CAM-2	you seen that car wash they have at Denver. they like mount it to the hard stands.
2108:14 CAM-2	that's the ideal way of doin' it man.
2108:17 CAM-1	yup.
2108:18 CAM-2	they ought'a have somethin' like that - this is New York you know. this is they ought'a have that out there.
2108:24 CAM-1	yup.
2108:25 CAM-2	zip zip zip man just you know. put it on the tab. just cruise on out and take off.
2108:30 CAM-1	that's really the only s- sure fire safe way to do it.
2108:35 CAM-2	yeah.
2108:38 CAM-1	have it be an airport function they just charge each airline as they come through.

AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2109:59 CAM-2	# man we pull up behind this eighty he might keep our wings clear for us.		
2110:03 CAM-1	well.		
2110:04 CAM-2	((sound of laugh))		
2110:07 CAM-1	it can cause us to re-freeze too.		
2110:09 CAM-2	yeah it's true.		
2110:12 CAM-1	I don't want to get very close to him.		
2110:47 CAM-1	oh man this is gotta be **.		
2110:49 CAM-2	how'd you like to be stoppin' a L ten eleven out there tonight. man I'd.		
2110:52 CAM-1	how'd you like to be what?.		
2110:53 CAM-2	try to stop an L ten eleven out there tonight, heavy.		
2111:16 CAM-2	I just want to check in with this guy.		

INTRA-COCKPIT COMMUNICATION TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATION TIME & SOURCE	CONTENT
		2111:18 RDO-2	ground USAir four oh five ah just checkin' with ya we're ah behind company on the inner.
		2111:22 GND-2	USAir four oh five, thank you sir. once you have access continue on the outer hold short of runway four at delta.
2111:29 CAM-2	what?		
2111:35 CAM-2	hold short of the outer *.		
2112:10 CAM-2	he said somethin' about delta to us?		
2112:13 CAM-1	yeah I don't know what he's tellin' us.		
2112:14 CAM-2	delta is down there.		
2112:16 CAM-1	yeah.		
2112:20 CAM-2	does he want us ta I don't I'm just assumin' this he don't want us to go around and cross down at delta does he? or anything get ahead of anybody.		
2112:31 CAM-2	I'd ask him to repeat it. what the hell hurt his feelings * I don't know.		
2112:42 CAM-1	well we'll clarify it with 'im.		
		2112:44 RDO-1	and ground ah USAir four oh five. I just want to clarify our taxi instructions one more time.
		2112:49 GND-2	USAir four oh five you ah are you right over here off of gate seven? right off my ah - behind company MD-eighty?
		2112:56 RDO-1	ah yeah we're behind the MD-eighty and we're on ah the inner holding short of echo.
		2113:01 GND-2	that's fine sir just do that for now.

INTRA-COCKPIT COMMUNICATION TIME & SOURCE	CONTENT	AIR-GROUND COMMUNICATION TIME & SOURCE	CONTENT
		2113:03 RDO-1	okay.
2113:06 CAM-2	it sure didn't sound like that that I mean. I I didn't unde:stand what he said.		
		2113:33 GND-2	USAir four oh five taxi across runway four at echo follow your company MD-eighty on alpha.
		2113:38 RDO-2	four oh five wilco.
2114:56 CAM-?	# man it's *.		
2115:45 CAM-2	do you want to go to flaps eleven?.		
2115:48 CAM-1	I'm tendin' to go to the eighteen. set it up for eighteen one twenty nine.		
2115.54 CAM-2	al:ight.		
2116:05 CAM-1	we'll reduce that Vee one down to about a hundred and ten knots or so.		
2116:22 CAM-2	okay.		
2116:23 CAM-1	man I just ah short runway goin' tha: fast, whew.		
2116:30 CAM-2	did you read that article .hat Robert @ wrote in Flight Crew View about Vee one?		
2116:35 CAM-1	yeah I th:nk I have.		
2116:36 CAM-2	it's an excellent article to have.		
2117:03 CAM-1	leavin' LaGuardia # man that's a monday morning flight. that'll probably be jammed.		
2117:10 CAM-2	yup.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2117:16 CAM-2	maybe they'll cancel the Greensboro and just send us to Charlotte.		
2117:18 CAM-1	they might yeah might have to.		
2117:28 CAM-1	I think if that - people go up to Greensboro -.		
2117:30 CAM-2	is there any way if if we shortened our overnight just went out there and flew the flight. ah could we do that legally?		
2117:42 CAM-1	you mean leave at departure time?		
2117:44 CAM-2	yeah.		
2117:45 CAM-1	waive.		
2117:46 CAM-2	in other words make it like a COD or somethin'.		
2117:51 CAM-1	let -.		
2117:52 CAM-2	in other words we would be on duty we would st-- we would.		
2117:59 CAM-1	I think we would still be on duty all day long. I mean I don't think they'll let us be on duty like that.		
2118:00 CAM-2	yeah.		
2118:01 CAM-1	they'll pay us one for one and three quarter from ah ten ten this aft this morning until tomorrow. you know ah would be fine with me I mean #.		
2118:11 CAM-2	yeah but we can't stay on duty.		
2118:12 CAM-1	I don't I don't I don't know how long. we're not allowed to be on duty more than we can go up to sixteen hours max.		

