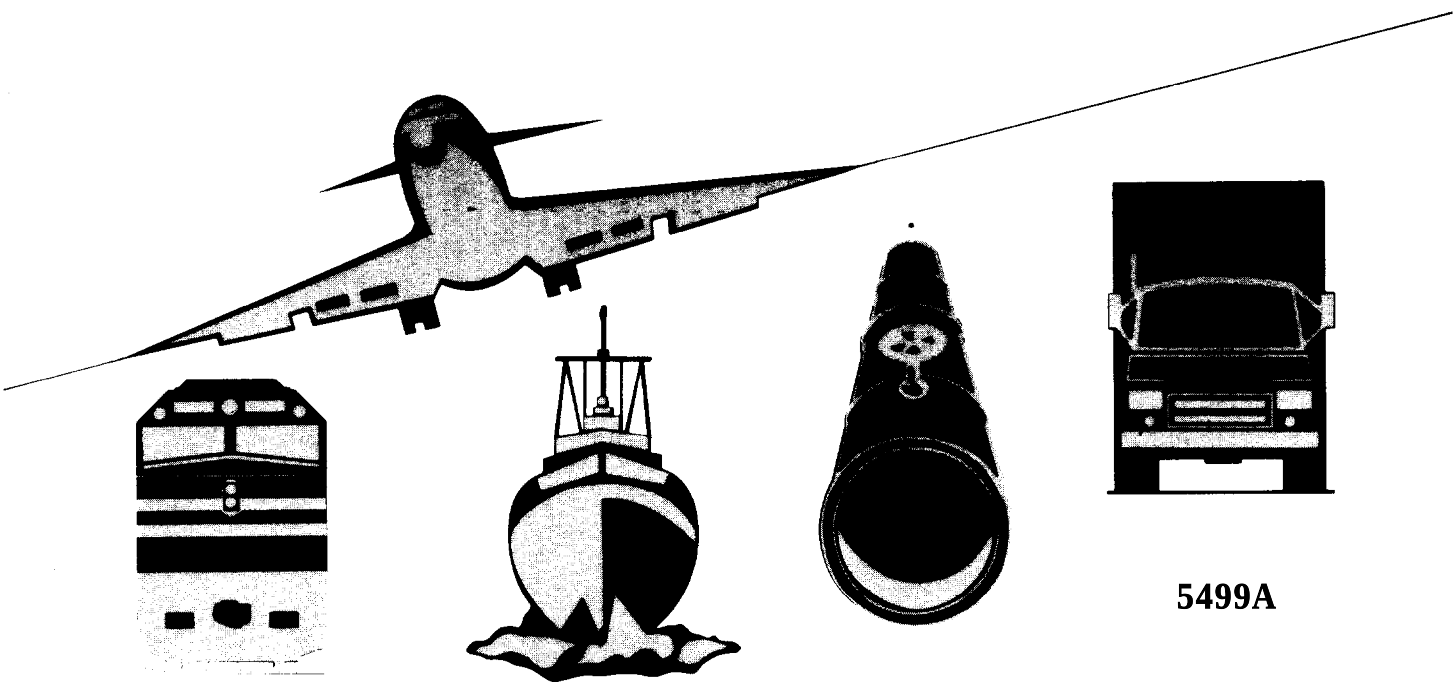
PB91-910410
NTSB/AAR-91/09

NATIONAL TRANSPORTATION SAFETY BOARD

WASHINGTON, D.C. 20594

AIRCRAFT ACCIDENT REPORT

RYAN INTERNATIONAL AIRLINES
DC-9-1 5, N565PC
LOSS OF CONTROL ON TAKEOFF
CLEVELAND-HOPKINS INTERNATIONAL AIRPORT
CLEVELAND, OHIO
FEBRUARY 17, 1991



5499A

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AIRCRAFT ACCIDENT REPORT

RYAN INTERNATIONAL AIRLINES
DC-9-15, N565PC
LOSS OF CONTROL ON TAKEOFF
CLEVELAND-HOPKINS INTERNATIONAL AIRPORT
CLEVELAND, OHIO
FEBRUARY 17, 1991

Adopted: November 16, 1991
Notation 5499A

Abstract: This report explains the crash on takeoff of Ryan International Airlines flight 590 at Cleveland, Ohio, on February 17, 1991. The safety issues discussed in the report are the dissemination of information regarding precautions to be taken when operating in conditions conducive to airframe ice and the particular susceptibility of DC-9 series 10 airplanes to control problems during takeoff when a minute amount of ice is on the wing. Recommendations concerning these issues were made to the Federal Aviation Administration.

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EXECUTIVE SUMMARY

About 0019, Sunday, February 17, 1991, Ryan International Airlines flight 590 (Ryan 590), a DC-9 series 10 airplane, crashed while taking off from Cleveland-Hopkins International Airport. The flightcrew consisted of two pilots. There were no other crewmembers or passengers on the flight, which was contracted to carry mail for the U.S. Postal Service. Both pilots were fatally injured, and the airplane was destroyed as a result of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the flightcrew to detect and remove ice contamination on the airplane's wings, which was largely a result of a lack of appropriate response by the Federal Aviation Administration, Douglas Aircraft Company, and Ryan International Airlines to the known critical effect that a minute amount of contamination has on the stall characteristics of the DC-9 series 10 airplane. The ice contamination led to wing stall and loss of control during the attempted takeoff.

The safety issues discussed in this report include the dissemination of information regarding precautions to be taken when operating in conditions conducive to airframe ice and the particular susceptibility of DC-9 series 10 airplanes to control problems during take off when a minute amount of ice is on the wing.

NATIONAL TRANSPORTATION SAFETY BOARD
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RYAN INTERNATIONAL AIRLINES
DC-9-15, N565PC
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1. FACTUAL INFORMATION

1.1 History of the Flight

About 0019, Sunday, February 17, 1991, Ryan International Airlines flight 590 (Ryan 590), a DC-9-15, crashed while taking off from Cleveland-Hopkins International Airport (CLE). The flightcrew consisted of two pilots. There were no other crewmembers or passengers on the flight, which was contracted to carry mail for the U.S. Postal Service. Both pilots were fatally injured, and the airplane was destroyed as a result of the accident.[1]

Ryan 590, which was operating under 14 Code of Federal Regulations, Part 121, originated at Greater Buffalo International Airport (BUF), New York. The flight departed BUF on schedule at 2255, Saturday, February 16. After the stop at CLE, the flight had a proposed final destination of Indianapolis International Airport (IND), Indiana.

About 2250, approximately 55 minutes before Ryan 590 landed at CLE, the flightcrew of Continental Airlines flight 8953, a DC-9, radioed a pilot report (PIREP) to CLE Approach Control. The flightcrew reported that they had encountered moderate turbulence and rime icing from 3,000 to 7,000 feet during climbout. CLE Approach Control passed the information contained in a second PIREP, not recorded by the National Weather Service (NWS), at 2329:58, to both Ryan 590 and to a Pan American Airlines flight that also had been monitoring that frequency. CLE Approach Control described the information as "two pilot reports moderate rime icing reported 7,000 feet on to the surface during the descent that was by a 727, and also moderate chop turbulence from 4,000 feet on to the surface." The flightcrew of Ryan 590 acknowledged receiving this information as they were executing an instrument landing system (ILS) approach to runway 23 left at CLE.

Ryan 590 landed at CLE at 2344. The flightcrew taxied to the mail ramp so that mail could be transferred. Some of the mail from BUF was unloaded at CLE, and additional mail destined for IND was loaded aboard. The pilots reportedly remained in the cockpit during the stop at CLE.

[1] Unless otherwise noted, all times listed are local, eastern standard time, based on the 24-hour clock.

Snow, reported as dry and blowing, fell throughout the approximately 35 minutes that Ryan 590 was on the ground at CLE. Neither Ryan 590 nor any other flight that took off from CLE during the evening or early morning hours of February 16-17, 1991, requested or received deicin service. Ten minutes after the accident, the temperature at CLE was 23% Fahrenheit (F), and the dewpoint was 20° F.

The CLE air traffic control (ATC) tower issued the departure clearance to Ryan 590 at 0006:38. At 0009:18, the flightcrew asked for taxi clearance from "south cargo." The ATC controller issued the clearance and informed the flightcrew that the last reported braking action, which the flightcrew had described as "fair," was when Ryan 590 arrived. Ryan 590 taxied for takeoff on runway 23 left and, at 0018:17, was cleared for takeoff to "fly runway heading."

Some witnesses described seeing the airplane lift off from the runway, saying that at 50 to 100 feet above ground level it rolled to the right, followed by a severe roll to the left, past the 90° position, and crashed. Other witnesses described the first unusual movement as a slight roll to the left, followed by a substantial roll to the right, with an increase in pitch attitude, and a more severe roll to the left before impact.

The tower controller saw the roll sequence differently. He stated that after the airplane rotated and lifted off at around 100 feet altitude, he saw it make a quick bank to the left, followed by a quick bank to the right. He then observed a fireball come out of the rear of the airplane. He stated that these actions were "all together, real quick," in that sequence. After the fireball, he saw the airplane bank farther right 90°, increase pitch attitude, continue to roll past the 90° point to an inverted position, and impact with the ground.

About the time of the attitude changes, flames or "a fire ball" were seen from the rear of the airplane. Some witnesses saw flames coming from the left engine.

The cockpit voice recorder (CVR) tape revealed that the captain made the following callouts during the takeoff sequence: "Vee one," at 0018:44; "rotate," at 0018:45; "vee two," at 0018:48; "plus ten," at 0018:49; and "positive rate," at 0018:50.[2] The captain then warned the first officer three times in quick succession to "watch out," beginning at 0018:51 and ending about 1 second later. At 0018:52, immediately after the last call to "watch out," the CVR recorded sounds similar to engine compressor surges, and, at 0018:53, the sounds of a stick shaker. The sound of the first impact occurred at 0018:57.

The airplane's left wing struck the grass on the right side of the takeoff runway. After leaving an approximately 1,600-foot path of wreckage off the right side of the runway, the airplane came to rest, inverted, on the runway, about 6,500 feet from the threshold.

'Reference CVR transcript, appendix B.

Airport rescue and fire fighting (ARFF) service personnel arrived at the airplane 2 to 3 minutes after impact.[3] Both pilots were found in the cockpit, fatally injured. Rescue personnel extinguished the ground fire and removed the bodies of the pilots.

The accident occurred during the hours of darkness at 41°24.3'N and 81°51.5'W.

1.2 Injuries to Persons

	Flightcrew	Cabin Crew	Passengers	Other	Total
Fatal	2	0	0	0	2
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	2	0	0	0	2

1.3 Damage to Aircraft

The airplane was destroyed in the crash and postimpact fire. The airplane was valued at around $4.062 million.

1.4 Other Damage

There was no other property damage.

1.5 Personnel Information

1.5.1 The Captain

The captain was born on October 8, 1946. He held an Airline Transport Pilot (ATP) certificate for airplane, single-engine and multiengine land, and he was rated in the CE-500, DC-8, DC-9, B-727, B-737, and B-747. He had accumulated approximately 10,505 total flight hours, of which 505 were in the DC-9 series 10. In addition, he flew the DC-g-30 for about 3 years in the U.S. Air Force.

According to records of the Federal Aviation Administration (FAA), the captain was subject to possible certificate action for a runway incursion incident that he was involved in on November 4, 1989. According to the records, he taxied a DC-9 aircraft onto a runway at Greater Cincinnati Airport without clearance and powered backwards off the runway using powerplant reversing systems to avoid conflict with an aircraft that had initiated takeoff. Action was pending by the FAA at the time of the accident to suspend his ATP certificate for 30 days.

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[3] The clock time at the ARFF facility was not synchronized with that of the airport's tower. The arrival time of the first ARFF vehicles is estimated.

The captain received his initial type rating in the DC-9 on August 24, 1989, and completed his initial operating experience (IOE) on October 28, 1989. His last proficiency check was on January 16, 1991, and his last line check was on August 9, 1990. His last recurrent training was on July 19, 1990.

The captain flew six successive night flights on the BUF-CLE-IND and return route the week before the accident. The captain then flew another six successive nights with the same first officer each night, including the night of the accident. The captain had 1 day off before these last six flights. All of these flights were on the same route, from BUF through CLE to IND, and return to BUF through CLE. Each day during the 2-week duty period, the flightcrews stayed at the same hotel adjacent to BUF. The total flight time for the six successive nights, which included the night of the accident flight and the leg from BUF to CLE, was 19.6 hours.[4]

1.5.2 The First Officer

The first officer was born on October 8, 1962. He held an ATP certificate for airplane, multiengine land, and was rated in the SD3, a British-manufactured twin turbopropeller airplane. He held commercial privileges for airplane, single-engine land.

The first officer's records indicate that he had accumulated approximately 3,820 total flying hours, of which 510 were in the DC-9. However, only about 30 hours were in the DC-g-10 with Ryan.

The first officer was a furloughed USAir first officer. He received USAir's initial DC-9 ground school training on January 26, 1990. He completed his flight training on February 13, 1990, and his IOE on February 20, 1990. His experience at USAir was accrued in DC-9 series 30 airplanes.

He joined Ryan on January 28, 1991, and completed 60 hours of ground school training on February 2, 1991, which satisfied the requirements for both initial and recurrent ground school. He completed a proficiency check in the DC-9 series 10 airplane on February 8, 1991.

His 7-day total number of flight hours prior to the accident was 19.6 hours. They were accumulated during six successive nights, including the night of the accident flight, accompanied by the same captain on the same flight schedule. Virtually all of his flight time at Ryan was in the DC-9-10.

1.5.3 Flightcrew Activity Prior to Accident Flight

According to the airline's records, the captain and first officer had flown together Monday night on a flight from BUF through CLE to IND, returning through CLE, arriving at BUF about 0645 on Tuesday, February 11,

[4]Reference personnel information, appendix C.

1991. They flew the same trip each night until the accident. Witnesses indicated that the two flight crewmembers appeared to get along well.

At BUF, the flight crewmembers reported on duty and off duty at the crew hotel, adjacent to the airport. Witnesses reported that the captain and first officer spent most of their off-duty time at the hotel, often working out in the afternoons at a nearby exercise club.

During the six consecutive duty days, the pilots came on duty at the hotel around 2145. They used a FAX machine in the hotel to send paperwork to the airline. They would walk or be driven in a hotel van to their airplane. The airplane was parked about 1/4 mile from the hotel.

On the morning before the accident, the flightcrew flew the return flight from IND through CLE, arriving at BUF about 0640. A van driver for the hotel stated that he drove the captain and first officer to the local exercise club about 1630 that afternoon. The gym was closed, and the driver returned the two pilots to the hotel. The driver stated that during the return ride to the hotel the two pilots talked about "the little sleep they get." The driver stated that the captain had said that he was going to bed as soon as he returned to the hotel. Upon returning to the hotel, the captain retired to his room. The first officer telephoned his father about 1730. The conversation was described as normal.

The captain received a wakeup call at 2145 and checked out of the hotel at 2201. After completing their paperwork at the hotel's FAX machine, the two pilots departed. The hotel clerk was "pretty sure" they walked to the airplane. The weather was characterized as cold and windy without snow. A mechanic for the airline met the crew at the airplane. He stated that nothing appeared unusual. He said that both crewmembers seemed rested. The flight from BUF to CLE was uneventful.

In CLE, the operations supervisor for Emery Worldwide, a company contracted with the airline, took paperwork to the cockpit while the airplane was on the ground. He said that the crew remained in the cockpit. The supervisor stated that crewmembers normally leave the airplane for a walkaround, or at least to check the outside cargo door latch. He described the captain, whom he met briefly, as quiet and expressionless.

1.5.4 Medical Factors

1.5.4.1 General

The CVR tape recorded several coughing episodes by a crewmember just before the accident.

1.5.4.2 The Captain

The captain held a valid first-class medical certificate, dated October 1, 1990. No medical problems were noted. Vision and hearing were both noted as normal, without correction. The medical examiner added the remark: "excellent health."

According to his family, the captain had been in excellent health, having no major changes in health in the past year. Witnesses stated that the captain exercised regularly, did not smoke, and did not drink alcohol.

Both the airline's chief pilot at IND, and the director of hub operations at Dayton, Ohio, said that the captain might have suffered from a cold the week before the accident. A hotel employee stated that the captain was coughing on the evening of Saturday, February 16. The captain had bought cough drops before he departed on the accident trip. However, three other witnesses stated that the captain did not appear to have a cold.

Following the accident, nonprescription cold medications were found in the captain's possessions in the cockpit. They were Actifed Plus tablets, Sudafed 12-hour sustained action nasal decongestant tablets, Halls throat lozenges, and Vicks cough drops.

According to an operations officer at the airline, crewmembers having appropriate medical documentation would receive sick leave and would be replaced without loss of pay.

1.5.4.3 The First Officer

The first officer held a valid first-class medical certificate, dated September 13, 1990. No medical problems were noted. His vision and hearing were listed as normal, without correction. His father stated that the first officer had no health problems and that no changes in his health had occurred in recent months. According to witnesses, the first officer exercised regularly and drank alcohol sparingly.

1.6 Aircraft Information

The airplane's takeoff gross weight of approximately 82,000 pounds and center of gravity position were within limits.

The airplane's maintenance logs were examined for trends, flight control malfunctions, and inspection due dates. No inspections were overdue, and no items were found that affected the flight of the airplane. All applicable airworthiness directives (ADs) had been incorporated within the specified time periods.

The airplane was powered by two Pratt and Whitney JT8D-7B engines. The DC-9 series 10 airplane does not have wing leading edge devices to augment lift during takeoff and landing. All later models of the DC-9 and MD-80 airplanes have leading edge slats that are extended for take off and landing.

Ice protection for the DC-9 is provided for the following areas and components of the airplane:

Wing and horizontal stabilizer leading edges;

Engine nose cowls, guide vanes and bullets;

Cockpit windows and windshields;

Pitot tubes, static ports, ram air temp probe;

Stall warning lift transducers.

Heated air is used for thermal anti-icing of the wing leading edges and horizontal stabilizer leading edges. The air is supplied by 8th stage engine bleed air and is supplemented as necessary by 13th stage high-pressure bleed air. This source maintains system duct temperature between 450 and 490° F. A cross-over duct allows either engine to supply air to the system. Electrical resistance elements are used for all other anti-icing and deicing needs.

The airplane circuitry is so arranged through the ground control relay, that when on the ground, before takeoff, airfoil ice protection can be selected but will not operate until the airplane lifts off. Inhibiting operation on the ground was a design requirement since, without airflow over the wing, the wing temperatures would exceed structural limits.

Additional aircraft information is attached as appendix D. Company history provided by Ryan International Airlines is attached as appendix G. Aircraft information, relating to the aircraft takeoff performance is contained in section 1.17.1.

1.7 Meteorological Information

At 2220 on the evening of February 16, 1991, the surface weather map, prepared by the NWS, showed a low-pressure area centered over western Ontario, north of Lake Huron. A cold front extended southwestward from the low through the extreme northwestern portion of Lake Huron and northern Lake Michigan. The cold front turned from there west-southwestward from the low through central Wisconsin and along the Iowa-Minnesota border. The map also showed a warm front extending south-southeastward from the extreme northeastern portion of Iowa into central Illinois, then turning southward into the extreme southeastern portion of Missouri. There was a large high-pressure area centered over the extreme northeastern corner of Florida. Cleveland, Ohio, lay in a region in which the isobars were oriented southwest to northeast, within a relatively strong gradient between the low-pressure area over western Ontario and the high-pressure area over northeastern Florida.

The following surface observations were taken by the NWS at CLE:

Time--2350; type--record special; ceiling--indefinite, 1,500 feet obscured; visibility--l mile variable; weather--light snow; temperature--23° F; dewpoint--19° F; wind--220 degrees at 14 knots; altimeter--29.91 inches; remarks--runway 5R visual range 6,000 feet plus, visibility 3/4 mile variable 1 1/2 miles.

Time--0029; type--local; clouds--partial obscuration, Time--0029; type--local; clouds--partial obscuration, 2,000 feet scattered, ceiling measured 5,500 feet overcast; visibility 1 mile variable; weather--light snow; temperature--23° F; dewpoint--20° F; wind--220 degrees at 14 knots; altimeter--29.91 inches; remarks--runway 5R visual range 6,000 feet plus, visibility 3/4 mile variable 1 1/2 miles, snow obscuring 3/10 sky (aircraft mishap).

The following precipitation amounts were recorded at the NWS facility at CLE, February 16, and early February 17, 1991:

From	To	Liquid Equivalent	Snow
1845	0047	0.02 inch	0.7 inch
Midnight	0047	0.01 inch	0.2 inch
0047	0646	0.07 inch	1.4 inches

The winds were recorded by a wind gust recorder at CLE, as follows:

From	To	Range	Estimated Average
2330	2345	11 to 17 knots	14 knots
2345	0000	10 to 17 knots	14 knots
0000	0015	12 to 17 knots	14 knots
0010	0030	10 to 15 knots	13 knots

From 2200, February 16, until 0200, February 17, 1991, the runway visual range (RVR), measured at the approach end of runway 5 right at CLE, was 5,500 feet or greater.

At 0031, February 17, 1991, the observation from the local weather radar reported Cleveland to be in the center of an area 150 miles in diameter with 6/10 coverage of snow. There was no movement of the weather area observed. The top of the precipitation was uniform, at 11,000 feet.

The following PIREPs were reported about the time of the accident:

Location--over Dayton, Ohio; time--2210, February 16; altitude--35,000 feet, type aircraft--C-141; sky--cloud bases unknown, tops 20,000 feet; temperature--negative 53° C; wind--300 degrees at 17 knots.

Location--over Erie, Pennsylvania; time--2243; altitude--50 feet; type aircraft--AC-69; turbulence--light; remarks--occasional moderate chop, runway 24 300 to 500 feet agl [above ground level] plus/minus 15 knots, low-level windshear.

Location--over Cleveland, Ohio; time--2250; altitude--4,000 feet; type aircraft--DC-g; turbulence--moderate; icing--rime; remarks--during climb 3,000 to 7,000 feet.

The following are pertinent excerpts from the Area Forecasts that were issued by the National Aviation Weather Advisory Unit, Kansas City, Missouri, Saturday, February 16, 1991, at 2045, and valid beginning at 2100:

Flight precautions for Ohio: Icing and turbulence.

This area forecast incorporates the following AIRMETs (airman's meteorological information) still in effect: None.

Icing and freezing level valid until February 17, at 0900.

From Grand Forks, North Dakota, to Green Bay, Wisconsin, to Saranac Lake, New York, to Bristol, Tennessee, to Fort Dodge, Iowa, to Grand Forks, North Dakota:

Occasional moderate rime icing in clouds below 10,000 feet. Conditions continuing beyond 0400.

Freezing level: Surface throughout.

Turbulence and low-level windshear valid until February 17, at 0400.

From Caribou, Maine, to St. John, New Brunswick, to Norfolk, Virginia, to Atlanta, Georgia, to Lake Charles, Louisiana, to San Antonio, Texas, to Midland, Texas, to Wichita, Kansas, to Sault Saint Marie, Michigan, to Caribou, Maine:

Occasional moderate turbulence below 8,000 feet. Conditions continuing beyond 0400. Low-Level windshear potential in moderate to strong low-level winds over the area through 0400.

Significant clouds and weather valid until February 17, at 0400.

Lake Erie and Ohio:

8,000 to 10,000 feet broken to overcast, layered to 15,000 feet. After 2200, on February 16, becoming: 3,000 to 5,000 feet broken to overcast, layered to 15,000 feet. Widely scattered overcast, layered to 15,000 feet. Widely scattered visibility 3 to 5 miles in light snowshowers.

The following amended terminal forecast was issued by the NWS Office, at CLE:

Issued: February 16, at 2105
Valid: From 2100, February 16, to 2000, February 17

> Ceiling 1,000 feet obscured, visibility 1 mile in light snow and blowing snow, wind 220 degrees 20 knots gusting to 30 knots. Occasionally ceiling 2,000 feet overcast, visibility 4 miles in light snow. Low-level windshear. After 2300: ceiling 4,000 feet overcast, visibility 5 miles in light snow, wind 210 degrees 18 knots gusting to 28 knots. Occasionally ceiling 2,000 feet overcast, visibility 2 miles in light snow and blowing snow. Low-level windshear. After 0700: ceiling 4,500 feet overcast, wind 320 degrees 7 knots, chance of light snowshowers. After 1400: VFR.

