DEPARTMENT OF TRADE

Report on the accident to Redcoat Air Cargo Ltd Bristol Britannia 253F G-BRAC at Billerica, Massachusetts, USA, on 16 February 1980

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National Transportation Safety Board

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Aircraft Accident Report 3/81

National Transportation Safety Board
Washington DC 20594

Adopted 19 February 1981

Operator:	Redcoat Air Cargo Ltd
Aircraft Type:	Bristol Britannia
Model:	253F
Nationality:	United Kingdom
Registration:	G–BRAC
Place of Accident:	Billerica, Massachusetts, USA Latitude 42°31′45″N Longitude 71°15′08″W
Date and Time:	16 February 1980 at 1416 hrs (EST)

Synopsis

About 1416 eastern standard time, on February 16, 1980, Redcoat Air Cargo Ltd., Flight RY 103, a Bristol Britannia 253F, crashed into a wooded area adjacent to an industrial park and residential area in Billerica, Massachusetts, about 16 miles north-northwest of Boston Logan International Airport, Boston, Massachusetts, about 8 minutes after take-off from runway 33L. The crew radioed that their aircraft was not able to climb; the aircraft reached 1,700 ft and descended into the ground. Weather at Boston at the time was 400 ft overcast, visibility 1/2 mile in light snow and fog, and winds 360° at 11 knots. A SIGMET was valid for the Boston area calling for moderate to severe icing in precipitation. Pilots reported wind shear and turbulence in the Boston area and the crew of Flight 103 reported downdrafts. Of the eight occupants aboard Flight 103, seven were killed and one was seriously injured. The aircraft and its cargo were destroyed by impact and postcrash fire.

The National Transportation Safety Board determines that the probable cause of the accident was degraded aerodynamic performance beyond the flight capabilities of the aircraft resulting from an accumulation of ice and snow on the airframe before take-off and a further accumulation of ice when the aircraft was flown into moderate to severe icing conditions following take-off. Contributing to the cause of the accident were encounters with wind shear, downdrafts, and turbulence during the climb. The failure of the flightcrew to obtain an adequate pre-flight weather briefing and the failure of the National Weather Service to advise the flightcrew of a SIGMET for severe icing conditions were also contributing factors.

1. Factual Information

1.1 History of the Flight

On February 16, 1980, Redcoat Air Cargo Ltd., a Bristol Britannia Model 253F, British registry G–BRAC, was being operated under a British Air Operator Certificate as Flight RY103 from Boston, Massachusetts, to Shannon, Ireland. Flight 103 was the return flight of a Royal Air Force (RAF) weekly charter which originated in Lyneham, England, and carried cargo to Belize, Belize (formerly British Honduras). The accident flight was the first trip by Redcoat carrying cargo from Boston to Ireland. The flight was not operating as an RAF charter, although there were 446 lbs of RAF cargo aboard the aircraft.

The flightcrew had flown the aircraft from Belize to Boston on February 15, 1980, arriving about 1510. 1/ The aircraft was parked at the central cargo ramp at Boston's Logan International Airport, where cargo was loaded under supervision of the loadmaster. About 2200, after the cargo was loaded, the captain was called to taxi the aircraft from the cargo ramp to the transient aircraft parking area at the extreme southwest portion of the airport. The aircraft was then refueled with 6,650 gallons of jet A fuel and secured for the night.

About 1100, on February 16, the crew arrived at the airport. A crewmember, believed to be the navigator of Flight 103, entered the National Weather Service (NWS) office and requested a 500 millibar (mb) prognosis chart for the North Atlantic. The weather briefer suggested a 250-mb chart because the NWS does not issue 500-mb charts for the entire North Atlantic. The crewmember left the office and returned in a few minutes accompanied by other crewmembers of Flight 103. They requested forecasts for several airports in the British Isles. The weather briefer said that the crew appeared to be in a hurry; however, he suggested that they obtain forecasts for other stations in the New England states, and the Canadian maritime forecasts. When the briefer returned a short time later with the forecasts, the crew was on the way out of the office and he called them back. After receiving the forecasts, the crew again started to leave but the briefer again called them back to obtain their flight number for his records. Shortly after the crew finally departed, the briefer said he remembered that he had neglected to tell them about SIGMET 2/ India 2, which forecast occasional severe icing in precipitation in the New England area.

About 1155, the crew proceeded to the flight service station (FSS) and filed a flight plan.

In the meantime, the flight engineer and the ground engineer had proceeded to the aircraft to prepare it for departure. Since a snowfall during the night had left considerable snow on the aircraft, the flight engineer requested that local ground service sweep the snow off and that de-icing fluid be applied to the aircraft.

The flight engineer and other ground witnesses stated that there was a build-up of nearly 1 ft of snow against the right side of the fuselage, on the wings and horizontal stabilizer, and on the right side of each engine jet pipe. All of these areas were swept before de-icing fluid was applied. De-icing fluid was then applied to the entire upper surface of the aircraft, except for the top of the fuselage. The person who performed the operation stated

1/ All times herein are eastern standard based on the 24-hour clock.

2/ A forecast of significant and usually hazardous imminent meteorological phenomena severe enough to be of concern to pilots of all aircraft.

that one of the crewmembers stated that it was not necessary to de-ice the fuselage, as it appeared free of snow and ice. The flight engineer and ground engineer observed the snow being swept off the aircraft, then left the area while de-icing was performed.

During a post-accident interview, the flight engineer, who survived the accident, stated that snow was falling intermittently during the de-icing operation and before engine start, and that the snow was wet. The flight engineer stated that he walked around the aircraft after the de-icing was completed, and he checked all the control surfaces for proper clearance; he found them all to be satisfactory. Ground witnesses stated that they saw the ground engineer walk around the nose wheel area and then board the aircraft. No one saw the flight engineer or any other crewmember check control surfaces after de-icing was completed.

The remainder of the flightcrew arrived at the aircraft and boarded about 10 to 20 minutes after de-icing was completed. The flight engineer and the ground engineer reportedly had completed preparations and had boarded with the two passengers. Aircraft occupants now included the captain, first officer, flight engineer, navigator, loadmaster, ground engineer, and two passengers. After the occupants were aboard, the de-icing crew gave the wings and horizontal stabilizer a 'fast shot' of de-icing fluid.

After the engines were started, the aircraft remained parked for 20 to 25 minutes with the engines at idle. Flight 103 called clearance delivery at 1350:57 and was cleared to the destination airport via the flight plan route. The flight was instructed to maintain runway heading to 5,000 ft.

The departure runway was to be 15R. At 1358:48, however, the clearance was amended to change the departure runway to 33L. The amended clearance directed Flight 103 to depart on runway 33L and turn left to 315° at the 2-mile distance measuring equipment (DME) fix after departure. The flight engineer stated during the post accident interview that he released the flight control locks after the engines were started, and the control surfaces moved from their stowed position. He said he also lowered the flaps to full down, then brought them fully up and finally selected the 15° down position (take off position). The aircraft taxied from the ramp at 1355. The ramp supervisor stated that he saw snow and possibly frost beginning to accumulate on the leading edges of the wings as the aircraft left the ramp area. The flight engineer stated that the entry guide vane heat was on before taxying and that he recalled seeing the outside air temperature gauge at 6° to 8°C. He said that because snow was falling, he would have expected the temperature to be lower. He repeated that the snow was 'wet, it was mild. The snow that we were getting was very, very wet snow, very wet.' He said, 'each time we stopped, I leaped out of my seat, peered through the radio window and there was no buildup of snow or ice on the leading edge of the nacelle, around the intake or the leading edge of the main plane.' When asked how much of the wing he could see, he responded, 'from that position, practically to the wing tip.' He added, 'the top surface of it more or less. The top surface outboard of No. 1 engine.' He summarized, 'I am convinced that there was no appreciable ice build-up on the aircraft before we started to take-off.'

Flight 103 was instructed to follow an Eastern Airlines Boeing 727 on the outer taxiway, but was asked to hold twice on the outer taxiway while ground traffic conflicts created by the runway change from 15R to 33L were resolved. When the conflicting arriving traffic landed on runway 15R and the runway was clear, the Eastern 727 and Flight 103 were cleared to taxi outbound on 'Charlie' to the take off end of runway 33L. During Flight 103's hold on the outer taxiway, a witness in the airport operations tower saw what he believed to be Flight 103's engines being reversed. He said he saw snow swirling vertically near the engines of the stopped aircraft. The flight engineer stated that each time the aircraft was stopped on the outer taxiway, reverse thrust was selected momentarily because of the icy taxiway, and that snow did swirl up during the stops.

According to the flight engineer and the cockpit voice recorder (CVR) transcript, the normal taxi and before-take-off checklists were accomplished during the taxi to runway 33L. No abnormalities were apparent. At 1357, the first officer remarked, 'We'll have de-icing on as soon as we get airborne.' He then said 'We'll be in, be in the range as soon as we get airborne Rick, *.' 3/ The flight engineer responded, 'yeah, very likely.' When asked during the interview what was meant by this discussion, the flight engineer stated, '(a) that we would expect ice warning fairly shortly after take-off and (b) that we would be in the so-called temperature range for engine icing for the cowling, this is what we thought. I said that I would watch this and would be responsible for it.'

At 1407:11, Flight 103 was cleared for take-off and was asked to advise when they were rolling. At 1408:41, the tower controller asked Flight 103 if they were rolling yet and, at 1408:44, Flight 103 responded, 'One-oh-three okay just (goin'). 4/ At 1408:57, Flight 103 called, 'one-oh-three is rolling.' The first officer made the take-off. Two snowplow drivers watched the take-off and stated that it appeared normal and that the aircraft lifted off between runway 4L and taxiway 'November'. Another witness stated that the aircraft rotated for take-off near the intersection of runways 33L and 4L. These positions were 6,705 ft and 7,655 ft, respectively, from the take-off end of runway 33L.

The flight engineer stated during a postaccident interview that there were patches of slush on the runway surface. He said he could hear the slush hit the fuselage at times during the take-off roll, and did not consider the take-off run abnormally long because of the runway surface condition. He further stated that the aircraft encountered severe turbulence immediately after lift-off, and the turbulence was constant during the climb. When asked to describe the turbulence further, the flight engineer responded that it was like a 'high frequency buffet'. According to the flight engineer and the CVR transcript, the normal after-take-off-checklist items were accomplished, including the landing gear-up and flaps-up items. Maximum continuous power was called for and set at 1410:20, and the first officer called, 'Two DME, going left.' For about the next minute the flightcrew discussed the departure control frequency. At 1411:34, radio contact was established between Flight 103 and departure control. At 1411:36, the departure controller advised Flight 103 'RY one-oh-three, low-altitude alert, check your altitude, climb, and maintain niner thousand.' At 1411:42, Flight 103 replied, '. . . we're passing twelve hundred feet, cleared to niner thousand.' About 1411:22, the captain said, 'Ice warning,' and the flight engineer replied, 'It's actioned.' The CVR transcript revealed an intra-cockpit comment at 1411:52 by an unidentified crewmember, 'Bloody rough, isn't it?' At 1412:07, the captain asked, 'Got the de-icing on?' The flight engineer replied, 'Affirmative.' At that point the crew continued the climb check. The flight engineer said the first officer controlled the pressurization system, and probably opened the valve to begin pressurization when he made the remark 'commenced' during the climb check.