INTRA-COCKPIT COMMUNICATION | AIR-GROUND COMMUNICATION

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2118:19 CAM-2	yeah so what.		
2118:20 CAM-1	we can we can call them and see -.		
2118:22 CAM-1	yeah well I will.		
2118:26 CAM-1	I mean we're gunna' have to cause I'm just not that fluent with the regulations.		
2118:28 CAM-2	yeah I'm not either.		
2118:29 CAM	((sound of windshield wipers))		
2118:30 CAM-2	I think that they're gunna' have to give us the minimum rest.		
2118:34 CAM-2	I mean me personally I will get up and fly the damn thing. but you know I'll go I'll go you know.		
2118:39 CAM-1	yeah.		
2118:41 CAM-2	may as well let me but I mean that's just I'll waive anythin' to get home the last day you know.		
2118:45 CAM-1	woll we'd have to have eight hours of rest ah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
2119:56 CAM-2	I can try to make heads or tails out of this thing.		
2118:57 CAM-1	during the twenty four hours prior to the completion of the flight right? isn't that the way it works?		
2119:03 CAM-2	I could try I could try to make heads or tails out of this stuff.		
2120:16 CAM-2	a previous rule.		
2120:25 CAM-1	what it amounts to is that prior to ten o'clock. ten ten tomorrow. we've gotta' have eight hours of rest.		
2120:33 CAM-2	moreover under no circumstances that a flight crew member receive less than eight consecutive hour rest within a twenty four hour period.		
2120:42 CAM-1	so between ten ten today -.		
2120:44 CAM-2	this mornin'.		
2120:45 CAM-1	- and ten ten tomorrow, we have to get eight hours of rest. so they're gunna' I guess -.		
2120:51 CAM-2	like we have to be.		
2120:55 CAM-2	so there ain't there ain't no way.		
2121:33 CAM-2	I mean you could ask them if they could put thru like ah. I don't think that they could do a COD thing like that. just send us to I just don't think they can.		
2121:43 CAM-1	no.		
2121:46 CAM-1	either they gunna have to get another crew up there or ah there gunna have to delay the flight. there's just no other way.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
2122:40 CAM-2	oh man I've ah I've a control tower operator's certificate I do non-federal control tower that was fun I did that in college a little bit.		
2122:52 CAM-1	huh.		
2122:53 CAM-2	it was a college program.		
2122:58 CAM-2	haven't used it since I took my checkride or my check what ever the hell they call it.		
2123:04 CAM-2	look at all that stuff.		
2123:08 CAM-2	what is that? san sand.		
2123:09 CAM-1	sand I guess.		
2123:11 CAM-1	urea sand.		
2123:11 CAM-2	put that # out there.		
2123:13 CAM-2	((sound of laugh))		
2123:21 CAM-1	aviation.		
2123:24 CAM-2	aviation is my life.		
2123:49 CAM-?	((sound of yawn))		
2123:56 CAM-1	yeah they are either gunna' have ta' delay the flight or ah relieve us.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2124:04 CAM-2	well.		
2124:06 CAM-1	here's the deal I'm gunna offer 'em. if it's alright with ya'll.		
2124:15 CAM-1	you got a schedule?		
2124:18 CAM-1	see when the first flight out of Laguardia to Charlotte is?		
2124:26 CAM-2	Laguardia to Charlotte?		
2124:27 CAM-1	non-stop yeah monday morning. is that a new schedule?		
2124:32 CAM-2	yeah.		
		2124:34 GND-2	usair four oh five continue via alpha left turn on papa behind company tower's eighteen seven number five.
		2124:39 RDO-2	alpha papa behind company good day thank you.
2125:02 CAM-2	alpha to papa makin' makin' pro progress here.		
2125:09 CAM	((sound of windshield wiper))		
2125:42	((flight switched to tower frequency))		
2125:59 CAM-?	uhh.		
2126:09 CAM-?	oh # it's under New York.		
2126:15 CAM-2	alright.		
2126:18 CAM-2	the first non-stop to Charlotte is seven oh five.		
2126:21 CAM-1	what's the next one then?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2126:22 CAM-2	eight twenty five.		
2126:24 CAM-1	alright let me see. leaves at eight twenty five?		
2126:27 CAM-2	and then nine fifty.		
2126:29 CAM-1	nine fifty. when would that one get into Charlotte?		
2126:32 CAM-2	eleven forty six.		
2126:34 CAM-1	# they all.		
2126:36 CAM-2	that's us ain't it?		
2126:39 CAM-1	no.		
2126:39 CAM-2	well we go to.		
2126:39 CAM-1	we go to greensboro and we get in at eleven fifty three. so it ain't gunna get us home any earlier.		
2126:50 CAM	((sound of windshield wipers start))		
2127:23 CAM	((sound of windshield wipers stop))		
2127:33 CAM-1	yeah we're just gunna have to delay the flight that's all there is to it unless they got somebody else there.		
2129:30 CAM-2	looks pretty good to me from what I can see.		
2129:34 CAM-1	yeah.		

