Canadian Aviation Safety Board
Bureau canadien de la sécurité aérienne

AVIATION OCCURRENCE REPORT

ARROW AIR INC.
DOUGLAS DC-8-63 N950JW
GANDER INTERNATIONAL AIRPORT,
NEWFOUNDLAND
12 DECEMBER 1985

REPORT NUMBER 85-H50902

Civil Aviation Occurrence Report

Canada

The Canadian Aviation Safety Board investigated this occurrence for the purpose of advancing aviation safety. It is not the object of the Board to determine or apportion any blame or liability.

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SYNOPSIS

The aircraft was on an international charter flight from Cairo, Egypt to Fort Campbell, U.S.A., with planned stops at Cologne, Germany and Gander, Newfoundland. During take-off from Gander, the aircraft crashed and burned approximately one-half mile off the departure end of runway 22. All 256 passengers and crew sustained fatal injuries.

The Canadian Aviation Safety Board was unable to determine the exact sequence of events which led to this accident. The Board believes, however, that the weight of evidence supports the conclusion that, shortly after lift-off, the aircraft experienced an increase in drag and reduction in lift which resulted in a stall at low altitude from which recovery was not possible. The most probable cause of the stall was determined to be ice contamination on the leading edge and upper surface of the wing. Other possible factors such as a loss of thrust from the number four engine and inappropriate take-off reference speeds may have compounded the effects of the contamination.

Ce rapport est également disponible en français.

28 October 1988

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1.0 FACTUAL INFORMATION

1.1 History of the Flight

On 11 December 1985, Arrow Air Flight MF1285R, a Douglas DC-8-63, U.S. registration N950JW, departed Cairo, Egypt on an international charter flight to Fort Campbell, Kentucky (Ky), U.S.A. via Cologne, Germany, and Gander, Newfoundland. On board were 8 crew members and 248 passengers. The flight was the return portion of the second in a series of three planned troop rotation flights originating at McChord Air Force Base (AFB)*, Washington, U.S.A. and terminating in Fort Campbell. The flight had been chartered by the Multinational Force and Observers (MFO) to transport troops, their personal effects, and some military equipment to and from peacekeeping duties in the Sinai Desert. All 248 passengers who departed Cairo on 11 December 1985 were members of 101st Airborne Division (United States Army), based in Fort Campbell.

The flight departed Cairo at 2035 Greenwich Mean Time (GMT)** and arrived at Cologne at 0121, 12 December 1985 for a planned technical stop. A complete crew change took place following which the flight departed for Gander at 0250.

The flight arrived at Gander at 0904. Passengers were deplaned, the aircraft was refuelled, trash and waste water were removed, and catering supplies were boarded. The flight engineer was observed to conduct an external inspection of portions of the aircraft. The passengers then reboarded.

Following engine start-up, the aircraft was taxied via taxiway "D" and runway 13 to runway 22 for departure. Take-off on runway 22 was begun from the intersection of runway 13 at 1015.

The aircraft was observed to proceed down the runway and rotate in the vicinity of taxiway "A". Witnesses to the take-off reported that the aircraft gained little altitude after rotation and began to descend. Several witnesses, who were travelling on the Trans-Canada Highway approximately 900 feet beyond the departure end of runway 22, testified that the aircraft crossed the highway, which is at a lower elevation than the runway, at a very low altitude.

Three described a yellow/orange glow emanating from the aircraft. Two of the witnesses testified that the glow was bright enough to illuminate the interior of the truck cabs they were driving. The third attributed the glow to the reflection of the runway approach lighting on the aircraft.

Several witnesses observed the aircraft in a right bank as it crossed the Trans-Canada Highway. The pitch angle was also seen to increase, but the aircraft continued to descend until it struck downsloping terrain approximately 3,000 feet beyond the departure end of the runway (See Appendix A).

The aircraft was destroyed by impact forces and a severe fuel-fed fire. All 256 occupants on board sustained fatal injuries.

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* See Glossary for all abbreviations and acronyms.

** All times are GMT unless otherwise stated. (GMT equals Newfoundland standard time plus 3 hours and 30 minutes.)

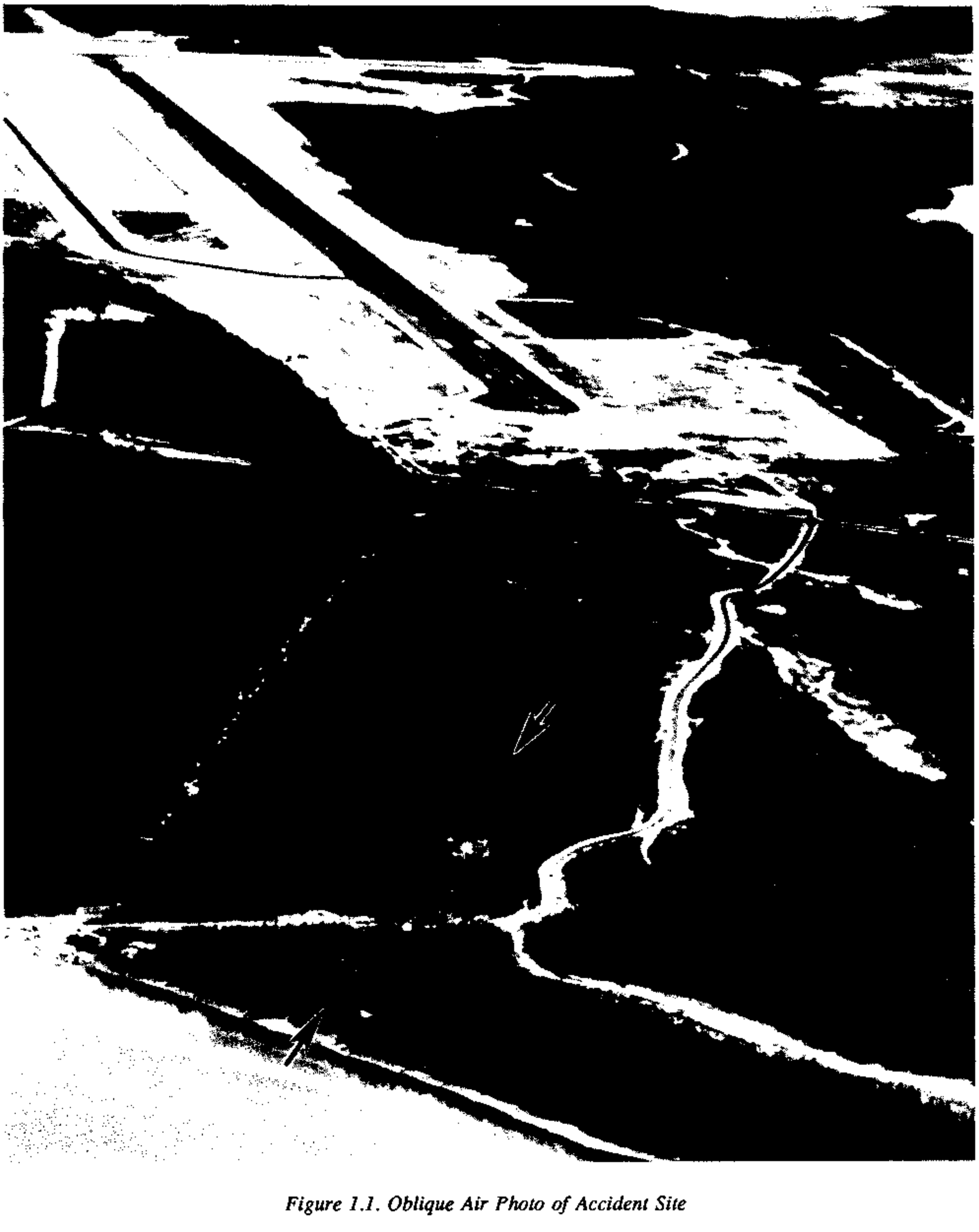

Figure 1.1. Oblique Air Photo of Accident Site

The accident occurred at 1016 during the hours of darkness at lat 48°54'40"N, long 54°34'35"W* at an elevation of 279 feet above sea level (asl).

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	8	248	–	256
Serious	–	–	–	
Minor/None	–	–	–	–
Total	8	248	–	256

1.3 Damage to Aircraft

The aircraft was destroyed.

1.4 Other Damage

The aircraft struck and destroyed an unoccupied shed.

1.5 Personnel Information

	Captain	First Officer	Flight Engineer
Age	45	45	48
Pilot Licence	Airline Transport (U.S.A.)	Commercial (U.S.A)	Flight Engineer (U.S.A.)
Medical Expiry Date	6/2/86	21/3/86	10/5/86
Total Flying Time	7,001 hr	5,549 hr	9,436 hr
Total on Type	1,081 hr	918 hr	1,732 hr
Total Last 90 Days	231 hr	155 hr	247 hr
Total on Type Last 90 Days	231 hr	119 hr	247 hr
Hours on Duty Prior to Occurrence	9 hr	9 hr	9 hr
Hours off Duty Prior to Work Period	15 hr	15 hr	15 hr

The flight crew was qualified in accordance with current U.S. regulations. There was no evidence to suggest that they lacked appropriate experience to conduct the flight safely. They had been flying together as a crew from 01 December 1985 and had accumulated over 55 flight hours.

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* Units are consistent with official manuals, documents, reports, and instructions used by or issued to the crew.

The captain was employed initially by Arrow Air in January 1982 as a Boeing 707 first officer. He was upgraded to captain status in June 1982, and, in September 1982, he was appointed as a Boeing 707 check airman. He later transitioned to the DC-8 as captain and, in September 1983, was appointed chief pilot Boeing 707/DC-8. In 1984, he was appointed as the vice-president and director of Flight Operations but left this management position and returned to the line as a 707/DC-8 captain, continuing as a check-pilot for both aircraft types. His last recurrent DC-8 training was completed in November 1985. The captain occupied the left seat during the accident take-off.

The first officer had been employed by Arrow Air since June 1981. He was initially employed as a Boeing 707 first officer and subsequently transitioned to the DC-8 and then to the DC-10 aircraft. In October 1985, after Arrow Air had cut back its DC-10 operations, he returned to flying the DC-8. His last DC-8 recurrent training was completed at that time. The first officer occupied the right seat and was at the controls at the start of the take-off roll.

The flight engineer had been employed by Arrow Air since 1981. He was qualified on the Boeing 707, DC-8, and DC-10 aircraft. His last recurrent training on the DC-8 was completed in October 1985.

The flight crew was the crew of Arrow Air Flight MF1285, which had originated at McChord AFB on 10 December. The crew arrived in Cologne from McChord AFB at 1031 local time, 11 December 1985. They arrived at their hotel at about 1100 local time and had to wait about 30 minutes before checking in because of a room reservation problem. They left the hotel at 0200 local time, 12 December 1985.