There were no SIGMETs, (significant meteorological information) convective SIGMETs, or AIRMETs valid at the time of the accident.

There were no center weather advisories or meteorological impact statements issued by the Center Weather Service Unit at the CLE Air Route Traffic Control Center (ARTCC) valid at the time of the accident.

The weather observer on duty at the NWS Forecast Office at CLE told the Safety Board that she came on duty at midnight on the day of the accident. She did not witness the accident. She stated that at midnight the intensity of the snowfall was somewhat variable, and starting to decrease. She noted that the snow was dry and not mixed with any other type of precipitation. At 0047, about 28 minutes after the accident, she reported a snow depth of 9 inches. She determined the depth by calculating the average of 10 measurements she took at that time.

NWS data shows that the period of snowfall experienced at the time of the accident began at 2023, Saturday, February 16, 1991. It snowed continuously, through the time of the accident, until 1302, February 17. Prior to the snowfall commencing on February 16, the measured snow on the ground at CLE was also 9 inches. The lack of accumulation was due primarily to blowing snow.

A low level wind shear alert system (LLWAS) is installed at the Cleveland Hopkins International Airport and was in operation during the late evening and early morning hours of February 16. During the period from 0018:20 to 0019:00, the approximate time that flight 590 was on the runway, the average center field (sensor No. 1) wind was 221° true at 11.8 knots.

1.8 Aids to Navigation

There were no reported difficulties with aids to navigation.

1.9 Communications

There were no reported difficulties in communications between CLE, ATC, and Ryan 590.

1.10 Aerodrome Information

The runways at CLE were 5 right-23 left, 5 left-23 right, 10-28, and 18-36. At the time of the accident, CLE had published ILS approaches to runway 5 right, runway 23 left, and runway 28. The airport also had an NDB (nondirectional beacon) approach to runway 23 left.

Runway 23 left was 785 feet msl (mean sea level) at its approach end and 766 feet msl at its departure end. It was 8,998 feet long by 150 feet wide. It had a grooved asphalt surface.

Runway 5 left-23 right was 7,095 feet long by 150 feet wide. Runway 10-28 was 6,015 feet long by 150 feet wide. Runway 18-36 was 6,411 feet long by 150 feet wide.

An airport diagram is provided as figure 1.

1.11 Flight Recorders

A tape type CVR (Fairchild model 100, serial number 1174) and a flight data recorder (FDR) (Sundstrand Data Control Universal Flight Data Recorder, model UFDR-GOUS, serial number 6538) were installed and operating on Ryan 590 at the time of the accident.

The CVR recorded about 32 minutes of sounds received through the cockpit intercommunications system (ICS) and cockpit area microphones. The CVR tape recording began at 2347:06, with the flight in the process of taxiing to the South Cargo mail ramp at CLE. The tape stopped at 0018:58, after the first impact but before the airplane came to rest. The CVR transcript is attached as appendix B.

A Sound Spectrum Study of the CVR tape reveals that sounds associated with rotation of the engines' turbine sections were identified once the engines accelerated to above 73 percent N2 (power turbine speed) in the takeoff roll at 0018:26.6. According to the study, the signatures increased to approximately 97 percent N2 but were not identifiable after approximately 0018:50.

The FDR recorded the following parameters:

a. Altitude (feet)

b. Magnetic Heading (degrees)

c. Computed Airspeed (knots IAS)

d. Normal Acceleration (Gs)

e. Microphone keying (on, off)

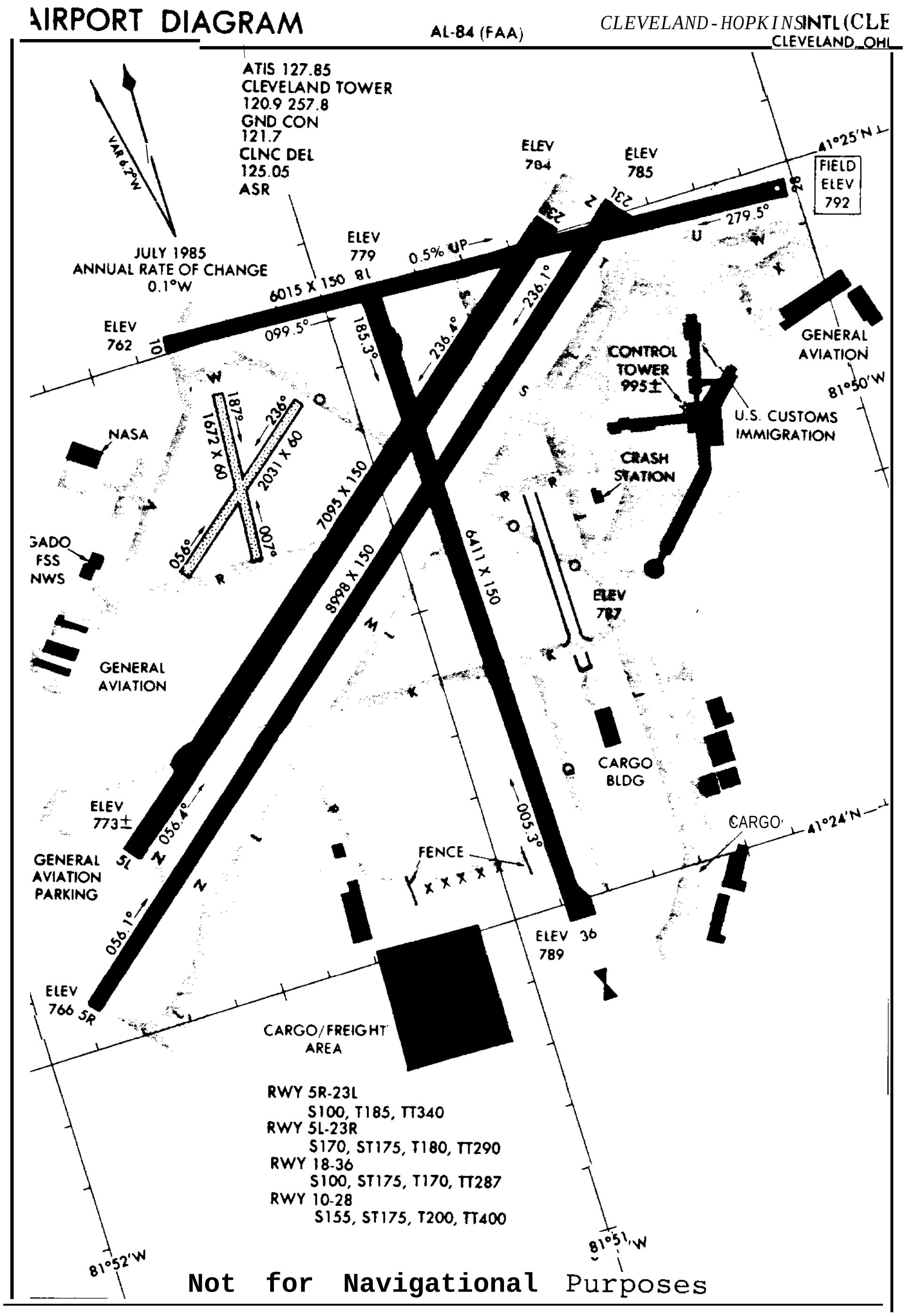

Figure 1.--Airport diagram.

1.12 Wreckage and Impact Information

1.12.1 General Description

At the first point of impact in the snow-covered grass to the right of the runway, the ground scars were about 6 inches wide. They arched toward the runway and ended at the right edge. Impact marks started on the right edge about 5,078 feet from the beginning of the runway, and continued to the point at which the fuselage came to rest.

The airplane came to rest, inverted, about 6,500 feet from the beginning of the takeoff runway. The landing gear remained extended. The left wing was destroyed. Fractured pieces of the wing lay along an approximately 1,600-foot path of wreckage on the snow-covered grass off the right side of the runway and parallel to it. The left engine and fractured sections of the engine's cowling lay near the end of the wreckage path, about 700 feet from the fuselage. The right wing and right engine remained with the airplane and sustained limited damage.

The cockpit and the section of the cabin forward of the front wing spar were partially separated from the remainder of the fuselage, still attached by electrical cables, hydraulic lines and flight controls. There was severe crushing to the top and upper left portions of the cockpit and forward fuselage.

There was residual jet fuel and a strong odor of fuel in the ground scars to the right of the runway, near the fractured sections of the left wing.

A faint scar, about 100 feet long, was noted at a point approximatedly 3,440 feet from the beginning of the runway. Examination of the bottom of the tail of the airplane revealed a worn or flattened area on the hard metal tiedown eye. The scar on the runway was about 1/4 inch wide. The tiedown eye was about 1/4 inch wide. The scar was found as some of the snow was melting from the runway, on the day following the accident. No metallic residue was found in the scar, and no wreckage from the airplane was found in that area.

1.12.2 Engines

The damage to the left engine's fan indicated high rotor speed at the time of impact. The fan was torn rearward and tilted outward about 20°. The No. 1 bearing support was forced into a position forward of the No. 1 bearing. All the first-stage fan blade airfoils for the left engine were fractured immediately above their blade platforms. The blade roots remained in the fan rotor disk. An examination of the fan blade airfoil fractures revealed only tensile and shear overload separations indicative of impact damage. Twenty-six of the fan blade airfoils were lodged in the engine inlet area. All the first-stage stator vanes were dislodged from their installed positions, and most of the first-stage stator assembly was crushed rearward.

Five second-stage fan blade airfoils on the left engine were fractured above their blade platforms. Most of the remaining second-stage fan blade airfoils were bent about 60° in the direction opposite compressor rotor rotation.

Mud was found heavily packed into the upper portion of the left engine's fan inlet area, especially in the top portion of the inlet. The mud extended through the third-stage compressor stator vane area and into the secondary air flow path of the outer fan duct. Mud deposits progressed through the fan discharge duct and terminated in the engine's exhaust duct.

The entire outer skin of the left engine's front compressor fan case was found torn open between the front and rear mounting flanges. The entire circumference of the rear compressor fan outer case was fractured at the rear mounting flange. The right engine was still attached to the aft fuselage and exhibited little damage.

1.12.3 Fuselage, Wings, and Empennage

The cockpit sustained substantial impact damage, especially on the upper left side. The cockpit and forward fuselage, forward of the forward wing spar, were twisted approximately 30° to the right relative to the position of the forward fuselage area.

There was extensive damage to the interior of the airplane, some of which resulted from the crushing damage on the top of the fuselage. The floor tiedown system remained integral to the structure, except in the area of the major cabin fracture, immediately forward of the front wing spar.

The six cargo containers remained substantially in place, except for the third container from the front, which was near the fuselage fracture. Station number 1 had no container or bin but was used for open bulk loading. It did not contain any cargo on the accident takeoff. Damage to the forward cargo compartment and bins 2, 3, and 4 prevented an accurate determination of the weight of each bin.

No indication of fractures, other than those resulting from overload as a result of impact, were found on the cargo door on the left side the fuselage. The six cargo door latches were locked and in place.

Pieces of red lens material, of the type installed on the airplane's left wing tip navigation light, were found at the initial point of impact (about 4,912 feet from the beginning of the takeoff runway and 130 feet to the right of the runway's centerline). The fractured left wing tip was found near the initial point of impact. The outboard end of the wing tip was compressed, and there was no evidence of bending and scratches on the top and bottom surface areas.

The aileron, flap, and flight spoiler control surfaces, actuators, and control cables were torn from the left wing as the wing disintegrated during the ground impact sequence. These components were recovered in the wreckage found along the right side of the takeoff runway.

The left wing's flaps were torn from their attachment points during the impact sequence. The fractured flap sections and the actuation mechanisms for the left wing's flaps exhibited no evidence of preimpact failure. An impact mark in the fairing between the left wing and the fuselage fairing indicated that the flaps were at approximately 20° at the time of impact.

The left wing's spoilers were recovered from the path of wreckage and examined. No evidence of preimpact separation or failure of the spoiler system was found. The left wing's spoiler actuators were torn from their normal mounting points as a result of the impact sequence. The actuators were found with their pistons retracted. The actuators were disassembled under the direction of the Safety Board, and examined for impact marks. No impact marks were found. Both spoiler bypass operating valve handles were examined and found in the "ON" position.

The right wing remained attached to the fuselage. The control surfaces were intact, still attached to the right wing, and relatively undamaged. The right wing's aileron control and balance tabs indicated "right wing down." The loss of control cable tension was traced to impact damage.

The right wing's flaps were still attached to the wing and were nearly in the retracted position. The wing was inverted after impact, as was the fuselage. A breach in the hydraulic system resulting from impact damage allowed the unpressurized actuators to move to the retracted position under the weight of the flap structure.

The right wing's spoilers were still attached to the wing, stowed in the down (retracted) position. Both inboard and outboard spoiler actuators were removed from the wing, disassembled under the direction of the Safety Board, and examined. No impact marks were found on the actuator cylinder bore or piston.

The flap bus cables that interconnected the left and right wing flaps were examined and found intact, despite separation of the left wing from its flap system.

The horizontal stabilizer was intact, with minor damage to the surfaces and crushing damage to the left tip. The horizontal stabilizer and, to a greater degree, the vertical stabilizer exhibited postcrash fire damage.

Both jackscrew drive motors of the horizontal stabilizer trim system had separated as a result of ground impact. The followup and stabilizer position cables were also inoperable as a result of impact.

The horizontal stabilizer's trimmed position was determined by measuring the system's jackscrew. Safety Board investigators measured from the bottom surface of the upper stop of the assembly to the top of the jackscrew gimbal, a distance determined to be 5.5 inches. Twenty-one jackscrew threads were visible between these reference points. Extrapolating from the airplane manufacturer's engineering data, these positions indicated a horizontal stabilizer setting of 3.4°, airplane nose up.

All elevator hinge points were intact, and all pivot points were free to operate. Each of the four elevator control cables was movable in both directions.

The vertical tail structure was fractured midway between the fuselage and the horizontal stabilizer (T-tail). The damage was consistent with crushing damage to the left horizontal stabilizer tip. The vertical tail exhibited fire damage, including an extensive amount of soot and some heat patterns that appeared to be mainly vertical, indicating a zero airspeed, postcrash fire.

The rudder was attached to the vertical stabilizer and was badly burned. The worst fire damage was on the lower rudder area, nearest the tailcone fairing (the lowest portion of the rudder was uppermost on the assembly as the fuselage lay inverted in the fire after impact). All rudder hinge points were intact and free to operate. The rudder power unit remained undamaged in its installed position. The rudder trim and load feel actuator were removed from the wreckage by Safety Board systems investigators. No anomalies were found. Rudder trim, as determined by measuring the rudder trim actuator, was found to be neutral. The yaw damper actuator was removed from the wreckage and no preimpact damage was found.

1.12.4 Flight Controls and Systems

Safety Board investigators established that there was continuity of the flight control system and that fractures in the system resulted from impact damage. The evidence did not indicate control cable corrosion, fraying, or visible wear on any control cable. Control cable tension and alignment with guides and rollers remained after the accident, except in areas near the fuselage fracture or other impact damage.

The flap position handle was damaged as the result of the impact. The handle was approximately 3.5 inches forward of the aft end of the slot in the pedestal assembly. The trailing edge of the handle was found approximately 0.5 inch above the 30° flap detente. The flap handle was in one piece bent toward the left side of the cockpit.

On the impact-damaged instrument panel, the flap position indicators read:

Left-hand needle - 0

Right-hand needle - Reversed off the scale

Examination of the cockpit overhead panel found the Emergency Power Switch - "OFF," and the Battery Switch - "OFF." The Airfoil Anti-Ice Switches were both "OFF." The Engine Heat Switches were both "ON." The aft left, center and right Fuel Boost Pump switches were in the "ON" position;

the forward left switch was "ON," and the center and right switches were "OFF." The Engine Fuel Heat switches were in the "OFF" position.

Fuel remained in the airplane's right wing tanks throughout the impact. The postimpact ground fire was outside the fuselage, resulting from broken fuel lines. The remaining fuel leaked out of the wing onto the ground prior to removal of the wreckage.

Both hydraulic reservoirs were empty. There was no exterior damage to either reservoir. Hydraulic fluid was leaking from fractured tubing and was trapped within actuator bodies. There was no evidence of preimpact contamination of fluids or preimpact heat distress in the hydraulic system.

The high-pressure hydraulic accumulator for augmenting the elevator system was charged to 500 pounds per square inch (psi). The low-pressure accumulator was charged to 20 psi. All other hydraulic system accumulators indicated a charge of 1,000 psi.

All three landing gears were found extended and locked, and the landing gear structure indicated no failures. There was no indication of overheat or excessive wear on the brakes. All the tires were inflated and undamaged.

There were no anomalies in the airplane's electrical system and associatedwiring. There was no evidence of burning, or arcing or other preimpact damage. The batteries were recovered intact in the wreckage. All the fire extinguishing containers were fully charged.

There was no evidence of preimpact failure of the airplane's pneumatic system. The ducting was intact, except for areas near the left engine and cockpit that were damaged from the impact sequence.

1.13 Medical and Pathological Information

Autopsies of the two pilots revealed that they died of severe trauma to the head and upper abdomen.

Toxicological testing of urine and blood samples of the two pilots was completed by the Cuyahoga County Coroner's Office. The samples were negative for alcohol, major drugs of abuse, and prescription and over-the-counter drugs.

1.14 Fire

There was a fire after impact. It was outside the fuselage and aft of the wing area. The most intense fire damage occurred in the area of the vertical stabilizer. There was no fire damage inside the fuselage, except for scorching on fiberglass insulation that was exposed to the outside through a hole in the fuselage made by the departing left engine.

1.15 Survival Aspects

The cockpit overhead, especially on the left side, was crushed in several areas. The resulting loss of occupiable space made the accident nonsurvivable.

1.16 Tests and Research

1.16.1 Aircraft Performance

The Safety Board conducted an airplane performance study using recorded radar data, CVR, and FDR information. The data from the various sources were correlated as a function of time by matching the FDR microphone keying parameter to the associated radio transmissions. Thus, indicated airspeed, pressure altitude, normal acceleration, and airplane heading at the time of specific cockpit activity could be examined for the takeoff phase of the flight. The radar data began just before Ryan 590 took the active runway and were used to confirm the starting point for the takeoff and ground speeds during the takeoff roll. Relevant sounds and dialogue from the CVR were:

0018:17.5 - TWR - Ryan five ninety cleared for takeoff fly ah runway heading

0018:24.6 - CAM - ((sound of engines increase in speed))

0018:33.0 - CAM1 - engines are stabilized, power's set for departure.

0018:37.5 - CAM1 - fuel's even kind'a balanced.

0018:39.4 - CAM1 - one hundred knots.

0018:41.3 - CAM - ((sound like runway noise (banging))

0018:44.9 - CAM1 - Vee one.

0018:45.9 - CAM1 - rotate.

0018:48.3 - CAM1 - Vee two.

0018:49.2 - CAM1 - plus ten.

0018:50.4 - CAM1 - positive rate.

0018:51.2 - CAM1 - watch out.

0018:51.7 - CAM1 - watch out.

0018:52.1 - CAM1 - watch out.

0018:52.3 - CAM - ((sounds similar to engine compressor surges start))

0018:53.1 - CAM - ((sound similar to stick shaker starts))

0018:55.5 - CAM - ((sound of engine compressor surges stop))

0018:56.0 - CAM - ((sound of stick shaker stops))

0018:56.78 - CAM - ((sound of first impact))

0018:56.82 - CAM - ((sound of second louder impact))

0018:57.6 - CAM - end of recording

The resulting correlation of airspeed, pressure altitude, normal acceleration, and airplane heading as a function of the common time reference is shown in figures 2 through 5 respectively. It is noted in figure 4 that the scatter of the normal acceleration values recorded on the FDR made the data difficult to interpret and of limited reliability. Consequently, a moving average technique was used to smooth this data. The resulting normal acceleration plot was considered as the best one obtainable for evaluation of the airplane's flight performance.

The data from figures 2 through 5 were evaluated to determine the path and distance travelled by the airplane as a function of the various events that occurred from the beginning of the takeoff roll to the point of initial ground impact. The recorded airspeed values were converted to groundspeed using the headwind component determined from the airport LLWAS wind measurement of 11 knots. Both groundspeed and heading were integrated to develop the correlation of airplane position and key events shown in figure 6.

The time and the runway position corresponding to liftoff was determined from the recorded altitude data. Previous studies and analyses of FDR data obtained during flight tests have shown that the pressure measured by the airplane's static system is affected by the proximity of the ground during the takeoff rotation and liftoff.

Figure 7 shows the typical altitude and airspeed variations from the start of the takeoff roll until the airplane leaves ground effect. Rotation of an airplane during takeoff changes the airflow patterns across the static ports, resulting in a static pressure measurement that is higher than the actual static pressure. The difference between the measured and the actual pressure is called the static position error and is apparent by corresponding errors in the recorded altitude and airspeed. On Figure 7, "delta H" and "delta V" represent the transient position errors associated with angle-of-attack (AOA) in ground effect. The measured values of altitude and airspeed as recorded on an FDR decrease below actual values during this time, with liftoff occurring near the bottom of the altitude dip. According to the manufacturer, the normal indicated altitude dip that occurs during the takeoff rotation of a DC 9-10 airplane is about- 50 feet (below field elevation).

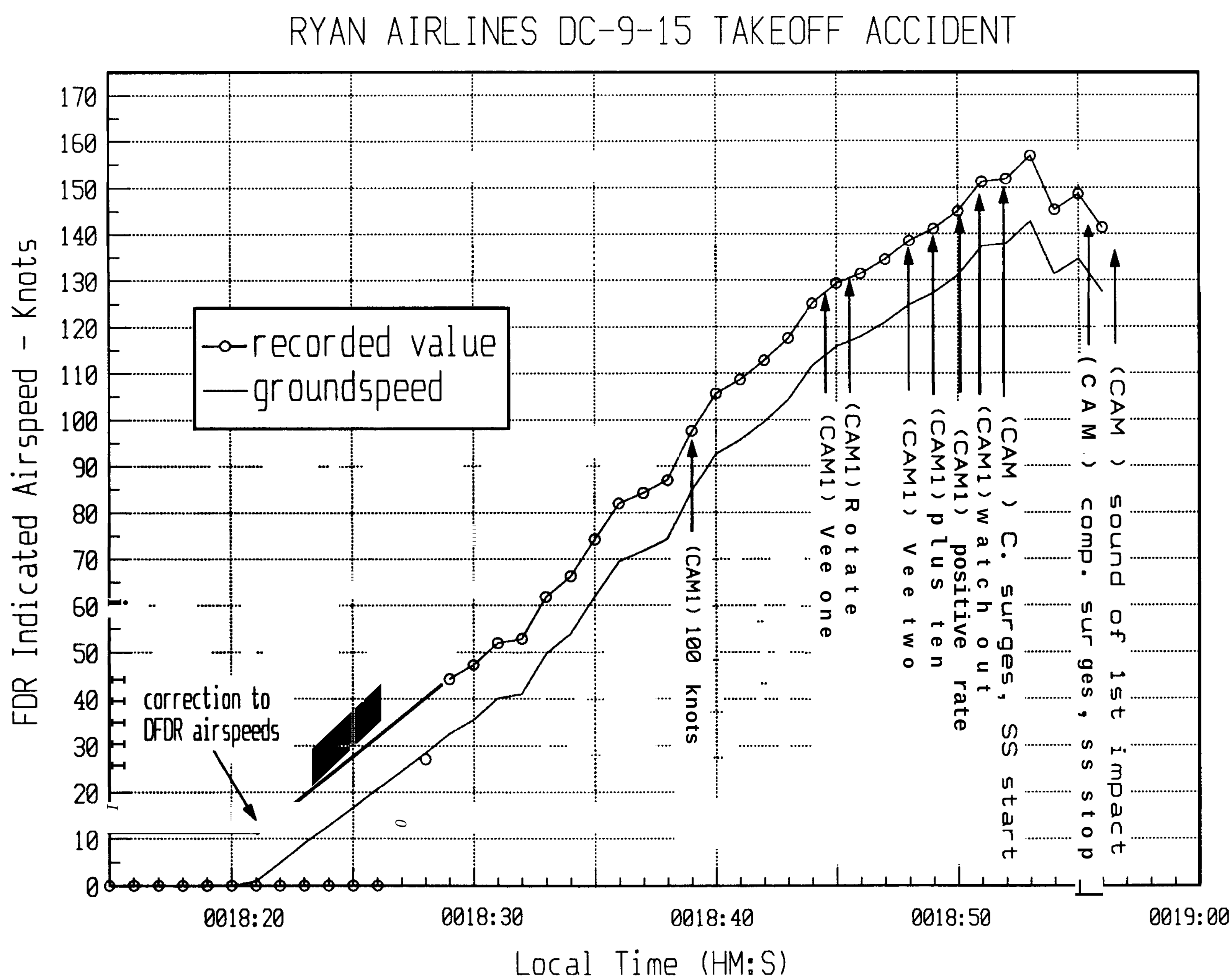

Figure 2.--Indicated airspeeds versus time.