The flight engineer stated that about the time the low-altitude alert was received, the aircraft was in clouds and was experiencing severe turbulence. He said the aircraft was moving rapidly about all three axes. He said he was not concerned about the climb rate until the low-altitude alert was received. He also said that the captain and first officer did not seem concerned about the climb rate at this point.

3/ Asterisks indicate unreadable words.
4/ Unclear word

At 1412:49, the departure controller received a second low-altitude alert and advised, 'RY one-oh-three, low-altitude alert, check your altitude immediately, shows one thousand four hundred feet, the minimum safe altitude in that area is one thousand seven hundred feet.' The captain replied, 'one-zero-three roger, we're getting a lot of chop here.' At 1413:03, the first officer said, 'Cowl heat and icing can go off now can't it?' The flight engineer replied, 'Cowl heat's not on.' The captain said, 'Go at V2 plus three then, Jack.' 5/ The first officer replied, 'Okay not climbing at the moment.' The flight engineer repeated, 'Cowl heat's not on.'

During the post-accident interview, the flight engineer stated that he was extremely concerned about the proximity of the terrain after the controller's second alert. He said he was sure the captain and first officer were equally concerned. When asked about the use of cowl heat, the flight engineer stated that he had momentarily (less than 30 seconds) turned on the cowl heat for Nos. 1 and 4 engines, noticed the expected drop in torque, and then returned the switches to off. He said torque returned to normal values. He said that his comments about cowl heat's not being on were verifying to the crew that the heat was, in fact, off. He could not recall any airspeeds being flown, but he did recall that the first officer raised the nose after the second low-altitude alert and the captain's directive to 'go at V2 plus three . . . .'

The departure controller requested Flight 103 to turn right to 360°. The captain replied at 1413:41. 'RY one-oh-three, we're getting some pretty severe downdrafts here.' The controller responded, 'One-oh-three roger, when you leave four thousand, five hundred feet, the . . . air gets quite a bit smoother up there from a pilot report I received ten minutes ago.' The captain replied, 'I'm pleased about that, thank you, sir.' The controller added, ' * there is wind shear at that altitude that you're at now.' That transmission was followed by the sound of a microphone button being keyed.

The flight engineer stated that wing heat was not used during the flight '. . . because I didn't want to have the penalty for thrust.' However, he verified that he observed no deficient engine power indications for the entire flight.

The following cockpit conversation ensued:

1414:08	FE	– I think we'll.
	FE	– I think we're.
	FO	– Full power
	FO	– Full power
	FE	– I think we'll have a little bit more power out of it.
1414:14	FO	– Yes.
1414:17	FO	– Bloody thing's going down.
1414:26	FO	– Any icing?
1414:30	Navigator	– No, there's nothin on the wings.
	FO	– Going down.

At 1414:35, the captain called departure control and asked, '. . . one-zero-three, are we close to high ground here, we just don't seem to be climbing?' The controller responded, 'RY one-oh-three ah * you show one thousand two hundred now, understand you can't climb.' The captain replied, 'That's affirmative.' The controller asked Flight 103 if it

5/ It was assumed that the V2 plus 3 speed referred to by the captain was the V2 speed of 133 knots, with flaps 15 degrees, printed on the take-off data card. This assumption was based on the opinion of the chief pilot of Redcoat Air Cargo Ltd., who reviewed the CVR transcript and company procedures.

wanted to return to Boston. The transmissions recorded on the CVR were beginning to break up at this point; however, at 1415:11, the controller asked if the aircraft was in visual flight rules (VFR) conditions and the captain replied, 'No we're IFR (instrument flight rules).'

The following intra-cockpit conversation occurred in the next few seconds:

1415:22	FO	– Okay, do you want to jettison, Bill?
1415:23	Capt	– Yeah, start jettisoning fuel.
1415:25	FO	– You take control, now
	Capt	– Okay (* my stick), * * * * * 6/
1415:36	Navigator	– You're very low, I can see the ground.
1415:38	FE	– Yeah, we're dumping fuel.
1415:57	Capt	– Get round here you bugger.
	Capt	– Controls are frozen. (* try it)
1416:00	FO	– Get some power up
1416:02	FE	– We have full power now.
1416:05	Capt	– In a stall
1416:07	Capt	– Look out
	Capt	– Hold on
1416:08	Sound of impact.	

At 1415:41, the captain radioed, 'One-oh-three we're dumping fuel, we're still sinking.' That radio transmission was not received by Boston departure control; however, witnesses on the ground near the accident site heard the transmission on a radio scanner. No sound of the stall warning stick-shaker was recorded on the CVR, not did the flight engineer report hearing it.

Numerous ground witnesses saw the aircraft during the approximate 16 miles of flight. The consensus of their observations was that the aircraft was lower than they expected. Witnesses near the airport reported that the aircraft was climbing slowly and it was much lower than they would have expected it to be. Several said the speed appeared to be slow, the aircraft nose high, and the engines at high power. They also said the wings had been 'wobbling.' All said that the landing gear and flaps were up, and none saw fire or smoke before impact. The witnesses reported seeing the aircraft below the clouds on occasions and entering or leaving the clouds at different locations along the route. They said it was in a climbing attitude, but not gaining altitude. A few witnesses near the point of final impact said that the aircraft flew directly over their houses in a nose-high attitude and the wings had struck trees. However, inspection of these areas and follow-up interviews revealed that the aircraft had not actually touched the trees, but it was extremely low.

The flight engineer stated that the aircraft was in clouds from about 500 to 600 ft above the ground for nearly the entire flight. Radar information revealed that at 1413:24 the aircraft entered a gradual right turn from a course of about 315°. Radar contact was lost when the aircraft was about 0.7 mile from the accident site and at an elevation of 600 ft m.s.l.

The aircraft crashed into a wooded area adjacent to an industrial area and just short of a residential area. The crash path was oriented on a magnetic bearing of 050° and was about 1,502 ft long from initial contact with the trees to where the main wreckage came to rest. A severe post-crash fire erupted immediately.

6/ Unclear words – could be 'low and sinking.'

The accident occurred in daylight hours at an elevation of 170 ft. The location was 42°31′45″ N and 71°15′08″ W.

1.2 Injuries to Persons

Injuries	*Crew*	*Passengers*	*Other*
Fatal	5	2	0
Serious	1	0	0
Minor/None	0	0	0

1.3 Damage to Aircraft

The aircraft was destroyed by impact and post-crash fire.

1.4 Other Damage

A number of trees were destroyed by the crash and subsequent fire.

1.5 Crew Information

The crew was certificated and qualified to conduct the flight. The crew consisted of the captain, first officer, flight engineer, and navigator. Two additional crew members were a loadmaster and a ground engineer.

1.6 Aircraft Information

G–BRAC, a Bristol Britannia 253F, serial No. 13448, was certificated, maintained, and equipped in accordance with current British regulations. (See Appendix C.) G–BRAC was a 4-engine turboprop manufactured by Bristol Aircraft Company. Its Certificate of Airworthiness was issued by the U.K. Civil Aviation Authority.

The investigation did not reveal the exact manner in which the cargo was loaded aboard G–BRAC. According to statements from persons involved, cargo loading began shortly after G–BRAC arrived in Boston on February 15, 1980, with the loadmaster supervising the loading. Loading was begun with a truckload of 30 items weighing an estimated 22,000 lbs. The heavier items were loaded first from the front of the aircraft along the right side to the rear. The loading was then stopped until a second truck arrived containing an estimated 12,500 lbs of cargo. When the heavier items from the truck were all loaded on to the cargo area floor, some lighter cartons were loaded on top of the heavier cargo in the fuselage. The remainder of the lighter items were placed below the floor in cargo compartments. The entire fuselage load was covered by heavy netting and secured. Twenty-four cartons and one skid weighing a total of about 2,297 lbs were not loaded. The flight engineer stated that he was present during the loading and that the cargo was left behind because the aircraft's weight capacity was reached. Persons associated with the shipment stated that the cargo was left behind because the aircraft cargo space was full.

The aircraft loading sheet found aboard Flight 103 showed the following weight 7/ distribution of the load:

7/ The British use the metric system in weight and balance computation. Both kg and lbs are used herein depending on the reference from which the particular weight was taken. Both are reported on occasion for clarity.

Under Floor Holds			Cabin Bays		
No. 1	–	Empty	No. 5	–	2,800 kg
No. 2	–	660 kg	No. 6	–	4,000 kg
No. 3	–	500 kg	No. 7	–	3,000 kg
No. 4	–	Empty	No. 8	–	2,800 kg
			No. 9	–	1,100 kg

The Safety Board's investigators were unable to determine how the loadmaster arrived at the various cargo bin weights, because the individual cartons and skids did not have unit weights on them, nor did the shipper or freight forwarder provide the loadmaster with accurate documentation of the exact weights of the items. Discrepancies were found in the estimates of unit weights made by the shipper and individuals involved with the shipment. Similarly, the exact total weight placed aboard Flight 103 could not be verified. The items left behind were weighed and those weights were compared with items reportedly aboard the aircraft. Using those figures, the weight used by the loadmaster of a load totaling 14,860 kgs (32,760 lbs) is calculated to have been reasonably accurate. The Safety Board did not determine whether that weight included the 446 lbs of RAF cargo already aboard. The estimated weight of actual cargo loaded at Boston, based on documents and statements provided to the Safety Board, was estimated to have been about 13,874 kgs (30,587 lbs). This figure takes into account an arithmetic error of 946 kgs (2,085 lbs) more than the actual weight made by the shipper.

After the aircraft was refueled with 6,650 gallons of jet A fuel, the weight sheet showed the total fuel aboard for take-off as 26,600 kgs 56,643 lbs). A review of the flight engineer's trip record from Belize to Boston showed 21,600 kgs fuel aboard for take-off at Belize and that the actual burn-off may have been about 390 kg less than expected, which would place the actual fuel aboard for take-off at Boston at 26,900 kgs.

The aircraft was last weighed on June 3, 1977. The documents aboard the aircraft show the empty aircraft weight as 40,263 kgs (88,765 lbs). There were three amendments to the weight documents for equipment added to the aircraft which brought the empty weight to 41,148 kgs (90,715 lbs). The most recent weight sheet for the aircraft showed an Aircraft Prepared for Service (APS) 8/ weight of 41,551 kgs (91,604 lbs). This was adjusted for 44 kgs of additional equipment, a triple-unit passenger seat, which brought the APS to 41,595 kgs. Additional crew, passenger, and baggage weights were added to the adjusted APS weight to arrive at the dry operating weight of 42,015 kgs (92,627 lbs). Take-off fuel weight was added to this figure to arrive at the wet operating weight, and cargo weight was added to arrive at the take-off gross weight. The estimated take-off gross weight for Flight 103 was calculated as follows:

Dry operating weight – 42,015 kgs
Take-off fuel – 26,990 kgs (based on fuel slips and actual fuel burn from Belize)
Cargo (loaded) – 13,874 kgs
Cargo (aboard) – 181 kgs 9/
Calculated take-off weight – 83,060 kgs (183,115 lbs) 10/

8/ The APS weight is the result of adding normal crew weight, drinking water, navigation equipment, ships library, and other items.