The hotel rooms were determined to be quiet, and there were meal facilities on the premises. The hotel staff was of the opinion that the crew did not leave the hotel during the crew rest period. The captain was reported to be awake from 1900 local time. He used the telephone several times between 1900 and the time of departure to check on the status of the inbound flight from Cairo.

This same crew had also operated the first of the three planned rotation flights from McChord AFB to Cologne, and the return portion from Cologne to Fort Campbell. Between the first and second MFO rotation flights, the flight crew operated flights between Cecil Field Naval Air Station (NAS), Florida; Anchorage, Alaska; Lemoore NAS, California; and Oakland, California.

Upon completion of their 12 December flight to Fort Campbell, it was the stated intention of the crew to ferry the aircraft to Oakland, California, where maintenance was scheduled. No crew rest was planned at Fort Campbell prior to this flight.

The crew's schedule for the month of December 1985 follows.

Place	Local Time	GMT	Ground Time(hr)	Block Time(hr)
* Arr. McChord AFB Area	2155(01)	*** 0555(02)		
** Dep. McChord AFB, Wash.	0218(03)	1018(03)	34:33	
Arr. Gander, Nfld.	1257	1627		6:09
Dep. Gander	1405	1735	1:08	
Arr. Cologne, Germany	2352	2252		5:17
Dep. Cologne	1852(04)	1752(04)	19:00	
Arr. Bangor, Maine	2135	0135(05)		7:43
Dep. Bangor	2235	0235	1:00	
Arr. Ft. Campbell, Ky.	0050(05)	0550		3:15
Dep. Ft. Campbell	0750	1250	7:00	
Arr. Cecil Field NAS,Fla.	0927	1427		1:37
Dep. Cecil Field NAS	1236	1736	3:09	
Arr. Anchorage	1706(05)	0206(06)		8:30
Dep. Anchorage	1940(06)	0440(07)	26:34	
Arr. Lemoore NAS, Calif.	0145(07)	0945		5:05
Dep. Lemoore NAS	1120	1920	9:35	
Arr. Oakland Calif.	1215	2015		0:55
Dep. Oakland (Deadhead)	1545	2345		
Arr. McChord Area	1735	0135(08)		
Dep. McChord	1208(10)	2008(10)	66:33	
Arr. Gander	2312	0242(11)		6:34
Dep. Gander	0030(11)	0400	1:18	
Arr. Cologne	1031	0931		5:31
Dep. Cologne	0350(12)	0250(12)	17:19	
Arr. Gander	0538	0908		6:18
Dep. Gander	0640	1010	1:02	
Accident	0646	1016		

* Arrival
** Departure
*** Date in Brackets December

During the month of November, the captain logged 33 hours 9 minutes of flight time as indicated below:

November 1	2 hr 35 min
November 2	5 hr 50 min
November 3	6 hr
November 4	2 hr 41 min
November 23	5 hr 24 min
November 24	2 hr 25 min
November 26	4 hr 51 min
November 27	3 hr 20 min

In addition, he completed simulator training on 10 and 11 November.

During the month of November, the first officer logged 62 hours 18 minutes of flight time as indicated below:

November 1	2 hr 35 min
November 2	5 hr 50 min
November 3	6 hr
November 4	2 hr 41 min
November 7	3 hr 15 min
November 8	6 hr 15 min
November 9	2 hr 42 min
November 10	3 hr 23 min
November 11	5 hr 40 min
November 14	2 hr 38 min
November 16	53 min
November 17	8 hr 26 min
November 20	2 hr 35 min
November 22	6 hr 38 min
November 23	2 hr 47 min

During the month of November, the flight engineer logged 64 hours 15 minutes of flight time as indicated below:

November 1	7 hr 46 min
November 2	8 hr
November 4	7 hr 50 min
November 5	8 hr 21 min
November 6	8 hr 16 min
November 7	8 hr 15 min
November 8	7 hr 32 min
November 9	8 hr 15 min

1.6 Aircraft Information

Manufacturer	Douglas Aircraft Company
Type	DC-8-63
Year of Manufacture	1969
Serial Number	46058
Certificate of Airworthiness	Valid
Total Airframe Time	50,861 hr
Engine Type (4)	Pratt & Whitney JT3D-7
Maximum Allowable Take-off Weight	355,000 lb
Recommended Fuel Type	Jet A or Jet B

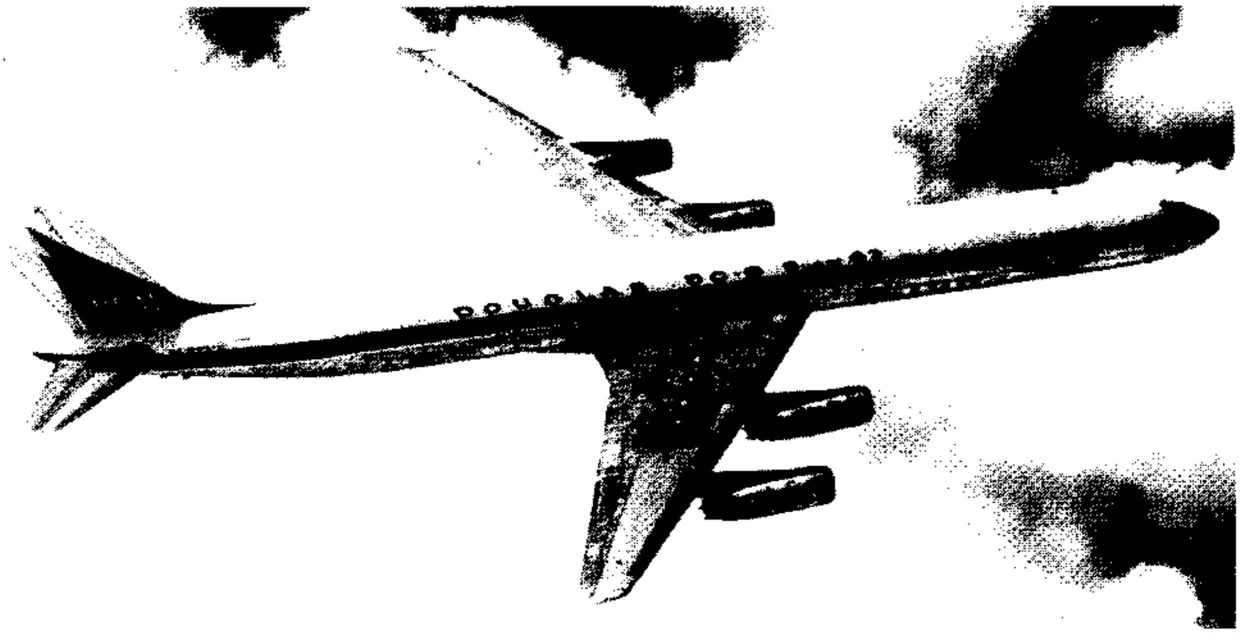


Figure 1.2. DC-8-63 Aircraft

The maximum allowable zero fuel weight (ZFW) was 230,000 pounds. The crew-calculated weight and centre of gravity for the departure from Gander were within the prescribed limits.

The aircraft was owned by International Air Leases and leased to Arrow Air in October 1984.

Prior to departure from McChord AFB on 10 December 1985, the aircraft had undergone maintenance at Oakland, California to rectify a number of deferred maintenance items (DMIs), including action to correct a reported rubbing associated with movement of the co-pilot's control yoke. The action taken was a check and cleaning of the area under the cockpit floor, following which it was noted that the yoke operated normally with no rubbing. The aircraft departed Oakland for McChord with the following four DMIs remaining.

DMI Number	MEL* Ref.	ITEM
21052	None	Forward belly door balance cable broken (deactivated door).
20980	33-1	Pilot overhead control lights rheostat inoperative.
20979	None	Altimeter bug guards missing.
21017	52-1	Belly door light remains on.

* MEL - minimum equipment list.

Aircraft log sheets pertaining to flights after arrival in McChord AFB, on 10 December 1985, were not recovered. It was determined from the crew who flew the Cologne/Cairo flight sectors on 11/12 December that no further unserviceabilities had been entered prior to the aircraft's departure from Cologne on 12 December 1985. Servicing action in Cologne upon return from Cairo had included an oil top-up on each engine, the addition of seven quarts of hydraulic fluid to the hydraulic system, filling of the aircraft water system, and attempts to repair a leaking coffee maker.

No mention of any unserviceabilities was made by crew members to the servicing crew at Gander. The servicing crew did not observe any abnormalities with the aircraft.

The crew who flew the aircraft on the Cologne/Cairo flight sectors reported that there was a "ratchetting" when the co-pilot's control column was moved. This ratchetting was described as a clicking sound accompanied by a soft vibration and slight restriction in movement near the forward limit of the column travel. This information was passed verbally to the repair technician in Cologne, but no attempt was made to trouble-shoot the defect, nor was any entry made in the aircraft log.

The number four engine exhaust gas temperature (EGT) was reported to be indicating about 40 degrees hotter than the other three. The crew was adjusting the throttle during take-off and climb to keep the EGT under limiting values. Reportedly, this condition had existed for some time and was known to the crew of the accident flight. A review of the aircraft maintenance records determined that this temperature differential had been entered on previous occasions and was believed to be the result of a problem with the temperature indicating system.

The Board held a public inquiry into this accident in April 1986. At the inquiry, conflicting testimony was heard regarding the in-flight illumination of an engine thrust reverser unlocked light. The co-pilot and flight engineer of the Cologne/Cairo sectors reported that one of four such lights was occasionally illuminating in light turbulence during cruise. They could not identify the specific engine, but the first officer believed it was either the number three or the number four. The captain did not recall such illumination, nor could he recall any such observation by the other flight crew members.

Similarly, there was conflicting testimony regarding two missing side panels in the number three cargo pit. The flight engineer on the Cologne/Cairo sector testified that, while supervising the loading of the aircraft in Cairo, he observed that the panels were missing, and, as a result, fluid lines were exposed. He further testified that he informed the captain. The captain testified that he could not recall being so advised by the flight engineer.

In May 1981, the aircraft experienced an uncontained failure of the number one engine during take-off at Casablanca, Morocco. Considerable shrapnel-type damage was sustained by both wings, the landing gear, and the horizontal stabilizer. Major repairs, including the repair of punctures and dents to the ailerons, flaps, and horizontal stabilizer, were carried out by the aircraft operator, Union des Transports Aériens, after the accident, and the aircraft was returned to service. As part of the repair process, engineering drawings were submitted to Douglas Aircraft Co. for their approval. The repairs, as planned by the operator, were approved by Douglas Aircraft Co., subject to certain conditions. Certain repairs were considered by Douglas to be temporary in nature and therefore life-limited. It was their recommendation that these repairs be replaced after a specific number of flight hours and, in the interim, be subject to inspection at regular intervals.

In November 1981, the aircraft was sold and imported back to the United States. At that time, Federal Aviation Administration (FAA) Form 337, Major Repair and Alteration, was completed by the vendor. The specific repairs accomplished were identified, and replacement and inspection cycles as recommended by Douglas Aircraft Co. were detailed.