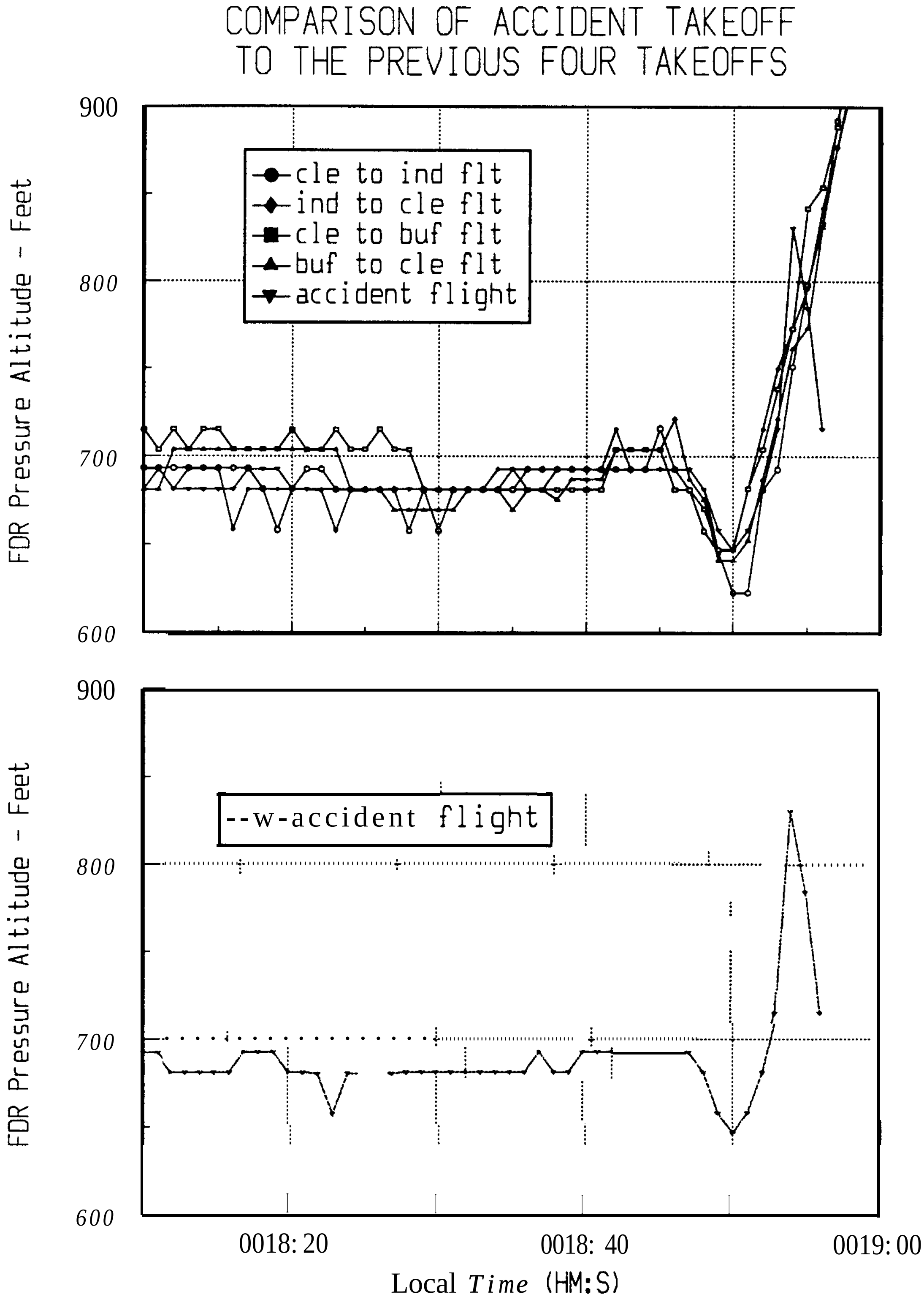

Figure 3. --Altitude versus time.

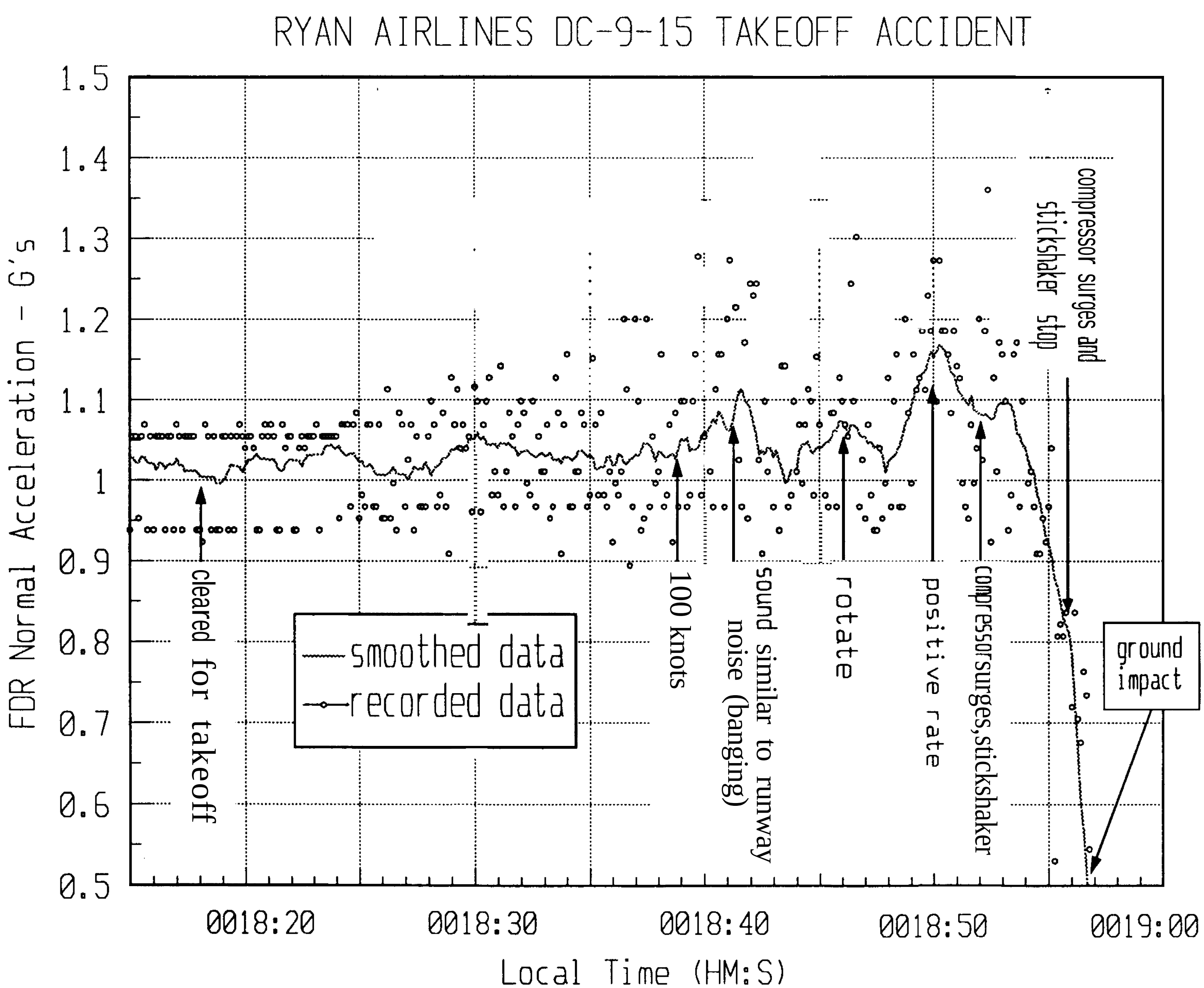

Figure 4. Normal acceleration versus time.

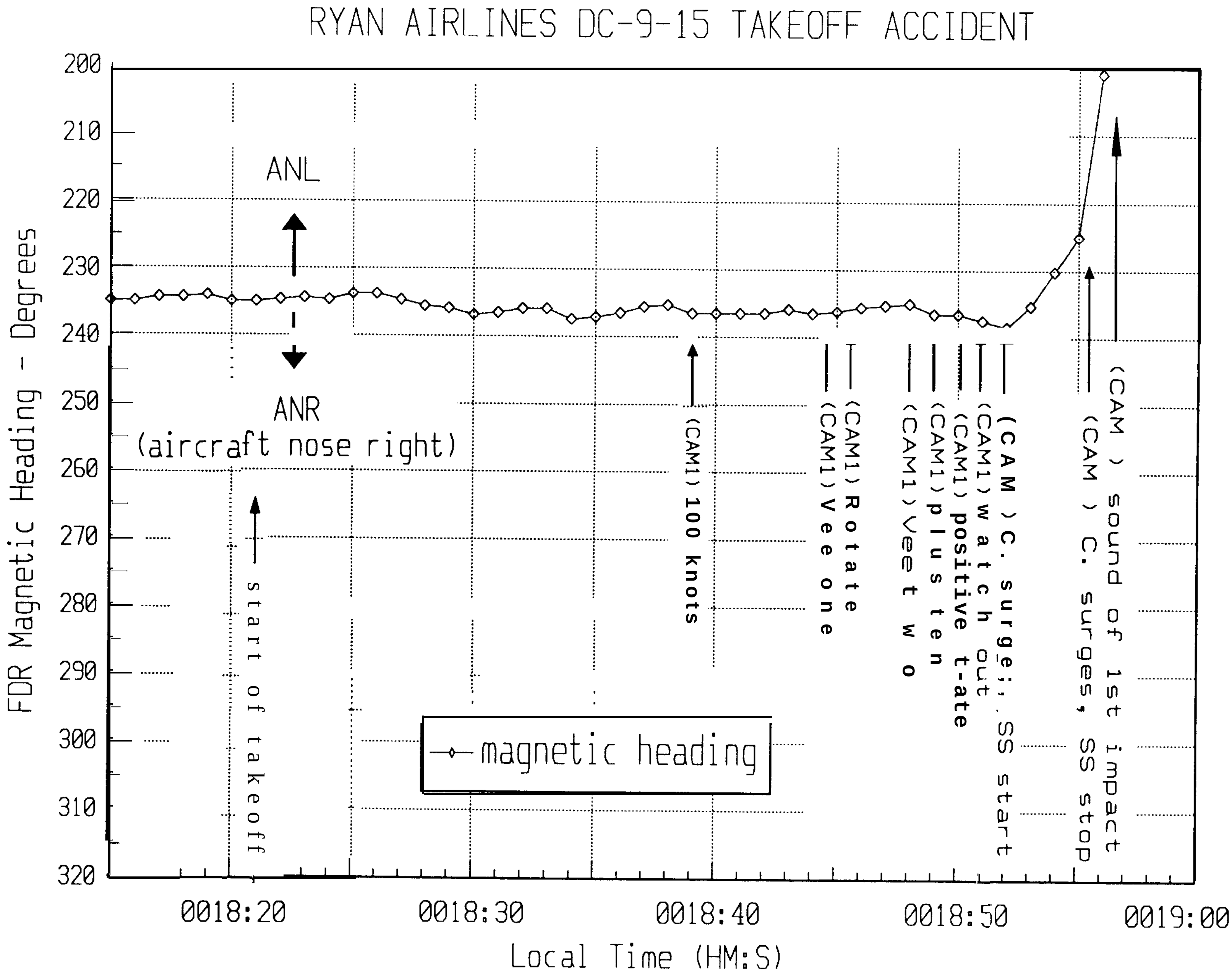

Figure 5.--Airplane heading versus time.

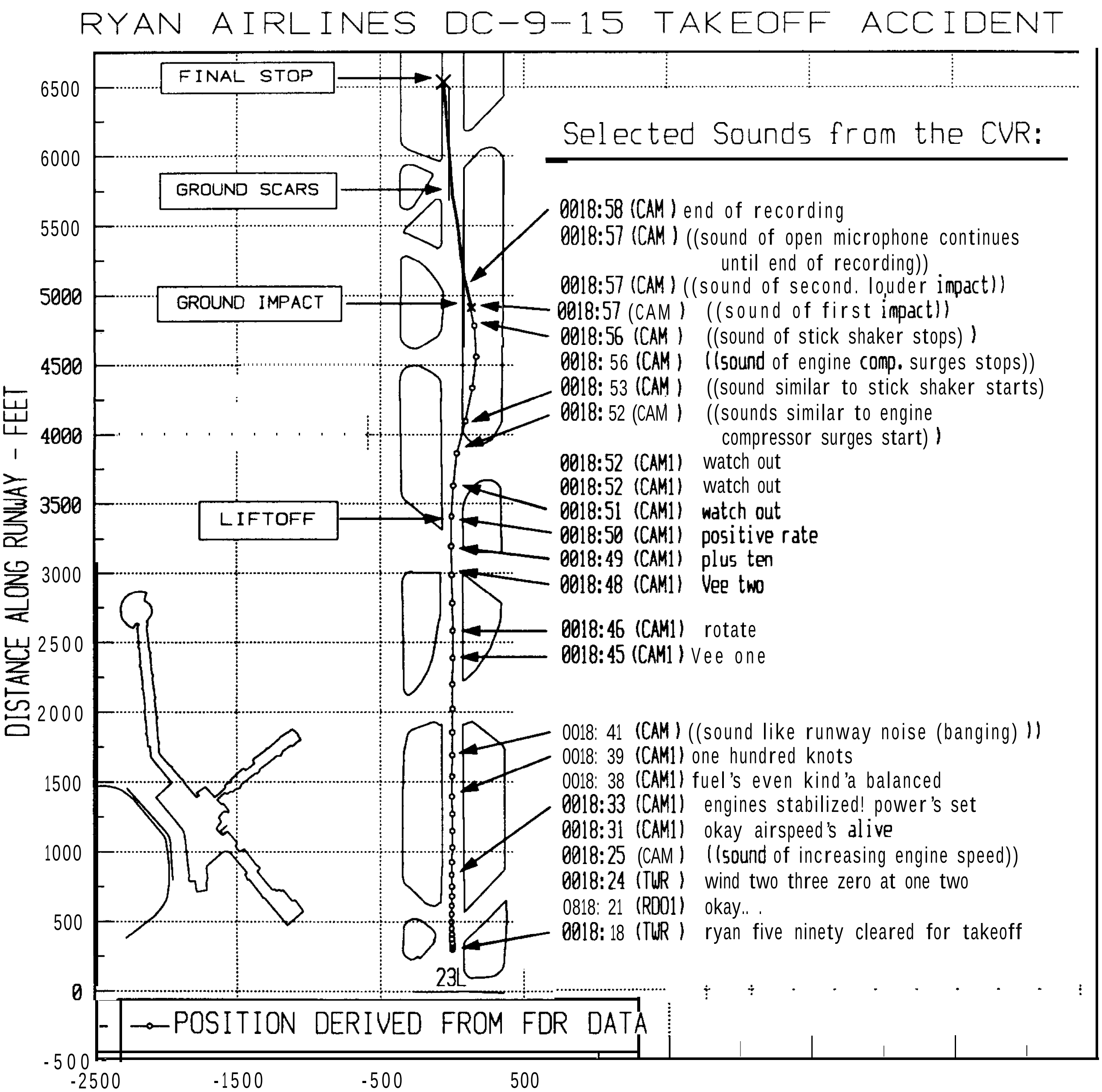

Figure 6. --Ryan 590 sequence of events.

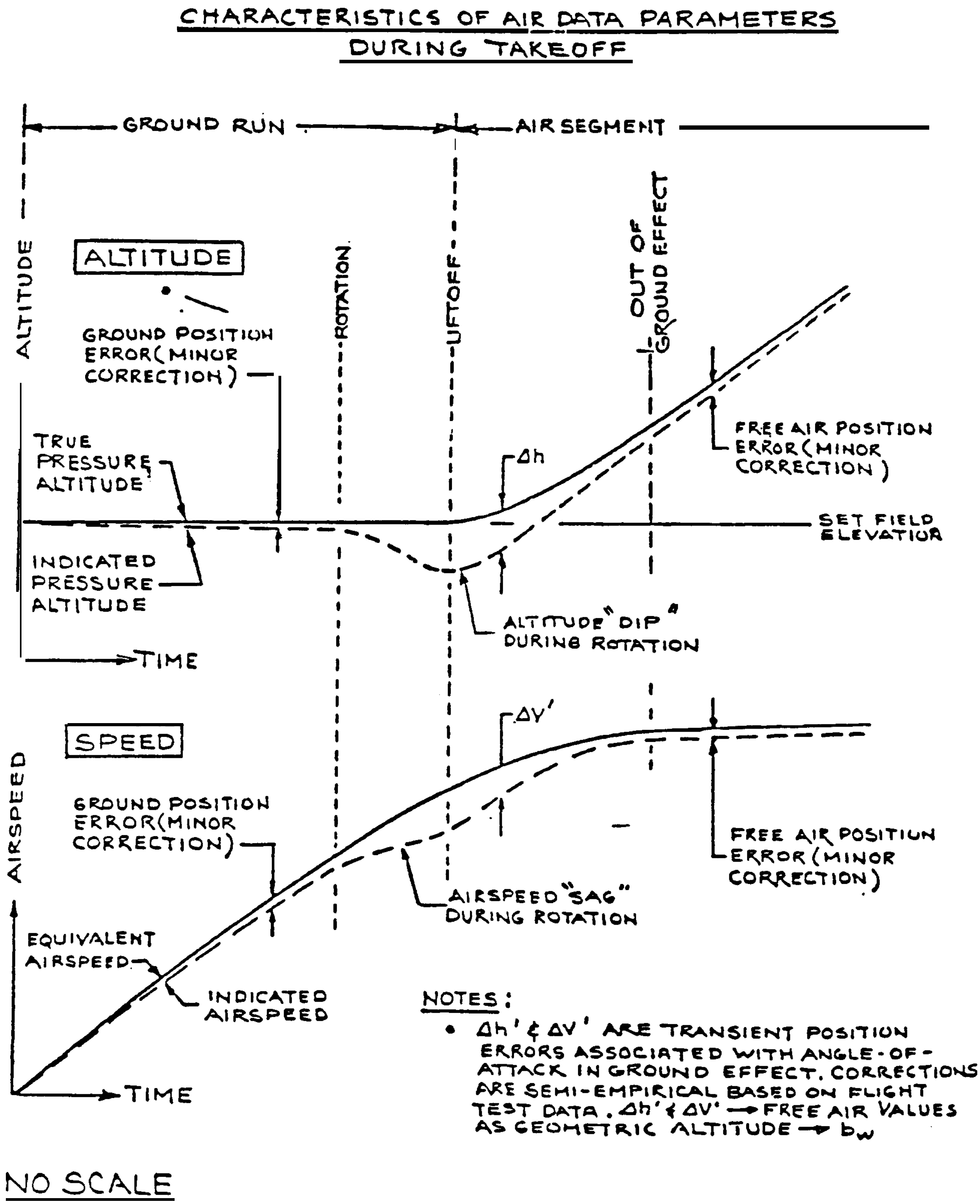

Figure 7.--Air data parameters during takeoff.

The pressure altitude data plotted in figure 3 indicated an altitude dip to about 46 feet below field elevation which was typical for the takeoff rotation and liftoff maneuver. The bottom of the dip occurred at 0018:50. The determination that liftoff occurred at 0018:50 is consistent with an increase in normal acceleration above 1 g and a corresponding "positive rate" call on the CVR.

The recorded airspeed at 0018:50 was about 145 KIAS. Because the static pressure error at liftoff affects airspeed as well as altitude, it was determined that the actual liftoff airspeed was about 148 knots, 3 knots higher than the recorded value.

The smoothed normal acceleration data showed that the maximum value reached during the flight was about 1.17 g. This value was attained shortly after liftoff. Sounds similar to compressor surges were heard on the CVR starting at 0018:52.3, when the normal acceleration was 1.08 g. The sound of a stick shaker stall warning commenced 0.8 seconds later. By this time, the normal acceleration had risen to 1.1 g but decreased sharply to 0.7 g at the time of impact.

The recorded heading values, show that Ryan 590 abruptly turned to the left at 0018:52, about the same time that sounds of compressor surges and the stick shaker were heard on the CVR. The left turn continued until impact.

The stall warning system on the DC 9-15 activates a stick shaker when the AOA increases to a specified margin below which aerodynamic stall of the wing occurs. Under normal conditions, the pilot will be warned by the control column vibration when the AOA corresponds to an airspeed about 1.1 times the minimum stall speed ($V_s$min) demonstrated in flight tests. The normal AOA for stall warning activation on the DC 9-15 is about 12°. Because the stall warning system is activated by transducers that sense AOA, the actual airspeed at which the stick shaker will activate depends on the instantaneous maneuvering load factor and any aerodynamic inefficiencies of the wing. Similarly, because the AOA at which aerodynamic stall occurs can be reduced by factors such as airfoil surface roughness or contamination, the airspeed margin between the onset of the warning and stall can be reduced or eliminated. Under such conditions, stall can occur abruptly and without warning.

There is a 4-second "lockout" period before the stall warning system is armed. This period begins when the nose strut oleo is fully extended. The purpose of the lockout is to prevent distraction from nuisance stick shaker activation during takeoff rotation. After the stall warning system is armed, it should activate instantly if required. It is assumed that the nose strut oleo extended 1 second after the captain called "rotate." Therefore, the stall warning system was armed at approximately 0018:51 and activated 2 seconds later at around 150 knots indicated airspeed (KIAS).

The sounds of engine compressor surges that were heard on the CVR were consistent with approach to aerodynamic stall. Engine compressor surges were encountered during flight tests when the airplane was flown in a high AOA and/or in a wing stalled condition. The surges were attributed to the turbulent air at the engine inlet resulting from separation of the airflow over the wings.

To provide a comparison of the takeoff performance of the accident aircraft, the manufacturer provided the theoretical takeoff and performance data for a DC 9-10 airplane weighing 82,250 pounds for a 20^{o} flap takeoff and the existing environmental conditions.

The takeoff data confirmed VI, V_r, and V_2 speeds of 128, 132, and 137 KIAS, respectively, and these speeds correspond closely with the accident flight recorded speeds at the times of the associated speed callouts on the CVR. Further, the theoretical performance data showed that Ryan 590 accelerated normally and that the distance travelled from the start of the takeoff roll to reach the Vl and "rotate" speeds were nearly equal to the expected values.

The theoretical performance data indicated that the airplane would be expected to liftoff at about 142 KIAS. The liftoff speed for Ryan 590 was about 6 knots higher.

The manufacturer's data also showed that under the accident conditions, the airplane should have had more than 20 knots of stall margin at the time of liftoff. The theoretical minimum stall speed was 113 KIAS and the 1 g stall speed was 119 KIAS at 14^{o} AOA. With 1 g normal acceleration, the airplane should have been capable of decelerating to 123 KIAS before stick shaker activation AOA (12^{o}) was reached.

The accident flight takeoff performance was also compared with the takeoff performance indicated by the FDR data during previous takeoffs of the accident aircraft.

As the airplane transitioned to climbing flight on previous takeoffs, there was a buildup in normal acceleration, followed by a return to near 1 g values. A comparison of the accident takeoff to the previous four takeoffs is plotted in figure 8. Smoothed acceleration curves for the previous takeoffs were offset so that the beginning of each buildup coincides with that of the accident flight. All five takeoffs display an increase in normal acceleration early in the transition phase, except that the buildup in g values during the accident takeoff abruptly ended after reaching about 1.17 g, and then decreased prematurely. On the previous flights, the positive normal accelerations were sustained for 3 to 5 seconds reaching peak values between 1.2 g and 1.3 g.