9/ The cargo manifest showed 446 lbs (202 kgs) of RAF cargo aboard; however, a corrected message was received from Redcoat Air Cargo Ltd., stating that the RAF cargo weighed 400 lbs (181 kgs).

10/ Based on cargo weights as reported and estimated by the shipper.

The weight sheet found aboard Flight 103 showed the weights as follows:

Dry operating weight	– 42,015 kgs
Take-off fuel	– 26,600 kgs (figure shown on the weight sheet)
Cargo	– 14,860 kgs
Take-off weight	– 83,475 kgs (184,030 lbs)

The certificated maximum take-off gross weight for the aircraft was 83,915 kgs (185,000 lbs). The center-of-gravity (c.g.) allowable range for the take-off weight of 83,475 kgs was between 112.7 ins. (forward limit) and 98.42 ins. (aft limit) forward of the datum with the landing gear down and flaps extended. The aft limit moves to 93.14 ins. for landing gear up and flaps retracted (cruise). The c.g. limits for maximum take-off gross weight of 83,915 kgs are 113.39 ins. and 93.14 ins., respectively.

The loadsheet for Flight 103 showed a laden c.g. as 22 per cent. This percentage is derived from a balance computer on which the various weights are entered and a laden index is derived. The laden index gives a reading of 22 percent standard mean chord (SMC) for the calculated take-off weight. Twenty-two percent SMC equates to 111.6 ins. forward of the datum. This is within the c.g. allowable range, about 2 ins. aft of the forward limit. Witnesses to the loading operation stated that the loadmaster checked the nose landing gear strut extension on several occasions during the loading operation.

The maintenance records for the aircraft showed a write-up in June 1979 as follows: 'Climb performance below normal; off-loading of hydraulics produced 'thump' and return to normal performance.' The maintenance corrective action involved full landing gear retraction tests during which the nose gear forward left-hand and right-hand doors drooped. The doors were adjusted, and the aircraft was released for flight. There were no further write-ups on this problem.

British Aircraft Corporation (BAC) document No. FRD/175/A/13, dated December 17, 1964, revealed that the RAF had experienced deficient climb performance with this particular aircraft, G–BRAC. The RAF had reported that the time to climb performance was substantially inferior (–34 per cent) to that specified in the performance data. Considerable evaluation was made of the engine performance, the airframe effects, and pitot/static problems.

During two BAC test flights, the time to climb to 25,000 ft was 9 per cent and 26 per cent greater than specified values. The second test climb was made with entry guide vane heat on which was found to account for the greater time. With the entry guide vane heat on, 2½ per cent less power was measured than was measured on the first flight. The flight test results showed that the mean engine power was about 4½ per cent less than that specified for the fleet. Also, the tests showed 3½ per cent excess drag during the climb from small amounts of surface roughness. The combination of power loss and excess drag was sufficient to account for the deficit in climb performance of 9 per cent greater time to 25,000 ft. The tests failed to determine the reason for the discrepancy between the reported climb deficit of 34 per cent and the observed value of 9 per cent. However, several items of maintenance, including resealing and painting, were performed on the aircraft before the tests to 'clean up' the airframe aerodynamically. Also, rigging and symmetry were verified and the engine compressors were washed.

A more recent flight test was conducted by Airline Engineering Ltd., at Luton, England, on June 30, 1978. The airframe time was 19,140:24 hours with total landings of 7,703. All performance criteria including time to climb were within acceptable tolerances.

1.7 Meteorological Information

1.7.1 General

The weather in the Boston area during the morning and early afternoon of February 16, 1980, was characterized by low overcast and obscured skies with visibilities ranging from ½ to 2 miles in snow and fog. Temperatures were slightly below freezing with winds from the northwest to east at 7 to 14 kns. A frontal inversion extended northward from the surface warm front south of Boston to over the Boston area. The thickness of the cooler air beneath the inversion in the vicinity of Boston was apparently quite variable based on aircraft reports of turbulence, wind shear, and icing. Moreover, winds and precipitation, as reported by witnesses at the airport and along the flightpath of Flight 103, were variable. Some witnesses reported gusty winds with dry snow, while others reported wet snow and freezing rain with no appreciable wind. (See appendix D.)

1.7.2 Surface Observations

The following surface observations were taken on February 16, 1980, for the times and places indicated:

Boston

Time–1354: type–record special; ceiling–partial obscuration measured 400 ft overcast; visibility 2 miles; weather–light snow and fog; temperature–30° F; dewpoint–24° F; wind–330° 11 kns; altimeter–29.39 ins; remarks–snow obscuring 2/10 sky; runway 04 runway visual range 3,000 ft variable 6,000 ft.

Time–1429; type–special; ceiling–partial obscuration measured 400 ft overcast; visibility ½ mile; weather–light snow and fog; wind–360° 13 kns; altimeter–29.36 ins; remarks–snow obscuring 4/10 sky, runway 04 runway visual range 3,000 ft variable 4,000 ft.

1.7.3 Weather Radar

At 1330, the NWS radar at Chatham, Massachusetts, reported an area of 8/10 coverage of light rain and snow, with intensity unchanged since last report. The northwest edge of this area was about 14 miles southeast of Boston. At 1430, the Chatham radar reported an area of 8/10 light rain and snow, intensity unchanged since last report. The northwest edge of this area was about 5 miles southeast of Boston. The radar meteorologists at Chatham stated that there were no significant weather radar echoes over the flightpath of Flight 103. A review of the radar photographs covering the period 1258 to 1432 showed that observable precipitation remained slightly southeast of Boston until 1421 when the northwestern edge of the observable precipitation just reached the airport.

1.7.4 Pilot Reports

A Swissair DC–10 landed on runway 33 at Boston Logan at 1441. An analysis of the digital flight data recorder provided a vertical temperature trace during the aircraft's letdown and approach.

The sounding plotted from these data showed a mixed surface layer about 400 ft thick. Above this was a poorly defined temperature inversion, which became isothermal about

2,000 ft and conditionally unstable above about 4,000 ft. The temperature was –0.5° C at the surface, –2.1° at the top of the mixed layer, and +0.3° C at the top of the inversion.

The captain of the Swissair Flight said he encountered IFR conditions during the descent with light snow and light turbulence, no icing was observed. He said less than 1 in. of snow accumulated on the wings in about 40 minutes ground time, which required de-icing before departure.

An Aer Lingus Boeing 707 landed on runway 15R about 9 minutes before Flight 103 departed on runway 33L. The captain said he encountered heavy precipitation in the form of snow during the approach. He said ice accumulated on the windshield wiper, but he did not observe airframe ice, and that his aircraft is not prone to that type of icing. He stated that moderate turbulence was encountered between 3,000 and 1,000 ft.

A Delta Airlines Boeing 727 in an approach to runway 15R about 10 minutes before Flight 103 made its take-off encountered rime ice and snow. The captain of the Delta 727 said that between 3,000 and 2,000 ft, the aircraft encountered severe turbulence and a wind shear of between 15 to 20 or more kns. He made a PIREP immediately to tower. He said he noted a 10-kn tailwind component during the approach, executed a missed approach, and subsequently was cleared for and landed on runway 33L. He said moderate turbulence was encountered on the approach to runway 33L.

The following pilot report was filed with the Boston Flight Service Station:

> Time–1405: location–between Bangor and Boston, altitude–2,000 ft, type aircraft–Cessna 310, remarks–low level wind shear about 2,000 ft.

The following pilot reports were received by the Boston-Logan tower:

> Time–1349: location–departing Logan, remarks–Delta Flight 169 issued a wind shear report: Between 1,000 and 1,500 ft moderate turbulence and wind shear, lost 10 to 20 kns.
>
> Time–1410: location–approaching Logan, remarks–Delta Flight 204, Boeing 727, between 3,000 and 2,000 ft, lost 20 kns; described as a 'heck of a shear.' At 500 to 600 ft, the pilot reported 'bad turbulence.'
>
> Time–1410: location–approaching Logan, remarks–Eastern Flight 372 reported a 'ripple.' The flight reported no wind shear on arrival.

1.7.5 *Ground Witnesses*

A witness in the immediate vicinity of the accident site said moderate to heavy precipitation of fine grain powder snow was falling at the time of the accident. He said there was no wind, no wet snow, and no ice pellets.

Another witness about 7 to 8 miles north of Billerica stated that he saw large snowflakes at the time of the accident. He said the snow on the ground was wet and mushy. He drove about 5 miles farther north where he saw dry, powdery snow on the ground.

A third witness proceeding north on Route 3A from Burlington Center, Massachusetts, only a few miles from the accident site, stated that at 1400 he encountered freezing rain on his automobile windshield. He said the freezing rain continued long enough to cause him some difficulty driving.

Numerous other witnesses were interviewed who had observed variable precipitation conditions from freezing rain and ice pellets to dry, powdery snow and wet snow.

1.7.6 *SIGMET's*

The following SIGMET's were issued by the National Weather Service Forecast Office, Boston:

SIGMET INDIA 2:
Valid: 1200 to 1600

States: Maine, New Hampshire, Vermont, New York, Pennsylvania, New Jersey, Rhode Island, Massachusetts, Connecticut, and coastal waters.

Area: 85 miles east of Bridgeport, to 200 miles east of Providence, to 95 miles southeast of Atlantic City, to 40 miles southwest of Harrisburg, Pennsylvania, to Barre-Montpelier, Vermont.

Frequent moderate to occasionally severe icing, icing in precipitation. Freezing level surface to 3,000 ft. Conditions generally improving in Pennsylvania, but likely continuing elsewhere by 1600 e.s.t.

SIGMET JULIETT 1:

Valid: 1425 to 1800 – [issued about 9 minutes after the accident].

States: New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and adjacent coastal waters.

Area: From Concord, New Hampshire, to 200 miles east of Providence to 120 miles south of Providence to Newark, New Jersey.

Locally severe turbulence below 3,000 ft, with low level wind shear likely central and east Maine and Rhode Island, south and east Connecticut, associated with low centered coastal Connecticut and warm front east-northeastward over Cape Cod. Condition moving northeastward across coastal waters and ending by 1800 e.s.t.

1.8 Aids to Navigation

There was no evidence that Flight 103 encountered navigational problems. The Air Traffic Control (ATC) radar equipment used to provide service to Flight 103 was operating properly at the time of the accident.