No evidence was found to indicate that the specific inspections had been carried out. However, the repairs were in locations that would normally be inspected during routine inspection cycles.

In June 1984, repairs to the trailing edge honeycomb panels of the left and right wings, which were nearing the end of their life-limits as recommended by Douglas Aircraft Co., were inspected by an FAA designated engineering representative. As a result of this inspection, replacement of the honeycomb panels was extended to the next heavy check, subject to the inspection cycle recommended by Douglas Aircraft Co.

At the Board's public inquiry, Arrow Air's Director of Maintenance testified that he had been unaware of the Casablanca accident and subsequent repairs to the aircraft. He had no knowledge of the required inspection cycle or the life-limits on the repairs accomplished in 1981. Examination of the aircraft records determined that, although a heavy check had been accomplished after June 1984, replacement of the trailing edge repairs had not occurred. The life-limits on the other repairs had not been reached at the time of the accident.

In the days following the accident, numerous individuals came forward to relate their observations regarding the condition of the aircraft and to describe certain events that had occurred in the several months preceding the accident. Most of these observations related to the condition of the cabin and were considered by the Board to be primarily cosmetic in nature. Several of the observations did relate to the airworthiness of the aircraft and were determined to be either unserviceabilities that had been entered in the aircraft technical log and rectified or claims that could not be confirmed.

A review of aircraft servicing and maintenance records for the six-month period from June to December 1985 revealed that replenishment of aircraft hydraulic fluid was a recurring action. In the two days prior to the accident, 13 quarts (six quarts at McChord AFB and seven quarts at Cologne) of fluid were added to the system.

The aircraft potable water system had a history of leaks. The most recent maintenance on the system was performed at Oakland prior to the initiation of the 10 December flight from McChord AFB. In response to a maintenance entry that indicated that the system supply line was leaking in the number three cargo pit, the following rectification was entered: "Replaced line at seat 27 ABC. Replaced line in forward pit #1, lav line broken."

The water system was again leaking when the aircraft arrived at McChord on 10 December 1985. It was reported that potable water was not available to the rear lavatory. Problems with the system were mentioned by the captain in a telephone call from Gander to Arrow Air dispatch in Miami, just prior to the accident. The system was last filled prior to departure from Cologne on 12 December 1985.

Upon completion of the December 10/12 rotation flights, the aircraft was to be ferried to Oakland for replacement of the number four engine T-3 turbine disk which had 88 hours of service life remaining.

1.7 Meteorological Information

1.7.1 General

On 12 December 1985, the Gander weather was dominated by a deep, almost stationary, low pressure system situated about 250 miles south of Greenland. This low produced a moist northwesterly flow, giving overcast conditions with occasional light snow, very light snow grains, and very light freezing drizzle.

1.7.2 Forecast Weather

The 12 December area forecast for the Fortune, St. Georges, Exploits, and Bonne Bay Regions issued at 0530Z, valid for the period 0600 to 1800Z, forecast ceilings of 1,500 to 2,500 feet above ground level (agl), with cloud tops 6,000 feet agl. Visibility was forecast to be two to six miles in light snow showers.

For the eastern regions, where an onshore or upslope flow was present, forecast ceilings were 500 to 1,500 feet agl with occasional light freezing drizzle.

Light to moderate rime icing in cloud was forecast except for moderate clear icing in the light freezing drizzle. The freezing level was forecast to be at the surface.

The terminal forecast for Gander, issued at 0430Z 12 December, indicated an overcast ceiling at 1,500 feet agl, accompanied by light snow showers, variable to an overcast ceiling at 500 feet agl, with visibility reduced to two miles in light snow showers and occasional light freezing drizzle.

1.7.3 Surface Observations

The Gander weather was generally as forecast. Throughout the evening of 11 December and the early morning hours of 12 December, ceilings varied between 500 and 1,400 feet agl, with visibilities between 2 1/2 and 12 miles. Precipitation was present in the form of light to very light freezing drizzle, snow grains or snow.

Surface observations from Gander taken between 0600Z and 1030Z were as follows:

0600Z	measured ceiling 1,400 ft broken, 2,800 ft overcast, visibility 10 mi in light snow, barometric pressure 1011.6 mb, temperature -4°C, dew point -5°C, wind 330°T at 4 kt, altimeter setting 29.84 in. Hg, strato cumulus 6 tenths, strato cumulus 4 tenths.
0645Z (Special)	measured ceiling 1,200 ft overcast, visibility 2 1/2 mi in light snow grains, wind 330 T at 5 kt, strato cumulus 10 tenths.
0700Z	measured ceiling 1,200 ft broken, 2,200 ft overcast, visibility 2 mi in light snow grains, barometric pressure 1011.6 mb, temperature -4°C, dew point -5°C, wind 330°T at 4 kt, altimeter setting 29.85 in. Hg, strato cumulus 8 tenths, strato cumulus 2 tenths.
0740Z (Special)	600 ft scattered, measured ceiling 1,200 ft broken, 2,200 ft overcast, visibility 5 mi in very light freezing drizzle and light snow grains, wind 300°T at 5 kt, stratus fractus 3 tenths, strato cumulus 5 tenths, strato cumulus 2 tenths.

0800Z	600 ft scattered, measured ceiling 1,200 ft broken, 2,000 ft overcast, visibility 8 mi in very light freezing drizzle and light snow grains, barometric pressure 1011.6 mb, temperature -4°C, dew point -5°C, wind 300°T at 5 kt, stratus fractus 3 tenths, strato cumulus 5 tenths, strato cumulus 2 tenths.
0900Z	600 ft scattered, measured ceiling 1,200 ft broken, 2,200 ft overcast, visibility 10 mi in very light freezing drizzle and light snow grains, barometric pressure 1011.6 mb, temperature -4°C, dew point -5°C, wind 300°T at 4 kt, altimeter setting 29.85 in. Hg, stratus fractus 5 tenths, strato cumulus 4 tenths, strato cumulus 1 tenth.
0945Z (Special)	700 ft scattered, measured ceiling 1,200 ft overcast, visibility 12 mi in very light snow grains, wind 290°T at 4 kt, stratus fractus 5 tenths, strato cumulus 5 tenths.
1000Z	700 ft scattered, measured ceiling 1,200 ft overcast, visibility 12 mi in very light snow grains, barometric pressure 1011.8 mb, temperature -4°C, dew point -5°C, wind 290°T at 4 kt, altimeter setting 29.86 in. Hg, stratus fractus 5 tenths, strato cumulus 5 tenths.
1030Z (Accident Special)	700 feet scattered, measured ceiling 1,200 ft broken, 2,500 ft overcast, visibility 12 mi in very light snow grains, barometric pressure 1011.8 mb, temperature -4°C, dew point -5°C, wind 290°T at 2 kt, altimeter setting 29.85 in. Hg.

(For definitions of precipitation types and rates see Appendix B.)

1.7.4 Precipitation and Surface Temperature Record

Between 0600 and the time of the accident, the surface temperature recorded at Gander ranged between -3.8 and -4.2 degrees Celsius. The dew point ranged between -4.5 and -5.1 degrees Celsius.

Precipitation in the form of light snow fell from 0600 to 0645. Light snow grains commenced at 0645 and continued until 0945. Very light freezing drizzle was reported between 0740 and 0945. Between 0945 and the time of the accident, recorded precipitation consisted only of very light snow grains.

Weather observations at Gander are taken from two locations. The primary observation site is located on the roof of the terminal building; a second observation site is located at ground level about 200 feet from the terminal building. When freezing precipitation is present or suspected, weather observers use an ice accretion indicator composed of a small piece of aluminum alloy similar to that found in aircraft structure. It is placed outside at the observation site and inspected for the presence of freezing precipitation at each observation. Mandatory weather observations are taken every 30 minutes, at the hour and half hour.

When freezing precipitation is present, the indicator is removed and a new one installed at each mandatory observation. Prior to installation, the indicator is pre-cooled to ambient temperature. Thus, when observed at the next observation following installation, the indicator shows the type and quantity of freezing precipitation which occurred in the previous 30 minutes.

The weather observer on duty at the time of the occurrence testified at the Board's public inquiry that, in the several hours preceding the accident, he had made regular visits to both observation sites to check on the icing indicators. He stated that, at his 0900 observation, he observed a small amount of freezing drizzle on the indicator at the roof observation site. He described it as small areas comprising 10 to 15 per cent of the surface area of the indicator. Also present, mixed in with the freezing drizzle, were snow grains which had adhered to the surface of the indicator. Together, the freezing drizzle and snow grains covered approximately 30 per cent of the indicator's surface. The result was a thin, rough layer resembling medium grit sandpaper which could be removed with a finger-nail. The indicator at the ground level observation site was substantially the same. As a result of this observation, the precipitation on the 0900 surface observation report was indicated as very light freezing drizzle and light snow grains.

Following the 0900 observation, the indicators at both observation sites were changed in accordance with standard procedure. The freezing precipitation observed on this indicator at 0930 again consisted of freezing drizzle mixed with snow grains, but the quantity was less than that observed at 0900. However, the texture of the surface was the same, and the decrease in quantity was not sufficient to result in a change to the precipitation indicated on the 0900 surface observation report.

Following the 0930 report, the indicators were again changed. They were inspected at 0943, at which time, only snow grains were observed in a small quantity. There was no freezing drizzle present. As a result of this observation, the observer determined that the freezing drizzle had ended and that the intensity of the snow grains had reduced. Accordingly, a special weather observation report was issued at 0945 which indicated precipitation as very light snow grains.

Similar observations of small amounts of snow grains were made at 1000 and 1030. During his several visits to the observation site after 0945, the observer did not observe any evidence of freezing drizzle.

Throughout the period, no appreciable difference was noted between the indicators at the two observation sites.

Precipitation accumulation is measured over a six-hour period. The measurements pertinent to the accident were for the period 0601 to 1200Z, 12 December 1985. In that time, the measured precipitation was freezing drizzle - trace (less than 0.2 millimetres); snow grains 0.2 centimetres, water equivalent 0.2 millimetres.

1.7.5 Pilot Reports

A British Aerospace VC-10 aircraft landed at Gander at 0626, approximately four hours before the accident, and departed Gander at 0716, three hours before the accident. The flight crew of this aircraft reported that no significant icing was encountered on either approach or departure. Precipitation described as light grainy snow was reported during the approach, station stop, and departure. No significant or unusual weather conditions were encountered.