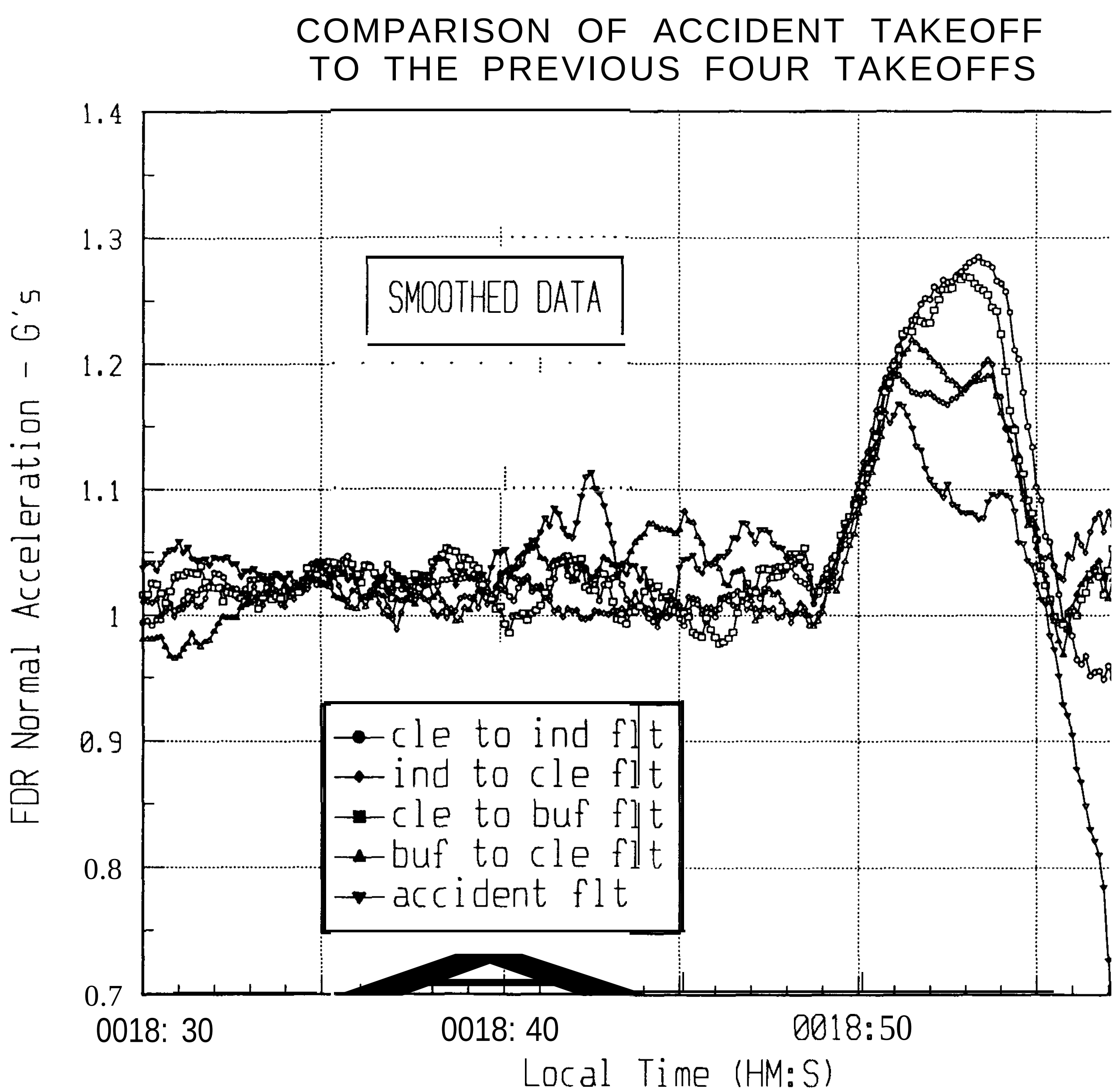

Figure 8.--Normal acceleration data for previous takeoffs.

1.17 Additional Information

1.17.1 DC-9 Series 10 Takeoff Accidents Attributed to Wing Ice Contamination

Between 1968 and 1987, there were four accidents involving DC-9 series 10 airplanes in which there was a loss of control shortly after takeoff.[5] In all cases, the investigation showed that the airplanes accelerated normally and reached airspeeds at which they should have been capable of establishing and sustaining a safe climb. Instead, all were observed to enter steep roll attitudes and descend to the ground. Also, in all of these accidents, witnesses reported, and the sounds on the CVRs confirmed, that engine compressor surges occurred as the airplanes descended.

All of the accidents occurred in weather conditions that were conducive to the accumulation of ice or snow on the fuselage and aerodynamic surfaces. The Safety Board found that the cause of each of these accidents was an attempt to take off with some airfoil contamination that prevented the wings from producing the normal and required amount of lift. The Safety Board is not aware of any similar accidents involving later model DC-9 or MD-80 aircraft.

1.17.2 Douglas' Actions Regarding Wing Contamination

The accidents since 1968 have motivated the manufacturer to identify the performance penalties associated with wing contamination and issue educational material to operators of Douglas Aircraft Company aircraft regarding this hazard. During the 20-year span, at least 10 technical articles have appeared in magazines or in All Operators Letters that were distributed to the flight training departments of air carriers that were known to be currently operating DC-9 aircraft. Of the DC-9's currently operating in the United States, 74 carry passengers and 19 carry cargo.

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[5]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, Neuark, 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)

Outside the United States, 20 of the airplanes carry passengers and 4 of them carry cargo.

The following paragraphs have been extracted from a technical paper prepared by the Deputy Chief Design Engineer, DC-9 Program. The paper, entitled, "The Effect of Wing Ice Contamination on Essential Flight Characteristics," was presented in 1988 and 1991:

> *Contamination of critical aerodynamic surfaces by ice, frost, and/or snow has been identified as the probable cause of a significant number of aircraft accidents. In most cases, the ice contamination has not been large ice accretions on the leading edges or thick layers of adhering snow on the top of the wings. Rather, dangerous reductions in stall margins and handling qualities can occur because of ice-related roughness equivalent to that of medium-grit sandpaper.*
>
> *The most predominant adverse effect of ice contamination is on the lifting characteristics of the wing. It may be recalled that wing lift coefficient varies with angle of* attack,--- *Under normal conditions, the airflow over a wing smoothly follows the shape of the wing, as shown in the lower photograph, and lift varies directly with the angle of attack. At some fairly high angle of attack, the airflow begins separating from the wing, causing the lift curve to become nonlinear, or "break." When the airflow is essentially fully separated, --- the wing is considered fully stalled. Between the point where the airflow begins separating and full stall is a region often called "stall onset," where flight characteristics become increasingly degraded as the angle of attack increases.*
>
> *The normal variation of lift with angle of attack can be significantly altered by ice contamination. --- The typical effect is to alter the variation of lift with angle of attack, reduce the maximum lift capability of the wing, and cause the wing to stall at a lower than normal angle of attack. As will be shown shortly, these effects can be quite large.*
>
> *For an airplane trimmed for takeoff, the stabilizer is set to balance the moments due to both aerodynamic forces and center of gravity location so that the stick force at climb-out speed ranges from none to a slight pull. This balance is upset by wing ice contamination, particularly on contemporary aircraft with tapered, swept wings. With contamination on the wings, the aircraft will increasingly behave as if it was mistrimmed in the airplane nose-up direction as the angle of attack is increased. This will result in the aircraft's pitching up more rapidly than normal during the takeoff rotation, and will require an abnormal push force to maintain the desired airspeed during climb.*

During a normal takeoff, the aircraft speed schedules are established for angles of attack below that for stall onset or activation of stall-warning devices dependent on angle of attack, such as a stick shaker (Figure 5a). However, for an airplane with ice contamination, not only does stall onset occur at a lower than normal angle of attack, the airplane angle of attack must be increased in order to produce the required lift at normally scheduled speeds. This compounding effect rapidly results in the aircraft's operating into the "stall onset" part of the lift curve (described earlier), and the increasingly unsteady airflow over the wing results in correspondingly degraded lateral stability, requiring larger and larger control wheel inputs to keep the aircraft from rolling off. As the amount of contamination increases, the airplane becomes increasingly unstable, eventually stalling without stick shaker activation at speeds normally scheduled for takeoff. An All Operators Letter dated November 7, 1985, included the following information:

There have been three takeoff accidents of DC-9 Series 10 aircraft (two or which resulted in destroyed aircraft) in which the adverse effects of ice contamination on the wings is believed to have caused premature airframe stall at lower than normal angles of attack, accompanied by engine surging and/or compressor stalls of sufficient magnitude to result in thrust degradation.

Douglas test data shows that when stalls were performed at high altitudes, where Mach number effects resulted in the stalls occurring at about 3-1/2 degrees lower angle of attack than at low altitude, engine compressor stalls, occurred, with accompanying momentary decreases in EPR and N. These results suggest the possibility that stalling the DC-9 Series 10 at lower than normal angles of attack, such as will occur when the wings are contaminated with ice, can result in degraded engine operating characteristics. The cause is suspected to be engine ingestion of the low energy wake, from the stalled wing, that passes over the nacelle inlets at normal stall angles, but which enters the inlet at abnormally low stall angles. This hypothesis seems to be supported by the reported engine behavior in the three accidents.

Ice accumulation on the wing upper surface is very difficult to detect. It cannot be seen from ahead of the wing during walkaround, and the slats may not feel particularly cold. It may not be detectable from the cabin because it is clear and wing surface details show through, and it is very difficult to see from behind the wing, particularly if the wing is wet.

On March 21, 1991, following the accident of Ryan 590, Douglas issued another letter to the operators of DC-9 airplanes describing the icing hazard. The letter is contained in appendix E.

1.17.3 Ryan International Airlines' Procedures

1.17.3.1 Normal DC-9 Takeoff Procedures

The Ryan International DC-9 Operations Manual contained the following procedures for DC-9 takeoff:

> After the initial alignment, the Captain will release the nosewheel steering and the Pilot flying will revert to rudder pedal steering. Apply forward column pressure as necessary to retain good steering and a smooth riding nosewheel. DO NOT "WALK" RUDDER during the takeoff roll.

NOTE: During takeoff, especially on wet or slushy runways, the forward column pressure should be reduced to minimum by approximately 70 KTS (start of tire hydroplaning). This will decrease the possibility of water ingestion and, compressor stall, and help rotation to be smoother at VR.

> At 100 KTS the Pilot Not Flying will call out "100" and at the computed speeds will call out "V_1." "ROTATE."
>
> Under the balanced runway length concept, an abort at V_1 will require every foot of the remaining runway. Anything less than a maximum effort throughout the entire stopping attempt will result in running off the end of the ruway. Barring an actual engine failure (prior to V_1), the aircraft has a greater capability to successfully continue the takeoff than to stop. Serious consideration should always be given to continuing the takeoff rather than aborting at high speeds where abnormal conditions other than engine failure are encountered prior to reaching V_1.

NOTE: The decision to abort is always SCD (Subject to Captain's Discretion). **ALL** rejected takeoffs will be done by the Captain, except in case of Captain incapacitation.

> At the call of "ROTATE," the Pilot Flying will initiate a smooth, steady up elevator movement requiring a positive pull force and a five-second interval to rotate to an approximate 15° pitch attitude.
>
> If speed command information is available, it should be used to provide a target V_2 attitude for V_2 airspeed. Because of various overspeed schedules, a minimum of V_2 airspeed must be maintained to assure obstacle clearance. Some computers will command greater attitudes than 15° for -10 aircraft.

NOTE: If aircraft does not rotate after a greater than normal elevator back pressure is applied, use NOSE UP TRIM to effect rotation.

CAUTION: *Early or over-rotation can cause the tail to strike the runway.*

With a POSITIVE RATE of climb indicated on the altimeter, the Pilot Not Flying will then call "Gear Up," and the landing gear handle will be raised to the up position by the Pilot Not Flying. Check that the red landing gear UNSAFE Lights and the amber gear door OPEN Lights are out. Continue climb to 1000' AFL (Above Field Level) at MINIMUM V_2 AIRSPEED, MAXIMUM PITCH ATTITUDE 15^o, accepting an airspeed greater than V_2 when it occurs. No turns to be made below 400' feet AGL. Above 400 feet AFL maximum bank angle is 15^o dirty or clean until reaching BSEC (Best Single Engine Climb) speed, and then maximum bank angle of 30^o thereafter.

1.17.3.2 Procedures and Guidance for use of Anti-ice and Deice Equipment Inflight

The airline's DC-9 Operations Manual provided cold weather operating guidance/information for pilots in the Limitations, Normal Procedures, Supplemental Procedures sections, and in Operating Notices (which were required to be entered in the front of the manual until the information was incorporated in the appropriate manual text). The Limitations information included maximum and minimum temperatures for the takeoff, en route and landing phases of flight, which were not exceeded in this operation. It also contained a prohibition against takeoff with more than 1/2 inch of standing water or slush, and imposed the requirement for " . ..chine tires [shaped for deflection of precipitation] or nose wheel spray deflectors." Reduced Thrust Takeoffs were prohibited on contaminated runways, and with Engine Anti-ice on. The Ice and Rain Protection System Limits were established, as follows:

AIRFOIL ANTI-ICE/DEICE

For takeoff and intial climb below 800 feet AGL: Airfoil Anti-Ice/Deice must be OFF.

During takeoff when airfoil ice protection becomes effective, the drop in EPR (engine pressure ratio) should not be recovered.

ENGINE ANTI-ICE

Engine Anti-ice shall be turned ON for taxi, takeoff and initial climb when the outside air temperature is 6^oC (42^oF) or less and ANY of the following conditions exist:

Visible moisture is present.

Icing conditions exist or are anticipated.

Ambient air temperature and **dewpoint** *are within* **5°F** *of each other.*

NOTE: Fog is considered visible moisture when it restricts visibility to one mile or less.

MAX RAN AIR TEMPERATURE (RAT) for use of Engine Anti-Ice:

On the Grd/Takeoff **+10°C (50°F)**

When setting Takeoff Power with ambient temperatures below **+10°C (50°F),** *EPR loss due to engine anti-ice should be recovered.*

When operating at maximum continuous, max climb, or max cruise limits, EPR loss due to engine anti-ice and/or airfoil ice protection should NOT be recovered.

ENGINE **&** *WING ANTI-ICE*

Minimum N_1 *for Engine and Wing Anti-Ice System Operations:*

Severe Icing:	**70%**
Moderate Icing:	**55%**
Occasionally Increased to:	**70%**

The Normal Procedures section of the DC-9 Operations Manual contains Anti-icing Procedures, in part, as follows:

Anti-icing Procedures

Engine/AIRFOIL ANTI-ICE should be used in flight when icing conditions are anticipated or encountered. Always place **IGNition** *switch to A or B position before turning* **ENGine ANTI-***ICE switches ON. For optimum life of the ignition system, alternate between the A and B positions approximately every 10 minutes.*

If either engine is unspooled in icing conditions for 10 minutes, the throttles should be advanced until the surge bleeds are closed and stabilized for 30 seconds.

Use AIRFOIL anti-ice system in flight if airframe icing conditions are anticipated or encountered but not until 800 feet AFL or above during takeoff.

For TAIL de-ice momentarily push TAIL de-ice button after each icing encounter at approximately 20 minute intervals in continuing icing conditions, at the start of a long instrument approach in icing conditions, and, again, approximately

1 minute prior to extension of 30^{o} or 50^{o} FLAPS and slowing to 1.3 Vs speed. For normal approach this would be just prior to landing gear extension.

Additional guidance for in-flight operations in icing conditions is contained in the airlines' training manual, in part, as follows:

General

It is difficult to establish a standard technique for the use of anti-ice, however, the following are general guidelines:

Position ENGINE START switches to FLIGHT before turning on engine anti-ice.

If engine anti-ice is to be used during takeoff, turn it on as soon as practical after engine start. Use engine anti-ice when taxiing in blowing or loose snow.

When flying in stratified clouds at higher cruise altitudes, icing is rarely encountered at temperatures below freezing and anti-ice should not be required, however, it must be kept in mind that under certain conditions, stratus clouds over or near large bodies of water or vertically developed clouds may contain sufficient quantities of super cooled water to require the use of anti-ice at temperatures well below freezing. Cloud density and temperature should be considered in your decision to use anti-ice.

When descending through clouds with a TAT of $5^{o}C$ or below, consideration should be given to the use of engine anti-ice.

Wing Anti-Ice

Cloud density and temperature should also be considered in your decision to use wing anti-ice. You should also monitor the windshield wiper pivot screws for ice accumulation.

To reduce exposure to ice buildup on the flaps, it is recommended that in icing condition not more than flaps 5 be used until nearing the final approach fix.

If an approach is made in icing conditions or there is slush or loose snow on the airport, the flaps should not be retracted to less than 25 after landing. The airplane should be inspected and deiced if necessary prior to further flap retraction or the next takeoff.

1.17.3.3 Departures in Icing Conditions

The Normal Procedures section of the airline's DC-9 Flight Manual contains reference to aircraft preflight inspections, as follows:

Aircraft Inspection

An aircraft inspection will be made at origination stations, overnights, or when resuming interrupted flights when the airplane has been left unattended for an extended period of time. Such checks are made to determine any unreported damage which could in any way render the aircraft unairworthy. Items requiring maintenance shall only be corrected by RYAN INTL. personnel or their designated representatives.

Exterior Inspection

The exterior portion of the inspection will be accomplished by the First Officer. While checking the listed items, note the general condition and appearance of the aircraft for indications of defects or improper installation of required equipment.

The airline's DC-9 Flight Manual provides a detailed description of the standard pattern to follow, with specific items to be inspected.

The airline's director of hub operations told Safety Board investigators that the airline's policy has always been for a member of the flightcrew to perform a walkaround inspection of the airplane before each flight. The B-727 Operations Bulletin 90.3, Before Flight and Quick Turnaround Responsibilities, Second Officer Duties, contained the following in part:

He will then monitor the cargo on/off operation from outside the aircraft, noting that the cargo door sill protectors are in place, and will perform a brief aircraft exterior inspection. On 727-200 aircraft the S/O will install the Cargo Loading Body Support (tail stand) if the aircraft is to be loaded or offloaded of cargo.

Similar duties had not formally been incorporated in the DC-9 flight manual because of the longstanding practice of complying with this requirement. The director emphasized that the walkaround requirement was especially important when there was a possibility of ice on the wing.

The company issued Operations Bulletin 89.4, DC-9 Winter Operations, on November 15, 1989. It was required to be placed in the front of the DC-9 Flight Manual and contained the following:

DC-9 WINTER OPERATIONS

GENERAL

During the winter season low temperatures and accumulations of water, rain, ice, snow, slush and frost on either the aircraft or airport surface can make operations difficult, hazardous or impossible. It is, therefore, very important for all crewmembers to be alert to existing and anticipated weather conditions, both on the ground and in the air.

PREFLIGHT

The aircraft preflight is of utmost importance. All control surfaces must be free of ice, snow, or frost. Associated hinges, tracks, and actuators should be checked for trapped moisture which could freeze.

Carefully inspect fuselage where lights and antennas are located, which may have been damaged or missing following de-icing procedures.

Check landing gear wheel well areas for accumulation of ice, slush, or snow; control cables, moving parts, position indicating switches and limit switches are of particular concern.

All snow must be removed from the nose radome area to prevent snow from blowing back and obscuring pilots' vision during takeoff.

Windshield heat must be on for at least 10 minutes prior to de-icing, to prevent the windshield from cracking should hot de-icing fluid inadvertently be sprayed directly on it.

1.17.3.4 Actions Following the Accident

Following the accident the company issued Operations Bulletin 91.2 takeoff Pitch Limitation on March 6, 1991:

Until further notice the maximum pitch attitude during takeoff will be limited to a 15^{o} deck angle. The rate of rotation should be smooth (NOT GREATER THAN 3^{o} PER SECOND) and consistent. The 15^{o} limitation may require an initial climb greater than V2+10 to obstacle clearance altitude at the lower takeoff weights.

In the event of an engine failure or excessive rotation, stop the rotation at the engine-out attitude of approximately 11^{o}. If you have rotated past the engine-out attitude, smoothly return to the engine-out pitch attitude. (Note pitch attitude varies with takeoff gross weight). Know your engine-out attitude prior to takeoff roll.

Reducing the deck angle if higher than the engine-out attitude will help stabilize the aircraft and prevent roll and compressor stalling. DO NOT OVER CONTROL roll with ailerons. CONTROL YAW WITH RUDDER. The engine-out attitude is not *restricted to the engine-out situation. It should be used to help stabilize the aircraft when:*

Engine failure occurs

Mistrim *occurs*

Improper CG

and may be considered when encountering icing, turbulence, heavy precipitation.

On March 11, 1991 they issued Operation Bulletin 91.3 Aircraft Walkarounds:

Aircraft shall be inspected at each intermediate stop (walkaround). This responsibility rests with the Captain, who may delegate the First Officer to perform the inspection. NO AIRCRAFT SHALL DEPART AN INTERMEDIATE STOP WITHOUT THE WALKAROUND BEING COMPLETED.

The inspection shall cover:

Bird Strikes

Hydraulic Leaks

Condition of Tire and Brakes

Wing Contamination

Condition of Wing Leading Edges

Flaps, Flight Control Surfaces, etc.

When weather conditions exist that may cause wing contamination, the leading edge and upper surface shall be inspected. A ladder has been provided for this purpose. NO AIRCRAFT may depart any station with any wing or tail contamination. If in doubt, DE-ICE!

On May 31, 1991, a Cold Weather Operation section was incorporated in the Normal Procedures section of the DC-9 Operations Manual. The content of this addition is essentially the same as the Douglas All Operators Letter that was issued November 7, 1985.

1.17.4 Federal Aviation Regulations Relevant to Operation In Icing Conditions

The following paragraphs have been extracted from Title 14 Code of Federal Regulations:

Part 91 - General Operating and Flight Rules: Paragraph 91.209 Operating in icing conditions

(a) No pilot may take off an airplane that has-

(1) Frost, snow, or ice adhering to any propeller, windshield, or power-plant installation, or to an airspeed, altimeter, rate of climb, or flight attitude instrument system;

(2) Snow or ice adhering to the wings, or stabilizing or control surfaces; or

(3) Any frost adhering to the wings, or stabilizing or control surfaces, unless that frost has been polished to make it smooth.

Part 121 - Air Carriers: Certification and Operations: Paragraph 121.629 Operation in icing conditions

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

(b) No person may take off an aircraft when frost, snow, or ice is adhering to the wings, control surfaces, or propellers of the aircraft.

In December 1982, following several icing-related takeoff accidents involving transport-category and general aviation airplanes, the FAA provided extensive guidance on wing contamination in its 37-page Advisory Circular (AC) 20-117. In essence, the AC reaffirms the necessity of adherence to the "clean airplane concept" in flight operations. The AC states that the only way to ensure that an airplane is free from surface contaminants is through close visual inspection before it actually takes off. According to the circular, the many variables affecting ice formation (AC 20-117 lists 13 significant ones) preclude a pilot from (a) assuming that his airplane is clean simply because certain precautions have been taken or certain ambient conditions exist, and (b) assuming his airplane is clean simply because he is within a certain arbitrary timeframe between the last inspection of the airplane and takeoff.

1.17.5 Previous Safety Board Actions

As a consequence of investigating several ac:cidents involving airframe icing, the Safety Board has been attentive to the hazards of winter operations. The Safety Board has totally supported the "clean wing" concept that an aircraft's aerodynamic surfaces must be free of ice or snow contamination before departure.

Following the Air Florida B-737 accident of January 13, 1982,[6] the Safety Board recommended on January 28, 1982, that the FAA:

A-82-7

Immediately review the predeparture deicing procedures used by all air carrier operators engaged in cold weather operations and the information provided to flightcrews to emphasize the inability of deicing fluid to protect against reicing resulting from precipitation following deicing.