1.9 Communications

The CVR recording revealed that the crew encountered difficulty in receiving the Automatic Terminal Information Service (ATIS) and field condition report broadcasts before starting the engines. After the engines were started and the radios were powered by the aircraft generators, radio reception was improved. Although the ATIS and field condition report broadcasts were garbled, the cockpit conversation revealed that the crew received the appropriate information.

The departure control frequency transmitted to Flight 103 by clearance delivery was spoken phonetically as: '. . . departures will be one twenty four one . . .', which could be interpreted as 120.41 or 124.1. Flight 103 read back the frequency as: '. . . departure frequency one two zero decimal four one . . .', ie 120.41. At the completion of the read-back, the controller acknowledged, 'Your clearance correct . . .' The correct phonetic phrase for the departure frequency should have been, 'one two four point one.' A review of the CVR tape revealed that the crew encountered difficulty contacting departure control because they attempted to tune the radio to 120.41. The first indication of that difficulty was recorded on the CVR at 1410:28. The captain, first officer, and flight engineer discussed the frequency for about 53 seconds before the error was noticed. Contact with departure control was established at 1411:33 on frequency 124.1.

There were no further communications difficulties until 1415:01, when the CVR recording revealed that the incoming transmissions were beginning to break up.

1.10 Airport Information

The Boston Logan International Airport, elevation 20 ft, is served by five hard-surface runways. Runway 33L, 10,081 ft long, was being used for departures at the time of the accident. Field Condition Report No 4, issued at 1324, was being broadcast on frequency 125.55 and was current during the time the crew of Flight 103 prepared to taxi and take-off.

According to ground witnesses and other crews operating at Logan Airport when Flight 103 was on the ground, the taxiways and runway 33L was snow-covered and icy. The crew of an Eastern Airlines B–727, which departed ahead of Flight 103 on runway 33L, stated that there were drifts of snow across the runway which the aircraft struck during take-off. The consistency of the snow varied from loose dry snow to wet slushy snow.

1.11 Flight Recorders

1.11.1 Cockpit Voice Recorder

The Fairchild cockpit voice recorder was located in the wreckage in the area behind the galley in the extreme aft cabin area. The recorder had experienced severe impact and fire damage. Much of the external case, including the front panel with the data plate, was missing and the remainder was burned. The inner portion of the tape was distorted and brittle from heat, which was transmitted to the tape from the spindle. The last 20 minutes of the tape were readable and were transcribed. The flightcrew wore 'hot microphones' which were fed directly to the recorder. The fidelity was excellent, except that the electrical gains for the crew mikes and the radio inputs were out of balance. This caused difficulty in reading out the area microphone and crew conversations during incoming radio transmissions.

1.11.2 Flight Data Recorder

A Lockheed Air Service 109-C, serial No. 516, flight data recorder (FDR) was installed in the aircraft. The recorder was located in the wreckage in its normal installed position in the empennage section, aft of the rear pressure bulkhead. It was not burned and showed no evidence of impact.

The foil recording medium was examined at the Safety Board's laboratory. The examination revealed that the traces for the various recorded parameters were being scribed in an active manner; however, the traces were not usable for the accident flight. The cassette was loose in the recorder housing allowing the foil cassette to move up and down when the recorder shook. Measurement of the trace excursions showed that the movement was as much as 1/16 inch. Examination of the foil take-up spool drive wheel, which engages the teeth of the drive sprocket at the bottom of the cassette, revealed bright witness marks where the gears were disengaging and re-engaging at times. The traces associated with the accident flight covered about 2 minutes. This fact, plus the fact that the horizontal reference line trace was erratic, precluded the use of recorder traces to reconstruct the accident flight.

Examination of the foil revealed that the recorder had operated erratically on previous flights, but not as severely as on the accident flight. The erratic operation occurred mostly during approach and landing when vibrations are generally more severe as a result of flap and landing gear extension.

1.12 Wreckage and Impact Information

The aircraft passed through trees and struck the ground on a magnetic heading of 050°. (See Appendix E). It initially struck a tree about 60 ft above the ground adjacent to a parking lot. A portion of the left horizontal stabilizer was found about 255 ft beyond initial tree contact. There was no evidence of other tree contact for about 450 ft, where several tree tops were broken. The aircraft continued over a relatively clear area with no ground contact. About 700 ft beyond the initial impact area, the aircraft passed through a thick stand of trees for about 250 to 300 ft. The swath through these trees was immediately adjacent to a building north-northwest of the trees. The swath indicated that the aircraft was in a right bank of about 30° to 45° as it cut through the trees. The proximity of the adjacent building was such that the left wingtip had passed just above the top of the building, which was about 40 ft high. Portions of the left elevator, left horizontal stabilizer, and left wingtip were found among the trees under the swath.

The aircraft struck the ground about 200 ft beyond the last stand of trees, slid across an open area, and entered another stand of trees where it came to rest. The wreckage path was about 1,502 ft from initial tree impact to where the farthest portion of the fuselage came to rest. The width of the swath and wreckage scatter was about 200 ft. The aircraft slid into the last stand of trees with its nose to the right. The remains of the cockpit structure and nose section, including the nose landing gear, were found along the right side of the crash path. The aircraft broke up considerably during the crash sequence, especially in the forward fuselage and wing areas. The engines and propellers were damaged severely and disrupted during the impact.

Most of the wreckage sustained severe postcrash fire damage and the fuselage structure was nearly consumed by fire. The cockpit structural pieces and flight deck components were damaged by fire, but some major portions escaped fire damage. Both wings sustained severe impact damage and major portions were consumed by postcrash fire.

The vertical stabilizer and rudder assembly were found near the extreme end of the crash swath. It was separated from the fuselage structure and escaped fire damage. Numerous pieces of the left horizontal stabilizer and elevator were found along the entire wreckage path. Only a few pieces of the right horizontal stabilizer and elevator were located in the debris. All three landing gear assemblies were located within the main wreckage area.

Because of impact and postcrash fire damage, flight control system continuity could not be established. The elevator control linear/rotory actuator located in the empennage was found in the full nose-up position on both elevators. The elevator trim tab worm gearbox on the left elevator was found at the 22° tab-down position, which is equivalent to nearly full nose-up trim.

The flight deck seats and flight deck materials were scattered in an area about 50 ft by 200 ft. The only seat recovered was the first officer's; it had separated from the floor structure, and the seatback had failed in an aft direction. The remainder of the occupant restraint systems were consumed by fire.

The cockpit overhead F-1 panel was badly burned. All of the switches and indicators for control of the de-ice and anti-ice systems were damaged by impact and fire to the extent that no useful information could be obtained.

Both fuel dump chutes were located. The left chute was in the extended (open) position. The right chute was damaged to a degree that its position at impact could not be determined. There was fuel residue on the snow and foliage on the ground short of the impact area.

1.13 Medical and Pathological Information

Autopsies and toxicological analyses were performed on the remains of the captain and the first officer. The examinations revealed no pre-existing or incapacitating pathology which would have affected the crew members' ability to conduct the flight safely. The toxicological analyses were negative for alcohol; basic, neutral, and acidic drugs; and carbon monoxide.

External examinations were conducted on the remains of the other fatally injured occupants. Three bodies sustained severe burns. The other two were not burned. There were soot deposits in the throats of the burned victims. A blood sample obtained from only one of the burned bodies contained 51 per cent carbon monoxide. Toxicological samples were not taken from the remaining victims.

The four fatally injured flight deck occupatns sustained multiple severe impact injuries. The loadmaster and two passengers, who were seated in the rear cabin in a triple-occupancy, aft-facing passenger seat, sustained severe postcrash thermal injuries. They had no external evidence of skeletal fractures.

The sole survivor (flight engineer) sustained a fractured skull, compound fractures of the left arm and both legs, and chest injuries.

1.14 Fire

According to ground witnesses, fire erupted shortly after the aircraft struck the ground. The fire was initially confined to an area about 40 ft wide and gradually spread north from the aft fuselage. Fire equipment was on scene at 1425, about 9 minutes after the accident, and included contingents from Billerica (4 engines), Hanscome Field (1 engine), Wilmington (1 engine), and Woburn (1 engine). The Hanscome crash truck applied an aqueous-film-forming-foam blanket over the crash site, and the fire was extinguished about 1505.

1.15 Survival Aspects

The occupiable area of the flight deck was destroyed by impact. All flight deck occupants were ejected during the crash sequence, except the navigator who remained strapped to the remains of his seat. Rescue personnel removed the surviving flight engineer and the deceased flight deck occupants before fire entered the area near the aircraft.

The bodies of the occupants seated in the aft-facing passenger seat in the rear of the cargo compartment were found in the immediate area of the tail section.

1.16 Tests and Research

1.16.1 Powerplants

After initial on-scene examination, the engines and propeller assemblies were moved to the Butler Aviation facility at Boston Logan Airport for detailed examination. The examination revealed no evidence of pre-impact mechanical failures to the engines or propellers. The entry guide vane valves were found open on all four engines. The wing anti-ice and engine cowl heat valves were closed on all four engines. Examination of all propeller hub gears revealed impact marks at points consistent with flight blade angles.

1.17 Additional Information

1.17.1 Aircraft Performance

The take-off data card for the accident flight was found in the wreckage; the card showed the calculated take-off weight as 83,915 kgs (185,000 lbs). The flight engineer stated that he had completed the card as part of his pre-flight duties. The following entries were found on the card:

Flaps	— — 15°
V1	— — 115 kns
V2	— — 133 kns
FISS 11/	— — 147 kns
Minimum torque	— — 760 lbs
Maximum jet pipe temperature	— — 542°
QNH	— — 995 mbs

A review of the flight manual performance charts revealed the above figures to be correct for the existing conditions. The expected distance from the start of the take-off roll to the point of lift-off was calculated to be 4,095 ft, assuming the ambient conditions for the accident flight with a clean runway surface, and for full-rated engine performance.

The recorded time between the cockpit callouts of V1 and V2 was about 10 seconds longer than expected. According to estimates made on the take-off performance from contaminated runways for the Britannia, water or slush accumulations of ¼ in. can cause the lengthened take-off roll observed for Flight 103 and the extended time between V1 and V2.

The power-on, flaps-up stall speed for the aircraft was calculated to be 118 kns indicated airspeed (KIAS) at the calculated take-off weight. The power-off, flaps-up stall speed was calculated to be 125 KIAS.

The following torque losses with various bleeds operating were reported by the aircraft manufacturer. The figures are torque loss per engine in lbs per square inch:

Cowl heat	— — 5 lb/in^2
Wing anti-icing	— — 50 lb/in^2
Pressurization	— — up to 20 lb/in^2
Entry guide vanes	— — 3 to 5 lb/in^2

11/ Flaps in safety speed — the speed assumed for the flightpath after the flaps are retracted at 400 ft.