A Boeing 737 aircraft departed Gander approximately 45 minutes after the arrival of MF1285R and 30 minutes before the accident. The pilot of that aircraft testified that the cloud base was about 700 feet agl, with cloud tops about 4,000 feet asl. During climb-out, he encountered moderate icing in cloud. He estimated that it took approximately one minute to climb through the cloud layer. During this time, he observed about one-quarter inch of ice accrete on the windscreen centre post. Below the cloud, he did not perceive any icing, either in flight or during the taxi out on the take-off roll. It was his belief that the ice which did accumulate on the aircraft was mainly clear ice. The ice did not present any difficulties because of the very short duration of time spent in cloud. It dissipated quickly after climbing clear of cloud. He further testified that the flight conditions after take-off were smooth. No turbulence or wind shear was experienced.

A Piper PA-31 landed on runway 31 at Gander at 1016, approximately 30 seconds after the accident. The crew of this aircraft reported icing conditions in the cloud layer between 4,000 feet asl and 700 feet agl. The icing was sufficient to obscure the view from the cockpit. Only a small area of the windshield was reported to be clear. Precipitation described as drizzle was reported to be falling. No other significant or unusual weather conditions were reported.

About 20 minutes after the accident, another Boeing 737 aircraft landed at Gander. The captain of that aircraft testified that, during his approach to land, cloud tops were encountered at about 4,000 feet asl, and the cloud base was about 700 feet agl. He could not recall encountering any icing. He did encounter very light precipitation below cloud. He described it as a very light drizzle but could not determine if it was freezing drizzle. Flight conditions on approach were further described as smooth with light wind and no turbulence.

1.8 Aids to Navigation

The Gander Area Control Centre (ACC) is equipped with an Airport Surveillance Radar (ASR-5)and a Joint En Route Terminal System (JETS) which is an automated system that provides tracking of secondary surveillance radar data which are displayed to the controller in alphanumeric format. Altitude is determined from Mode C output of the aircraft transponder and indicates in 100-foot increments above sea level. Altitude data are provided to the transponder from either the pilot's or co-pilot's normal static system; true altitude is about 35 feet less than indicated altitude at 165 knots indicated airspeed (KIAS). Ground speed is computed from the smoothed velocity vector and is essentially a weighted average of the track speed.

Radar data are not recorded at Gander. However, the departure controller observed the secondary radar target of the aircraft as it moved down the runway. The data block ground speed increased to 150 knots, and the Mode C altitude readout remained at 500 feet asl throughout the attempted take-off. The target was observed to move to a position about one quarter of a mile beyond the departure end of the runway, where it entered the "coast" mode. At no time did the altitude reading change from its initial reading of 500 feet.

1.9 Communications

The flight crew received taxi clearance to runway 22 at 1009. Their instrument flight rules (IFR) clearance was received and read back while taxiing. During taxi, the crew was asked to expedite taxiing because of traffic on a 12-mile final approach to runway 31. The aircraft was then directed to turn right onto runway 22, and, at 1014, take-off clearance was issued and acknowledged. Take-off did not commence until approximately 45 seconds after the take-off clearance was acknowledged. There were no further transmissions from the aircraft after the acknowledgement of the take-off clearance.

1.10 Aerodrome Information

Gander International Airport is a publicly licensed airport owned and operated by Transport Canada. It is located adjacent to the town of Gander, Newfoundland. The airport reference elevation is 496 feet asl.

Runway 22 is 10,500 feet long by 200 feet wide and asphalt surfaced. The runway incorporates a 300-foot displaced threshold leaving a take-off run available (TORA) and accelerate-stop distance available (ASDA) of 10,200 feet. The take-off distance available (TODA) is 11,200 feet (including a 1,000-foot clearway), and the threshold elevation is 452 feet asl. The threshold elevation of runway 04 is 425 feet asl, which results in an average runway downslope of 0.25 per cent. (See Figure 1.3.)

MF1285R taxied for departure via runway 13/31 and turned right onto runway 22. From the point where the take-off was commenced, about 300 feet of the available take-off distance was behind the aircraft, thus the take-off run available for departure was approximately 9,900 feet.

In order to use all 10,200 of the runway, it would have been necessary for the aircraft to back-track a short distance to the north of runway 13/31. On the morning of the accident, the portion of runway 22 north of runway 13/31 had not been cleared of snow.

Beyond the departure end of runway 22, the terrain slopes down quickly to Gander Lake, located about one mile from the end of the runway. The Trans-Canada Highway crosses the extended runway centre line at a right angle about 900 feet beyond the end of the runway. Where the two intersect, the highway is 38 feet below the elevation of the departure end of the runway.

For several hours prior to the departure of MF1285R, light to very light precipitation in the form of snow, snow grains, and freezing drizzle had been falling. As a result, airport maintenance crews had been, and were continuing to plough, sweep, and apply urea to the runways. A runway condition report was issued at 0810Z. The reported condition for runway 22 was 40 per cent bare and wet, 60 per cent rough ice, with the centre 100 feet of the runway urea treated. On arrival, the pilot of MF1285R reported to air traffic control (ATC) that the landing braking action on runway 04 was good.

The pilot of a Boeing 737 aircraft which departed Gander about 30 minutes before the accident reported after the accident that runway 22 was wet with possibly some ice and slush. He experienced no difficulties of any kind during taxi and take-off.

1.11 Flight Recorders

The aircraft was equipped with a Sundstrand AV-557A cockpit voice recorder (CVR) and a United Control FA542 flight data recorder (FDR).

The CVR retains the last 30 minutes of four channels of information, recording them on an eight track reversing one-quarter-inch tape made of Vicalloy that travels at a speed of two and three-quarter inches per second.

The FDR scribes measurements of pressure altitude, indicated airspeed, magnetic heading, and vertical acceleration on a 4.9-inch-wide stainless steel foil moving at 0.1 inch per minute. The

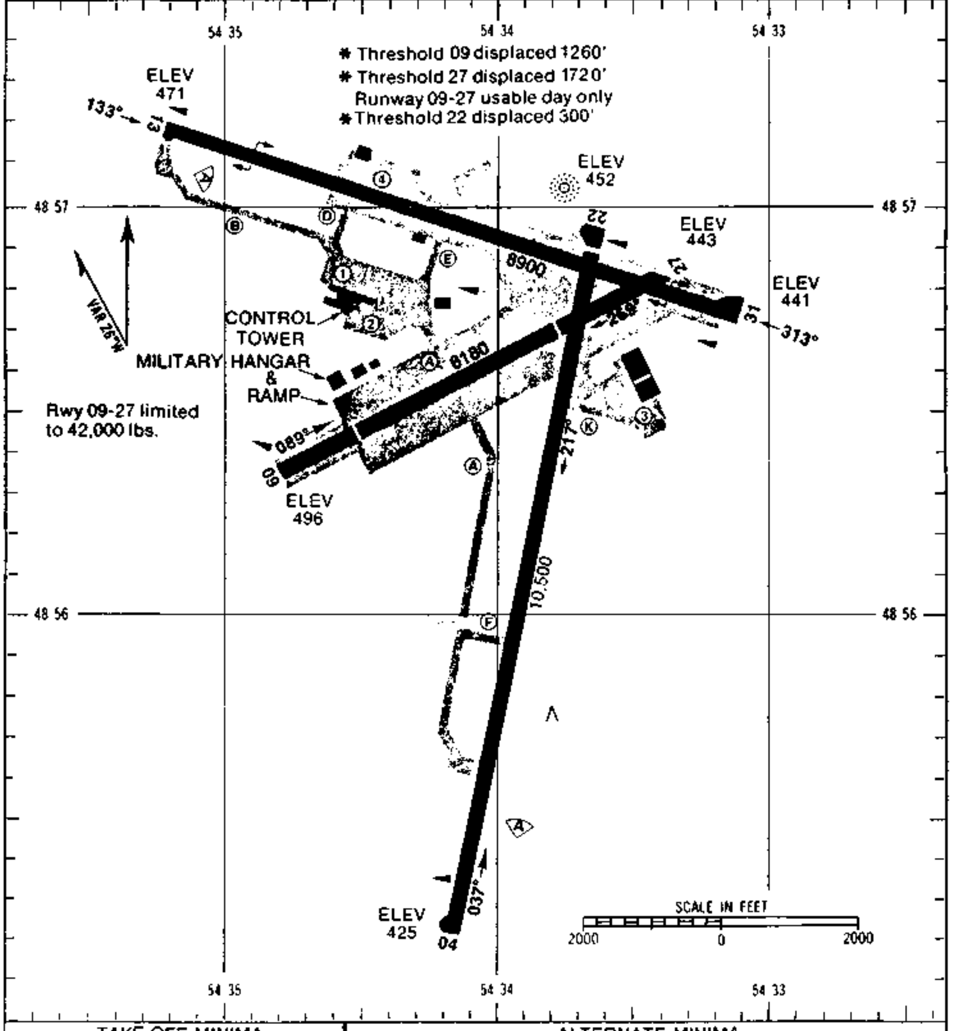
AERODROME CHART

Produced by Surveys and Mapping Branch
Department of Energy, Mines and Resources

GANDER INTL
GANDER NEWFOUNDLAND

VOT	GND	TWR	DEP
114.8	121.9 275.8	118.1 236.6	128.5 384.5

DECLARED DISTANCES	04	* 22	* 09	* 27	13	31		
TORA	10,200	10,200	3200	3200	8900	8900		
TODA	11,050	11,200	4200	4200	9900	9900		
ASDA	10,500	10,200	3200	3200	8900	8900		
LDA	10.500	10,200	3200	3200	8900	8900		


54 35
54 34
54 33
* Threshold 09 displaced 1260'
* Threshold 27 displaced 1720'
Runway 09-27 usable day only
* Threshold 22 displaced 300'
ELEV 471
133°
13
ELEV 452
48 57
22
ELEV 443
8900
27
ELEV 441
31
313°
VAR 29°W
CONTROL TOWER
MILITARY HANGAR & RAMP
8180
Rwy 09-27 limited to 42,000 lbs.
089°
09
ELEV 496
217°
10,500
48 56
ELEV 425
04
037°
SCALE IN FEET
2000
0
2000
54 35
54 34
54 33

TAKE-OFF MINIMA	ALTERNATE MINIMA				
Standard	CATEGORY	A	B	C	D
	PRECISION	600-2			700-2
	NON PRECISION	800-2			

AERODROME CHART *CHANGE* Hangar & ramp designated military

EFF 14 FEB 85

GANDER NEWFOUNDLAND
GANDER INTL

Figure 1.3. Gander International Airport Diagram

scribe marks are discrete samples made at one-second intervals, except for the vertical acceleration which is normally recorded 10 times per second. Other continuously marking stylii record one-minute time intervals, times of all radio transmissions, and whether the recorded heading is in the northerly or southerly sector of the compass. The foil length of 200 feet provides for 400 hours of recording on one side of the foil. The unit was last calibrated on 11 November 1982.

Both recorders were recovered from the accident site on the afternoon of the accident and were immediately flown to the Flight Recorder Playback Centre (FRPC) of the National Research Council for readout and analysis.