INTRA-COCKPIT COMMUNICATION | **AIR-GROUND COMMUNICATION**

TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2129:27 CAM-2	it pretty much stopped the precip.		
2129:49 CAM-1	the after start is done is that correct?		
2129:51 CAM-2	yes before takeoff to go.		
2131:20 CAM-2	you want a Vee one call at one ten?		
2131:21 CAM-1	yeah.		
2131:25 CAM-1	got one landin' here on one three.		
2131:28 CAM-2	yeah there sandin' that other one there.		
2131:34 CAM-1	it's really amazing that they coordinate all this stuff.		
2131:36 CAM-2	no #.		
2131:39 CAM-2	cause they got to talk to approach and even center I guess now.		
2131:41 CAM-1	yeah.		
2131:43 CAM-2	just to sand the runway.		
2131:45 CAM-2	it all just backs up.		
2131:46 CAM-1	yeah.		
2131:56 CAM-1	flaps eighteen.		
2131:57 CAM	((sound similar to flap handle being moved))		
2131:58 CAM-1	before takeoff checks.		
2132:01 CAM-2	APU		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2132:02 CAM-1	it's on.		
2132:04 CAM-2	yaw damper?		
2132:05 CAM-1	in.		
2132:12 CAM-2	lift dumpers?		
2132:13 CAM-1	armed and ready.		
2132:14 CAM-2	ready right. collector tank indicators?		
2132:16 CAM-1	black.		
2132:17 CAM-2	black right. flight controls?		
2132:19 CAM-1	checked.		
2132:20 CAM-2	tops checked. takeoff data thrust indicators?		
2132:24 CAM-2	sixty six thousand flaps eleven one ten one twenty nine one thirty four. checked bugs set?		
2132:31 CAM-1	ah flaps eighteen please.		
2132:34 CAM-2	one ten one twenty four one twenty nine. I'm sorry flaps eighteen.		
2132:40 CAM-1	alright yeah one ten one twenty four one twenty nine - checked bugs set.		
2132:46 CAM-2	checked bugs set. flaps?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
2132:49 CAM-1	eighteen selected and indicated.		
2132:51 CAM-2	eighteen selected and indicated. stab and trims? point nine up. zero zero.		
2132:59 CAM-1	point nine up?		
2133:00 CAM-2	yeah.		
2133:01 CAM-1	zero zero.		
2133:03 CAM-2	okay and takeoff briefing?		
2133:06 CAM-1	right to zero seven five two and a half LaGuardia DME left to zero four zero.		
2133:13 CAM-2	right five thousand to the line.		
		2133:50 TWR	USAir four oh five taxi into position and hold one three.
		2133:52.8 ((until)) 2133:54.7 RDO-2	position and hold one three USAir four oh five.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
2133:56 PA-2	ladies and gentleman from the flight deck we're now number one for departure and we would like our flight attendants to please be seated thank you.		
2134:02 CAM-2	flight attendants notified transponder and flight director's on before takeoff check's completed.		
2134:10 CAM-2	okay ignition's on flaps eighteen a little discrepancy in our heading of about ah I guess that's this grid up here.		
2134:39 CAM	((sound of wipers start and continue until end of recording))		
		2134:51 TWR	USAir four oh five runway one three cleared for takeoff.
		2134:54.5 ((until)) 2134:56.4 RDO-2	cleared for takeoff USAir four oh five.
2134:56.6 CAM	((sound similar to parking brake being released))		
2134:58.7 CAM	((sound of increasing engine noise))		
2135:00.5 CAM-1	power's stabilized.		
2135:02.3 CAM-1	detent set takeoff thrust.		
2135:07.6 CAM-2	takeoff thrust's set temps okay.		
2135:12.3 CAM-2	power's, looks good.		
2135:17.1 CAM-1	eighty knots.		
2135:17.7 CAM-2	eighty knots.		
2135:22.72 ((until)) 2135:24.72 CAM	((sound similar to nine thumps))		
2135:25.4 CAM-2	vee one.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	**CONTENT**
2135:26.2 CAM-2	vee R.		
2135:28.40 CAM	((sound similar to nose strut extension))		
2135:29.4 CAM	((sound of windshield wiper))		
2135:30.17 CAM	((sound of snap))		
2135:30.56 CAM	((sound similar to magnetic indicators click))		
2135:30.67 CAM	((sound similar to magnetic indicators click))		
2135:33.2 CAM	((sound of stick shaker starts and continues until end of recording))		
2135:33.4 CAM	((sound of stall warning beep))		
2135:34 CAM-?	*.		
2135:35.2 CAM-1	God.		
2135:38.3 CAM	((sound of five stall warning beeps))		
2135:39.7 CAM-?	# come on.		
2135:40.78 CAM	((sound of first impact))		
2135:41.4 CAM	((sound of stall warning beep))		
2135:41.58 CAM	((sound of second impact))		
		2135:41.77 RDO-?	((sound of microphone key for 0.05 seconds))
2135:42.05 CAM	((sound of third impact))		
		2135:42.25 RDO-?	((sound of microphone key for 0.34 seconds))
2135:42.72	End of recording		

The surviving First Officer reviewed the group's transcript on April 29, 1992 and had the following suggested additions or changes:

Page 12
Change CAM-2 to CAM-1 at 2116:30.
Change CAM-2 to CAM-1 at 2116:36.

Page 13
Change CAM-1 to CAM-2 at 2117:03.
Change CAM-2 to CAM-1 at 2117:10.
Change CAM-1 to CAM-2 at 2117:28.
Change CAM-2 to CAM-1 at 2117:30.
Change CAM-1 to CAM-2 at 2117:42.
Change CAM-2 to CAM-1 at 2117:44.
Change CAM-1 to CAM-2 at 2117:45.
Change CAM-2 to CAM-1 at 2117:46.