The airborne performance of Flight 103 was evaluated using data from several sources. Since FDR data were not available for the performance study, stored radar tracking information for Flight 103 was obtained and used to determine its position over the ground and altitude in hundreds of ft m.s.l. Twenty-eight radar 'hits' were recorded for the airborne portion of Flight 103's flightpath. (See Appendix F). The first hit was at 500 ft m.s.l. in the initial climb and the last hit was at 600 ft m.s.l. about 0.7 mile before the crash. The highest altitude recorded was 1,700 ft m.s.l. The radar hits were 12 seconds apart. These data were used to calculate probable groundspeed and rates of climb and descent. In general, the aircraft climbed between about 400 and 750 ft per minute (fpm) to 1,700 ft, where it began descending about 500 fpm until impact.

An Aer Lingus B-707, which landed on runway 15R about 9 minutes before Flight 103 departed, passed through approximately the same airspace as did Flight 103. The FDR and stored radar information from the B-707 were obtained and analyzed to determine the upper winds acting on the aircraft. Comparison of the B-707's groundspeed and ground track in relation to the aircraft's true airspeed and heading provided wind velocities and directions. The raw wind calculations for the B-707 flight from 4,000 ft down to 1,000 ft showed winds in intensity from 50 kns to 8 kns which varied in direction from 136° to 272°. From 1,000 ft to about 400 ft, the winds were variable in direction and velocity (3 to 20 kns). These winds were based on radar hits 12 seconds apart, and therefore a smoothing technique was used to provide a wind model which was used in the performance analysis.

The calculated wind model and radar information for Flight 103 were entered into a computer programme at NASA's AMES Research Centre to obtain the accident aircraft's performance capabilities. The computer program incorporated local magnetic variation, winds, temperatures, estimated gross weight, and thrust. Power settings were maximum continuous and full power. These were based on testimony from the flight engineer and on data from the CVR. The data derived from the computer program were aircraft flightpath, vertical acceleration, roll angle, pitch angle, indicated airspeed, angle of attack, and thrust versus drag plots.

In general, the computer-derived data show near-normal indicated airspeeds in the climb to 1,700 ft, but with a much lower rate of climb, about 400 fpm actual versus the normal rate of about 1,200 fpm. The angle of attack was fairly constant, 8° to 11° up to 1,700 ft, and began to increase during the descent to over 21° at 900 ft. During the descent, the airspeed decreased to between 132 and 143 kns with the rate of descent about 400 to 500 fpm to 900 ft, where the airspeed dropped to 119 kns.

The computer-derived performance data were consistent with a rapid drag increase as the aircraft began the descent from 1,700 ft. Table 1 contains relevant parameters derived from the computer analysis of Flight 103's performance.

The computer-derived data of Flight 103's performance were largely based on recorded radar information and aircraft gross weight and power estimates. Winds were derived from correlating readings of another aircraft's flight data recorder and the Federal Aviation Administration (FAA) radar plot of its track. Because of error tolerances inherent in each of the areas of base information, it cannot be concluded that at each point in time the accident aircraft was experiencing exactly the value of the specific parameters listed. It should be noted, for example, that aircraft altitude information is derived from aircraft static sources which are transmitted to and encoded by ground-based software in increments to the nearest 100 ft. Also, mathematical smoothing techniques were used to lessen the impact of fluctuations in the data that may have been the result of instrument and recording error tolerances. These data should be interpreted with the above limitations considered. However, the trends shown in the computer-derived performance data listed are representative of the general nature of the flight and the performance of the aircraft during the recorded portion of the flight and they are the best data available to evaluate Flight 103's performance.

1.17.2 Wing Surface Roughness

The following information was extracted from an article entitled 'Wing Surface Roughness, Cause and Effect.' 12/

> For full span upper wing surface roughness beginning at the leading edge and extending varying distances aft, the typical effects are a reduction of the maximum lift coefficient (increase in stall speed), a reduction of the angle of attack at which stall occurs, and a rapid post stall drag increase. The effects become more adverse as the size and chordwise extent of the roughness increase. They may also be accompanied by a reduction in lift at a given angle of attack and by an increase in the wing parasite drag.
>
> Further complicating the overall situation is that premature stall due to surface roughness effects occurs at a lower than normal angle of attack . . . . Therefore, it is possible that angle of attack dependent stall warning systems such as the alpha (a) vanes used on most current jet transports may not provide warning prior to actual stall.
>
> These effects are particularly important for early transport aircraft having no leading edge high-lift devices . . . . The effects of small amounts of wing surface roughness may not be particularly noticeable to a flightcrew operating within the normal flight envelope. Since all transport aircraft operating speeds have some margin above the actual smooth wing stall speeds, the roughness effects may have only decreased that margin. For example, a 1.3 Vs approach speed may have had the margin reduced to 1.1 Vs, leaving little actual stall margin for manoeuvring or gust tolerance.
>
> The author concluded, in part,
>
> Accumulations equivalent to medium or coarse sandpaper covering the full span of the wing's leading edge can cause a significant increase in stall speeds leading to the possibility of a stall prior to the activation of stall warning.
>
> Roughness occurring slightly aft of the leading edge on the wing's lower surface will have little effect on stall, but it does increase parasite drag which will affect take-off performance.

1.17.3 De-ice and Anti-ice Systems

Separate systems are incorporated in Bristol Britannia 253F aircraft for wing de-icing, tail unit de-icing, engine air-intake de-icing, windscreen heating, pressure-head heating, and sidescreen demisting. Two ice detectors are fitted on the lower surface of the aircraft nose. The formation of ice on these detectors activates the ice-warning circuit and brings into operation tail surface and elevator horn heat, propeller de-icing, and entry guide vane de-icing, provided the de-ice panel is configured properly. Wing and cowl de-ice heat provided by engine bleed air are controlled by switches in the cockpit.

12/ Brumby, Ralph E, DC Flight Approach Magazine, January 1979, pp 2 - 7

Table 1 Computer-Derived Performance Data for Flight 103

Time	*Altitude (m.s.l)*	*Ground Speed (kns)*	*Drag Coefficient*	*Indicated Airspeed (kns)*	*Angle of Attack (degrees)*
1410:24	500	1/	1/	1/	1/
1410:36	700	1/	1/	1/	1/
1410:48	700	1/	1/	1/	1/
1411:00	900	162	.058	164	11.3
1411:12	1000	164	.056	166	10.9
1411:24	1100	172	.050	174	10.0
1411:36	1000	176	.047	179	9.5
1411:48	1200	178	.046	180	9.3
1412:00	1200	174	.049	175	9.8
1412:12	1200	163	.058	165	11.2
1412:24	1300	163	.058	164	11.3
1412:36	1200	187	.042	188	8.7
1412:48	1400	190	.040	191	8.3
1413:00	1500	170	.052	171	10.3
1413:12	1600	169	.053	169	10.5
1413:24	1700	180	.047	178	9.5
1413:36	1600	165	.064	160	12.0
1413:48	1600	143	.101	136	16.4
1414:00	1500	146	.093	139	15.5
1414:12	1400	149	.087	143	14.9
1414:24	1300	141	.103	138	16.9
1414:36	1300	137	.112	132	17.4
1414:48	1200	139	.108	134	17.0
1415:00	1100	138	.111	133	17.7
1415:12	1000	128	.137	125	19.6
1415:24	900	122	.166	119	21.9
1415:36	700	1/	1/	1/	1/
1415:48	600	1/	1/	1/	1/

1/ Insufficient data points for computation.

1.17.4 *De-ice and Anti-ice Procedures*

The Operations Manual contains a note that wing heat should not be selected until ice accumulation is evident on the leading edges. There is a black strip painted on the outboard leading edge so that a crew member may view ice buildup.

The following are excerpts from the Bristol Britannia 253F approved Flight Manual:

Icing Protection Systems

Because of the possibility of overheating the engine and since the effect of the power loss on the take-off and balked landing performance has not been scheduled, the wing and engine anti-icing systems must not be switched on during take-off when performance is likely to be critical.

OPERATING PROCEDURES

1 Before entering any type of cloud or precipitation with an indicated outside air temperature below [IOAT] +12°C switch on (switches to MANUAL) the compressor entry guide vane heating of all engines; these must remain on for at least a further 15 minutes after leaving cloud.

2 Continuous operation in cloud or precipitation with the IOAT within the hand +2°C to –2°C should be avoided.

3 The propeller, tail unit and horn balance heating may be switched on (switches to MANUAL) at any time. However, when the ice warning lamp illuminates they must be switched on (MANUAL).

4 Wing heating should be switched on only when there is evidence (for example a definite decrease in IAS [indicated air speed]) that there is appreciable ice accretion on the wings.

Switch the engine air intake (cowl) de-icing on before entering cloud or precipitation at IOATs between +2°C and +12°C, unless the speed when entering these conditions is above 200 knots IAS and the temperature is within the critical range +2°C to +6°C. In this case speed must be reduced first and the realized IOAT at 200 knots IAS checked before engine air intake de-icing is used.

NOTES: (a) The engine air intake de-icing system is effective at speeds below 200 knots IAS. Above this speed its effectiveness is much reduced. When the IOAT is below +2°C the conditions are assumed to be Dry Ice conditions and the engine air intake de-icing system is not to be switched ON. Hence switch to MANUAL, compressor guide vanes only.

The flight engineer was questioned about his statement that the outside air temperature gauge read between 6 - 8°C (43 - 46° F) during the taxi to take-off when the reported temperature was 31°F. He stated that he knew it was higher than actual and mentally subtracted about 6°C from the reading on the ground. The chief engineer for Redcoat Air Cargo Ltd.,, verified that the crews were to use tower-reported temperatures, if available, for purposes of deciding to use cowl heat. The flight engineer and chief engineer stated that the lack of accuracy of the outside air temperature gauge was not unique to this aircraft, but was common to other Britannias as well.

In Section II of the Flight Manual, the following 'Special Condition of Flight' is included: 'The aeroplane is suitable for flight into moderate icing conditions.' The UK Civil Aviation Authority (CAA) was queried regarding its regulations pertaining to certification and operating rules for flight in icing. Following are excerpts from the CAA's reply:

> If severe icing is forecast, take-off should not be attempted . . . . While it is agreed that no specific instruction appears in the Flight Manual with regard to using wing anti-icing and its effect on aircraft performance, the instruction in the Flight Manual for anti-ice bleeds to be OFF for take-off is based on two assumptions:
>
> a) There will be no significant ice build up during the take-off and initial climb with the aircraft being operated under the icing conditions limitation (moderate icing), and
>
> b) the likelihood of engine failure in the late stage of the take-off or in the initial climb, say between V_1 and 400 feet is remote, the duration of this manoeuvre being about 15 seconds.

1.17.5 *Procedures for Dissemination of SIGMET Alerts by Air Traffic Control Facilities*

The procedures for dissemination of SIGMET alerts from air traffic control facilities are outlined in FAA Handbooks 7110.65A (Air Traffic Control) and 7110.10E (Flight Services). Handbook 7110.65A contains instructions that a SIGNMET alert be broadcast on all frequencies, except emergency frequencies, if the area affected by the alert is within 150 miles of the airspace under a facility's jurisdiction.