1.11.1 Cockpit Voice Recorder Playback

When the CVR was opened, it was found that the Vicalloy tape was broken in two places close to the tape reels with the piece of tape between the two breaks still in position around the capstans and the tape heads. Tape breakage of the type observed has been found in other accidents and is attributed to impact forces. Apart from the breaks, the tape was undamaged.

The pilot and co-pilot audio channels on the tape and the service interphone channel were found to be recorded normally. The cockpit area microphone channel, although it contained some level of indeterminate wide-band noise, did not have any of the normal crew conversation or background cockpit noise. Some very faint indecipherable voices were judged to be cross-talk from the pilot's audio channels. Occasional microphonic sounds were similar to those observed when the metal tape was momentarily disturbed close to the recording head. At the time of the accident, a number of brief higher amplitude signals were detected. These were determined to be the result of electrical disturbances associated with aircraft breakup.

1.11.2 Flight Data Recorder Readout

When the foil was examined under the microscope of the coordinate measuring machine, it was found that the altitude, airspeed, and heading stylus marks were of the normal elongated shape, although there was an irregularity in spacing of the discrete marks which was probably caused by imperfections in the torque applied to the take-up spool. This irregularity caused a small jump in foil movement every three to four seconds of a type that is frequently observed on this type of recorder.

The vertical acceleration stylus marks were substandard. Instead of fine marks from the pyramid-pointed stylus 10 times per second, there were only three or four overlapping round indentations between every jump in foil motion, suggesting that the indentations were being made only about once every second.

Because of the irregularities in the operation of the FDR, extraction of reliable data proved difficult. The coordinates of the stylus marks were initially read and converted into engineering units using standard calibrations. The initial data plots were then updated upon receipt of the recorder's last bench calibration report. Several attempts were then made to further refine the data. These attempts included a lengthy and time-consuming effort to recover and plot individual points of airspeed, altitude, and magnetic heading, assuming a one-second interval between stylus marks, thus circumventing the time errors due to fluctuations in the foil speed.

In order to provide some comparative data to check the validity of the recorder data, measurements were also made of the previous take-off from Cologne en route to Gander. As a further check of airspeed data and to determine the approach descent profiles, similar measurements were made of the approach and landing at Gander. The accuracy of the airspeed trace was considered to be better than plus or minus five knots.

Prior to the take-off, measurements were also made of the distance along the foil at which a stylus that was in continuous contact with the foil indicated keying of the radio transmitters. This procedure established correlation of the arbitrary elapsed time of the foil data with the GMT recorded on the ATC tape.

The recovered data are illustrated at Figure 1.4. The data plot represents an elapsed time of 1 minute 40 seconds commencing at 1014:33. Measurements were terminated where normal progression of the foil ceased. Subsequent to these points, a large number of stylus marks were evident for each parameter, all at approximately the same distance along the foil. These marks were assumed to have occurred during structural breakup.

Analysis of the recorded data indicated that the take-off roll commenced at 1015:06. Thereafter, airspeed increased steadily to a peak value of 172 KIAS 53 seconds after commencement of the take-off roll, and then decreased.

Examination of the vertical acceleration trace determined that lift-off occurred about 51 seconds after the commencement of the take-off roll.

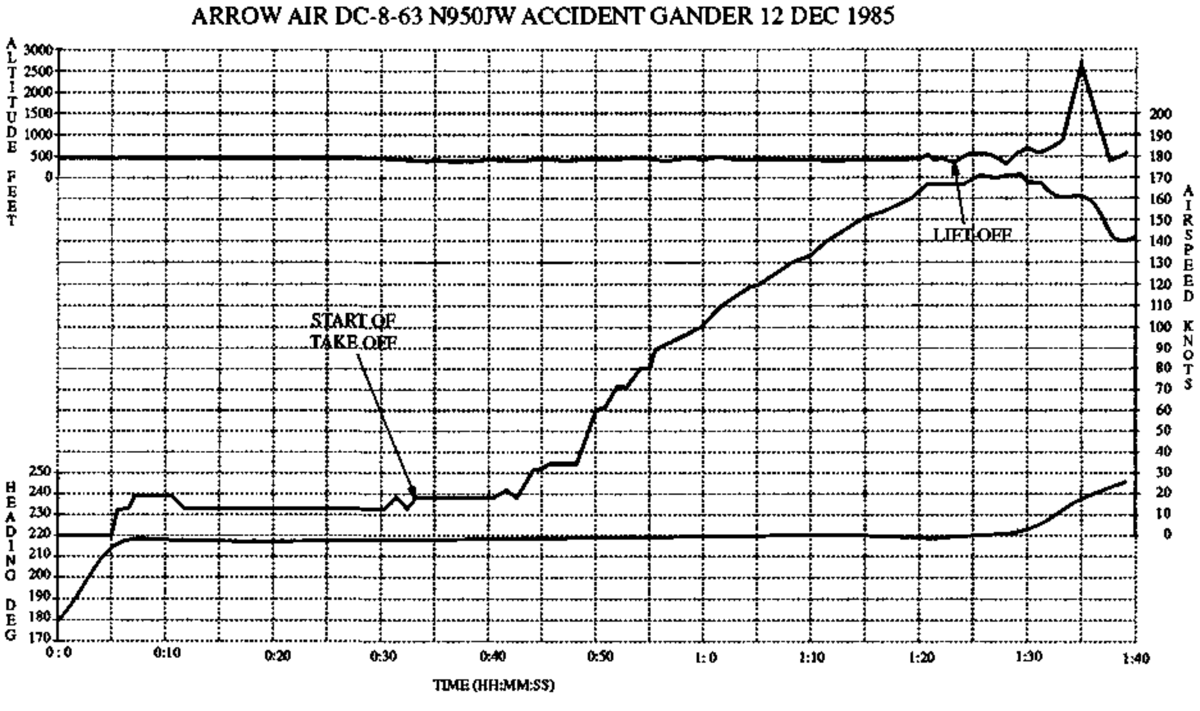


Figure 1.4. FDR Information for Accident Flight

Based on integration of the true airspeed with allowance for the reported wind, at 51 seconds after brake release, the aircraft was about 8,000 feet from the starting point of the take-off roll and crossed the end of the runway about 57 seconds after the start of the take-off.

As the maximum recorded airspeed was reached, the altitude measurements started to oscillate in an extreme manner. The fluctuations were too large to represent actual height variations and were therefore assessed to be largely due to static pressure errors associated with stall buffet.

No reliable time sequence of vertical acceleration values suitable for estimating flight path was derived. In addition, actual vertical acceleration could not be calculated because pitch and roll information was not available. It was determined that, within a few seconds of lift-off, the recorded vertical acceleration value reached a peak value of 1.26G (where 1.0G corresponds to level flight condition), decreased to about 0.88G, and subsequently oscillated between values as high as 1.30G and as low as 0.77G. During the last few seconds before impact, the values were almost entirely below the 1.0G level, reaching a minimum value as low as 0.72G.

The aircraft heading began to deviate to the right at about the time the peak airspeed was achieved. The heading continued to deviate to 25 degrees right of the runway heading before the FDR ceased operation.

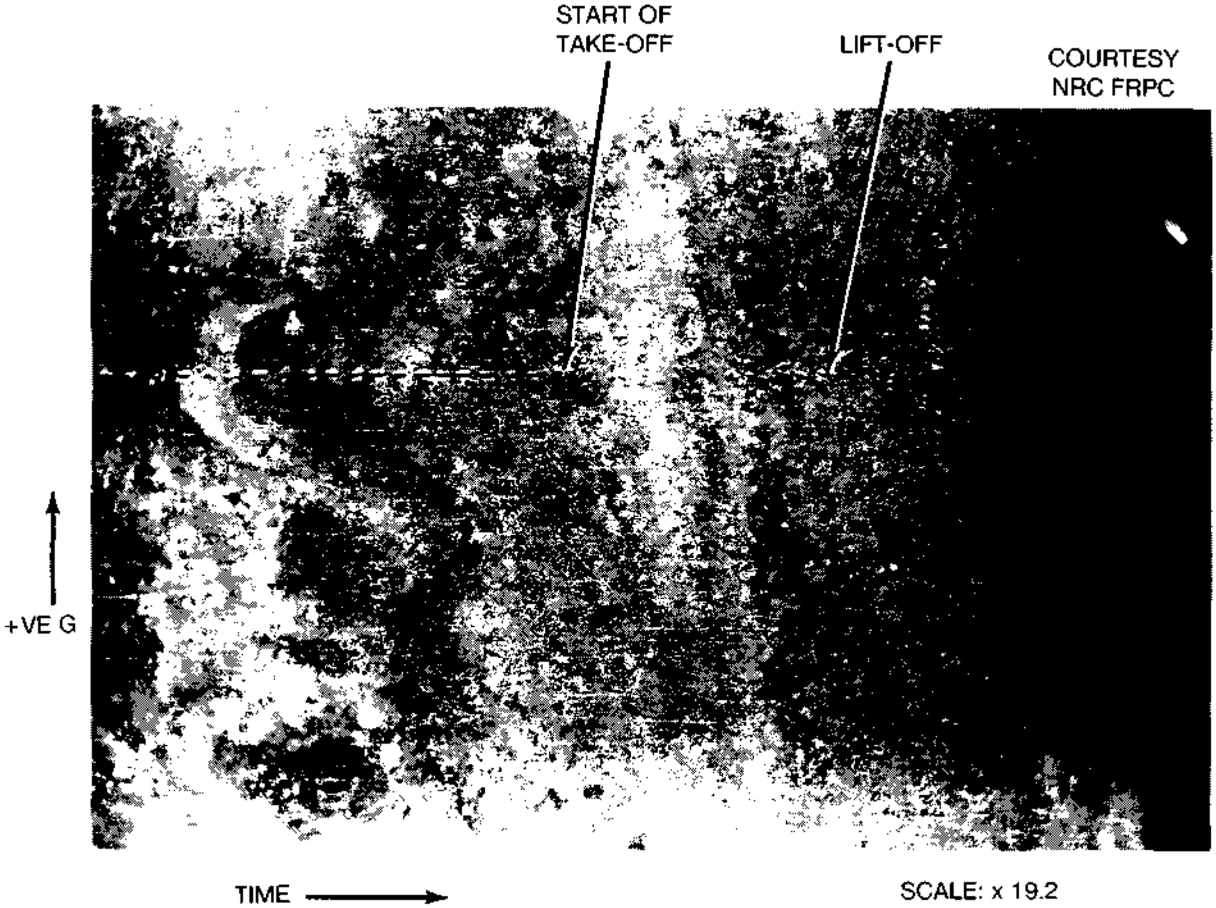


Figure 1.5. Photo of FDR Vertical Acceleration Trace

1.12 Wreckage and Impact Information

1.12.1 General

The aircraft struck downsloping terrain near the top of a wooded hillside, 2,975 feet beyond the departure end of runway 22, a distance of 720 feet to the right of the extended runway centre line. Initial impact with the terrain was a tree strike at an elevation of 279 feet asl. Ground elevation at this point is approximately 240 feet asl.