Page 14
Change CAM-1 to CAM-2 at 2117:51.
Change CAM-1 to CAM-2 at 2117:59.
Change CAM-2 to CAM-1 at 2118:11.
Change CAM-1 to CAM-2 at 2118:12.
Change CAM-2 to CAM-1 and add pause (-) between words yeah and so at 2118:19.
Change CAM-1 to CAM-2 at 2118:20.

Page 15
Change CAM-1 to CAM-1 at 2118:22.
Change CAM-1 to CAM-2 at 2118:26.
Change CAM-2 to CAM-1 at 2118:28.
Add words " I know that" to the beginning of CAM-2 statement at 2118:30.

Page 16
Change CAM-1 to CAM-2 at 2120:42.
Change CAM-2 to CAM-1 at 2120:44.
Change CAM-1 to CAM-2 at 2120:45.

Page 17
Change CAM-2 to CAM-1 at 2120:55.

Page 18

Delete end of phrase from "what ever ---" till the end of CAM-2 statement at 2122:58.

Add phrase "CAM-2 what ever the hell they call it." between statements 2122:58 and statement 2123:04.

Change CAM-1 to CAM-2 at 2123:21.

Change CAM-2 to CAM-1 at 2123:24.

Page 20

Change CAM-? to CAM-2 and delete "it's under New York." at 2126:09.

Add "CAM-1 it's under New York." between statement at 2126:09 and statement at 2126:15.

Page 22

Change CAM-2 to CAM-1 at 2131:34.

Page 24

Change CAM-2 to CAM-1 at 2132:24.

Change CAM-1 to CAM-2 at 2132:31.

Change CAM-2 to CAM-1 at 2132:34.

Change CAM-1 to CAM-2 and delete "checked bugs set" from end of statement at 2132:40.

Add "CAM-1 checked bugs set." between statement at 2132:40 and statement at 2132:46.

Page 26

Change CAM-2 to CAM-1 and delete remainder of statement after " -- flaps eighteen." at 2134:10.

Add "CAM-2 a little discrepancy in our heading of about ah I guess that's this grid up here." between statement at 2134:10 and "CAM ((sound of wipers --" at 2134:39.

Page 27

Change word " temps" to " checks" in statement at 2135:07.6.

Change CAM-2 to CAM-1 at 2135:12.3.

Page 28

Change Cam-1 to CAM-2 at 2135:35.2.

James R. Cash
Electronics Engineer

APPENDIX E

FOKKER SIMULATION TEST SUMMARY

R E P O R T
Fokker Aircraft B.V. Amsterdam
The Netherlands

issue date: June 1992 issue no:

security class Restricted | report no. VS - 28 - 33

TEST MATRIX

The test cases investigated comprise variations of pitch angle, pitch rate and rotation speed. Furthermore, the effect of upper surface wing contamination was considered. The test cases are summarized in a test matrix shown in the following table.

Configuration

Flaps = 18°
cg = 21 % max
V_{wind} = 10 kts
V_R = 124 kts

TOW = 65,250 lbs
Full TO Thrust
V_1 = 110 kts
V_2 = 129 kts

case	Wing contamination	Rotation speed (kts)	Rotation Procedure
1	No	$V_R + 2\frac{1}{2}$	Smoothly* to θ = 10°
2	No	V_R	Smoothly to θ = 15°
3	No	V_R	Fast** to θ = 15°
4	No	V_R - 10	Smoothly to θ = 15°
5	Yes+	V_R	Smoothly to θ = 10°
6	Yes+	V_R	Fast to θ = 10°
7	Yes+	V_R	Slow*** to θ = 10°
8	Yes+	V_R - 10	Smoothly to θ = 10°
9	Yes+	V_R + 10	Smoothly to θ = 10°
10	Yes+	V_R	Smoothly to θ = 15°
11	Yes+	V_R	Fast to θ = 15°
12	Yes+	V_R	Slow to θ = 15°
13	Yes+	V_R - 10	Smoothly to θ = 15°
14	Yes+	V_R + 10	Smoothly to θ = 15°

Note to Table:
- * $\dot{\theta}_{av}$ = 3°/sec
- ** $\dot{\theta}_{av}$ = 5°/sec
- *** $\dot{\theta}_{av}$ = 2°/sec
- \+ Roughness on wing upper surface k/c ≳ .00035; i.e., 1.0 to 2.0 mm per cm²

REPORT
Fokker Aircraft B.V. Amsterdam
The Netherlands

issue date: June 1992 issue no:

security class Restricted | report no. VS - 28 - 33

Table 2 Runway lengths

Case	XRW(m)	YRW(m)	HRW(m)	VAS(m/s)	Remarks
1 LOF 35ft	927.2 1130.1	-9.3 -7.8	3.1 13.8	68.1 71.5	no event
2 LOF 35ft	925.2 1109.2	-9.3 -8.0	3.1 13.9	68.1 70.7	no event
3 LOF 35ft	896.0 1032.2	-9.3 -8.4	3.2 14.0	67.1 68.6	no event
4 LOF 35ft	803.3 994.2	-9.4 -8.2	3.1 14.0	64.1 67.3	no event
5 LOF 35ft	931.7 1140.0	-9.3 -7.7	3.1 13.9	68.0 71.2	no event
6 LOF 35ft	904.4 1105.5	-9.3 -7.7	3.2 13.9	67.2 70.1	no event
7 LOF 35ft	969.3 1198.5	-9.4 -7.7	3.1 13.9	69.2 72.7	no event
8 LOF 35ft	780.3 1057.9	-9.4 -6.9	3.2 13.9	63.2 68.2	no event
9 LOF 35ft	1073.5 1268.1	-9.2 -7.7	3.1 13.9	72.2 74.6	no event
10 LOF 35ft	937.6 1139.5	-9.3 -7.6	3.2 13.9	68.2 69.0	stickshaker probable crash
11 LOF 35ft	900.5 1612.9 1887.6	-9.3 -2.7 -2.2	3.2 3.3 13.9	67.1 76.7 69.6	stickshaker stallhorn crash
12 LOF 35ft	945.5 1172.2	-9.3 -7.6	3.1 14.0	68.5 71.7	no event
13 LOF 35ft	785.7 1130.7 13[illegible]1.5	-9.4 -5.9 -4.1	3.1 4.0 13.9	63.4 67.1 67.5	stickshaker stallhorn crash
14 LOF 35ft	1066.1 1277.2	-9.2 -7.7	3.1 13.9	72.5 74.4	no event