In response, the FAA immediately transmitted the recommendation to all air carriers. Later that year, the FAA requested that each principal operations inspector actively review each air carrier's manuals and guidance on cold weather operations. The standards for this review included pertinent FARs, advisory circulars, and air carrier operation and maintenance bulletins.

Following the Continental Airlines DC-g-14 accident of November 15, 1987, the Safety Board issued nine safety recommendations to the FAA, two of which specifically addressed icing problems associated with the DC-9 series 10 airplanes. These were:

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 Operatings Inspectors to require that all McDonnell DC-g-10 series operators anti-ice airplanes with maximum effective strength glycol solution when icing conditions exist.

A-88-136

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

[6] 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)

The FAA responded to both of 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 8300.34, "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-g-10 operators establish special ice inspection procedures for the DC-g-10 aircraft. The FAA does not believe that there is anything unique about the DC-g-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, this latest DC-9 accident occurred. A further discussion of the Safety Board's current concerns regarding the icing hazard is included in the analysis of this report.

2.0 ANALYSIS

2.1 General

In the analysis of this accident, the Safety Board evaluated the roles of the environment, the airplane, and individuals and organizations involved in the manufacture, regulation, and operation of the airplane.

The captain and first officer were certificated and qualified for their respective positions in accordance with company standards and Federal regulations. The evidence indicated that the first officer was controlling the airplane and that the captain was performing the nonflying pilot duties during the takeoff. There is no evidence that the flightcrew had adverse medical histories, and the analysis of toxicological specimens obtained from the captain and the first officer did not detect any alcohol or other drugs. The possibility that the flightcrew's performance was affected by fatigue is considered in this analysis.

The airplane was certificated, equipped, and maintained in accordance with FAA regulations and company procedures. The weight and balance were within the prescribed limits for the takeoff, and the evidence from the wreckage examination confirmed that the trim and flaps were properly set for the takeoff conditions.

The investigation disclosed no evidence of any preexisting faults in the airplane's structure, systems, or engines that contributed to the accident. The engine compressor surges that were noted by witnesses and evident on the CVR during the attempted takeoff occurred as the airplane's stall warning stick shaker sounded. Flight tests previously conducted by the manufacturer and the investigation of other DC-g-10 takeoff accidents have shown that engine compressor surges do occur when the airplane is flown into a stall AOA condition. The surges are attributed to the resulting disruption of air flow aft of the airplane's wing at the engine inlet. The Safety Board thus concluded that the compressor surges were an effect of disrupted airflow and were not causal in this accident.

The meteorological information for the time of the accident did not indicate any significant changes in wind speed or direction in the Cleveland area. The airport gust recorder confirmed that the wind speeds ranged from 10 to 17 knots (averaging 14 knots) during the hour in which the accident occurred. Consequently, the Safety Board concluded that windshear was not a factor in the airplane's takeoff performance.

The abrupt decrease in the airplane's normal acceleration, the entry of the airplane into a steep roll attitude, the sounding of the stall warning stick shaker, and the occurrence of engine compressor surges at an airspeed 27 knots above the theoretical stall speed for the given conditions clearly indicate that the aerodynamic lift-producing capability of the wings was degraded. There are several possible reasons for a loss of aerodynamic efficiency, such as an improper takeoff configuration, extension of wing spoilers, and contamination or roughness of the airfoil surface. Because the evidence did not support either an improper takeoff configuration or an extension of wing spoilers, the analysis of this accident was focused on the possibility that some amount of ice or frozen snow was present on the wing leading edge or upper surface and that this contamination affected the airplane's flight characteristics.

2.2 Meteorological Conditions and Airframe Ice

The surface conditions at CLE were not necessarily conducive to accumulations of airframe ice because of the relatively low ambient temperature and the relatively dry snow. However, the airplane did fly through moderate rime icing during its descent for landing at CLE. Because the CVR began recording after the airplane landed at CLE, the Safety Board cannot determine if the flightcrew discussed the use of anti-ice protection during the descent.

However, the flightcrew had received ample weather information, including a PIREP, about icing conditions around CLE during the approach, so they should have selected both wing and engine icing protection during the descent for landing. In fact, there is reference on the CVR to use of these systems while the airplane was on the ground at CLE. The Safety Board concludes that the flightcrew most likely selected the system "on." Further, there was no evidence to suggest that the anti-ice system was inoperative.

The Safety Board considered the possibility that the pilots did use the wing anti-ice system during the descent and that moisture may have run aft of the heated wing surface and refrozen on the upper wing surface. However, information from the manufacturer indicates that the high temperatures (350° F or 177° C) of the heated wing surface would vaporize any liquid moisture on the wing and that the "runback" was unlikely. Nevertheless, this possibility cannot be ruled out.

The Safety Board believes that the most likely possibility of explaining the formation of ice on the wing surface is that the flightcrew used the wing anti-ice system during the approach and that the falling dry snow melted and refroze while the airplane was on the ground at CLE. The Safety Board believes that this scenario is possible because the wing would be "hot" upon touchdown (when the air/ground relay deactivates the anti-ice system automatically) and the blowing dry snow can melt on the wing and refreeze, as the wing temperature cools to below freezing.

2.3 Effect of Ice or Snow Contamination on Airplane Performance

The airplane's performance profile, which was developed during the investigation, and witness observations indicate that the takeoff roll and acceleration were normal until the airplane was rotated and lifted off the ground. The data showed that liftoff occurred at a slightly higher-than-normal airspeed and that the airplane began to climb. However, when reaching an altitude of 100 feet or less, the airplane rolled steeply. Although the tower controller reported seeing the airplane roll to the right and strike the ground in a nearly inverted attitude, the majority of witnesses and the physical evidence support a finding that the airplane's left wing struck the ground first.

Four previous accidents have been investigated by the Safety Board in which it was determined that DC-9 Series 10 airplanes have encountered nearly identical flight control difficulties during takeoff in conditions conducive to the accumulation of wing airfoil ice contamination.

The investigation of this accident provides substantial evidence that the rapid roll and descent after liftoff were the result of an aerodynamic stall. As in the previous accidents, the airplane was able to lift off and climb initially because of the influence of ground effect on the aerodynamic characteristics of the wing. When an airplane is close to the ground plane, the direction of airflow over the wing is altered. The result is that the wing will produce more lift at the same airspeed and AOA than it will when the airolane is in free air. This enhanced aerodvnamic oerformance diminishes as the airplane climbs and becomes almost negligible at a height equal to the airplane's wingspan, a distance of 87 feet for the DC-9-15.

Generally, an airplane's rotation speed is selected so that, with a normal rate of rotation, the airplane will lift off at a speed that offers a safe margin above the stall speed. In this case, the first officer rotated the airplane at the proper airspeed (132 knots) to ensure this stall margin. Normally, the airplane would have become airborne 2 or 3 seconds later at an airspeed of about 142 knots, providing more than 20 knots of stall speed margin. However, the FDR data showed that Ryan 590 lifted off about 4 seconds after the "Rotate" call and, assuming that the first officer rotated the airplane smoothly at around 3^{o} per second in accordance with the Ryan Operators Manual, the airplane was probably at a higher-than-normal pitch attitude with a correspondingly higher-than-normal AOA of 10^{o} or greater before it became airborne.

Because there was a faint scar on the runway surface about 3,440 feet from the beginning of the runway and an indication that the tail skid of the airplane had at some time been in contact with a hard surface, the Safety Board considered the possibility of a tail strike occurring during the takeoff, thereby placing the airplane at an AOA of even more than 10^{o} before or at liftoff. According to the manufacturer, to strike the tail with the wheels on the ground, the airplane would have to be rotated to a nose-up attitude between 11.5^{o} and 15.5^{o} depending upon the extension of the main gear struts. The Board believes that it is unlikely that the airplane reached a 15^{o} attitude before liftoff because of other evidence--the time distance study indicating that the airplane was airborne before the 3,400 foot distance mark and the delay in the stick shaker activation for about 2 seconds after it would have been armed. This delay in activation would not have occurred if the airplane had been at a 12^{o} or higher AOA at liftoff. Further evidence is provided by the magnitude of the "dip" in altitude on the FDR data, which is consistent with a normal rotation rate to the liftoff attitude. Nonetheless, the occurrence of a tail strike during an attempted takeoff with wing contamination could easily occur using normal pilot rotation procedures at proper airspeeds if the liftoff is delayed because of degraded aerodynamic performance of the wing.

The aerodynamic performance degradation notwithstanding, the airplane reached a combination of airspeed and AOA at which a vertical lift was developed that exceeded the airplane's gross weight. However, on the previous takeoffs of this airplane, the FDR data showed that a positive (greater than 1.0 g) normal acceleration was sustained for about 5 seconds with peak values between 1.2 and 1.3 g as the airplane transitioned to the climbing flightpath. In contrast, on the accident flight, the normal acceleration abruptly decreased after only 2 seconds, reaching a maximum of about 1.17 g. At the same time, the captain called "Watch Out" and, 1 second later, the airplane's heading deviated abruptly to the left and the engine compressor surges began. The Safety Board believes that this combination of events is consistent with an abrupt and unsymmetrical aerodynamic stall of the wings as the airplane reached a height where it lost the aerodynamic performance advantage of ground effect.

The start of the stick shaker 1 second after the stall indicates that the stall occurred at an AOA of about 12° and an airspeed of about 150 knots. Under normal conditions, with this combination of AOA and airspeed, the airplane should have been developing a normal acceleration (or load factor) greater than 1.4 g. Therefore, the Safety Board concludes that the lift coefficient for the wing of the accident airplane was nearly 30 percent less than the theoretical lift coefficient for a DC-g-series 10 wing. This degradation in aerodynamic performance is consistent with the performance decrement caused by minute amounts of contamination as cited by the manufacturer in several technical articles. According to the manufacturer, a wing upper surface contamination that is only .014 inch thick, about equal to the roughness of 80-grade sandpaper, can produce a 25-percent loss of wing lift. Therefore, the Safety Board concludes that the decrement in the aerodynamic lift-producing ability of the accident airplane was caused by an ice or snow accumulation on the wing that may have been less than .02 inch thick and barely perceptible from visual observation.

2.4 Flightcrew Performance and Guidance Provided by Operator

Ryan International Airlines acquired the DC-9 in 1989 and was reportedly not aware of the accident history or related documentation concerning the series 10 airplane vulnerability to control loss during takeoff with minute amounts of contamination on the wing. A wealth of information on the subject has been developed by McDonnell Douglas dating as far back as January, 1969. However, it is unlikely that the Douglas publications or All Operator Letters were sent to Ryan because, at the time of distribution, the company did not operate Douglas aircraft. Consequently, no specific information regarding the DC-9 icing history or special precautions relating to ground deicing was given to line pilots who were ultimately responsible for the safe operation of the aircraft.

The DC-9 Operations Manuals were basically developed by Ryan from the airplanes' previous owner's Operations Manuals, and certain purported Ryan practices were not incorporated into them. The requirement to conduct an exterior inspection of the airplane at intermediate stops was one of those practices not incorporated. In fact, the preflight inspection requirement in the Ryan DC-9 manual clearly indicated that exterior inspections were required only on originating flights or after the airplane had been left unattended. In contrast, the Ryan Operations Manual for the B-727 specified that an exterior inspection was required before each flight and assigned the conduct of the inspection to the second officer.

Following the accident, when Ryan discovered the DC-9 accident history and icing data, as well as the oversight regarding walk around inspections at intermediate stops, the company published Operations Bulletin 91.3 which includes the following guidance:

> When weather conditions exist that may cause wing contamination, the leading edge and upper surface shall be inspected. A ladder has been provided for this purpose. NO AIRCRAFT may depart any station with any wing or tail contamination. If in doubt, DE-ICE!

The Safety Board concludes, from the observations of witnesses, that neither of the flightcrew members exited the airplane to conduct a walk around inspection or a close observation of the wing surface. Further, the Safety Board concludes that the flightcrew did not violate written Ryan policy on this subject. The flightcrew may have observed the wing leading edge from the cargo loading door or the cockpit windows. However, in the existing lighting condition and from that distance, the detection of a critical, but minute, amount of ice would have been unlikely if not impossible.

The flightcrew may have been influenced by several factors in their decision to remain in the airplane. First, they may have believed that the air was too cold to contain liquid water that could freeze and stick to the wing surface--the ambient temperature was 23°F and the 14-knot wind was blowing dry snow off of other objects visible to the crew. Little information is available regarding the possibility of ice forming during the melting/cooldown period following the deactivation of wing anti-ice systems after landing. Second, the Safety Board noted that both crewmembers' experience prior to flying with Ryan was in DC-9 series 30 aircraft. The captain flew the C-9 in the U. S. Air Force, and the first officer flew the K-9-30 and DC-g-50 at USAir. Because these models have leading edge devices, they are not as vulnerable as the DC-9 series 10 airplane to critical performance degradation from small amounts of wing contamination. Therefore, even if the captain or first officer had encountered similar weather conditions prior to flying with Ryan, they most likely would not have encountered control problems and their concerns about the hazard of wing ice contamination would probably have been lessened.

Another consideration bearing on the crew's attention to the possibility of ice is the lack of de-icing activity by other operators. De-icing equipment had been standing by for approximately 1-1/2 hours and was immediately available. There was no evidence of fiscal or schedule pressures by the airline that would have discouraged the crew from using that equipment.

The Safety Board also considered the possibility that fatigue influenced the pilots' judgment during the ground operations at CLE and their decision not to conduct an exterior preflight inspection of the airplane. The flightcrew had flown the same nighttime schedule for 6 days, including the night of the accident, between BUF and IND with an intermediate stop each way in CLE. The captain had flown six successive night flights on the same BUF-CLE-IND and return route the week before the accident. He had 1 day off between the two periods of duty. The six flights, averaging about 3.8 hours each night, did not exceed FAA maximum flight time limitations; however, the captain's schedule had recently increased from the routine of flying for 5 days, followed by 9 days off-duty time at home in California. Although his family said that he was accustomed to night flying, the recent increase in duty and flight time could have induced fatigue.

There is evidence that the captain was suffering from a cold. The demanding duty schedule of 12 nights of flying during the last 13 days could have made recovery from illness more difficult and added to the negative effects of fatigue. The fact that the pilots did not exit the airplane for a preflight inspection in CLE suggests that the captain's decision making was affected by fatigue. Nevertheless, insufficient evidence exists to reach a firm conclusion on this issue.

Regardless of the factors that might have influenced the flightcrew's belief that an exterior inspection of the wing surfaces was unnecessary, the Safety Board believes that a preflight walkaround inspection of an airplane before each flight is a basic tenet for safe operations. Such an inspection is necessary to detect serious defects, such as bad landing gear tires, hydraulic leaks, and loose or missing panels, as well as to observe the wing and empennage surfaces.

Although the Safety Board supports the FAA's AC on wing contamination and concurs with the "clean airplane concept," the Safety Board believes strongly that the only way to ensure that the DC-9 series 10 wing is free from critical contamination is to touch it. Ladders or some other suitable equipment would be required to allow crewmembers to reach the wing, which is 7 feet above the ground. Similarly, for night operations, adequate lighting must be provided around the aircraft. Specifying such actions for only the DC-9 series 10 aircraft is not intended to suggest that other aircraft can operate without inspection for, and removal of, ice contamination; it is rather a reinforcement of the fact that visually imperceptible amounts of ice contamination may result in loss of control on the DC-9 series 10 aircraft.

During inclement weather, such as existed at CLE on the night of the accident, an inspection for possible ice contamination of the wings and empennage is an essential part of a flightcrew's responsibilities. Thus, the Safety Board concludes that the Ryan 590 flightcrew's failure to conduct a walkaround inspection was contrary to good practices. Further, the Safety Board believes that the flightcrew's failure to detect and remove ice contamination from the wings was a causal factor in this accident. The Safety Board also believes that factors which contributed to a lack of flightcrew guidance on the importance of such inspections and the flight characteristics of the DC-9 Series 10 airplane, in particular, were causal factors in the accident.

The Safety Board believes that after failing to detect and remove the accumulation of ice from the wing, there were no actions that the crew could have been reasonably expected to take that would have prevented this accident. The first officer followed the normal and prescribed procedures for the takeoff; that is, the rotation speed was that specified for the airplane's weight and the rotation rate was normal. When the airplane became airborne with a minimum stall speed margin, the stall was inevitable as the aerodynamic advantage of ground effect diminished. Further, the stall was most likely more sudden and severe than would have occured with an uncontaminated wing because a stall can progress from the wing tips inward. This causes the airplane to pitch nose up with a loss of roll control. The abrupt roll, occurring as one wing stalled before the other, was not controllable within the altitude available.

Under the circumstances for the takeoff of Ryan 590, it might have been possible to increase the liftoff speed stall margin and establish a climb without stalling by delaying the takeoff rotation, permitting additional acceleration on the runway. However, this procedure would have been improper because the increase in the rotation speed beyond that specified may have infringed upon the safety margin required by the Federal Aviation Regulations (FARs) in case of an engine failure during the takeoff. The rotation speed is currently based upon a minimum field length takeoff for the airplane's weight; that is, a field length that is sufficient to satisfy the balanced field concept where the accelerate-stop and accelerate-go distances are equal, assuming that an engine failure occurs at the decision speed, and also sufficient to satisfy the posttakeoff climb gradient requirement for obstacle clearance, as specified in the FARs. However, when operating on a runway longer than needed to meet this balanced or minimum field length criteria, a rotation speed higher than that currently specified could be used safely if the flightcrew were given sufficient information in their operating manuals to determine the maximum rotation speed that will still allow the required engine failure safety margins. The Safety Board believes that the FAA should require that this information be included in the manual to provide an additional takeoff safety margin for the DC-9 series 10 airplanes when they are operated from "unbalanced" runways in weather conducive to the formation of wing ice contamination, regardless of the other necessary measures to ensure that the wing is free of such contamination.

2.5 Dissemination of Airframe Icing Information

The written material, industrypresentations, and operator seminars that were offered for more than 20 years should have eliminated any operational problem with icing on the DC-9. However, similar accidents continue to occur. The Safety Board therefore concludes that efforts to educate line pilots of DC-9 series 10 airplanes about this problem have not been adequate. There are many reasons for the inadequacy of these efforts.

Much of the written material has been presented to airline management. There has been general agreement on the accuracy of the data, but no real understanding of the significance of the problem has been evident. Even in cases where the significance is understood, line pilots are apparently not giving the problem the attention that it merits.

Accumulations of ice as thin as 0.015 inch on the wings of a DC-9 can reduce the stall angle of attack below stall warning activation. Investigators have found that the vast majority of DC-9 series 10 pilots questioned are either unaware of these facts or lack an appreciation for the criticality of visually imperceptible amounts of wing contamination.

The Safety Board is concerned that when aircraft are sold, or when there are changes of pilots and instructors, an opportunity exists for the loss of 'corporate memory" of the significance of the icing problem on the DC-9. Although Douglas has issued material and urged that the wing icing problem be incorporated into the airplane flight manuals, they took no positive action to do so. By including the information in the approved Airplane Flight Manual, it would be directly available to the line pilots, and it would be transferred with the ownership of an aircraft when it is sold to a new operator. Ryan acquired eight DC-9s in 1989 and was unaware of the critical icing information until after the accident. If the information had been contained in the approved Airplane Flight Manual, the subject would have been emphasized in Ryan's initial training of its pilots.

Thus, the Safety Board believes that after four previous accidents, sufficient knowledge has existed within both the FAA and Douglas on the high vulnerability of the DC-9 series 10 to flight control problems in freezing weather conditions and that this information should have been disseminated in such a manner that it would be available to all of the pilots of these airplanes. The FAA could have required, and Douglas could have provided, additional information about this problem in the approved Airplane Flight Manual. Their failure to do so is a causal factor in this accident.

Similarly, the Safety Board believes that any operator acquiring a new model airplane in its fleet has an obligation to request from the manufacturer, and any other available sources, information unique to the safe operation of that airplane. If Ryan had fulfilled this obligation it would have become aware of the previous accidents involving wing ice contamination. Then Ryan would have been able to provide the training and guidance to its flightcrews that should have prevented this accident. Thus, the airline is also cited as a causal factor in the accident.

3.0 CONCLUSIONS

3.1 Findings

1. There was no evidence of preexisting airplane structural, systems, or engine faults that contributed to the loss of control of the airplane 7 seconds after liftoff from runway 23L at Cleveland-Hopkins International Airport.

2. Four previous accidents of DC-9 series 10 airplanes, also involving loss of control almost immediately after liftoff, were attributed to a loss of aerodynamic efficiency due to ice accumulation on the wings.

3. The accident airplane had flown through conditions conducive to the accumulation of moderate rime ice during the descent for landing at Cleveland-Hopkins International Airport, about 40 minutes before the accident, and the flightcrew probably used the wing anti-ice system during the descent.

4. Ground conditions at the Cleveland-Hopkins International Airport during the 35-minute turnaround were not conducive to airframe icing because of the dry snow and the low ambient temperatures; however, the melting and refreezing of snow on the previously heated wings could have produced an accumulation of ice on the wing upper surface.

5. The flightcrew did not exit the airplane to conduct an exterior preflight inspection at the Cleveland-Hopkins International Airport to verify that the wings were free of ice contamination, and a requirement for such an inspection was not specified in the Ryan DC-9 Operations Manual.

6. The first officer was controlling the airplane, and the takeoff roll and rotation were normal and accomplished in accordance with prescribed procedures.

7. The liftoff occurred at a higher-than-normal airspeed; however, the lift-producing efficiency of the wing was degraded by contamination, and the stall speed margin at liftoff was minimal.

8. There was some physical evidence but no evidence derived from the performance analysis to corroborate a tail strike at takeoff. However, a tail strike could occur with normal pilot procedures during an attempted takeoff with wing contamination.

9. *The airplane's wings stalled abruptly and without warning as the airplane began to climb and the aerodynamic advantage of ground effect diminished. At the time of stall, the airplane had sufficient speed to achieve a 1.4 g load factor with normal aerodynamic characteristics.*

10. *The engine compressor surges were caused by the disturbed airflow aft of the wing and at the engine inlet as the airplane approached stall.*

11. *The steep roll concurrent with stall was caused by the irregular lift distribution across the wing and was not controllable by the pilot, thereby preventing recovery.*

12. *The DC-9 series 10 has no wing leading edge lift augmenting devices and is particularly vulnerable to degraded aerodynamic performance as a result of minute amounts of wing contamination than the later model DC-9 and MD-80 airplanes that have leading edge devices.*

13. *The flightcrew had not been given specific training or other educational material to inform them of the more critical effects of wing contamination on DC-9 series 10 airplanes.*

14. *The Douglas Aircraft Company has issued numerous articles on the subject of wing contamination, but there is no system to ensure that the critical information reaches all line pilots of these airplanes.*

15. *Both the FAA and Douglas Aircraft Company have been aware for several years of the propensity of the DC-9 series 10 to the loss of control caused by wing contamination, but neither of them took positive action to include related information in the approved Airplane Flight Manual.*

16. *Had additional information or cautions about the high vulnerability of the DC-9 series 10 to loss of control caused by wing contamination been placed in the approved Airplane Flight Manual, it would have been available to line pilots.*

17. *Ryan International Airlines had the opportunity and obligation to request information relating to previously identified safety issues when it acquired the DC-9 airplanes in 1989 but failed to do so.*

3.2 *Probable Cause*

The National Transportation Safety Board determines that the probable cause of this accident was the failure of the flightcrew to detect and remove ice contamination on the airplane's wings, which was largely a result of a lack of appropriate response by the Federal Aviation Administration, Douglas Aircraft Company, and Ryan International Airlines to the known critical effect that a minute amount of contamination has on the stall characteristics of the DC-9 series 10 airplane. The ice contamination led to wing stall and loss of control during the attempted takeoff.

4. RECOMMENDATIONS

As a result of this accident, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> 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. (Class II, Priority Action) (A-91-123)
>
> 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°C and visible moisture exist or whenever the airplane recently encountered icing conditions. (Class II, Priority Action) (A-91-124)
>
> 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. (Class II, Priority Action) (A-91-125)
>
> 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. (Class II, Priority Action) (A-91-126)
>
> 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. (Class II, Priority Action) (A-91-127)
>
> 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. (Class II, Priority Action) (A-91-128)

In addition, the Safety Board reiterates the following safety recommendation to the FAA:

> 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 Douglas DC-g-10 series operators anti-ice airplanes with maximum effective strength glycol solution when icing conditions exist. (A-88-134)

This recommendation is now classified "Open-Unacceptable Response."