From that point, the aircraft continued its descent into the trees; initial ground impact occurred 920 feet beyond the first tree contact.

The wreckage trail was about 1,300 feet long and 130 feet wide. The trail was on a track of 240 degrees magnetic (M). The mean downslope of the terrain over which the wreckage was spread was seven degrees.

1.12.2 Breakup Sequence

Two separate and distinct swaths were cut by the aircraft as it initially descended into the tree canopy. Upon investigation, it was apparent that the lower of the two swaths, to the left when viewed in the direction of flight, was cut by the horizontal stabilizer and that the higher swath, to the right side, was cut by the right wing. The tree-swath pattern was consistent with a nose-high, right-wing-low attitude at impact.

As the aircraft descended lower into the trees, the different elevations of the two swaths evened out until there was no discernible difference at the point of ground impact.

Significant portions of the horizontal stabilizer and elevators had separated from the aircraft and were found between the initial tree strike and the point of ground impact. Portions of the right wing tip were also found between these two points. Damage patterns found on the leading edge of the wing tip, stabilizer, and elevator were consistent with a nose-up attitude and slight yaw to the right at impact.

At ground impact, the right wing sustained extensive damage. Both the number three and number four engines were torn from their pylons. A fuel-fed fire commenced at the impact point of the number four engine and spread down and across the wreckage trail in a diagonal manner toward the left side of the aircraft. The aircraft then began to yaw further to the right, and the empennage separated at the rear pressure bulkhead.

The remainder of the aircraft continued down the sloping terrain where it struck two rock outcrops, breaking off a substantial portion of the rear fuselage aft of the wings. By this point, the aircraft had yawed approximately 60 degrees to the right. The forward and centre sections of the fuselage then crossed a gravel access road where the left wing, remaining portions of the right wing, and cockpit section separated.

The centre section of the fuselage continued down the slope for a short distance where it came to rest in a shallow ravine. The lower portion of the wreckage trail was subjected to a severe fuel-fed fire which consumed a substantial portion of the wreckage.

A thorough search of the runway and the area between the runway end and initial impact point was conducted with the assistance of personnel from Canadian Forces Base Gander. No components or debris was located that could have come from the aircraft. There was no evidence that the aircraft tail had touched the runway during the take-off. (See Figure 1.6.)

1.12.3 Wreckage Examination

An extensive examination of the wreckage was conducted over a period of several months. Initial examinations at the site were conducted to locate and identify as many of the remaining components as possible. Selected items were recovered from the wreckage and moved to a secure area for further examination. Certain items were then shipped to the CASB's Engineering Laboratory in Ottawa for detailed examination and analysis.

The initial examination of the accident site and wreckage was hampered by falling snow. Within five days of the accident, a thick layer of snow blanketed the site. As a result of the combined effort of the United States Army, the Royal Canadian Mounted Police (RCMP), and the CASB, a second examination of the site was conducted between 05 January and 07 February 1986. The site was systematically cleared of trees, tents were erected, snow melted, and detailed documentation and examination of the site completed.

All wreckage was recovered from the site and moved to a secure hangar at the Gander Airport, where it was arranged in a grid pattern which matched the grid pattern established at the site. A

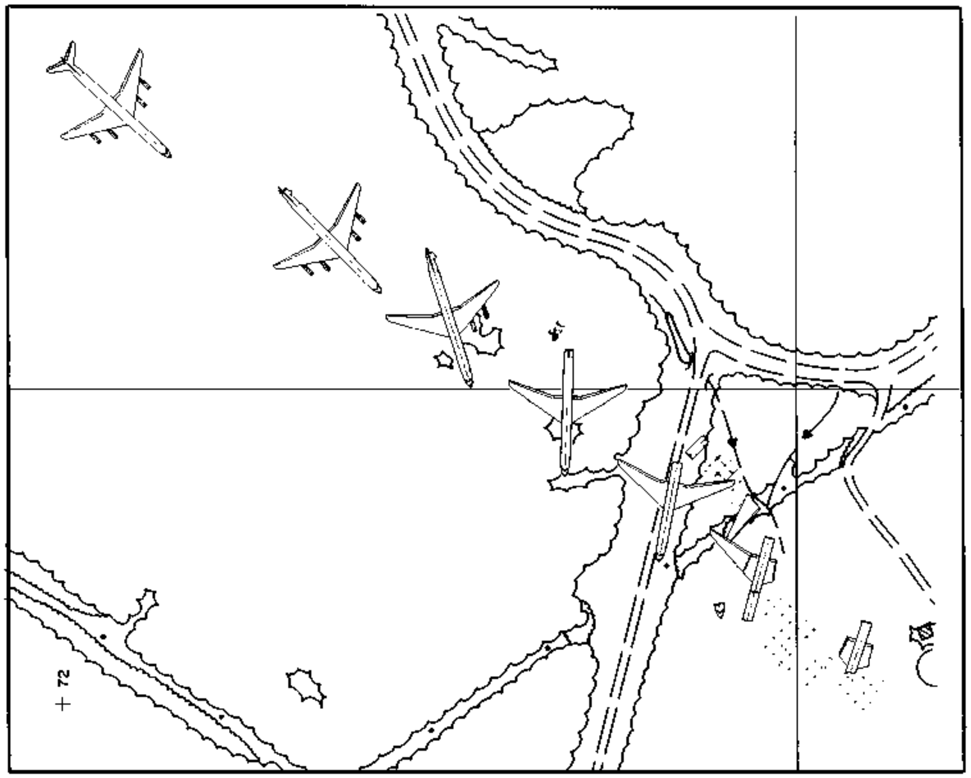


Figure 1.6. Aircraft Breakup Sequence

thorough examination of the wreckage was completed, and further selected components were forwarded to the CASB's Engineering Laboratory in Ottawa.

1.12.4 Description of Damage

1.12.4.1 Structures

Most of the wing was destroyed by impact. Significant portions were consumed by the intense post-crash fire. About 75 per cent of the aileron and flap surfaces were identified; however, less than 50 per cent of the spoiler surfaces were found. From the wreckage available for examination, no evidence was found of any pre-impact failure to the wing or any of its components.

The empennage had separated from the fuselage just forward of the rear pressure bulkhead. Portions had been subjected to the post-crash fire. The rudder was attached to the vertical fin and found at an angle of about 15 degrees left of neutral, with rudder trim at two degrees left of neutral. The upper parts of both components had been burned away. The root end of the right side of the horizontal stabilizer was still attached, and the jackscrew was still connected to the stabilizer. The amount of exposed thread corresponded to a 5.85-unit nose-up (ANU) stabilizer angle (this corresponds to a 6 ANU stabilizer angle on the flight-deck indicator +/-1 unit). The remainder of the right side of the stabilizer and all the left side had separated in several pieces after the first tree impact. The aircraft tail skid was recovered and examined. There was no evidence (i.e. scrape marks) that the empennage had struck the runway during take-off.

Reassembly of the separated portions of the stabilizer showed massive tree-impact damage. The elevators were damaged to a lesser extent due to the protection afforded by the stabilizer. Witness marks on the leading edge were consistent with an elevator position at impact of between 25 and 30 degrees trailing edge up. Impact damage at the hinges caused by overtravel was also consistent with an elevator-up position at impact.

Detailed examination of the elevator revealed the presence of a two-inch chordwise scratch on the leading edge of the left elevator. Corresponding to this mark was a mark on the plate covering the lightening holes in the left stabilizer rear spar. The nature of the marks was such that they could have been the result of a foreign object interfering with the movement of the elevator. It could not be determined if the marks were the result of impact or if they had existed prior to impact. There was no evidence of any pre-impact failure to the empennage or its components.

The fuselage had fractured into several sections and was substantially consumed by fire. From the wreckage available for examination, there was no evidence of any pre-impact failure associated with the fuselage.

Further examination of the wreckage was undertaken by a consultant employed by representatives of Arrow Air. This consultant found what he believed might be evidence of pre-impact explosive damage to the aircraft fuselage. The evidence consisted of a hole, roughly eliptical in shape, in a section of fuselage wall just aft of the right side forward door. The material that surrounded the hole exhibited an outward pucker, and the hole was assessed to be the result of an object striking the interior of the fuselage at high speed. A second hole was found in another unidentified section of fuselage. This hole was somewhat larger and also displayed outward deformation of the fuselage skin. As a result of his observations, the two sections of fuselage were subjected to additional examination at the Royal Canadian Mounted Police Central Forensic Laboratory and the CASB Engineering Laboratory. These examinations found no evidence to support the consultant's view that the holes had been caused by a pre-impact explosion. Forensic examination found no evidence of foreign material or explosive residue. The hole in the fuselage wall section aft of the right side forward door was attributed to an object being forced through the fuselage during breakup. In their examinations, CASB investigators observed other instances of curled over fractures (up to 360 degrees) which were directly attributable to impact damage which occurred during breakup. In the case of the second, larger hole, CASB investigators observed that the degree of curling at the edges of the hole was less than that of the other hole and that the edges were burned thin and were brittle, evidence of intense heat. The curled edges of this hole were attributed to sagging of the structure in the intense heat of the post-crash fire.

1.12.4.2 Systems Examination

The extensive impact and fire damage precluded a complete examination of the aircraft systems. As a result, the pre-impact integrity of the aircraft systems could only be determined as described below.

The systems examination was confined to an assessment of the position and pre-impact serviceability of individual components. In certain cases, fire had destroyed identification data plates. This made it impossible to determine the original position on the aircraft of a part, where there was more than one of a specific type in any one system. Where necessary and possible, examination of system components included internal examination and functional testing.

Both aileron actuators were recovered; however, no other aileron system components other than linkages adjacent to the actuators were found. The position of the ailerons at impact could not be determined. No pre-impact faults were noted in the components examined.

No identifiable sections of the elevator control system between the flight deck and the rear pressure bulkhead were located during the wreckage examination. The control linkage in the aft section of the fuselage was broken and had torn loose. All damage appeared to have been impact related.

No components of the rudder control system forward of the rear pressure bulkhead were found. The rudder hydraulic power package was in good condition with no external indication of pre-impact damage either to the package or to the attaching controls or linkages. The pack was removed, functionally tested, and no evidence of pre-impact faults was found.

The six flap actuators were recovered and examined to determine piston extension at impact. The cylinders were sectioned lengthwise, and the interior surfaces were examined. The severe post-accident corrosion of four of the cylinders precluded any determination as to the piston extension at impact. The two remaining cylinders were in good condition. Examination and analysis of the impact marks were not conclusive but suggested that flap position at impact was less than 25 degrees.