F-20 SIMULATED TAKEOFFS - PEAK WING ANGLE OF ATTACK

ROTATION RATE	10 DEG TARGET		15 DEG TARGET		ROTATION SPEED
	CLEAN	ICE	CLEAN	ICE	
	PEAK WING ANGLE OF ATTACK-DEGREES				
SLOW 2 DEG/SEC	...	...	...	...	VR - 7.5
	...	6.8	...	8.4	VR + 2.5
	...	...	...	...	VR + 12.5
MEDIUM 3 DEG/SEC	...	8.4	9.6	16	VR - 7.5
	7.1	7.3	8.8	12	VR + 2.5
	...	6.8	...	8.7	VR + 12.5
FAST 5 DEG/SEC	...	...	...	...	VR - 7.5
	...	8.7	10.1	13	VR + 2.5
	...	...	...	...	VR + 12.5

NOTE: CONTAMINATED WING STALL OCCURS AT AN AOA OF 9 DEGREES IN THESE SIMULATIONS.

APPENDIX F

PREVIOUS SAFETY BOARD AIRFRAME ICING SAFETY RECOMMENDATIONS

The Safety Board's first investigation of an air transport category structural icing accident involved a DC-9-15 airplane. The accident occurred on December 27, 1968, at the Sioux City Airport at Sioux City, Iowa. The airplane involved was operated by Ozark Air Lines, Incorporated. The Safety Board's finding of probable cause in that accident was:

> ...a stall near the upper limits of ground effect, with subsequent loss of control as a result of the aerodynamic and weight penalties of airfoil icing. The flightcrew failed to have the airfoil ice removed prior to the attempted takeoff from Sioux City...

The Safety Board also concluded in its report on that accident that:

> The captain failed to recognize the aerodynamic penalties of airfoil icing. He did not personally check, or require his first officer to personally check, the ice accumulation on the aircraft, although he was advised of its presence.

There were no safety recommendations issued related to the icing problem as a result of the Ozark Airlines accident. However, as a result of this and other structural icing accidents and incidents, including a Trans World Airlines DC-9-10 incident at Newark, New Jersey, on November 27, 1978, the Safety Board undertook a special study on aircraft icing avoidance and protection. The report on this study was adopted on September 9, 1981, and contained, among others, the following conclusions:

> While icing is an infrequent causal factor in aircraft accidents, it is a particularly hazardous one.
>
> Many pilots are either insufficiently trained or, in spite of training, they demonstrate a lack of respect for potentially hazardous conditions.

An aircraft could legally fly into an area of severe icing under 14 CFR 91 and 135, yet by definition the aircraft cannot control the hazard. There is a need to reconcile the contradiction between the definitions of icing severity in the Airman's Information Manual and the associated regulations.

The measurement and forecasting of the meteorological parameters associated with icing would be only the first of two parts of improved icing avoidance.

and:

The second and equally important part would be the evaluation of aircraft performance throughout a reasonable range of the meteorological parameters.

The safety recommendations that were issued with this report generally related to the measurement and forecasting of hazardous icing conditions. However, four safety recommendations were addressed to the Federal Aviation Administration which dealt with the issues in the above conclusions and are as follows:

A-81-115

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

A-81-116

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 conditions, as necessary.

A-81-117

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.

A-81-118

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.

These safety recommendations were pursued by the Safety Board for a number of years. On March 12, 1987, the Safety Board acted to classify Safety Recommendation A-81-117 as "Closed--Acceptable Action," with the statement:

> The Safety Board finds that the FAA's actions of issuing advisory Circulars 29-2 and 23.1419-1 and reorganizing the aircraft certification efforts comply with the intent of this recommendation. Safety Recommendation A-81-117 has been classified as "Closed--Acceptable Action."

On April 11, 1990, the Board acted to classify Safety Recommendation A-81-115 as "Closed--Unacceptable Action," with the words:

> 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."

Safety Recommendation A-81-116 was classified as "Open--Unacceptable Response," on the same date with the statement:

> The Safety Board recognizes that a vast amount of research and gathering of information has been accomplished and that the FAA intends to determine the appropriate course of action in the future. However, the content of this safety recommendation has not been addressed. The FAA has not shown the Safety Board that it has reviewed the Part 25 icing criteria or addressed the certification envelope. For these reasons, Safety Recommendation A-81-116 remains classified as "Open--Unacceptable Response."