The Safety Board considers that Safety Recommendation A-91-124, when accomplished, will satisfy the requirements of the following safety recommendation:

> Require all DC-g-10 operators to establish detailed procedures for detecting upper wing ice before takeoff. (A-88-136)

This recommendation is now classified "Closed-Unacceptable Action/Superseded."

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ James L. Kolstad
Chairman

/s/ Susan Coughlin
Vice Chairman

/s/ John K. Lauber
Member

/s/ Christopher A. Hart
Member

/s/ John Hammerschmidt
Member

November 16, 1991

James L. Kolstad, Chairman, filed the following dissenting statement:

I respectfully dissent from the report of the majority solely over the expression of probable cause. In my view, the probable cause of this accident was a failure of vigilance on the part of a cockpit crew, and it is vitally important not to dilute or mask this message by scattering the responsibility among impersonalized organizational structures, none of which had a direct hand in the decision-making in this cockpit.

The actual cause of this accident is almost certain -- wing ice that without warning stole essential lift at the most critical moment of flight, taking the lives of two fine men. While determination of the actual failure mode might seem a sufficient understanding of probable cause to the uninitiated, the Safety Board has traditionally gone further into the chain of events which lead to an accident to determine why the failure was permitted to occur. The reasons for doing this are important -- they relate to the ability of the Board to recommend preventive measures and galvanize the necessary actions and attitudes to preclude reoccurrence. The Board cannot prevent the formation of ice, but we may be able to increase the likelihood of its detection.

Flight 590 descended into Cleveland airport through icing conditions. Air traffic control had passed on two pilot reports of moderate rime icing down to the surface. (Moderate icing is not "moderate" in any commonly understood sense -- it means icing of such significance that even short encounters are hazardous and the use of de-icing or flight diversion is necessary.) The aircraft sat on the ground for 35 minutes in snow and freezing temperatures. De-icing equipment had been made available but was not used, and neither member of the crew took an opportunity to leave the aircraft and make an inspection of the exterior of the aircraft for signs of ice.

My colleagues believe that this last failure -- the failure to inspect -- was the result of poor organizational performance. The aircraft in question is especially susceptible to lift problems with wing ice. Because this problem was known but apparently not clearly communicated to the accident crew, the majority believe that the air carrier, the aircraft manufacturer and the Federal Aviation Administration were in the direct line of causation.

I think it is fair to say that each of these organizations might have performed better -- and that their failure contributed to the probability that an accident such as this might take place. And it is wholly appropriate that we recommend that these organizations do more to prevent a reoccurrence. But it is misleading to suggest that the dangers of ice were surprising, and that another piece of paper in the blizzard of information that pilots constantly receive would have prevented this accident. Under existing federal regulations it is unlawful to take off with ice adhering to wings. It is the responsibility of every pilot to adhere to this rule, not simply because it is a rule, but because the rule reflects the physics of flight. And it is important that this Board stress the responsibility of those in command of aircraft to stay in command, as it must go without saying that the proper execution of their duties is the single most important guarantor of safe flight.

In my view, the pride and professionalism of the pilot community has always been the most important determinant of safety in air transport. Fostering a sense of pride requires constant reinforcement of the responsibility entrusted to the individuals who command flight. This means an honest acknowledgment of shortcomings, as well as accomplishments.

/s/ *James L. Kolstad*
Chairman

Susan Coughlin, Vice Chairman, filed the following concurring statement:

I am concurring in the probable cause statement of this accident report, but with some reservations.

I have no difficulty in citing the crew's performance, in that I don't believe that this aircrew took such actions to insure that their aircraft was free of ice contamination before departing the gate at the Cleveland airport on the night of the accident, regardless of the type of aircraft they were flying. At a minimum, the Ryan DC-9 Winter Operations Bulletin 89.4 should have prompted the crew, in their pre-flight preparations, to explore more fully the extent to which the weather may have been a negative factor with implications affecting the safety of their flight. While this crew may have had no specific training from the airline on icing conditions, they clearly had at least some cues that icing **may** *be a factor on this particular night. Nevertheless, their collective resources didn't prompt them to inspect the aircraft from the outside either visually or* **tactually.** *This despite pilot reports of moderate icing, actual precipitation at the time of their departure, and claims from their management that not only were visual walk around inspections the common practice, they were formally required in the flight manuals for other aircraft in the fleet.*

However, the most critical cue that was not provided to the crew on the night of the accident was information that was apparently readily available and known throughout much of the aviation community, that being the sensitivity and vulnerability of the DC-9 Series 10 aircraft to minute amounts of ice contamination on the upper surfaces of the plane's wings. In my view, this lack of cohesive action by the aviation community at large to provide this critical information and guidance to line pilots of this specific aircraft type, left not only this aircrew, but others preceding it, hopelessly ignorant of the situations they faced.

In defining the aviation community at large, I find myself unable to exclude this agency. In 1985, following the crash of the Airborne Express DC-9 in Philadelphia, the Safety Board drafted, but apparently never adopted, an important recommendation to the Federal Aviation Administration, which would have required that the approved flight manuals for the DC-9 Series 10 *airplanes emphasize several points, among them the hazards of minute amounts of wing surface roughness (in this case ice) and its effect on stall speed. This recommendation was never adopted by the Board or forwarded to the FAA for consideration. The Philadelphia accident was the third in which a DC-9 Series 10 aircraft crashed during icing conditions.*

Then in 1988, prompted into action following the crash of the Continental Airlines DC-9 in Denver, the Safety Board did two things. First, they initiated a study into the effects of icing on this model aircraft, the results of which were never adopted or published. Secondly, the Board proposed, adopted, and sent several important recommendations to the FAA, among them A-88-136, requiring all DC-9 operators to establish detailed procedures for detecting upper wing ice before takeoff. The intent was that this information would be incorporated into the airline flight manual, and, therefore, be placed in the hands of every line pilot. When the FAA responded negatively, the Board was silent. The National Transportation Safety Board should have communicated its strong disagreement with the FAA's position swiftly and clearly.

We now find ourselves making the case once more for a safety issue that we were confident existed as early as 1985.

While I am concurring with the probable cause as adopted by the majority of the Board, I would have preferred that the scope of the cause be extended, and read:

> *The National Transportation Safety Board determines that the probable cause of this accident was the failure of the flightcrew to detect and remove ice contamination on the airplane's wings, in part because of a lack of cohesive action by the aviation community at large directed at the known critical effect that a minute amount of contamination has on the stall characteristics of the DC-9 Series 10 airplane, which can lead to wing stall and loss of control during an attempted takeoff.*

Although left unstated, the implication is that the definition of the aviation community at large includes, among possible others, the Federal Aviation Administration, the National Transportation Safety Board, Douglas Aircraft Company, Ryan International Airlines, and other operators of the DC-9 Series 10 aircraft, all of whom shared a responsibility to educate or be educated about the flight characteristics of this aircraft.

/s/ *Susan M. Coughlin*
Vice Chairman

APPENDIXES

APPENDIX A

INVESTIGATION AND HEARING

1. *Investigation*

The National Transportation Safety Board was notified of this accident at 0100 *on February 16,* 1991. *A full investigative team departed Washington at 0600 that day. Investigative groups were established for:*

a. *Airplane Performance*

b. *Air Traffic Control*

c. *Cockpit Voice Recorder*

d. *Digital Flight Data Recorder*

e. *Operations*

f. *Human Performance*

g. *Powerplants*

h. *Airplane Structures*

i. *Survival Factors*

j. *Airplane Systems*

k. *Weather*

Parties to the investigation were:

a. *Cleveland-Hopkins International Airport*

b *Douglas Aircraft Company*

c. *Emery Worldwide*

d. *Federal Aviation Administration*

e. *Pratt and Whitney*

f. *Ryan International Airlines*

g. *U.S. Postal Service*

2. *Public Hearing:*

No public hearing was convened on this accident.

APPENDIX B

COCKPIT VOICE RECORDER TRANSCRIPT

TRANSCRIPT OF A FAIRCHILD MODEL A-100 COCKPIT VOICE RECORDER S/N 1174, Removed FROM A RYAN INTERNATIONAL AIRLINES WCDONNELL DOUGLAS DC-g-15 AIRCRAFT, **N565,** WHICH WAS INVOLVED IN A TAKEOFF ACCIDENT ON FEBRUARY 17, 1991 AT THE HOPKINS INTERNATIONAL AIRPORT, CLEVELAND, OHIO

CAM	Cockpit area microphone voice or sound source
RDO	Radio transmission from accident aircraft
-1	Voice identified as Captain
-2	Voice identified as First Officer
-3	Voice identified as Ryan Airlines Cargo Agent
-?	Voice unidentified
GND	Cleveland Ground Controller
TWR	Cleveland Local Controller (Tower)
CLR	Cleveland Clearance Delivery Controller
CO1238	Continental Airlines flight twelve thirty eight
*	Unintelligible word
@	Nonpertinent word
#	Expletive deleted
%	Break in continuity
()	Questionable text
(())	Editorial insertion
	Pause
NOTE:	All times are expressed in Eastern Standard Time.

INTRA-COCKPIT TIME & SOURCE	CONTENT	AIR-GROUND COMMUN TIME & SUURCE
2347:06 Start of recording and transcript		
2347:42 CAM-1	look at the way the fuel is now.	
2347:45 CAM-2	all screwed up.	
2347:46 CAM-1	yup.	
2348:45 CAM-1	Viking.	
2350:46 CAM	((sound of englnet spooling down))	
2350:53 CAM-1	* run the checklist *.	
2350:54 CAM	((Sound of momentary power interruption to CVR))	
2351:21 CAM	((Sound similar to cockpit door opening and closing))	
2352:20 CAM	((sound of kay loader starts and continues until 0006:27))	
2352:55 CAM	((Sound similar to cockpit door openlng and closing))	
2352:56 CAM-2	what do you want out of Indy? twenty?	

INTRA-COCKPIT		AIR-GROUND COMMUN
TIME & SOURCE	CONTENT	TIME & SOURCE
2352:57 CAM-1	yes please.	
2353:03 CAM-1	well I don't know what to say about this fuel. I don't know what to say.	
CAM-?	*	
2353:14 CAM-1	how much you figure we burned on that leg?	
2353:17 CAM-2	ah five thousand. Five two.	
2353:19 CAM-1	yup.	
2353:37 CAM	((sound similar to cockpit door opening))	
2353:38 CAM-3	here's your load plans.	
2353:40 CAM-1	thanks.	
2353:41 CAM-3	okay.	
2353:43 CAM	((sound similar to cockpit door closing))	

INTRA-COCKPIT

TIME & SOURCE		CONTENT
2354:10	CAM-1	*yup I just don't know what to say about that thing.*
2356:05	CAM-2	*there's something wrong with this * too.*
2356:07	CAM-1	*okay.*
2356:52	CAM-2	*I'm ready for day off.*
2356:34	CAM-1	*you what?*
2356:55	CAM-2	*I'm ready for a day off.*
2357:00	CAM-2	*twenty 'en seven.*
2357:07	CAM-2	*now's the time for * to get you.*
2357:10	CAM-1	*no no you need rest.*
2357:11	CAM-2	*((sound of laugh))*
2357:12	CAM-2	*please.*

AIR-GROUND COMMUN

TIME & SOURCE

INTRA-COCKPIT

AIR-GROUND COMM

TIME & SOURCE	CONTENT
2357:13 CAM-1	*peace and quiet.*
2357:19 CAM-2	*no, when I need I need my rest, she just doesn't seem to understand just doesn't.*
2357:29 CAM-2	*like that nlght after we came in, I was so tired. Oh my god. Night before *.*
2357:39 CAM-2	*that was somethin'.*
0000:40 CAM-2	*they added these column wrong.*
0000:43 CAM-1	*huh.*
0000:48 CAM-1	*they added the column wrong, okay.*
0001:21 CAM-2	*they have seventeen three elghty one.*
0001:26 CAM-2	*two D three eighty sevens.*
0001:32 CAM-2	*right, three eighty seven.*
0001:42 CAM-2	*three eighty seven. Ninety pounds off.*

TIME & SOURCE	CONTENT

INTRA-COCKPIT		AIR-GROUND COMMU
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**
0002:28 CAM-2	*ah we countin' any of that center tank fuel there?*	
0002:30 CAM-1	*no.*	
0002:39 CAM-2	*do you have any idea how much freight we're gunna' be carrying when we ah get let out of Buffalo?*	
0002:45 CAM-1	*out of Buffalo?*	
0002:47 CAM-2	*like out of Buffalo when we get here?*	
0002:50 CAM-1	*it's usually around eight thousand, seven or eight out of Buffalo. It's usually about sixteen or seventeen out of Indy.*	
0002:55 CAM-2	*anyway there's no way you'd know though, being they don't give you any kind of a forecast for fuel burn purposes or anything like that.*	
0003:01 CAM-1	*no.*	
0003:09 CAM-2	*total amount of fuel fifteen eight eh.*	

INTRA-COCKPIT

AIR-GROUND COM

TIME & SOURCE	CONTENT	TIME & SOURCE
0003:11 CAM-1	yes sir that's fine.	
0004:35 CAM-2	what the hell's that? what is this thing here a Convair or somethin'? what is it?	
0004:46 CAM-1	I don't know what that is a Convair ah two twenty.	
0004:49 CAM-2	five eighty maybe?	
0004:51 CAM-1	I think doesn't a five eighty have four engines *?	
0004:57 CAM-1	I don't believe it.	
0004:59 CAM-2	that is an old ship.	
0005:03 CAM	((sound of knock on cockpit door))	
0005:05 CAM	((sound similar to cockpit door opening))	
0005:07 CAM-2	who is it? Close the door please.	

INTRA-COCKPIT		AIR-GROUND COMM	
TIME & SOURCE	CONTENT	TIME & SOURCE	CONTENT
0005:11 CAM-3	we're ready.		
0005:12 CAM-?	*		
0005:13 CAM-2	pump want the pumps?		
0005:14 CAM-1	yep.		
0005:18 CAM	((sound similar to cockpit door closing))		
0005:22 CAM-2	who is it? •		
0005:31 CAM-2	🖂		
0005:49 CAM	((sound similar to cockpit door opening))		
0006:11 CAM-1	you call the bl- ah doors at three and the blocks at five.		
0006:16 CAM	((sound similar to cockpit door closing))		
0006:21 CAM-1	I guess we'll get clearance on the roll, no problem.		
0006:24 CAM-2	huh # up.		

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0006:27 CAM-1	that's allright you were busy with the paper work. That's what'11 that's what'11 kill us.
0006:30 CAM-2	huh.
0006:32 CAM-1	not the aviation capabilities.
0006:39 CAM-1	five ninety.

AIR-GROUND COMM

TIME & SOURCE	
0006:38 RDO-2	clea
0006:42 RDO-2	Ryan clea
0006:52 CLR	Ryan clea file expe two fre zer
0007:09 RDO-2	fiv nin

INTRA-COCKPIT		AIR-GROUND COMM	
TIME & SOURCE	**CONTENT**	**TIME & SOURCE**	
0007:12 CAM	*((sound similar to engine spooling up))*		
0007:13 CAM	*((sound of momentary power interruption to the CVR))*		
		0007:13 CLR	*Ryan corr conte zero*
		0007:18 RDO-2	*roge*
0007:24 CAM-1	okay *ah thank you for that.*		
0007:27 CAM-1	*starting engines checklist at your leisure. I'm gunna leave the right mains on and the others off for the time being, just to burn it out and see what happens.*		
0007:37 CAM-2	*okay, cargo door tail stand?*		
0007:39 CAM-1	*checked and on board.*		
0007:40 CAM-2	*shoulder harness right?*		

INTRA-COCKPIT		AIR-GROUND COMMUN	
TIME & SOURCE	CONTENT	TIME & SOURCE	
0007:41 CAM-1	left.		
0007:43 CAM-2	pitot heat, windshield heat is oh on, fuel pumps are as required, right on and auxiliary hydraulic pump and pressure is on and checked.		
0007:51 CAM-2	and ah circuit. breakers?		
0007:53 CAM-1	in on the left.		
0007:54 CAM-2	checked right. Radios flight director are -?		
0007:57 CAM-1	one oh eight eight.		
0007:59 CAM-2	okay.		
0008:00 CAM-1	outbound about two forty on the heading is fine and ah two niner eight niner and I'm not gunna use my flight director. It worked just fine on the way in.		
0008:08 CAM-2	okay, fuel and oil?		

INTRA-COCKPIT

AIR-GROUND COMM

TIME & SOURCE	CONTENT	TIME & SOURCE
0008:10 CAM-1	test reset and used it's on it's skewed and I'm on the right mains.	
0008:13 CAM-2	and ah brakes and ignition?	
0008:15 CAM-1	brakes on alpha's ignition is brakes are set ignition is on alpha.	
0008:22 CAM-1	and if you are ready you can perform the after start checklist.	
0008:25 CAM-2	* ten thirty five.	
0008:43 CAM-2	okay annunciator are gear light?	
0008:46 CAM-1	checked. Higher.	
0008:49 CAM-2	ignition?	
0008:50 CAM-1	it's now off.	
0008:52 CAM-2	off. Electrical power checked. Engine anti-ice?	

INTRA-COCKPIT		AIR-GROUND COM[illegible]	
TIME & SOURCE	CONTENT	**TIME &** SOURCE	
0008:55 CAM-1	I just turned it on.		
0008:57 CAM-2	on. APU air is off and ah air conditioning packs are auto pneumatic cross feeds are closed • existing fuel cross feed is open.		
0009:08 CAM-1	okay.		
0009:09 CAM-2	alternate sorry aux pumps are on and checked and starting is complete.		
0009:12 CAM-1	okay thank you.		
0009:15 CAM-2	okay.		
		0009:18 RDO-2	and car
		0009:22 TWR	Ryc rui jui
0009:24 CAM-2	**		

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0009:32 CAM-2	okay flaps are twenty.
0009:33 CAM-1	good.
0009:34 CAM-2	trim?
0009:36 CAM-1	three point zero zero zero set for departure.
0009:37 CAM-2	okay two point nine.
0009:39 CAM-1	okay.
0009:41 CAM-1	EPR and IAS bugs?
0009:42 CAM-1	one ninety eight for full IAS one three seven left one three seven. Right.
0009:51 CAM-2	okay, and flight instruments?
0009:53 CAM-1	zero zero seven over here slaved.

AIR-GROUND COM

TIME & SOURCE	
0009:28 RDO-2	jul tha

INTRA-COCKPIT

AIR-GROUND COMMU

TIME & SOURCE	CONTENT
0009:57 CAM-2	okay and ah seven on the right.
0009:58 CAM-1	rechecked.
0010:00 CAM-2	okay and anti-skid is armed.
0010:02 CAM-1	okay.
0010:03 CAM-2	and controls and elevator power's free and checked.
0010:06 CAM-1	okay.
0010:07 CAM-2	fuel heat?
0010:08 CAM-1	leave it off please.
0010:12 CAN-2	pneumatic cross feeds are closed fuel cross feeds is open.
0010:15 CAM-2	APU - is -.
0010:16 CAM-1	secure the APU.

TIME & SOURCE	

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0010:19 CAM-2	comin' down.
0010:21 CAM-2	crew briefing?
0010:22 CAM-1	right seat.
0010:24 CAM-2	right seat, we'll go ah max power flaps twenty one twenty eight one thirty two one thirty seven as previous five thousand feet .
0010:34 CAM-1	straight out, if we have any problems we'll fly safely at thirty nine hundred I think that is min sector out of here. We'll do an ILS back into two three just as before. No questions.
0011:01 CAM-1	that's correct.
0011:12 CAM-1	I wonder how many of these ah government pay checks we're carrying today? did I tell you this is where I get my pay check, out of Cleveland.

AIR-GROUND COMMUN

TIME & SOURCE	
0010:58 TWR	Ryan was a calle
0011:03 RDO-2	five

INTRA-COCKPIT		AIR-GROUND COMMU
TIME & SOURCE	CONTENT	TIME & SOURCE
0011:19 CAM-2	*you did.*	
0011:28 CAM-2	*if we weren't so honest we could come up with a scheme.*	
0011:31 CAM-1	*((sound of laugh))*	
0011:35 CAM-2	*I'm so stupid.*	
0011:38 CAM-1	*that's right.*	
0011:41 CAM-2	*we should really be concentratin' on how the hell we can get back there into them containers.*	
0011:47 CAM-2	*one plane load and we can retire.*	
0011:51 CAM-2	*you know use our jump seating privileges and jump seat around to different banks * and ah get the cash for the day meet you in Rio.*	
0012:04 CAM-1	** they invited us to go to the ramp.*	
0012:07 CAM-2	*yeah never to be heard from -.*	

INTRA-COCKPIT

TJHE & SOURCE	CONTENT
0013:28 CAM-1	boy, that control circuit breaker when you put it in, feel how hot I don't know how hot your window is but this one is burning up.

AIR-GROUND COMMUNICAT

TIME & SOURCE	C
0012:43 C1238	Tower Cont is with yo
0012:46 TWR	Continenta Cleveland to land wi runway two fair by DC
0012:56 C1238	okay clear with fair thirty eig
0013:00 TUR	Continenta plus or mi way down f aircraft r thousand
0013:10 C1238	Continent you

INTRA-COCKPIT

AIR-GROUND COMM

TIME & SOURCE	CONTENT	TIME & SOURCE
0013:33 CAM-2	*yeah.*	
0013:34 CAM-1	*literally burning up.*	
0013:43 CAM-1	*get that warm and fuzzy feeling.*	
0013:50 CAM-2	*whoa * .*	
0014:04 CAM-2	*pneumatic air cart.*	
0014:08 CAM-1	*bankruptcy ah impounding notice.*	
0014:13 CAM-2	*who?*	
0014:15 CAM-1	*bankruptcy impounding notice.*	
0014:19 CAM-2	*yeah, more guys on the street. Ryan ain't gunna have a shortage if that keeps up, that's for certain.*	
0014:26 CAM-1	*right, we're fortunate to be here.*	
0014:31 CAM-2	*yeah.*	

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0014:33 CAM-I	to have to go through the humiliation of Eastern, Delta I mean ah American, Delta, United --.
0014:38 CAM-2	yeah.
0014:39 CAM-1	you have to go way down to the bottom. Go through that personnel profile you know, crap and then become an engineer bottom of the list nine thousand five hundred seniority number.
0014:46 CAM-2	yeah.
0014:57 CAM-1	they cut out of out of the interview class.

AIR-GROUND COMMU

TIME & SOURCE	
0014:51 Cl238	and a winds are a now
0015:00 TWR	ah tv

INTRA-COCKPIT | *AIR-GROUND COMMUN*

TIME & *SOURCE* | *CONTENT* | **TIME & SOURCE**

0015:03
CAM-2 *they cut half the class you know and the way they tell ya' is they you go to a guy and he gives you a little short interview about twenty minutes it's basically an application review and then asks you a couple of questions and then you go for a sin. Takeoff a ah level off at six head right for a VOR they give you a hold get it wrong they* **give :you** *another one you get that wrong it's only one aspect of the eleven things you can* *.