Eight of 10 flap tracks were recovered and examined for marks resulting from abnormal roller contact at the time of ground impact. Roller positions for various flap settings were measured on another DC-8-63 for comparison purposes. Multiple imprints were evident on most tracks. The most distinct marks were considered to be the most probable position at initial impact. Of the eight tracks recovered, only two could be identified as to installed position on the aircraft. These were the outboard flap, outboard tracks from each wing. Roller imprint marks on the right wing track were consistent with a flap position of 18 degrees. Several marks were observed on the left wing tracks consistent with a flap position between 5 and 12 degrees. Only one outboard flap centre track was recovered. It could not be determined on which wing it had been installed. Roller imprints on this track were consistent with a flap position of 17 degrees. Both outboard flap, inboard tracks were recovered, although installed position (i.e., left or right wing) could not be determined. Roller imprints on these tracks were consistent with a flap position of 23 degrees and 32 degrees respectively.

Both inboard flap, outboard tracks were recovered, although again, installed positions could not be determined. Imprint marks on one of these tracks were contradictory. Marks on the left-hand side of the track were consistent with a flap position of 50 degrees. Those on the right-hand side of the track were consistent with a flap position of 23 degrees. Imprints on the other inboard flap, outboard track were consistent with a flap position of 24 degrees. Only one inboard flap, inboard track was recovered. Again, it could not be determined on which wing it had been installed. Imprint marks on this track were consistent with a flap position of 18 degrees.

The three flap lockout cylinders were recovered and examined in an attempt to determine piston extension at impact. Each cylinder has an indicator rod to show the position of the piston. This rod is extended out of the cylinder when the flaps are up and is retracted when the flaps are extended. The three cylinders were severely fire damaged. The indicator rod of the outboard cylinder was fully retracted. All connections and the guide for the rod were burned away; the piston was partially melted. The mid-wing lockout was found with the piston at approximately mid-travel, and the piston was partially melted. The inboard indicator was in the fully retracted position. The piston was almost completely burned away; the end cap, including the indicator rod guide, was missing and appeared to have been destroyed by burning while still in place.

Since the outboard and mid-wing flap actuators are attached to a single flap panel which is sufficiently rugged to withstand significant twisting, it would not be possible for the outboard lockout cylinder to be fully retracted at the same time as the mid-wing cylinder was at half travel, unless a hydraulic line to the outboard actuator had ruptured. Similarly, for the inboard lockout cylinder to be in the fully retracted position, it would require rupture of a hydraulic line to an inboard actuator. The probability of two independent and simultaneous pre-impact hydraulic line ruptures is considered remote. Thus, it was apparent that some movement of the lockout cylinder pistons had probably occurred during aircraft breakup or the post-impact fire. Post-impact movement of the pistons was further supported by the extensive fire damage sustained by the lockout cylinders. Furthermore, the flap full-down position suggested by the inboard and outboard lockout cylinders was not supported by the roller imprint marks on the flap tracks. Thus, the condition of the three cylinders was such that no meaningful or reliable information with respect to flap position at impact could be determined.

The flap position indicator was recovered and examined. The pointer was relatively loose in the instrument and thus free to rotate, making the reading as found (38 degrees) unreliable. There was no impact damage within the instrument which would permit the determination of pointer position at impact.

Three of four wing slot actuators were recovered. One was fully extended, another was in the fully retracted position. The third, which was attached to a section of the left wing outboard slot, was found in the mid-travel position. However, upon examination, it was evident that this actuator had been in the extended position during the ground fire. The operation of the slot system is such that, when open, the outboard actuators extend, and the two inboard actuators retract. The installed position on the aircraft of the other two recovered actuators could not be determined because of the absence of data plates. There was no evidence of pre-impact failure in the three actuators recovered.

Both lateral control spoiler actuators were recovered. Piston extension was consistent with spoilers extended on the left wing and retracted on the right wing. The control lever and linkage for the ground spoiler system were not recovered. The hydraulic actuator was recovered in the fully extended position, which is consistent with spoilers retracted. There was no evidence of pre-impact failure in either system.

The only major components recovered from the hydraulic system were two engine-driven pumps. They were severely damaged by the impact, but there was no evidence of pre-impact failure.

Thirteen of 16 fuel valves were recovered. Valve position at impact could not be determined.

The landing gear selector was not recovered. Examination of the landing gear hydraulic actuators and landing gear determined that the landing gear was extended at impact.

The shut-off valves for the wing leading edge and horizontal stabilizer de-icing system were recovered and examined. All were determined to be in the closed position. The type of valve installed is spring-loaded to the closed position, thus the valves close when electrical power is lost. Accordingly, no useful information regarding the operation of the ice protection system was gained.

The four fire extinguishing agent containers installed in the aircraft wings were recovered from the accident site. One container remained fully charged, while the other three had been discharged. Each container incorporates two discharge valves, and the plumbing and control system permits the agent in either container of one wing to be directed into either engine on that wing. Each discharge valve is operated by an electrically initiated explosive cartridge which fires a small projectile to rupture a diaphragm and release the agent. The agent in the containers can also be released as a result of thermal discharge. This occurs when the pressure within the container reaches a preset value and a pressure release disc is ruptured. This feature prevents the container from rupturing due to internal pressure increase as a result of the container being exposed to excessive temperatures. Examination of the three discharged containers showed one with two small raised areas on the exterior surface, each diametrically opposite to the discharge valves, indicating that the projectiles had been fired after the agent had been discharged thermally during the post-impact fire. A second container had no raised areas on the exterior surface. When the discharge valves for this container were disassembled, the discharge projectiles were found in place, indicating that this container had also discharged thermally during the post-impact fire.

The third container also had no raised areas on the exterior surface. Disassembly of the discharge valves for this container revealed that one explosive cartridge had been fired. The absence of any raised areas on the container surface opposite the position of the discharge valves indicated that firing of the explosive cartridge and release of the projectile had occurred while there was still agent in the container to dampen the force of the projectile and prevent denting of the container surface. Examination of the aircraft records determined that the third container had been installed in the right wing of the aircraft. The installation of the container was reviewed with reference to maintenance manual drawings and through examination of the containers installed in the right wing of another DC-8 aircraft. This review determined that the discharge valve with the fired cartridge corresponded to the number three engine.

The main instrument panel with instruments was recovered relatively intact, but severely damaged. The recovered items, which included light bulbs from various warning, caution, and annunciation light systems, were subject to detailed examination and analysis at the CASB's Engineering Laboratory.

Most instruments recovered were either too severely damaged for analysis or revealed no significant or reliable impact readings.

Examination of the four engine pressure ratio (EPR) gauges revealed the following impact readings:

Number 1 engine - EPR 1.88;
Number 2 engine - EPR 1.34;
Number 3 engine - EPR 2.04;
Number 4 engine - EPR 1.96.

The co-pilot's airspeed indicator sustained only minor damage. The airspeed indicator was equipped with an external circumferential ring with two moveable plastic "bugs" which are normally used to mark reference speeds during the take-off and approach phases of flight. Upon examination, these two external reference "bugs" were found at settings which corresponded to speeds of 144 knots and 185 knots. An internal reference "bug", located behind the glass face of the instrument and controlled by a rotary knob, was found at a setting which corresponded to a speed of 158 knots.

The captain's airspeed indicator sustained significant burn damage. The internal bug was burned into position at 172 knots. No external "bug" ring was found on this instrument; it was determined that there was none installed at the time of the accident. The airspeed pointer indicated 165 knots.

A number of warning, caution, and annunciator lights were determined to be illuminated at impact. The time required for a light bulb of the type used to reach full incandescence is approximately 50 milliseconds. Thus, the breakup sequence of the aircraft must be considered in any assessment of the significance of the illumination of individual lights. Experience has shown that the illumination of lights is often the result of system failures caused by the gradual breakup of an aircraft. Thus, given the gradual breakup of the aircraft as it proceeded down the wooded slope, the illumination of any individual light is not considered reliable evidence of an aircraft system fault prior to impact.

The Master Fire Warning Light was recovered and examined. One of two bulbs in this light was determined to be off at impact. Examination of the other bulb was inconclusive.

One of four Engine Compartment Fire Warning Lights was recovered from the accident site and examined. It was determined to be off at impact.

Certain other lights considered to be relevant to the determination of the pre-impact integrity of aircraft systems were determined to be off at impact: PTC (pitch trim compensator) - Extend/Fail; Hydraulic Reservoir Low Pressure; Rudder Control Manual; and Wing Slot Door.

1.12.4.3 Engines

All four engines were found within the confines of the wreckage area. They had broken loose from their mountings and had lost their cowlings during impact. The engines and their accessories were recovered from the accident site and shipped to the CASB's Engineering Laboratory in Ottawa for detailed examination and analysis.

The damage patterns observed in the numbers one, two, and three engines were consistent with ground impact at high rotation speed. The front compressor assemblies on all three had sustained catastrophic damage, and the compressor rear hub was twisted off in torsional overload. The front compressor turbine shafts were twisted in excess of 30 degrees. The rear compressor on engines one and three were destroyed. The number two engine rear compressor was relatively undamaged. However, it was noted that this section of the engine had not sustained any crushing of the structure surrounding the rear compressor. The accessory gearbox drive coupling on all three engines had failed due to torsional overload.

Damage patterns in the turbine sections varied between the three engines. However, it was evident that the variation in damage was the result of differences in the amount of damage sustained by the surrounding structure.

The bleed valves on engines one, two, and three were determined to be in the closed position at impact, which is consistent with engine operation at high power. Metallization (impingement on hot surfaces in the engine of semi-molten aluminum alloy and titanium from a damaged compressor) was present in the transition duct in all three engines.

The damage sustained by the number four engine was consistent with a lower rotation speed at impact than that of the other three engines. Only the first two stages of the front compressor were damaged as a result of rotation, and little rotational damage was noted on the front compressor/shaft/turbine combination. The bleed valve was determined to be in the open position at ground impact. Debris from trees was found on the valve duct wall on both sides of the valve. The rear compressor and its turbine, however, showed heavy rotational damage at the fifteenth and sixteenth stage compressors and first stage turbine, consistent with some engine rotation at impact. Metallization (aluminum alloy and titanium) was present in the transition duct.

None of the engines displayed any physical evidence of pre-impact distress. Each had ingested debris during impact with the trees and ground. The number four engine displayed the greatest amount of wood ingestion. During engine disassembly, most of the wood debris was found in the high pressure section of the compressor.

The difference in impact rpm between the number four engine and the other three engines could not be precisely determined. Several attempts were made to determine the impact rpm of the number four engine through measurement and analysis of the front compressor turbine shaft torsional twist. An initial attempt resulted in an estimated ground impact rpm well below the normal engine-out windmill rpm. This estimate was determined to be invalid because it assumed that torsional twist of the shaft occurs entirely within the proportional limit of the elastic region, whereas permanent twist can only occur if the shaft has plastically deformed and thus requires a plastic analysis. Further attempts by the engine manufacturer and CASB investigators, both of which assumed plastic deformation properties, resulted in contradictory findings. The manufacturer's analysis concluded that the ground impact rpm of the number four was only between 12.9 and 14.0 per cent lower than that of the other three engines. The analysis conducted by CASB investigators concluded that ground impact rpm was between 40 and 43 per cent of maximum rpm. Due to the contradictory nature of the conclusions of these analyses and the requirement to, in each case, make a number of assumptions, it was not possible to attach a high degree of reliability to either conclusion. However, the open engine bleed valve found on examination of the number four engine is consistent with engine rpm at or below 53 per cent N_1.