Safety Recommendation A-81-118 was classified as "Open--Acceptable Response," also on April 11, 1990, with the statement:

> The FAA responded by stating that the specifics of this safety recommendation will be addressed once results of the study of aviation icing requirements described by the "National Plan to Improve Aircraft Icing Forecasts" are issued and once an improved icing severity index is developed and evaluated. This is expected in 1991. Although the Safety Board is disappointed that the FAA has not implemented this safety recommendation after 8 years, it will be maintained as "Open--Acceptable Response," pending further response.

Since the Board's report on aircraft icing, there have been four more structural icing accidents investigated by the Board. An Airborne Express, DC-9-15 crashed on takeoff in light freezing rain with ice and snow pellets on February 5, 1985, at Philadelphia, Pennsylvania; a Continental Airlines DC-9-14 crashed on takeoff in moderate snow and fog on November 15, 1987, at Denver, Colorado; a Ryan International Airlines DC-9-15 crashed while taking off from Cleveland Hopkins International Airport on February 17, 1991, in icing conditions; and the USAir Fokker 28-4000 crashed at LaGuardia Airport in Flushing, New York, on March 22, 1992. There were no safety recommendations issued as a result of the Airborne Express accident investigation. However, the report on the Continental accident contained nine safety recommendations addressed to the FAA, two of which specifically addressed icing problems associated with the DC-9-10 series of airplanes. These safety recommendations are:

A-88-134

Until such time that guidelines for detecting upper wing surface icing can be incorporated into the airplane flight manual, issue an Air Carrier Operations Bulletin directing all Principal Operations Inspectors to require that all McDonnell DC-9-10 series operators anti-ice airplanes with maximum effective strength glycol solution when icing conditions exist.

A-88-136

Require all DC-9-10 series operators to establish detailed procedures for detecting upper wing ice before takeoff.

The FAA responded to these safety recommendations in a January 30, 1989 letter. In response to Safety Recommendation A-88-134, the FAA stated:

On January 1, 1988, the FAA issued Action Notice 6300.34, "Aircraft Deicing Procedures" to bring the contents of Advisory Circular (AC) 20-117, "Hazards Following Ground Deicing and Operations in Conditions Conducive to Aircraft Icing," to the attention of operations and maintenance inspectors ... The FAA also issued Air Carrier Operations Bulletin No. 7-81-1, "Aircraft Deicing and Anti-icing Procedures," requesting that each Principal Operations Inspector become familiar with AC 20-117 and provide a copy of AC 20-117 to each of their certificate holders.

In response to Safety Recommendation A-88-136, the FAA stated:

The FAA does not agree with this recommendation and does not plan to require that DC-9-10 operators establish special ice inspection procedures for the DC-9-10 aircraft. The FAA does not believe that there is anything unique about the DC-9-10 series aircraft (including the absence of slats) that would warrant special ice detection procedures. It is a well-known fact that any ice, snow, or frost adhering to wings, propellers, or control surfaces can cause a degradation of aircraft performance and aircraft flight characteristics, the magnitude of which may be significant and unpredictable. It appears that, in the case of this accident, the flightcrew did not follow procedures in the flight operations manual with respect to the visual inspection of the aircraft....

The Safety Board did not reply to the FAA regarding its response to these safety recommendations as there was an effort underway to update the Board's position regarding the effects of structural icing on transport category aircraft. While that effort was being carried out, the Ryan Air accident occurred.

The Board's report on the Ryan Air accident contained six safety recommendations related to airframe icing (A-91-123 through -128). Also, in the Board's report on Ryan Air, Safety Recommendation A-88-136 was classified as "Closed--Unacceptable Action/Superseded," by Safety Recommendations A-91-123 through -125. The issue date for Safety Recommendations A-91-123 through -128 was December 11, 1991.

In an August 31, 1992, letter to the FAA, the Safety Board classified Safety Recommendation A-88-136 as "Closed--No Longer Applicable." This action was taken as a result of the issuance of Airworthiness Directive 92-03-01, which the Board found negated the need for Safety Recommendation A-88-134.

The FAA responded to these safety recommendations on February 27, 1992. The following statements were made for the pertinent recommendations:

> <u>A-91-123</u>
>
> Require the inclusion in the DC-9 series 10 Approved Airplane Flight Manual of a caution about the susceptibility of the airplane to flight control problems with minute and marginally detectable amounts of ice on the leading edge and upper surface of the wing.
>
> <u>FAA Comment.</u> The Federal Aviation Administration (FAA) issued Airworthiness Directive (AD) 92-03-01 (Docket No. 92-NM-01-AD) on January 3, 1992, applicable to McDonnell Douglas DC-9-10 series airplanes. The AD requires the inclusion of a cautionary note in the Airplane Flight Manual which specifies that wings without leading edge devices are particularly susceptible to loss of lift due to wing icing. Minute amounts of ice or other contamination on the leading edges or wing upper surfaces can cause a significant reduction in the stall angle-of-attack. The cautionary note also specifies that the increased stall speed can be well above the stall

warning (stick shaker) activation speed. This AD became effective on January 17, 1992.

A-91-124

Require in air carrier operations manuals and appropriate airplane flight manuals that flightcrews of DC-9 series 10 airplanes perform a visual and tactile inspection of the wing leading edge and upper surface using necessary equipment prior to departure whenever temperatures below 5^oC and visible moisture exist or whenever the airplane recently encountered icing conditions.