A statement signed by the Boston Flight Service Station Chief indicated that the in-flight specialists, responsible for broadcasting SIGMET alerts, over the air/ground frequencies failed to do so with SIGMET India 2 and SIGMET Juliett 1 on February 16, 1980.

Paragraph 330 of Handbook 7110.10E requires continuous, transcribed broadcasts of aeronautical and meteorological information on designated radio facilities. The designated facility in the Boston area is the Lyndy non-directional beacon (NDB), which transmits on 382 kHz. It is located 4.8 nmi north-northeast of the Local International Airport. Paragraph 331(c) requires the inclusion in the broadcast of adverse conditions from current SIGMET's. The appropriate SIGMET information was transcribed and broadcast over the Lyndy NDB by the Boston FSS on February 16, 1980. The CVR transcript revealed no discussion by the crew of Flight 103 about listening to the Lyndy NDB.

1.17.6 *De-icing Fluid*

The de-icing fluid used to de-ice the aircraft was a 30 per cent glycol, 70 per cent water mixture heated to about 180°F. The combination of heat and pressure removes snow and ice from the airframe. The glycol prevents water from refreezing during the de-icing operation. The fluid is not intended to prevent build up of snow or ice after the de-icing operation.

During the post accident interview, the flight engineer stated that he believed the de-icing fluid would provide more than 1 hour's protection from the freezing snow falling at the time. The Safety Board's investigators interviewed numerous flight crews of other air carriers and found that many of them assumed that de-icing fluid provided protection against refreezing.

Neither the manufacturer of the de-icing fluid nor the FAA have available data or published specifications on the continuing effects of the fluid after it is applied. The variables of ambient temperature, airframe temperature, precipitation intensity, and moisture content preclude such specifications.

2. Analysis

General

The investigation revealed that the crew was properly certificated and qualified to conduct the flight. There was no evidence of pre existing medical problems which affected the crew's performance of their duties.

The aircraft was equipped and maintained in accordance with applicable regulations. The aircraft was properly certificated.

Based on the evidence, the Safety Board considered several causal areas in this accident — power loss, airframe or flight control malfunction or failure, weight and balance, crew member actions, and meteorological conditions, including wind shear, turbulence, downdrafts, and icing. These aspects were analysed independently and then were considered as they related to each other.

Power Loss

The Safety Board considered three aspects of possible power loss as possibly causal in this accident: (1) mechanical failure(s), (2) a subtle decrease in power as a result of engine inlet or entry guide vane icing, and (3) less-than-optimum power because of other engine-air bleeds that were on. Mechanical failures were eliminated for several reasons. Most importantly, the flight engineer, whose primary flight duties involve monitoring powerplants during flight, stated that he observed no mechanical problems with the engines during the flight and that full power was available and used during the last portion of the flight. His statement is supported by the CVR. Further, the Safety Board's examination of the engines and propellers revealed that the engines were capable of, and were probably developing, full power at impact.

The second possibility, power loss involving a subtle decrease in power as a result of engine inlet or entry guide vane icing, was also discounted. The engine inlet (cowl) area and entry guide vanes are susceptible to ice build up with subsequent power loss and possible failure. Further, the use of cowl heat depends a great deal on the outside air temperature gauge reading, which the investigation revealed was not totally accurate. However, the first indication of engine icing problems would be a drop in torque and then a rise in jet pipe temperature. The flight engineer stated that he observed neither indication during the flight, nor did the captain or first officer remark about abnormal engine indications during the flight. Therefore, although the conditions of the flight were conducive to engine icing problems, if engine icing did occur, it was not sufficient to be noticed by the crew and certainly was not sufficient to cause the aircraft to descend and crash.

Third and finally, there probably was some power loss from optimum-rated full power because other engine air bleeds were on. The entry guide vane heat was on and the cabin pressurization bleeds probably were open. The torque losses (about 3 to 5 and up to 20 lb/in2, respectively) would decrease the power available slightly. The flight test data from previous performance tests on this aircraft illustrated that operation of entry guide vanes reduced power available for climb by 2 1/2 per cent. The exact amount of loss for pressurization was not calculated, but it would have had further negative effects on available power. Nevertheless, these values are not sufficient to account for the poor climb performance of Flight 103 or for the eventual descent into the ground. Had wing and cowl anti-ice bleeds been on, the loss in power would have been significant. However, the investigation revealed that the cowl heat was only on for a few seconds on Nos 1 and 4 engines and wing heat was not used. Therefore, the Safety Board concludes that power degradation because of engine bleeds was not significant enough to cause this accident. This conclusion is substantiated by the flight engineer's statement that he observed 'normal'torque indications which presumably were above the performance chart value of 760 lb/in2 entered on the take-off data card.

Airframe or Flight Control Malfunction or Failure

The possibility of flight control problems was considered because of the flight crew's remark just before impact about 'controls frozen.' Unfortunately, the break up during the accident and the post crash fire precluded a complete examination of the flight control system.

It would have been possible under the weather conditions for the elevator or elevator tab surfaces to have frozen together. That is, the elevator could have become frozen to the stabilizer or the elevator tabs could have become frozen to the elevator.

However, the Safety Board discounted these possibilities for several reasons. First, if the elevator became frozen to the stabilizer, the pilot could still have moved the control column and actuated the tabs. He would not feel 'frozen' controls. In this situation, the tab would be acting as a small elevator, but in the direction opposite to the normal deflection of the elevator. Therefore, if the pilot pulled back for nose-up, the nose would move down. This reversed response would have resulted in a nose-low attitude and impact. The observations of numerous witnesses and the nose-high attitude at impact discount this possibility.

Secondly, if the elevator tab had frozen to the elevator surface, the pilot would sense 'frozen controls;' however, he would have no control over the pitch attitude of the aircraft. The aircraft would respond to the last selected pitch input and the aerodynamic force of the 'frozen' tab would maintain that attitude. Since the elevator tab linear actuators and trim tab actuator were found in the full nose-up position in the wreckage, these controls were probably so positioned there at impact. Further, the pilot would not have been able to increase the angle of attack during the descent as demonstrated by the performance analysis.

Therefore, the Safety Board eliminated mechanical and icing problems with the flight control surfaces as causal to this accident. Although the meteorological conditions, the pre-flight activities, and the design of the sytem were conducive to frozen controls, the facts in this case do not support such a finding.

The CVR transcript, the flight engineer's statement, witness statements, and the examination of the wreckage eliminated airframe problems in this accident.

One airframe factor which could account for a small part of the poor climb performance is the effect of age and deterioration of airframe surfaces. These could raise the profile drag beyond normal performance chart data. The previous testing of this aircraft in 1964 for poor climb performance illustrated that surface roughness caused as much as 4 1/2 per cent excess drag. Although the tests conducted in 1978 did not demonstrate excess drag, about 2,823 hours of airframe time were accumulated following those tests. Nevertheless, in the accident case, had slight surface roughness existed, it could not account for the degraded climb performance evidenced.

The susceptibility of the airframe to parasite drag was illustrated by the write-up and corrective action regarding drooping nose gear doors in June 1979. The fact that the crew noticed poor climb performance and the measured effects in the previous testing illustrate the importance of a 'clean' profile and airframe surface. There was no evidence in this case to suggest gross external drag problems from airframe components or inherent skin roughness.

Weight and Balance

The length of the take-off roll for Flight 103 and the degraded climb performance suggest the possibility of an overweight or improperly balanced load. The Safety Board expended considerable effort in attempting to verify the weight and balance aspects of this accident. However, the circumstances of the loading and the lack of adequate documentation by the shipper precluded an exact determination of the weight and balance.

Although the aircraft dispatch papers and the Safety Board's calculations place the aircraft slightly below its certificated maximum gross weight, if these figures are correct, it was the result of the skill of the loadmaster in estimating the weight of unmarked cargo. The loadmaster apparently was aware of the overall gross weight of the cargo to be loaded and made a good estimate of individual items placed aboard the aircraft. If one assumes that the cargo gross weight was reasonably correct and that the aircraft prepared for service weight plus fuel was reasonably correct, then the take-off weight was near, but not over, the certified maximum weight allowable for take-off.

Regarding the balance of the aircraft, the investigation failed to provide evidence of the accuracy of the calculations. The crude technique of balancing the aircraft based on the extension of the nose wheel strut is not prudent and should not be condoned. There is no evidence on the CVR or from the flight engineer that the aircraft was noticeably out of balance at take-off. Moreover, if weight and balance was a problem, the aircraft would not have climbed initially as it did.

In summary, although the exact weight and balance could not be verified, the Safety Board believes that they were within limits, and therefore concludes that weight and balance was not causal to the accident.

Meteorological Conditions and Crew member Actions

The remaining causal areas involve the meteorological conditions and their effect on the aircraft and the crew members' actions to cope with those conditions.

All available meteorological data were examined to determine the conditions existing at the time of the accident and the conditions preceding the accident which may have had an influence on the flight of Flight 103. Snow and fog were reported at the airport throughout the morning period. Light rain was reported at South Weymouth. Three witnesses in different locations, but close to the accident site, reported moderate to heavy, fine, powdery snow; large snowflakes accumulating as wet, mushy snow; and freezing rain. From their reports, it is obvious that the type of precipitation and temperatures aloft varied widely within a relatively small area.

Based on the soundings and on pilot reports, the best estimate of the height of the frontal inversion in the vicinity of the flight track of Flight 103 was between 1,000 and 2,000 ft. The height would vary between those altitudes and would cause areas of above-freezing temperatures above the inversion at some points. There would have been turbulence, sometimes severe, in the vicinity of the inversion and, given the height variation of the inversion, different aircraft would have encountered the turbulence at different altitudes and locations.

Based on witness statements and on the condition of the air mass in the vicinity of the flight track of Flight 103, both rime and clear icing conditions would have been present intermittently. If the icing conditions were severe, indications of heavier liquid precipitation probably would have been present north of Boston on the NWS radar at Chatham. Nevertheless, the Safety Board believes that pilot reports, ground witness observations, and the variability of the inversion layer establish that intermittent areas of moderate to severe icing existed.

Analysis of average and maximum winds shows that Flight 103 probably encountered wind shear in the range of 29 to 33 kns above 1,000 ft. This shear would have decreased performance of Flight 103 during the climb. Since the conditions were not conducive to convective turbulence, any downdrafts would have been the result of turbulence along the inversion and would have been limited to with a few hundred feet of the inversion.

Take-off Roll and Initial Climb. – The meteorological conditions were further analysed for their effect on the performance of Flight 103 from the time it began its take-off roll until impact. The Safety Board believes that the extended take-off roll could have been brought about by runway surface conditions. The investigation revealed that there was an accumulation of snow and slush on the runway surface. In fact, an Eastern Airlines pilot reported that his aircraft hit snowdrifts on take-off. The temperature, the precipitation, and the operation of jet aircraft on the snow – and ice-covered runway, all were conducive to slush formation. Although there are no Flight Manual performance data available on the effects of slush or water on the take-off distance for this aircraft, the investigation revealed that as little as 1/4 in of slush or water on the runway surface could account for the longer-than-normal take-off roll. The flight engineer's statment that he heard slush striking the fuselage during the take-off roll confirms the fact that slush was present on at least part of the runway and in sufficient quantity to degrade acceleration.