0015:30
CAM-2 *come back around and shoot the ILS. Then they'll get you in this room and they come up and they just go okay.*

0015:37
TWR *Ryan f for ru*

0015:41
RDD-2 *Ryan f*

0015:44
CAM-2 *three two left.*

0015:46
CAM-1 *two three left.*

0015:47
CAM-2 *why do they keep* **sayin'** *three two they must 'a just got 'em the ah lined up.*

INTRA-COCKPIT

TIME &
SOURCE *CONTENT*

0016:06
CAM-1 *they just say you you and you; huh?*

0016:08
CAM-2 *yeah, and ah they read a list and they call all those people into one room and then you don't know if those are the people that got ejected or those are the people that got to stay.*

0016:28
CAM-2 *ah man and then they come out and your faces are so --.*

AIR-GROUND COMMUNI

TIME &
SOURCE

0015:51
TWR *Ryan fiv*
between
taxi ont
runway t

0015:57
RDO-2 **taxi** *ont*
three le

0016:26
TWR *ah that*

0016: 29
RDO-2 *Ryan fi*

0016:32
TWR *Ryan fi*
straigh
right c
make a
you

INTRA-COCKPIT

TIME &
SOURCE — CONTENT

0016:38
CAM- 1 — *1'11 make a one eighty right here if it's allright.*

0016:45
CAM- 1 — *leave in the middle of the story time.*

0016:52
CAM-1 — *well actually I was* **lookin'** *for two three over here but, it's wrong I guess,*

0017:02
CAM-2 — *two three left.*

0017:08
CAM-2 — *there's a lot of runways at this airport.*

0017:13
CAM- 1 — *okay, you can be real crestfallen when you leave that place, you know what I'm* **sayin'.**

AIR-GROUND **COMMUN**

TIME **&**
SOURCE

0016:40
RDO-2 — *one ei*
with u

0016:44
TWR — **allrig**

0016: 59'
TWR — *Ryan*
left

0017:04
RDO-2 — *two t*
ninet

INTRA-COCKPIT

AIR-GROUND COMMUNI

TIME & SOURCE	CONTENT
0017:16 CAM-2	oh man.
0017:18 CAM-1	cause you know you actually have the temptation to think hay they say I am a dog crap, 1 must be that way you know that's the worst thing about it.
0017:24 CAM-2	yeah.
0017:26 CAM-1	you know there's nothing wrong with you. You've done nothing wrong, every thing right, but they just arbitrarily said something and you got the temptation of believing them.
0017:39 CAM-2	* I em'.
0017:43 CAM-2	* TWA **American** ● .
0017:50 CAM-2	okay now I -.

TIME & SOURCE	
0017:48 TWR	Contlne left ta frequen
0017:51 C1238	Contlne ah we c

INTRA-COCKPIT

AIR-GROUND COMMUNICA

TIME & SOURCE	CONTENT
0017:58 CAM-1	let's be let's be turning the fuels on now.
0018:01 CAM-1	and turn off that.
0018:02 CAM-2	fuel cross feeds stowed.
0018:03 CAM-2	okay. Annunciator?
0018:05 CAM-1	be sure to thank'him when we takeoff, oh I'll do it cause I'll be talkin' to him.
0018:08 CAM-1	annunciators checked.
0018:09 CAM-2	flaps?
0018:10 CAM-1	twenty.
0018:11 CAM-2	twenty. Transponder DME, it's on.
0018:15 CAM-1	good.
0018:17 CAM-2	exterior?

TIME & SOURCE

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0018:18 CAM-1	on.
0018:24.6 CAM	((sound of engines increase in speed))
0018:31.1 CAM-1	okay air speed's alive.
0018:33.0 CAM-1	engines are stabilized, power's set for departure.
0018:37.5 CAM-1	fuel's even kind'a balanced.

AIR-GROUND COMMUNICAT

TIME & SOURCE	C
0018:17.5 TWR	Ryan five n fly ah runw
0018:20.7 RDD-1	okay we're two three l help
0018:24.4 TUR	you're very zero at one
0018:27.0 RDO-1	hay that's
0018:29.0 TUR	allright

INTRA-COCKPIT		AIR-GROUND COMMUNICA	
TIME & SOURCE	CONTENT	TIME & SOURCE	
0018:39.4 CAM-1	*one hundred knots.*		
0018:41.3 CAM	*((sound similar to runway noise (banging)))*		
0018:44.9 CAM-1	*Vee one.*		
0018:45.9 CAM-1	*rotate.*		
0018:48.3 CAM-1	*Vee two.*		
0018:49.2 CAM-1	*plus ten.*		
0018:50.4 CAM-1	*positive rate.*		
0018:51.2 CAM-1	*watch out.*		
0018:51.7 CAM-1	*watch out.*		
0018:52.1 CAM-1	*watch out.*		
0018:52.3 CAM	*((sounds similar to engine compressor surges start))*		

INTRA-COCKPIT

TIME & SOURCE	CONTENT
0018:53.1 CAM	*((sound similar to stick shaker starts))*
0018:55.5 CAM	*((sound of engine compressor surges stops))*
0018:56.0 CAM	*((sound of stick shaker stops))*
0018:56.78 CAM	*((sound of first impact))*
0018:56.82 CAM	*((sound of second louder impact))*
0018:57.6	*end of recording*

AIR-GROUND **COMMUNIC**

TIME & SOURCE	
0018:55.8 RDD-?	*((sound seconds))*
0018:57.4 RDD-?	*((sound continue*

APPENDIX C

PERSONNEL INFORMATION

The Captain

The captain was hired by Ryan International Airlines on August 9, 1989. He had previously served as a pilot with the U.S. Air Force, flying the C-9, the military version of the DC-9. After leaving active duty, he served as a pilot with a number of airlines, including Ozark Airlines, World Airways, Overseas National Airlines, Challenge Air, as well as additional small airlines.

The captain's family said that he was used to night flying as a result of his military flight time and that he liked flying for Ryan. His typical schedule with the airline was 5 nights on duty, followed by 9 nights off duty. While off duty, he would return to his family in Oakland, California.

This duty schedule changed several weeks before the accident, however, as the result of a major expansion of the airline's contract to carry mail for the U.S. Postal Service. The expansion occurred during the Persian Gulf conflict, and related to a limitation on the size and weight of packages allowed aboard passenger-carrying airlines. During the expansion period, the airline hired new pilots, and increased the duty hours of experienced pilots. The captain had last visited his family for about 5 days, ending about 2 weeks before the accident. The 2 weeks between his last visit home and the accident was described as the longest period that the captain had been on duty with the company. He flew two successive groups of flights, separated by one day off. In each group of flights, he flew for 6 consecutive nights, including the night of the accident. All of the flights were on the same route. He had been scheduled to return home on Friday, February 15, 1991, but advised his family that he would be working additional days and that his time of return was uncertain.

The captain was described by the airline's Director of Hub Operations as a pilot with average skills who took criticism well. The chief pilot at Ryan's Indianapolis base described the captain as having very good command authority and being smooth on the controls.

The captain received discipline from Ryan on two occasions. He received a written warning in August 1990 for landing without having computed appropriate landing data. He also received a verbal warning for using an unauthorized identity card to gain access to another airline's jump seat.

The airline's president noted that the captain had been involved in a business venture in which he had distributed literature that falsely claimed he was in an existing partnership with the airline. The airline's president had discussed this activity with the captain, and the airline required the captain to recall the literature. Safety Board investigators learned that a similar claim of a partnership relationship between a former employer and the captain had resulted in the captain leaving a previous flying position.

The captain was not known to have experienced any major changes in his financial or personal situations during the year preceding the accident. There were no major illnesses of family members or friends during the past year. He possessed a valid California driver's license and had no record of vehicle accidents or major violations. The captain had no record of criminal arrest.

The captain's flight background had some record gaps in it. When he joined Ryan, he certified that his pilot's logbook had been lost during a short-term operation in Ireland, in 1986. The lost logbook was said to have 10,000 flight hours documented in it.

The First Officer

The first officer was hired by Ryan International Airlines on January 28, 1991. He was described as "loving aviation." He decided to enter the field as a profession after graduating from college and working briefly as a stockbroker. He completed lessons to become a private pilot and subsequently a commercial pilot, He then became a flight instructor and charter pilot, and a commuter airlines pilot for Princeton Airlink, Holiday Airlines, and American Eagle/Command Airways. The first officer's flight experience as a commuter airline pilot was from December 1986 to December 1989. He was then hired by USAir as a DC-9 first officer. He was furloughed by USAir in January 1991.

The first officer was described by the airline's chief pilot at the Indianapolis base as very personable and eager to do a good job. The first officer had been the first member of his ground school class at Ryan to enter line service. The chief pilot noted that the captain of the accident flight had commented early in the week of February 11, 1991, that the first officer was "a good man." The chief pilot also said that another Ryan captain had previously commented favorably about the first officer's performance.

The first officer reportedly said to family members that the captain of the ill-fated flight was "a very informative individual," and "very knowledgeable."

The first officer was not married. There was no indication that he had experienced any major changes in his financial or personal situations in the 6 months prior to the accident. His New Jersey driver's license record showed that he was involved in a motor vehicle accident on March 28, 1990, for which no points were charged, and that he had been charged with a speeding violation on August 15, 1988 (61 mph in a 50 mph zone). There were no other violations in the 3 years before the accident. He had no criminal record.

APPENDIX D

ADDITIONAL AIRCRAFT INFORMATION

A review of the maintenance records for the airplane indicated that the DC-9-15, serial number 47240, had a total flight time of 47,574.3 hours at the time of the accident. The last "B" level inspection was conducted by Ryan International Airlines on January 6, 1991, when the airplane had a total airframe time of 47,457.2 flight hours. The last "C" level inspection was conducted on February 7, 1990, in Oklahoma City, at a total airframe time of 46,781.3 hours.

Seven engine-related discrepancies, with corrective actions, were recorded in the operator's Service Difficulty Reports within the 90-day period prior to the accident. Two of the discrepancies, noted on November 24, 1990, and December 20, 1990, and subsequently corrected, pertained to the airplane's anti-ice protection system. The discrepancies were written up as:

0 No. 2 engine EPR [engine pressure ratio] dropped 0.04 with engine anti-ice On. R & R [removed and replaced] all 3 engine AI [anti-ice] valves. Replaced 0 ring on PT2 [inlet total pressure] probe.

0 No. 2 EPR dropped .04 with AI on. Sealed area around P2 probe.

Subsequent to this corrective action, the No. 2 engine EPR with the application of anti-ice was not listed as a discrepancy.

The No. 1 engine, a Pratt & Whitney model JT8D-7B, serial number 654010, was manufactured by Pratt and Whitney. It had been installed on the airplane on February 25, 1990, and accumulated 791 hours of operation since installation and 890 cycles since installation. Total time on the engine was 30,437 hours, with 40,461 total cycles. The engine received its last Class B inspection on January 6, 1991, and accumulated 117 hours since inspection.

The No. 2 engine, also a Pratt & Whitney model JT8D-7B, had serial number 653913. It had been installed on the airplane on December 15, 1987, and accumulated 2,255 hours and 2,410 cycles since installation. Total time on the engine was 35,506 hours, with 24,243 total cycles.

APPENDIX E

DOUGLAS AIRCRAFT COMPANY LETTER AND ICING REPORT

MCDONNELL DOUGLAS

Douglas Aircraft Company

March 21, 1991
Cl-TMR-058

Dear

Several weeks ago, a DC-9 Series 10 aircraft crashed on takeoff. While the cause of the accident has not yet been firmly established, the facts are disturbingly similar to previous accidents which have been attributed to airframe ice.

While each of the previous accidents had its own unique situation, the common thread is that ice, ice/snow mix, frost or some combination of these, was present on the lifting surfaces at the start of the takeoff. Douglas has published numerous letters, articles and advisories on the topic of airframe and airfoil ice, its detection and effects. We believe that some of the information contained in those publications is worth repeating.

Ice contamination adversely affects (1) straight-wing aircraft such as the Nord 262 and numerous general aviation aircraft, (2) small turbojet aircraft with conventional airfoils (i.e., no leading edge high lift devices) such as the Learjet, (3) larger aircraft with conventional airfoils such as the F-28, DC-9-10, and DC-8, and (4) aircraft with leading edge high lift devices such as the 737. In most takeoff accidents, the ice contamination has not been large ice accretions on the leading edges, or thick layers of adhering snow on top of the wings. Rather, dangerous reductions in handling qualities and stall margins can occur because of icing roughness equivalent to that of MEDIUM GRIT SANDPAPER. This seemingly modest amount of contamination can result in pitching moment changes during takeoff rotation that cause the airplane to increasingly behave as if it were mistrimmed in the nose up direction. Following lift off, degraded lateral stability requires larger and larger control wheel inputs to keep the airplane from abruptly rolling off, possibly followed by premature stall at lower than normal angles of attack. Additionally, the airflow into the engines may become disturbed causing compressor surges and momentary losses of power.

As might be expected, the leading edge portion of the wing and the wing upper surfaces are the most sensitive to surface roughness, such as that caused by ice contamination. Ice accumulation on the wing surface is very difficult to detect. It cannot be seen from ahead of the wing during walkaround, is very difficult to see from behind the wing, and may not be detectable from the cabin because it is often clear and wing surface details may show through.

3855 Lakewood Blvd., Long Beach, CA 90846-0001 (213) 593-5511 TELEX 67-4357

These contaminants produce three major aerodynamic effects:

1. When operating in the low speed regime common to takeoff and final approach, the stall margins at the target airspeeds are substantially reduced.

2. For a given angle of attack, the wing produces less lift and therefore requires higher pitch attitudes (and/or higher speeds) to achieve liftoff.

3. The angle of attack at the point of stall is reduced to below that of an uncontaminated wing, and may cause the stall to occur before stall warning devices activate.

A particularly hazardous situation results from a descent in which the aircraft picks up a small amount of ice on the leading edge during the approach. If the crew is not aware that ice is present after landing, the aircraft may not be de-iced during a brief turnaround. When the ice contaminated aircraft rotates on the next takeoff, it will not come off the ground at the expected pitch attitude and rotation will continue at an increasing rate until liftoff is finally achieved. Often this occurs at a very steep angle, perhaps steep enough to begin stalling the wing and disturbing the airflow into the engines.

There is nothing demanding, tricky, or unusual about the DC-9-10/15 Series wing. While it exhibits slightly different characteristics than other DC-9 series aircraft, it is not unlike other clean wing aircraft. Millions of hours of safe operations are mute testimony to its inherently sound design which is based on decades of research and development of similar designs. Nonetheless, it is sensitive to small amounts of ice, snow, freezing precipitation, and frost contamination on the wing leading edge or upper surface. Scrupulously careful ice inspections shortly before takeoff are a must whenever atmospheric conditions make it prudent to do so. Even suspicious conditions justify inspection or precautionary de-icing. Crews should be encouraged to taxi-back for a second de-icing if a delayed takeoff in freezing precipitation raises any question of wing condition. During descent, precautionary anti-ice application is also a wise investment.

We hope that you will make the contents of this letter widely available to your flight crews, ground crews, and flight training people. In addition we have included a list of articles and publications focused on cold weather operations and will be pleased to forward copies to you on request.

Yours very truly,

T. M. Ryan, Jr.
Vice President
Flight Operations/Labs/Safety
& Training

JPL:csl

COLD WEATHER OPERATIONS ARTICLE/PUBLICATION LIST

1. KNOW YOUR DC-9 LETTER NO. 9, JANUARY 30, 1969
2. KNOW YOUR DC-9 LETTER NO. 12, FEBRUARY 16, 1970
3. KNOW YOUR DC-9 LETTER NO. 21, DECEMBER 11, 1972
4. KNOW YOUR DC-9 LETTER NO. 22, FEBRUARY 8, 1973
5. KNOW YOUR DC-9 LETTER NO. 23, MARCH 14, 1973
6. DC-8/DC-9/DC-10 OPERATORS LETTER Cl-270-CLS-L1108, NOVEMBER 16, 1976
7. DC FLIGHT APPROACH NO. 32, JANUARY 1979
8. DOUGLAS SERVICE MAGAZINE ARTICLE, SEPTEMBER/OCTOBER 1982
9. DC FLIGHT APPROACH NO. 41, DECEMBER 1982
10. 1984 TEAM CONFERENCE, OPERATORS EXPERIENCE, PAGE 4.40
11. 1985 TEAM CONFERENCE, X-ITEM, PAGE 5.1
12. ALL DC-9/MD-80 OPERATORS LETTER Cl-E60-HHK-L197, NOVEMBER 7, 1985
13. 1986 TEAM CONFERENCE, X-ITEM, PAGE 5.39
14. ALL OPERATORS LETTER (AOL) 9-1704, DATED MARCH 13, 1986
15. ALL OPERATORS LETTER (AOL) g-1750, OCTOBER 14, 1986
16. SERVICE RELATED STUDY ITEM (SRSI) 176
17. DOUGLAS PAPER NO. 8127, SEPTEMBER 20 - 22, 1988
18. DC-8/DC-9/MD-80/DC-10/KC-10 OPERATORS LETTER Cl-E60-HHK-89-L038, JANUARY 19, 1989
19. DC-9 MAINTENANCE MANUAL CHAPTER 12-53-O
20. MD-80 MAINTENANCE MANUAL CHAPTER 12-30-o

DOUGLAS PAPER 8501

THE EFFECT OF WING ICE CONTAMINATION ON ESSENTIAL FLIGHT CHARACTERISTICS

by

R. E. BRUMBY

presented to

68TH AGARD FLUID DYNAMICS PANEL SPECIALISTS MEETING

ON EFFECTS OF ADVERSE WEATHER ON AERODYNAMICS

Toulouse, France

April 29 - May 1, 1991

Douglas Aircraft Company

MCDONNELL DOUGLAS

THE EFFECT OF WING ICE CONTAMINATION ON ESSENTIAL FLIGHT CHARACTERISTICS

by

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SUMMARY

Contamination of critical aerodynamic surfaces by ice, frost, and/or snow has been identified as the probable cause of a significant number of aircraft accidents. In most cases, the ice contamination has not been large ice accretions on the leading edges or thick layers of adhering snow on the top of the wings. Rather, dangerous reductions in stall margins and handling qualities can occur because of ice-related roughness equivalent to that of medium-grit sandpaper. This paper describes typical effects of such roughness on lift, drag, and pitching moment, and the corresponding effects on longitudinal and lateral control characteristics during rotation and liftoff. Of great importance is that the visual, aural. and tactile clues signaling a developing critical situation occur within a very few seconds, and usually do not correspond to any for which a flight crew has been trained or has previously experienced.

DISCUSSION

In recent years, a number of weather-related accidents has stimulated a renewed interest in the effects of adverse weather on aerodynamics. Among these effects is the contamination of aerodynamic surfaces by ice, frost, and/or snow. While such contamination can adversely affect most basic aerodynamic parameters, this presentation focuses primarily on the overall degradation of essential flight characteristics during the takeoff of an airplane that has an ice-contaminated wing.

Most regulations typically prohibit takeoff with ice on the critical surfaces of the aircraft (Table 1). For various reasons. however. flight crews will initiate a takeoff with some form of ice contamination on the wings and control surfaces. The result can range from little or no significant control problems to total disaster.

A somewhat in-between case is shown in Figure 1. This airplane made a normal approach into Sioux City. Iowa, in 1968. Mild icing was encountered during the approach, but the flight crew elected not to turn on the airfoil ice protection. During the turnaround. a light freezing drizzle was falling The flight crew was advised by ground maintenance personnel thar there was ice on the wing and asked if the airplane should be de-iced. The flight crew declined the offer and proceeded with the takeoff. As the landing gear began to retract, the aircraft rolled violently to the right. Rudder and aileron application brought the right wing up; however, the roll continued to the left until the left wing contacted the runway. The captain succeeded in leveling the aircraft before it hit the ground about 110 feet beyond the end of the runway and skidded into a grove of trees where it came to rest, as shown in the figure.

Table 1
Federal Air Regulations Applicable to Ice, Frost, or Snow Accumulations Prior to Takeoff

PART 91 - GENERAL OPERATING AND FLIGHT RULES
§91.209 OPERATING IN ICING CONDITIONS

(a) NO PILOT MAY TAKE OFF AN AIRPLANE THAT HAS:

(1) FROST. SNOW. OR ICE ADHERING TO ANY PROPELLER. WINDSHIELD. OR POWER PLANT INSTALLATION. OR TO AN AIRSPEED. ALTIMETER. RATE OF CLIMB, OR FLIGHT ATTITUDE INSTRUMENT SYSTEM:

(2) SNOW OR ICE ADHERING TO THE WINGS. OR STABILIZING OR CONTROL SURFACES; OR

(3) ANY FROST ADHERING TO THE WINGS OR STABILIZING OR CONTROL SURFACES. UNLESS THAT FROST HAS BEEN POLISHED TO MAKE IT SMOOTH

PART 121 - CERTIFICATION AND OPERATIONS
§121.629 OPERATION IN ICING CONDITIONS

(a) NO PERSON MAY DISPATCH OR RELEASE AN AIRCRAFT. CONTINUE TO OPERATE AN AIRCRAFT EN ROUTE OR LAND AN AIRCRAFT WHEN IN THE OPINION OF THE PILOT IN COMMAND OR AIRCRAFT DISPATCHER (DOMESTIC AND FLAG AIR CARRIERS ONLY) ICING CONDITIONS ARE EXPECTED OR MET THAT MIGHT ADVERSELY AFFECT THE SAFETY OF THE FLIGHT

(b) NO PERSON MAY TAKE OFF AN AIRCRAFT WHEN FROST. SNOW. OR ICE IS ADHERING TO THE WINGS. CONTROL SURFACES. OR PROPELLERS OF THE AIRCRAFT

Figure 1. There Is No Such Thlng as "A **Little** Ice"

Table 2 lists a number of icing-related accidents. While it is by no means inclusive. it does illustrate that ice contamination is quite democratic, adversely affecting straight-wing aircraft such as the Nord 262 and numerous general aviation aircraft; small turbojet aircraft with conventional airfoils such as the Learjet; larger aircraft with conventional airfoils such as the F-28. DC-9-10. and DC-8; and aircraft with leading edge high-lift devices such as the 737.

The most predominant adverse effect of ice contamination is on the lifting characteristics of the wing. It may be recalled that wing lift coefficient varies with angle of attack, as shown in Figure 2. Under normal conditions, the airflow over a wing smoothly follows the shape of the wing. as shown in the lower photograph. and lift varies directly with the angle of attack. At some fairly high angle of attack, the airflow begins separating from the wing. causing the lift curve to become nonlinear, or "break." When the airflow is essentially fully separated. as shown in the upper photograph, the wing is considered fully stalled. Between the point where the airflow begins separating and full stall is a region often called "stall onset." where flight characteristics become increasingly degraded as the angle of attack increases.

The normal variation of lift with angle of attack can be significantly altered by ice contamination. As shown in Figure 3a, the typical effect is to alter the variation of lift with angle of attack, reduce the maximum lift capability of the wing. and cause

Table 2
Some Takeoff Accidents Where Wing Ice Contamination Is Considered to Be a Contributing Factor

DATE	AIRLINE	LOCATION	ACFT TYPE	PRECIPITATION/OBSERVATIONS
27 DEC 68	OZARK	SIOUX CITY	DC-9-10	LIGHT FREEZING DRIZZLE
26 JAN 74	THY	CUMAOVAS, TURKEY	F28	PROBABLE CAUSE: FROST ACCRETION ON THE WINGS
03 JAN 77	JAL	ANCHORAGE	DC-8-62	FOG
04 JAN 77		FRANKFURT	737	LIGHT SNOW/25-DEGREE WHEEL REQD AFTER LIFTOFF. RIME ICE OBSERVED ON WING
27 NOV 78	TWA	NEWARK	DC-9-10	BLOWING RAIN AND SNOW
20 DEC 78	N40SN	MINNEAPOLIS	LEARJET	PROBABLE CAUSE: SNOW AND ICE ON WINGS
19 JAN 79	N73161	DETROIT	LEARJET	PROBABLE CAUSE. PREMATURE STALL CAUSED BY ACCUMULATION OF WING ICE
12 FEB 79	ALLEGHENY	CLARKSBURG	NORD 262	LIGHT SNOW - FROZEN SNOW PHOTOGRAPHED ON EMPENNAGE AFTER ACCIDENT
18 FEB 80	REDCOTE	BOSTON	BRISTOL 253	LIGHT SNOW
13 JAN 82	AIR FLORIDA	WASH D.C.	737	MODERATE-TO-HEAVY SNOWFALL
06 FEB 85	AIRBORNE	PHILADELPHIA	DC-9-10	LIGHT FREEZING RAIN, ICE AND SNOW PELLETS, FOG
12 DEC 85	ARROW AIR	GANDER	DC-8-63	LIGHT FREEZING DRIZZLE, SNOW GRAINS
15 NOV 87	CONTINENTAL	DENVER	DC-9-10	MODERATE SNOW, FOG
18 JAN 88	N2614U	NEW MEXICO	CESSNA 402	PROBABLE CAUSE: ICE/FROST REMOVAL INADEQUATE
06 FEB 88	N2832J	CALIFORNIA	CESSNA A188B	PROBABLE CAUSE: ICE/FROST REMOVAL INADEQUATE
23 DEC 88	N5570H	MONTANA	PIPER PA-11	PROBABLE CAUSE: WING ICE
10 MAR 89	AIR ONTARIO	DRYDEN	F28	HEAVY SNOW
25 NOV 89	KOREAN AIR	KIMPO	F28	DENSE FOG, ICE ON THE WING

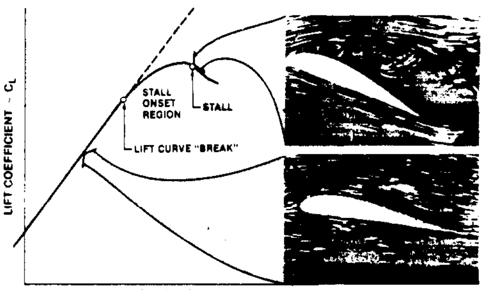


Figure 2. Airflow Over an Airfoil and Its **Effect** on **Lift**

the wing to stall at a lower than normal angle of attack. As will be shown shortly. these effects can be quite large.