FAA Comment. On January 3, 1992, the FAA issued AD 92-03-01 (Docket No. 92-NM-01-AD) applicable to McDonnell Douglas DC-9-10 series airplanes. This AD requires a revision to the Airplane Flight Manual Limitations Section which specifies that takeoff may not be initiated unless the flightcrew verifies that visual and physical checks of the leading edge and upper wing surfaces have been accomplished when the outside air temperature is below 6^oC and the difference between the dew point temperature and outside air temperature is less than 3^oC or visible moisture is present. This AD became effective on January 17, 1992.

A-91-125

Require Principal Operations Inspectors to review certificate holders operating DC-9 series 10 airplanes to determine the adequacy of flightcrew training programs related to airframe icing conditions.

FAA Comment. The FAA agrees with the intent of this safety recommendation and plans to issue an air carrier operations bulletin (ACOB) directing principal operations inspectors (POIs) to review flightcrew training programs of certificate holders that operate DC-9-10 series airplanes. This ACOB will direct POI's to ensure that specific attention is directed toward the adequacy of training objectives, methods, media, and evaluation techniques which involve instruction related to airframe icing conditions.

A-91-126

Evaluate the need for actions as described in Safety Recommendations A-91-123 through A-91-125 for other transport category turbojet airplanes that do not have leading edge devices and are particularly susceptible to flight control problems arising from small amounts of frost, ice or snow on the wings.

FAA Comment. The FAA conducted a survey of Boeing, Douglas, and Lockheed airplanes not having leading edge devices, other than the DC-9-10 series airplane, and found that these airplanes are not considered particularly susceptible to flight control problems arising from small amounts of frost, ice, or snow on the wings. The FAA is continuing its effort to identify other transport category turbojet airplanes which do not have leading edge deice or anti-ice devices.

A-91-127

Evaluate a procedure to use the maximum rotation speed during takeoff that will retain the presently required end of runway and climb gradient safety margins when operating on runways that exceed the minimum takeoff runway length required; require operators to provide maximum rotation speed information to DC-9-series 10 flightcrews for use in winter operations.

FAA Comment. The FAA has studied various proposals to increase the rotation speed during takeoff. These proposals were further evaluated and rejected as operationally unsatisfactory. The FAA believes that the actions required by AD 92-03-01 mentioned in response to Safety Recommendations A-91-123 and -124 are intended to prevent ice contamination which could result in the degradation of wing lift and stall at lower than normal angles-of-attack during takeoff.

A-91-128

Require air carrier operators, when acquiring a new model aircraft, to formally request from the manufacturer all pertinent information previously disseminated regarding the operation of the particular aircraft type.

FAA Comment. The FAA will issue an ACOB directing that POIs request that operators who add a new type aircraft to their fleet acquire all available information from the manufacturer which is pertinent to the operation of the aircraft before introducing the aircraft into revenue service.

Based on these responses, the Safety Board classified the recommendations as follows:

A-91-123:	Closed--Acceptable Action
A-91-124:	Closed--Acceptable Action
A-91-125:	Open--Acceptable Alternate Response
A-91-126:	Open--Unacceptable Response
A-91-127:	Open--Unacceptable Response
A-91-128:	Open--Acceptable Alternate Response

The reasoning for each action was as follows as transmitted to the FAA in the Board's June 25, 1992, letter:

A-91-123

The Safety Board is pleased to note that on January 3, 1992, the FAA issued Airworthiness Directive (AD) 92-03-01 (Docket No. 92-NM-01-AD) fulfilling the intent of Safety Recommendation A-91-123, which is now classified as "Closed--Acceptable Action."

A-91-124

The Safety Board notes that AD 92-03-01 requires a revision to the airplane flight manual specifying that a visual and hands-on check must be accomplished before takeoff. The AD fulfills the intent of this safety recommendation, which is now classified as "Closed--Acceptable Action."

A-91-125

The Safety Board notes that the FAA agrees with the intent of this safety recommendation and intends to issue an Air Carrier Operations Bulletin (ACOB) on this subject. Accordingly, Safety

Recommendation A-91-125 is classified as "Open--Acceptable Alternate Response."

A-91-126

From your response, we assume that you intended to refer to airplanes that do not have leading edge devices. In that case, we would like to know the basis upon which the Douglas DC-8 was evaluated since some of the manufacturer's own literature cites that airplane's susceptibility to control problems with minimal wing contamination.

On March 22, 1992, a Fokker F-28 crashed during takeoff at LaGuardia Airport in weather conditions conducive to the accumulation of snow or ice on the airplane. While the investigation is not complete, the Safety Board is examining the possibility of degraded aerodynamic performance resulting from wing contamination. Because the Safety Board believes that the FAA should take more positive action to ensure that the operators of airplanes, other than the DC-9 series 10, adequately address the problems of winter operations in flight manuals and training programs, Safety Recommendation A-91-126 is classified as "Open--Unacceptable Response."

A-91-127

The Safety Board continues to believe that procedural changes that can provide greater safety margins between takeoff speed and aerodynamic stall speed can be implemented without compromising other takeoff safety considerations on those infrequent occasions when snow or ice contamination are possible.

We understand that the use of higher rotation speeds must be predicated upon available runway length and proper engine performance as the airplane reaches currently specified rotation speeds. However, the Board believes that pilots can be trained to revert to normal takeoff procedures in the event of an engine failure. Furthermore, the Board believes that the modification of procedures in those instances when wing contamination is possible is analogous to the procedures contained in the Windshear Training Aid approved by the FAA for use when an encounter with a microburst windshear is recognized during takeoff. The Safety Board requests that the FAA reconsider its position on Safety Recommendation A-91-127, which is classified as "Open--Unacceptable Response."