The late lift-off may also be attributed to the degraded lift capability of the aircraft. The Safety Board's investigation strongly suggests that snow and ice had accumulated on the lifting surfaces of the aircraft before the take-off attempt. Although such accumulations would not produce appreciable parasite drag during the take-off roll, they could easily increase the airspeed required for lift-off and therefore require a longer take-off roll.

As a result of interviews with the witnesses and the flight engineer and recorded radio calls, it is evident that about 45 to 60 minutes elapsed from the time the aircraft was de-iced and the time the take-off was initiated. It was snowing intermittently during this period and the surface temperature was near freezing. Additionally, snow was blown about by the engines during ground activities and easily could have stuck to areas of the wings. Furthermore, the aircraft had been refueled the night before and sat in sub-freezing temperatures. Therefore, the wing sections adjacent to the fuel cells would be susceptible to re-freezing of melted snow and ice following de-icing. Evidence indicates that the de-icing fluid would not necessarily prevent ice and snow from accumulating during the time period involved. In fact, one witness stated that he saw ice or frost adhering to the leading edge of the wings before the aircraft taxied from the ramp. Such formations could easily increase the airspeed and angle of attack required to achieve lift-off.

The flight engineer stated that he checked the wings and saw no build-up before take-off. However, he could not see the entire wing from his position or from any other part of the cockpit. Additionally, even if he could have seen the wing, refrozen water on the wing would be difficult to see. The wind tunnel test results reported in DC Approach Magazine and known aerodynamic facts illustrate that even small amounts of wing surface roughness, including ice, snow, or frost, can seriously degrade lift capability.

In view of the facts regarding the ground operations and the operating environment, the Safety Board concludes that ice and snow accumulations on the aircraft's lifting surfaces combined with the effects of the slush-covered runway to produce the longer-than-normal take-off roll of Flight 103. It is also concluded that the ice or snow accumulations were the major factor in the lower-than-predicted initial climb performance.

The Safety Board's performance analysis revealed that drag remained fairly constant throughout the climb to 1,700 ft, although it was higher than expected. Also, angle-of-attack remained fairly constant as airspeed increased to near the expected climb speed. The performance analysis reveals that the aircraft was climbing an average of about 400 fmp, and the CVR reveals that the crew was accomplishing their after-take-off checks routinely. The Safety Board cannot explain the crew's lack of verbalized concern about the poor climb rate. One would expect the crew, at least, to have sensed or recognised the poor performance and commented on it. Possibly, the crew was performing its normal tasks while attempting to analyse the situation. The captain and the first officer may have, in fact, recognised the reason for the degraded climb capability but they made no overt comment. Assuming power was being attained as desired, the increased drag would most likely be accounted for by wing surface roughness from ice or snow, and would be so attributed by the crew.

Other meteorological conditions which could have combined to degrade the initial climb capability were low-level wind shear and turbulence. There were several PIREP's for the Boston terminal area reporting moderate to severe turbulence and wind shear. Also, the flight engineer reported 'severe turbulence' shortly after lift-off and for the remainder of the flight. The flight engineer's description of the turbulence immediately after lift-off as 'high frequency buffeting' suggests that at least part of the 'turbulence' he reported was the result of aerodynamic buffet which could indicate that part of the aircraft's wing was stalled. Debris, such as ice, snow, or refrozen water, on the wing, especially in the root area, would cause airflow separation and buffet. In addition, the FDR traces for the accident flight show that external forces were shaking the inadequately secured recorder more than on other recorded flights. During cruise, the traces were normal; however, they became erratic during take-off, descent, and landing, especially when the landing gear and flaps were extended. Aerodynamic buffet in the landing configuration is the most likely explanation for the divergence of the traces on previous flights. Since the condition suddenly worsened for the recorded portion of the accident flight, there apparently existed strong external forces which were transmitted to the FDR.

Further, the Safety Board's analysis of flight crew statements and FDR's from other aircraft operating in the same airspace as Flight 103 substantiates the presence of low-level wind shear and turbulence. These conditions would have decreased the climb capability of the aircraft, but were not sufficient to account for the total loss of performance. The Safety Board believes that wind shear and turbulence combined with the aerodynamic buffet, caused by airflow separation because of wing surface roughness from ice or snow accumulations, accounted for the degraded initial climb performance.

There was no evidence that flight crew actions were improper, as far as flight control manipulation or flight procedures during the initial climb were concerned. The only questionable crew involvement in the take-off and initial climb phase pertains to pre-flight activities and the decision to depart following the delay after de-icing. They should have been aware of the environmental conditions and of their possible hazardous effect on aircraft performance. There is no way to predict what action the crew would have taken had they been aware of the SIGMET India 2's content. However, this lack of information about imminent hazardous weather must be considered a factor in the crew's decision to depart. The fact that the flight crew was apparently in a hurry during the weather briefing may account for their not having received the SIGMET.

Additionally, the SIGMET for the Boston area was not contained in the ATIS broadcast for Boston. This was the only other means by which the crew could have become aware of SIGMET India 2, since the transmissions required of the Boston FSS over its air/ground frequencies were not accomplished as required, and the flight crew apparently did not monitor the Lyndy NDB weather information. The fact that the FSS failed to make the broadcast over its air/ground frequencies is not a factor in this case, because the crew was not aboard the aircraft when the SIGMET should have been broadcast. Although they did monitor the ATIS, current procedures do not specify the inclusion of SIGMET notification on the ATIS. The Safety Board believes that the ATIS broadcast is an important means by which SIGMET notification can be made. Such a procedure would close an existing gap in the important communications process of real-time weather information transmission to pilots.

Since the flight manual does not approve flight into severe icing, the crew probably would not have departed if they had been aware of SIGMET India 2. The Safety Board, therefore, concludes that the failure to receive SIGMET India 2 was a factor in this accident. The crew's hurried approach to the weather briefing and the NWS briefer's oversight contributed to this aspect of the cause.

Loss of Climb Capability and Descent. Factors analyzed thus far were not sufficient to cause the accident; they merely put the aircraft in a degraded performance condition. About the time the controller issued the second low-altitude alert, the aircraft was climbing and the lack of high terrain ahead would have allowed for an eventual safe climb and probably a successful en route phase. However, numerous events occurred about the time the second low-altitude alert was issued and in the seconds thereafter.

The performance analysis shows that the aircraft began to lose additional climb performance about the time of the second alert. The crew's only comment was '. . . we're getting some chop here'. The climb rate obviously had decreased to a point where the captain became concerned and told the first officer, 'try it at V2 plus three, Jack,' to which the first officer replied, 'Okay, not climbing at the moment'. Two reasons probably prompted this remark by the captain. First, the second low-altitude alert probably caused the captain to suspect that the aircraft was approaching higher terrain. Secondly, the captain apparently suspected a severe downdraft or wind shear and instructed the first officer to fly at an airspeed which would give the aircraft a better climb gradient. Therefore, the first officer probably pulled the nose up to hold 136 kns (V2 + 3 kns). This conclusion is substantiated by the performance study, which showed the speed to be 136 kns shortly after the captain's statement. Under most conditions that speed would give a better climb gradient; however, with the airframe icing condition that probably existed, the increased angle of attack would not have provided the rate of climb that would normally be expected. In fact, with the existence of airframe icing this speed could be below the optimum climb performance and, in addition, it could have accelerated the accumulation of more ice, further depreciating performance. Thus, while the low-altitude alert may have prompted an overreaction on the part of the pilot in terms of increasing the pitch attitude, it is understandable in terms of the overall situation facing the flight. Moreover, the Safety Board believes that regardless of the control inputs, climb performance had already deteriorated to the point where recovery was impossible.

The expected power-on stall speed for the configuration would be about 118 kns. When the aircraft was slowed to 136 kns, it would be operating about 1.15 x Vs. Normally that margin would be sufficient to achieve a better gradient of climb; however, it places the aircraft dangerously close to stall speed. Any bank angle, wind shear, or debris affecting the lifting surfaces could cause the onset of stall. Also, the accompanying rapid increase in drag would serve to compound the performance problem.

Additionally, the actual stall speed of the aircraft was probably in fact higher than 118 kns because of the wing surface roughness. As stated in the Douglas document, 'The effects of small amounts of wing surface roughness may not be particularly noticeable to a flight crew operating within the normal flight envelope. Since all transport aircraft operating speeds have some margin above the actual smooth wing stall speeds, the roughness effects may have only decreased that margin. For example, a 1.3 x Vs approach speed may have had the margin reduced to 1.1 Vs, leaving little actual stall margin for maneouvring or gust tolerance'. Therefore, the crew action of slowing to 136 kns (V2 + 3) probably placed the aircraft at, or very near, the higher-than-normal stall speed for the contaminated lifting surfaces. This conclusion is substantiated by the fact that the stall warning stickshaker did not activate. The airspeed did not actually decrease to the normal stickshaker speed before the lifting surfaces began to stall.

The Safety Board believes that multiple meteorological conditions contributed to the loss of climb and subsequent descent into the ground. Turbulence, wind shear, and downdrafts, even in combination, would not account for the entire descent over the distance involved. Also, the weather and performance analyses of Flight 103's flightpath and analysis of the Aer Lingus B-707 flight path did not show a prolonged severe downdraft or wind shear. Turbulence alone could not generate the loss of performance demonstrated over the extended period of time. Therefore, the Safety Board examined the possibility that air frame icing degraded the lift capability to a point where flight was no longer possible.

The Safety Board believes that when the aircraft was encountering wind shear, turbulence, and downdrafts, airframe ice also was rapidly accumulating. This accumulation, in addition to that incurred during ground operation, caused further loss of lift and added drag which the aircraft could not overcome. Moreover, at the low airspeed, the angle-of-attack was increased to a point where icing was accumulating on the fuselage and undersurface of the aircraft, which would add weight rapidly and increase parasite drag. In the rapidly changing conditions, heavy accumulations could occur in a very short time. The descent was, therefore, inevitable.

The fact that the flightcrew did not select wing heat during the flight must be viewed in the context of the Flight Manual operational restriction and the fact that the flightcrew apparently did not note any appreciable ice accumulation on the wings. Furthermore, the captain would have had to have in mind the considerable torque loss (about 50 lbs/in2) per engine if wing heat were selected, which would have further degraded the climb performance. The possibility that early selection of wing heat might have melted sufficient ice to have improved the aircraft performance to a point where it could have continued its climb cannot be rejected. However, such an action would have involved departure from established operational procedures and the resultant loss of torque might easily have compounded the already deteriorating situation. Therefore, in view of the known factors accounting for degradation of aircraft performance and the numerous undeterminable variables, it was not possible for the Safety Board to resolve the effect of the use or non-use of wing heat during the flight as a factor in this accident.