Wing ice contamination can also significantly affect the airplane drag as shown, again typically, in Figure 3b. The effects on drag can be large enough that the difference between available thrust and drag can adversely affect the airplane's climb capability. This not only would make it difficult for the airplane to clear obstacles by the required distances, it could possibly result in the airplane's inability to climb at all if an engine fails during takeoff.

Figure 4 depicts a typical total airplane pitching moment curve. For an airplane trimmed for takeoff, the stabilizer is set to balance the moments due to both aerodynamic forces and center of gravity location so that the stick force at climb-out speed ranges from none to a slight pull. Thrs balance is upset by wing ice contamination, particularly on contemporary aircraft with tapered. swept wings. With contamination on the wings. the aircraft will increasingly behave as if it was mistrimmed in the

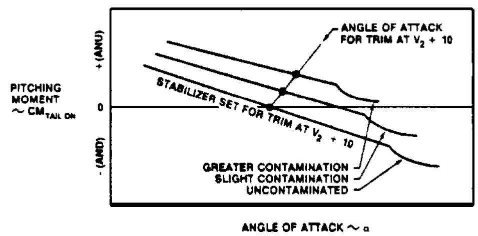


Figure 4. **Effect of** Wing Ice Contamination on Pitching **Moment**

airplane nose-up direction as the angle of attack is increased. This will result in the aircraft's pitching up more rapidly than normal during rhe takeoff rotation, and will require an abnormal push force to maintain the desired airspeed during climb. As with other effects. this pitch-up tendency becomes more pronounced as the amount of ice contamination increases.

During a normal takeoff, the aircraft speed schedules are established for angles of attack below that for stall onset or activation of stall-warning devices dependent on angle of attack. such as a stick shaker (Figure 5a). However, for an airplane with ice contamination, not only does stall onset occur at a lower than normal angle of attack, the airplane angle of attack must be increased in order to produce the required lift at normally scheduled speeds (Figure 5b). This compounding effect rapidly results in the aircraft's operating into the "stall onset" pan of the lift curve (described earlier), and the increasingly unsteady airflow over the wing results in correspondingly degraded lateral stability, requiring larger and larger control wheel inputs to keep the aircraft from rolling off. As the amount of contamination increases, the airplane becomes increasingly unstable. eventually stalling without stick shaker activation at speeds normally scheduled for takeoff (Figure 5c).

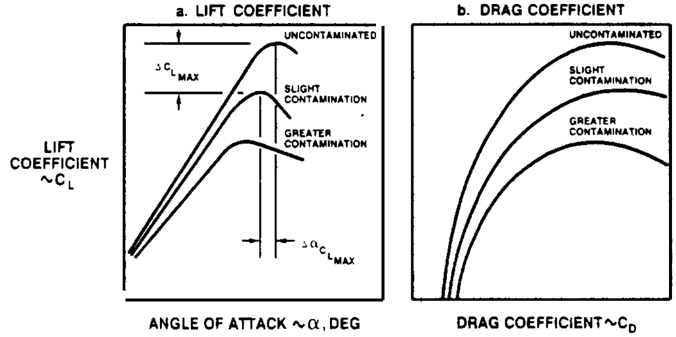


Figure 3. **Effect** of Wing Ice Contamination on Litt and Drag Coefficients

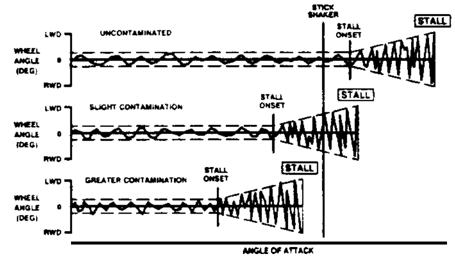


Figure 5. Effect of Wing Ice Contamination on Lateral Control Characteristics

Figure 6 shows an empirical correlation of lift loss due to wing surface roughness. including ice contamination. It is interesting to note that this simple correlation encompasses data representing a Reynolds Number range from 6×10^5 up to 29×10^6 and airfoil shapes ranging from simple symmetrical sections to those representative of second-generation turbojet aircraft (see Table 3).

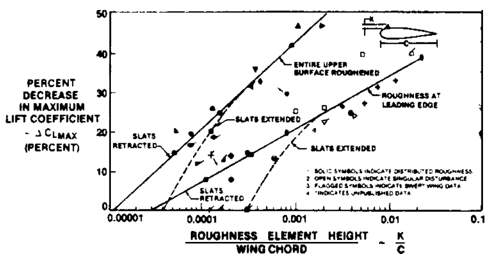


Figure 6. Correlation of the Effect of Wing Surface Roughness on Maximum **Lift Coefficient**

The lower line in Figure 6 shows the lift loss due to a localized strip or narrow band of contamination on the leading edge. Much of the data for the lesser amounts of contamination have been obtained from maintenance or flight training experience where some form of contamination such as insect debris, chipped paint, or burred rivets caused premature stall when the slats were retracted, but caused little or no noticeable effect when the slats were extended. Wind tunnel data indicate that as the contamination on the leading edge becomes larger, such as for in-flight ice accretions on the leading edge, slat extension will no longer recover the lift losses.

The upper line in Figure 6 shows the lift loss due to roughness on the entire upper surface of the wing. such as might be caused by frost, snow. or freezing drizzle while the aircraft is on the ground. Of particular note is the very large degradation for even the smaller amounts of contamination. Also of interest are the relatively recent data developed by Boeing during flight testing of second- and third-generation transport aircraft with slats extended. These data suggest that with essentially the entire wing upper surface covered with even small amounts of contamination, slat extension provides little or no recovery of lift losses.

Although Figure 6 shows a significant difference in lift loss between a narrow band of roughness at the leading edge and roughness over the entire upper surface. It is worthy to note that recent unpublished data for slight roughness extending aftward from the leading edge to about 7-percent chord on both the upper and lower surfaces (as might occur during a mild icing encounter) can cause lift losses similar to those caused by a fully roughened upper surface.

Figure 7 expands the data from Figure 6 into an operationally meaningful percent increase in stall speed. From this figure, the Importance of maintaming the "clean wing" philosophy begins to show, because it becomes readily apparent that it takes only a relatively small amount of roughness on the wing upper surfaces to cause large increases in stall speeds even with slats extended. Further expanding the data to compare the measure of roughness (K/C) with various grades of abrasive paper, an estimate can be made (Figure 8) of the stall speed increase that would occur on an aircraft about the size of a DC-9. 737, or BAC-I 1 1 if the wing upper surface was contaminated by ice having the roughness of various grades of abrasive paper. Those familiar with the icing roughness that can occur during a freezing drizzle or when snow has partially melted and then refrozen to a surface will probably agree that this range of roughness is not at all unusual under such conditions. With the stall speed increases shown in Figure 8. stall warning margins and margins to stall decrease markedly or disappear altogether.

Table 3
References for **Figure** 6

SYM	REYNOLDS NO	TYPE OF ROUGHNESS	REFERENCE
●	26×10^6	SAND GRAIN BAND	"THEORY OF WING SECTIONS" (ABBOT)
□	31×10^6	PROTRUDING STRIP	NACA TR446
◆	31×10^6	MULTIPLE GROOVES	NACA TN457
▲	31×10^6	CARBORUNDUM GRIT	NACA TN457
◣	5×10^6	SAND GRAINS	"AERODYNAMSCHE PROFILE" (RIEGELS)
▶	6.3×10^5	WIRE MESH ON SURFACE	NACA TM375
◁	3.1×10^6	FWD FACING STEP	NACA TN457
◇	3.1×10^6	PROTRUDING STRIP	NACA TR446
○	3.1×10^6	PROTRUDING STRIP	NACA TR446
○	3.1×10^6	PROTRUDING STRIP	NACA TR446
●	3.6×10^6	CARBORUNDUM GRIT	NACA TN457
▼	—	FROST (IN ICING TUNNEL)	NACA TN2962
◢	24×10^6	INSECT CONTAMINATION	FLIGHT TRAINING INCIDENT (DC-9)
○	4.5×10^6	SIMULATED TAILPLANE ICE	DC-9
▷	5.5×10^6	SIMULATED TAILPLANE ICE	DC-10
▽	7.8×10^6	SIMULATED DEICER BOOT*	C-133
●	7.0×10^6	CARBORUNDUM GRIT	R&M 1703
✚	24×10	CHIPPED PAINT ON L.E.*	DC-9
◆	29×10^6	BALLOTINI	NPL AR1308
■	24×10^6	BURRED RIVETS ON L.E.	DC-9
●	3.2×10^6	SIMULATED FROST	FFA RPT AU-902
○	1.8×10^6	SIMULATED WING ICE	FFA RPT AU-995
●	—	SIMULATED ICE ROUGHNESS	ICAO BUL OCT 77
●	-24×10^6	SIMULATED FROST	(P737) BOEING AIRLINER, OCT 83 (FROST 8
●		SIMULATED FROST	(737) VKI LECTURE (FROST 2)
◣		SIMULATED FROST	(757) VKI LECTURE (FROST 2)
▶		SIMULATED FROST	(767) VKI LECTURE (FROST 2)
⦿		DC-9 WIND TUNNEL	TEST LB-155AN

NOTE 737 AND 767 WITH MID SLATS

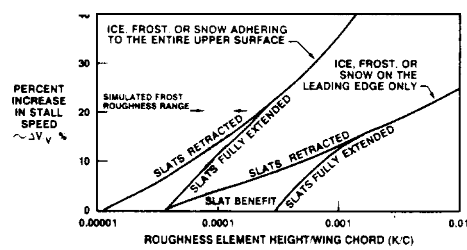


Figure 7. Approximate Effect of Wing Ice Contamination on Airplane Stall Speed

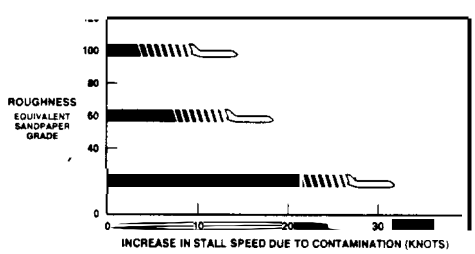


Figure 8. Approximate Effect of Wing Upper **Surface** Ice Contamination on the **Stall** Speed of a Typical Small Turbojet Transport

As noted earlier, the increases in stall speed also occur at much lower than normal angles of attack (Figure 9). This can have at least two adverse effects. First, many contemporary stall warning systems are actuated at prescheduled angles of attack. If wing ice contamination causes a stall before this prescheduled angle is reached, the flight crew will receive no warning of impending stall. Second. the reduced stall angle of attack compounds the problem of the tendency of an ice-contaminated airplane to pitch up during rotation, increasing the risk of overshooting the stall angle shortly after liftoff.

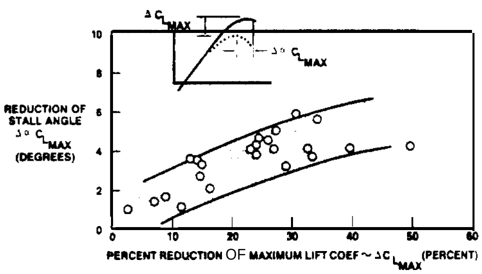


Figure **9.** Reduction of the Angle of Attack at **Stall Due** to Wing **Surface Roughness**

The overall effects of wing ice contamination on various flight characteristics of an aircraft during takeoff are summarized in Figure 10. In this figure, stick force is the amount of push or pull on the control column required to manage the pitch attitude of the aircraft. Pitch attitude is the angle of the airplane with respect to a horizontal reference plane; angle of attack is the angle of the airplane with respect to its flight path: and wheel angle is the rotation of the control wheel required to manage the bank, or roll attitude, of the airplane.

For an uncontaminated airplane, the stick force to rotate and acquire the target climb speed are typically as shown by the solid line. The pitch attitude and angle of attack increase to their normal values. and there are no abnormal control wheel requirements except those caused by outside influences such as crosswinds or gusting.

The scenario changes for an ice-contaminated airplane. Part way through the takeoff rotation, the aircraft begins pitching up at a faster than normal rate, as shown by the dashed line in Figure IO. If the flight crew is familiar enough with the airplane's normal characteristics, it might recognize the abnormal rate of rotation and counter it with an immediate forward push on the control column. If done in sufficient time, there should be little pitch attitude and angle of attack overshoot into the stall onset region, and any roll perturbations will probably be controllable with prompt wheel input. If the angle-of-attack overshoot is successfully transitioned. forward pressure will likely be required to maintain the target climb speed until the stick force is trimmed out. Failure to recognize any abnormal increases in the rotation rate at, or immediately following, liftoff can result in significant angle-of-attack overshoot, accompanied by abrupt roll excursions and aerodynamic stall close to the ground.

Of great importance is the time span in which the adverse handling characteristics are manifested. Typical certified takeoff performance is based on a rotation rate of about 3 degrees per second (liftoff normally occurs at about 7 to 9 degrees pitch altitude). It is in the vicinity of liftoff attitude that the abnormal pitch-up due to ice contamination begins to become increasingly apparent and, since the airplane's angle of attack is increasing at much higher rates than in any other pan of the normal flight envelope. the airplane can reach stall onset angles a very few seconds after liftoff, with full stall occurring only a second or IWO after that. Thus, the flight crew of an ice-contaminated airplane is placed in a situation where the visual, aural, and tactile clues of a developing critical situation occur within a very few seconds. Since this does not correspond to any situation for which they have been trained or may have previously experienced, attempting takeoff of an ice-contaminated aircraft can result in an unacceptable safety hazard.

CONCLUSION

From an aerodynamic viewpoint, there is no such thing as "a little ice." Strict attention should be focused on ensuring that critical aircraft surfaces are free of ice contamination at the initiation of takeoff.

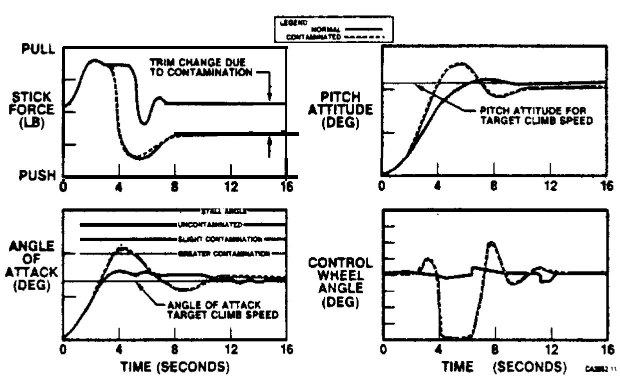
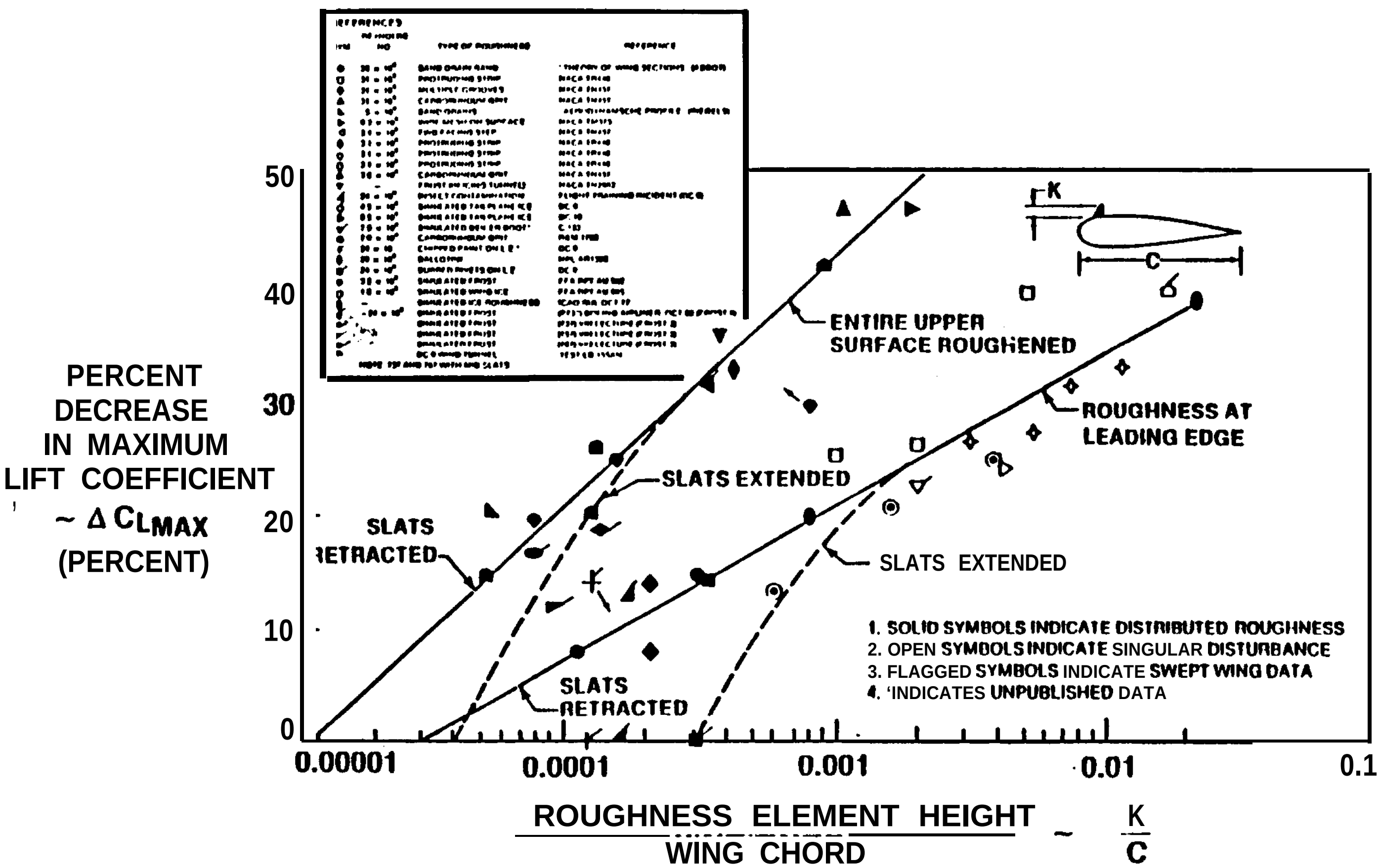


Figure 10. **Effect** of Wing ice **Contamination** on Longitudinal Control **Characteristics**

APPENDIX F

DOUGLAS AIRCRAFT COMPANY GRAPHIC ILLUSTRATION

A CORRELATION OF THE EFFECT OF WING SURFACE ROUGHNESS ON MAXIMUM LIFT COEFFICIENT



APPENDIX G

COMPANY HISTORY PROVIDED BY RYAN INTERNATIONAL AIRLINES, INC.

Ryan International Airlines, Inc., is a Kansas Corporation which was founded in 1973. From 1969 to 1973, Ronald D. Ryan was chief pilot for a real estate development company and manager of its flight operations department. That department was spun off as a separate entity in 1973 with Mr. Ryan as President. The new entity began as a fixed base operation in Wichita, Kansas, and offered charter services in a single Lear Model 24B business jet. The original facility had 8,100 square feet of hangar space and 2,000 square feet of office space.

Ryan grew steadily over the years and by 1978 had developed a need for additional space. In 1979, Ryan added a one million dollar expansion to its existing facility. The combined facility then had an 8,100 square foot hangar, principally for the show and storage of airplanes and a 12,700 square foot, 26 foot ceiling hangar for airplane maintenance. In addition, Ryan had approximately 10,000 square feet of office space.

In 1978, Ryan began operation of Cessna Citation aircraft for Emery Airfreight. By 1981, Ryan was operating eight Cessna Citation aircraft each night for Emery across the nation.

In late 1981, Ryan was selected as a major large aircraft carrier for the Emery Airfreight system. Ryan began operations with five Boeing 727-100C aircraft in November 1981. These aircraft were operated on a nightly basis and maintained an on-time performance record of well over 99 percent. Ryan has operated air transport category aircraft for Emery from that time to the present except for a short interlude in late 1988 and early 1989.

In 1981, in order to provide additional space, Ryan purchased a leasehold interest in the adjacent Floair hangars at Wichita Mid-Continent Airport, and spent approximately seven hundred thousand dollars remodeling the facility. This added to the Ryan home base two additional 10,000 square foot maintenance and storage hangars and approximately 5,000 square feet of office facilities.

The combined facilities gave Ryan approximately 45,000 square feet of hangar facilities and 15,000 square feet of office facilities at its home office location in Wichita, Kansas.

Ryan began passenger operations in January 1984, with two Boeing 727-100s, which were based in Philadelphia and Baltimore. In January 1985, Ryan added a Boeing 727-200 Advanced aircraft, which also was based in Philadelphia. The airplanes were available for charter and regularly served the charter market both domestically as well as internationally.

In 1985, Ryan sold its two Boeing 727-100 aircraft to Avensa, and in 1986 its Boeing 727-200 aircraft to E. Systems. All were sold for substantial profits.

In 1985, Ryan was selected by UPS to operate eight Boeing 727-200 advanced freight aircraft in the UPS overnight system. Ryan maintained the most reliable service record in the UPS fleet, even though these aircraft were undergoing a massive modification to install a new and previously unproven conversion to freight from passenger configuration.

Because of this record and because of Ryan's expertise in aircraft technical management, in 1986 Ryan was selected to operate the first new Boeing 757 freighter aircraft in the UPS system in one of the largest air transport contracts ever awarded. Ryan eventually operated five of these fifty million dollar aircraft in the UPS system and trained UPS personnel to facilitate their eventually bringing these aircraft in-house.

In mid-1986, the stock of Ryan was sold to PHH Group, Inc., a major New York Stock exchange company. While under PHH control, the entrepreneurial spirit and service philosophy of Ryan seemed to flounder. The Emery business was lost in June of 1988 and the UPS business was lost in November 1988.

In July 1988, Ronald D. Ryan bought back from PHH the fixed base operation and the right to use the Ryan name. In January 1989, Mr. Ryan repurchased the remainder of the company, including all of its domestic and international airline operating authorities and certificates.

Mr. Ryan immediately began to restore the management team which had been with him over the years. Within a few months, all of the top managers had returned, and Ryan was prepared to resume major operations.

On July 14, 1989, Ryan entered into a new contract with Emery to operate eight Douglas DC-9-15F aircraft, beginning August 21, 1989. These were to be operated in the United States Postal Overnight system. The start up of these aircraft went smoothly. However, approximately two weeks before the start date, Ryan was asked to take on an additional nine Boeing 727-100C aircraft, because Air Train was unable to accomplish this task. Ryan was able within this span of two weeks to complete the start up of the eight DC-9s and the nine Boeing 727s, without incident. On-time performance standards have been excellent.

The Boeing 727 aircraft in the Emery Overnight system were all being operated by Orion in 1989. Ryan found out that Orion was publicly stating that it was going out of business, December 31, 1989. Ryan approached Emery about the possibility of Ryan operating the aircraft then being operated by Orion. Agreements were signed on December 21, 1989. On January 2, 1990, Ryan began operating 25 Boeing 727 aircraft nightly, in the Emery system. The start-up was without incident and an excellent on-time performance record has been maintained.

Ryan's current fleet consists of twenty-four Boeing 727-100C aircraft and seven Douglas DC-9-15F aircraft. They are based throughout the country, and operate either in the U.S. Postal Service Day or Overnight system, or the Emery Overnight system.