A-91-128

The Safety Board notes that the FAA will issue an ACOB implementing the intent of this safety recommendation, which is classified as "Open--Acceptable Alternate Response."

On May 21, 1992, the FAA responded further to Safety Recommendations A-91-125 and -128. The FAA's comments were as follows:

A-91-125

On April 17, 1992, the FAA issued Air Carrier Operations Bulletin (ACOB) 3-92-1, Airframe Icing Training for Aircrews operating DC-9-10 Series Airplanes, DC-9-80 Series Airplanes, and Model MD-88 Airplanes. This bulletin directs principal operations inspectors (POIs) to ensure that their respective operators are aware of airframe icing problems and that the flightcrew training programs and operations manuals contain guidance and procedures for conducting visual and physical (hands on) inspections of these aircraft when icing conditions exist. This bulletin also directs POIs to give special attention to the adequacy of training objectives, methods, media, and evaluation techniques which involve instruction related to airframe icing conditions.

A-91-128

On April 10, 1992, the FAA issued ACOB 8-92-1, Requesting Previously Disseminated Information Regarding the Operation of a New Model Aircraft. This ACOB directs POIs, as part of the authorization to include a new model airplane into a fleet used for revenue flights in air transportation, to encourage their assigned operators to formally request all pertinent information that is unique to the safe operation of that model aircraft.

Based on this response, on July 17, 1992, the Board classified both Safety Recommendations A-91-125 and A-91-128 as "Closed--Acceptable Alternate Action." The reasoning for these classifications was as follows:

A-91-125

The Safety Board notes that the FAA issued Air Carrier Operations Bulletin (ACOB) 3-92-1, Airframe Icing Training for Aircrews operating DC-9-10 Series Airplanes, DC-9-80 Series Airplanes, and Model MD-88 Airplanes. This bulletin directs POIs to ensure that their respective operators are aware of airframe icing problems and that the flightcrew training programs and operations manuals contain guidance and procedures for conducting visual and physical (hands on) inspections of these aircraft when icing conditions exist. Based on the above information, Safety Recommendation A-91-125 is classified as "Closed--Acceptable Alternate Action."

A-91-128

The Safety Board notes that the FAA issued ACOB 8-92-1, Requesting Previously Disseminated Information Regarding the Operation of a New Model Aircraft. Based on the above information, the Safety Board classifies Safety Recommendation A-91-128 as "Closed--Acceptable Alternate Action."

Safety Recommendations A-91-126 and -127 continue to be held as "Open--Unacceptable Response." The Safety Board is awaiting further response to these safety recommendations.

APPENDIX G

SAE GUIDELINES FOR HOLDOVER TIMES

TYPE I AND TYPE II FLUID MIXTURES AS A FUNCTION OF WEATHER CONDITIONS AND OAT

Table 1. Guideline for Holdover Times Anticipated by SAE Type II and ISO Type II Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION! THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY.
IT SHOULD BE USED IN CONJUNCTION WITH PRE-TAKEOFF CHECK PROCEDURES.

OAT °C	OAT °F	Type II Fluid Concentration Neat-Fluid/Water (% by Volume)	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours: minutes) FROST	FREEZING FOG	SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
0 and above	32 and above	100/0	12:00	1:15-3:00	0:25-1:00	0:08-0:20	0:24-1:00
		75/25	6:00	0:50-2:00	0:20-0:45	0:04-0:10	0:18-0:45
		50/50	4:00	0:35-1:30	0:15-0:30	0:02-0:05	0:12-0:30
below 0 to -7	below 32 to 19	100/0	8:00	0:35-1:30	0:20-0:45	0:08-0:20	CAUTION! clear ice may require touch for confirmation
		75/25	5:00	0:25-1:00	0:15-0:30	0:04-0:10	
		50/50	3:00	0:20-0:45	0:05-0:15	0:01-0:03	
below -7 to -14	below 19 to 7	100/0	8:00	0:35-1:30	0:20-0:45	List of Symbols °C = Celsius °F = Fahrenheit Vol = Volume OAT = Outside Air Temp.	
		75/25	5:00	0:25-1:00	0:15-0:30		
below -14 to -25	below 7 to -13	100/0	8:00	0:35-1:30	0:20-0:45		
below -25	below -13	100/0 if 7°C(13°F) Buffer is maintained	A buffer of at least 7°C(13°F) must be maintained for Type II used for anti-icing at OAT below -25°C(-13°F). Consider use of Type I fluids where SAE or ISO Type II cannot be used.				

Table 2. Guideline for Holdover Times Anticipated by SAE Type I, and ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION! THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY.
IT SHOULD BE USED IN CONJUNCTION WITH PRE-TAKEOFF CHECK PROCEDURES.

Freezing Point of Type I fluid mixture used must be at least 10°C(18°F) below OAT.

Outside Air Temperature °C	Outside Air Temperature °F	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes) FROST	FREEZING FOG	SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
0 & above	32 & above	0:18-0:45	0:12-0:30	0:06-0:15	0:02-0:05	0:06-0:15
below 0 to -7	below 32 to 19	0:18-0:45	0:06-0:15	0:06-0:15	0:01-0:03	CAUTION! Clear ice may require touch for confirmation
below -7	below 19	0:12-0:30	0:06-0:15	0:06-0:15		