In summary, the Safety Board concludes that the take-off roll was longer than normal because of slush on the runway and decreased lift from ice or snow on the wings which accumulated during the ground operation. The initial climb rate was less than expected because of wing surface roughness from ice and snow, turbulence, and wind shear. At about 1,600 ft, a possible down draft with associated wind shear was encountered. At the same time, the airspeed was reduced by the pilot in an effort to gain more altitude as a result of the low-altitude alert issued by the controller. Airframe icing was occurring rapidly, which further degraded the lift capability and the aircraft entered a descent in a nearly stalled condition from which it did not recover. The Safety Board believes that the accident was not inevitable because of wind shear, turbulence, or down drafts. These conditions were merely factors which had degraded the climb capability to a point where the low-altitude alerts were issued and airspeed was bled off to gain height. The overwhelming factor was the pre-existing and rapidly accumulating airframe ice. Recovery could have been accomplished from any of the other conditions; however, the icing effect was more pervasive and caused a considerable increase in drag and loss of lift.

It is very possible that if the aircraft had not encountered moderate to severe in-flight icing, it would have continued to climb safely. Conversely, if the aircraft had not departed with pre-existing ice or snow on the airframe, it might have been able to overcome the in-flight icing conditions. Therefore, these two factors in combination must be considered as the cause of the degraded aerodynamic performance of the aircraft.

Survival Aspects

The potential for survival in this accident was affected by the extensive break up of the cockpit area and the postcrash fire. All of the occupants in the cockpit area sustained severe impact-type injuries. The occupiable space of the cockpit was disrupted and destroyed during the ground slide and impact with trees. The cockpit occupants' restraint systems were destroyed during the break up rendering them useless. The occupants were thrown free allowing them to contact the aircraft structure and the surrounding trees and terrain. These uncontrolled movements caused the multiple severe injuries. Only the flight engineer's injuries were not fatal. His postcrash survival was the result of expeditious and effective rescue and medical treatment. The other four cockpit occupants suffered fatal impact injuries which rendered rescue efforts useless.

Although the general area of the aft fuselage, where the remaining three occupants were located, was virtually consumed by fire, the investigation revealed that it did not break up as extensively as did the forward portion. Examination of those three bodies included findings of products of combustion in their tracheae and an elevated carbon monoxide level in one body, and showed that the three occupants in the aft fuselage area died from the effects of fire. The lack of autopsy information precluded the determination of why the three were unable to escape or if they were even capable of escaping after the crash. It is known that the post crash fire propagated rapidly and prevented a successful rescue attempt in that area of wreckage.

The multiple unknowns and variables of the impact sequence and the extensive fire damage precluded an accurate determination of decelerative forces during impact. However, the relatively low speed at impact with the trees (probably slightly above the stall speed of 118 KIAS) and the gradual deceleration through the trees and over the ground most likely placed the forces well within human tolerance. Therefore, the Safety Board concludes that the break up of the structure and loss of restraint made the crash non survivable for the forward occupants, and that the post crash fire made the crash non survivable for the aft occupants.

3. Conclusions

3.1 Findings

1 The flightcrew was properly certificated and qualified to conduct the flight.

2 The aircraft was maintained according to approved procedures and regulations.

3 The flightcrew failed to adquately familiarise themselves with the existing weather conditions because of their hurried approach to the weather briefing.

4 The flightcrew of Flight 103 did not receive a SIGMET for moderate to severe icing during the pre-flight weather briefing.

5 The aircraft was not certificated to be flown in severe icing conditions.

6 The aircraft was certificated to be flown in moderate icing conditions although no Flight Manual performance data were provided for take-off with engine or airframe de-icing equipment operating.

7 There were no airframe, flight control systems, or powerplant malfunctions before impact.

8 The aircraft was probably at or slightly below its certificated maximum take-off gross weight.

9 The centre of gravity location could not be verified, but probably was within limits.

10 The aircraft was taxied in a snowfall for 45 to 60 minutes after airframe de-icing.

11 The take-off roll was longer than normal because of slush on the runway and degraded lift capability because of snow or ice on the airframe.

12 Low-level wind shear and turbulence existed in the Boston area at the time of the take-off.

13 Moderate to severe icing conditions existed in clouds in the initial climb area of Flight 103.

14 The flight encountered downdrafts, turbulence, wind shear, and icing during the climb.

15 The climb rate was less than expected because of accumulated frozen ice and snow on the wings and the effects of turbulence, wind shear, and downdrafts.

16 The crew responded to an ATC low-altitude alert warning by raising the aircraft's nose, which caused the speed to decrease to a value too slow for the degraded lift capability.

17 Rapidly accumulated airframe ice overcame any excess lift capability and increased drag and weight to a point where recovery was no longer possible.

18 The impact forces of the accident were survivable; however, the cockpit structure was compromised causing fatal impact injuries.

19 The three occupants in the aft cabin area survived the impact but succumbed to the effects of fire.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of the accident was degraded aerodynamic performance beyond the flight capabilities of the aircraft resulting from an accumulation of ice and snow on the airframe before take-off and a further accumulation of ice when the aircraft was flown into moderate to severe icing conditions following take-off. Contributing to the cause of the accident were encounters with wind shear, downdrafts, and turbulence during the climb. The failure of the flightcrew to obtain an adequate pre-flight weather briefing and the failure of the National Weather Service to advise the flightcrew of a SIGMET for severe icing conditions were also contributing factors.

4. Safety Recommendations

As a result of this investigation, the Safety Board, on June 3, 1980, recommended that the Federal Aviation Administration:

> Insure that the ATIS advisories contain all essential forecasted meteorological conditions, including SIGMET's, which are likely to affect aircraft operating in terminal areas served by the ATIS. (Class II, Priority Action) (A-80-46)

On August 29, 1980, the Federal Aviation Administration responded:

> The FAA Facility Operation and Administration Handbook (7210.3E) is being revised to include notification of appropriate current SIGMETs and PIREPs in ATIS broadcasts . . . .

Also, as a result of this investigation, the Safety Board, on November 14, 1980, recommended that the Federal Aviation Administration:

> Advise operators of the potential hazard of an accumulation of wet snow on airfoil surfaces after de-icing with a diluted ethylene glycol solution. (Class I, Urgent Action) (A-80-112)
>
> Initiate a study of the effectiveness of ethylene glycol-based de-icing fluid concentrations as an anti-icing agent under differing icing and snow conditions. (Class II, Priority Action) (A-80-113)
>
> Publish and distribute to operators detailed information regarding the characteristics of de-icing/anti-icing fluids and guidelines regarding their use. (Class II, Priority Action) (A-80-114)

On February 11, 1981, the Federal Aviation Administration responded:

> The FAA concurs in . . . safety recommendation (A-80-112) and we are preparing an operations bulletin to emphasize the dangers of snow accumulation on aircraft following de-icing. Operators will be requested to review their de-icing and anti-icing procedures in view of these accidents. A copy of the operations bulletin will be forwarded to the Board when it is issued.
>
> [Regarding safety recommendation A-80-113:] During the April 1969 FAA Aircraft Ice Protection Symposium, it was emphasized that prior to flight, the final inspection must assure a clean-surfaced wing. This requirement remains valid regardless of the effectiveness of either fluid used; de-icing or anti-icing. The FAA believes these criteria are adequate for release to taxi.
>
> The FAA does not concur in . . . safety recommendation (A-80-114) because we believe the manufacturer, rather than the FAA, should be charged with this action. Detailed information regarding the characteristics of de-icing/anti-icing fluids and guidelines regarding their use should be obtained from the manufacturer of the product, since only this source has the test data to back up claims of the effectiveness of its product.

We do, however, appreciate the intent of the recommendation. Accordingly, we plan to issue an operations bulletin which will request air carrier certificate holders to ensure that de-icing/anti-icing procedures are included in their manuals.

We believe these actions will fulfill the intent of Safety Recommendations A-80-112 through A-80-114.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ *JAMES B KING*
Chairman

/s/ *FRANCIS H McADAMS*
Member

/s/ *PATRICIA A GOLDMAN*
Member

/s/ *G H PATRICK BURSLEY*
Member

ELWOOD T DRIVER, Vice Chairman, did not participate.

FRANCIS H McADAMS, Member, filed the following concurring statement:

I agree generally with the Board's conclusions and probable cause, but I do not agree with the following two statements of the majority.

The Board states: (1) 'Thus, while the low-altitude alert may have prompted an over-reaction on the part of the pilot in terms of increasing the pitch attitude, it is understandable in terms of the overall situation facing the flight'. p 28, and (2), ' . . . regardless of the control inputs, climb performance had already deteriorated to the point where recovery was impossible', p 29.

Insofar as the first conclusion is concerned, I agree the pilot's reaction may have been understandable. However, the question the Board must answer is, was it the correct or best decision. The Board has a statutory responsibility to prevent similar accidents from occurring, and in carrying out this responsibility it must evaluate the facts objectively. If an erroneous or not-the-best decision is made, the Board should focus upon this fact in the interest of accident prevention.

As to the second conclusion, I do not believe it is a valid statement. Based upon the computer analysis and the CVR transcript, it appears the aircraft still had some climb capability, even at 178 kns. There was no immediate need to reduce airspeed by 42 kns since the altitude at this point was 1,700 ft. Therefore, the report should have contained a critical analysis of the captain's decision to reduce airspeed from approximately 178 kns, while the aircraft still had climb capability, to $V_2 + 3$ (136 kns) by increasing the angle of attack from 9.5^o to 16.4^o 1/.

1/ A speed of V_2 is not necessarily the best speed for maximum climb capability under all conditions. V_2 is the recommended speed for the best climb capability with take-off flaps when the critical engine is lost between 35 ft and 400 ft above the take-off surface.

The captain's decision was made following the low-altitude alert, transmitted at 1412:48 when the aircraft was at an altitude of 1,400 ft and an airspeed of 191 kns. 2/ Following the low-altitude alert, the aircraft continued to climb approximately 300 ft, to 1,700 ft. As a result of the captain's decision at 1413:12, the airspeed was decreased from 178 kns at 1413:24 to 136 kns at 1413:48, and the angle of attack increased from 9.5^{o} to 16.4^{o}. The abrupt reduction in airspeed and increased angle of attack was made within 24 secs and not accomplished incrementally. Further, the aircraft was at the minimum safe altitude of 1,700 ft when the reduction in airspeed was made.

Therefore, in the interest of preventing similar accidents from occurring, I believe the Board should have pointed out that the decision to reduce airspeed to $V_2 + 3$ may not have been the best decision under the circumstances. I agree that there probably should have been some increase in the angle of attack and a reduction in airspeed, but not the substantial and abrupt change that was ordered by the captain. The captain should have first determined if all climb capability was lost, and, if so, reduced airspeed to the flaps-in safety speed of approximately 150 kns which should have produced climb capability despite ice accumulation, rather than abruptly sacrificing 42 kns of airspeed to maintain altitude. If there had not been the abrupt change in airspeed and continuous increase in angle of attack, the accident may have been avoided.

2/ Computer analysis of Flight 103's performance.