The engine fuel control units (FCU) were recovered from the site and disassembled at the Air Canada maintenance facility in Montreal under the control and supervision of CASB investigators.

No pre-impact failures were noted with the exception of a ruptured pressure regulator valve diaphragm in one FCU. The serial numbers of only two of the recovered FCU's matched those recorded in the aircraft records. The records indicated that these two FCU's had been installed on the number three engine and number four engine. The serial number of the FCU with the ruptured diaphragm did not match any of the serial numbers recorded in the aircraft records. However, its location in the wreckage suggested that it had been installed on the number four engine. All four units were free of contamination and, except for the ruptured diaphragm, were assessed as being in good condition.

It could not be determined if the diaphragm had ruptured prior to or as a result of impact. Except for the split in the diaphragm material, the diaphragm was in otherwise good condition, no deterioration in the fabric was noted. Ruptures of the type found are commonly found in fuel systems following a crash. They result from fuel pressure spikes which occur during aircraft breakup when fuel lines are pinched and collapsed. Tests conducted using an otherwise serviceable unit with the ruptured diaphragm installed indicated that the regulator was adjustable with the ruptured diaphragm. For a given throttle position, 6 per cent more fuel than normal would have been supplied to the engine with the ruptured diaphragm.

Three of the four fuel pumps were recovered and disassembled. No contamination or pre-impact failures were noted. Four fuel booster pumps were recovered and disassembled. No contamination or pre-impact failures were noted. A check of the serial numbers of these components determined that the serial numbers recorded in the aircraft technical logs did not match the serial numbers of the components installed on the aircraft. Installed positions could not be determined.

Three of the four engine constant speed drives were recovered and disassembled. No pre-impact failures were noted. They were assessed as being in good condition. Two of the recovered constant speed drives were determined to be from the numbers one and two engines. The installed position of the third recovered constant speed drive could not be determined. Only remnants of the fourth constant speed drive were recovered.

All eight engine inlet guide vane anti-icing valves were recovered. All valves were open, consistent with engine anti-ice being on at impact.

A separate examination of the engines was conducted by the same consultant employed by representatives of Arrow Air who had found what he believed to be was possible evidence of a pre-impact explosion in sections from the fuselage. This examination concentrated on inspection of the engine inlet guide vanes to see if evidence of engine ingestion of fuselage debris could be detected. His examination of what had been identified as the inlet guide vanes of the number three engine found three consecutive vanes which displayed a slight flattening on the leading edge. Examination of these vanes at moderate magnification showed that the middle one had a faint marking of red-orange color on the leading edge. The consultant hypothesized that the marks on the vanes were the result of ingestion of fuselage debris which had originated from what he considered to be a pre-impact explosion occurring just aft of the right side forward door. Later examination by CASB investigators determined that the inlet guide vanes in question were from the number one engine, and not the number three engine. It was further noted that the guide vanes had been subjected to intense heat during the post-crash fire and that any colouring material present prior to the fire would likely have burned off. Lastly, the red-orange colour observed on the guide vane was almost identical to that of the front-end loader which had been used to recover the engines from the accident site. Numerous examples of this post-accident red-orange paint transfer from the recovery machinery were evident on all four engines. CASB investigators concluded that the marks and colouring on the guide vanes occurred after impact, during wreckage recovery.

A consultant employed by a representative of one of the deceased flight crew members examined the engines and observed metal and fibre particles and what he considered to be unusual sooting in the area of the fuel nozzles of the number four engine. As a result, the number four engine fuel nozzles were removed from the engine and bench tested at the maintenance facility of a major Canadian airline. This testing was carried out by technicians of the airline experienced in the testing of fuel nozzles and in assessing their condition. No blocked nozzles were detected, and, in the opinion of the technicians, the flow patterns of all nozzles were acceptable. There were only a few nozzles where the fuel flow was not even throughout the full 360 degrees. Although they did not consider the condition of these nozzles to be suitable for installation in a newly overhauled engine, they were considered acceptable as in-service components. The technicians stated that any effect these nozzles could have had on engine operation would have been unmeasurable.

Further examination of the engine by CASB investigators found no evidence of heat distress indicative of poor nozzle flow patterns on any of the combustion chambers. The metal and fibre particles found on the nozzles were assessed to be the result of the tree/ground impact sequence. The particles covering the nozzle orifices were not solidly encrusted since they were easily pushed aside by the fuel flow – the nozzles were not mechanically cleaned prior to the test. The fibre particles were identified as wood particles. The metal particles were assessed to be from the compressor section of the engine and the result of engine breakup during the impact sequence. The titanium and aluminum alloy metallization on the surface of the transition ducts of all four engines confirms that debris was being propelled through the engines during the breakup sequence.

The sooting in the area of the nozzles was considered consistent with the disruption of engine airflow and resulting changes to the fuel/air mixture that would have occurred due to tree ingestion.

At the request of the Board, additional examination of the number four engine was undertaken by an independent metallurgical engineer. The primary purpose of this examination was to assess the pre-impact condition of the engine and estimate its power output at impact. Upon completion of his examination and analysis, the consultant concluded that:

1. The number four engine did not exhibit any component failure or malfunction prior to impact with the trees.

2. The number four engine had not flamed out by the time of initial impact with trees.

3. The number four engine was damaged due to ingestion of tree fragments and ground impact.

4. The number four engine bleed valve opened due to engine deceleration that most likely occurred as a result of ingestion of tree fragments.

5. The number four engine power setting at initial tree impact could not be established with certainty; however, the observed engine damage caused by tree fragment ingestion and resulting deceleration was consistent with high power setting.

1.12.4.4 Thrust Reversers

All four engine thrust reverser assemblies were recovered from the accident site and subjected to detailed examination and analysis.

The deployment of the thrust reversers involves two actions: the rearward movement of the translating ring with the deflector doors in the faired position; and a final rearward movement of the translating ring (approximately seven inches) during which the stop on the latch rod contacts and operates an actuating mechanism, causing the deflector doors to open. The deflector doors can only be in the deployed position if the translating ring is in the full-aft position. (See Figure 1.7.)

The number one reverser was heavily damaged by impact but had remained relatively intact. The engine exhaust nozzle had separated from the engine at the aft engine flange and remained trapped inside the reverser assembly. The outboard deflector door was pulled slightly aft but was essentially faired with the translating ring. The inboard door was pulled partially out at the forward edge and the rear edge had buckled the adjacent area of the translating ring inward. Examination of the deflector door upper actuating arm showed marks in the slots adjacent to the arm, evidence that the doors were faired at impact. The skin and structure around the lower actuating arm was deformed inward, trapping the arm in the deflector door closed position. Further evidence that the translating ring had been in the forward position was provided by the position of the slider on the lower track; it was found close to the forward end of the track. It was concluded that the number one reverser assembly had been in the forward thrust position, with the deflector doors faired and the translating ring in the forward position (stowed) at impact.

The number two reverser assembly was substantially damaged and torn into a number of separate pieces at impact. The engine exhaust nozzle had torn from the engine just aft of the rear flange. The translating ring and the deflector doors were heavily damaged by impact. The aft mount of the reverser lower track remained attached to the nozzle together with the slide and a portion of the lower forward section of the reverser translating ring. The slide was towards the aft end of the track but was still more than 16 inches forward of the rear stop. Only the outboard door remained attached to the largest piece of the translating ring. When recovered, this door was in the faired position relative to the ring structure but was not trapped solidly in this position, and movement could have occurred during breakup. However, witness marks at the upper actuating arm of the outboard door indicated that it was in the faired position at the time of major crush. The inboard deflector door was torn into two main pieces. A heavy scrape mark in the material at the edge of the slot around the inboard door lower actuating arm gave clear indication that the door had been pulled from the faired position during ground impact. The outer cylinder of the hydraulic actuator was found near the forward end of the piston rod; the cylinder wall was ruptured longitudinally from an internal overpressure. Such damage could only occur if the piston rod, which is attached to the translating ring, was forward when ground contact caused it to be moved violently aft relative to the pylon. It was concluded that the number two reverser was not in the reverse thrust position at impact. The position of the slide on the lower track was attributed to scrubbing action during impact which occurred before the slider was trapped by track deformation.

The number three reverser had been completely flattened during impact, trapping the engine exhaust nozzle inside the translating ring, clear evidence that the reverser was in the stowed position at impact. The slide was near the forward end of the track. The inboard deflector door was torn in two. The lower portion was trapped in the faired position.

The outboard deflector door was also torn in two. Both the upper and lower sections were found in the faired position relative to the attached pieces of the translating ring. The hydraulic actuator had broken away from the reverser and the pylon. The gland nut and inner sleeve were at the forward end of the piston rod, and the cylinder was split longitudinally from internal overpressure. This overpressure damage was consistent with the translating ring being in the forward position at impact. It was concluded that this reverser assembly was in the forward thrust position with the deflector doors faired and the translating ring in the forward (stowed) position at impact.

The number four reverser assembly had separated from the exhaust nozzle at impact. The forward loop of the translating ring assembly was broken with pieces missing from both sides. The lower deck was twisted 180 degrees around the rear section of the ring so that the forward face of the upper part of the translating ring was at one end of the assembly and the forward face of the lower portion was at the other end. The outboard deflector door was trapped by the structure in the faired position at the lower hinge point. The metal skin in this area was deformed inward, trapping the actuating arm in the faired position. The upper actuating arm for this door was torn away from the translating ring, but there were clear witness marks on the slot edge showing that the arm was in the faired position at the time this damage occurred (Figure 1.8.). The inboard deflector door was torn away from the upper attachment point and was twisted to the deployed position. There was moderate to heavy damage to the forward edge of this door. There were deformed areas to the aft end of the actuating arm slots at both the upper and lower hinge points, evidence that the actuating arms for the inboard deflector door were also in the faired position at impact (Figure 1.9. and Figure 1.10.). The lower track was severely twisted but remained attached by the slide bracket to the forward edge of the translating ring. The slide was within 12.5 inches of the forward position and could not have slid forward after this impact deformation had occurred (Figure 1.11.). The hydraulic actuator was near the forward end of the piston rod. The outer cylinder had split lengthwise, with the material around the split bowed out (Figure 1.12.). This evidence was consistent with rapid extension of the actuator by external forces, and further confirmed that the translating ring had been in the forward position at the time of ground impact. It was concluded that the number four reverser was in the faired position with the translating ring in the forward (stowed) position at ground impact.

No failures were noted in any of the four reverser systems other than those resulting from impact.

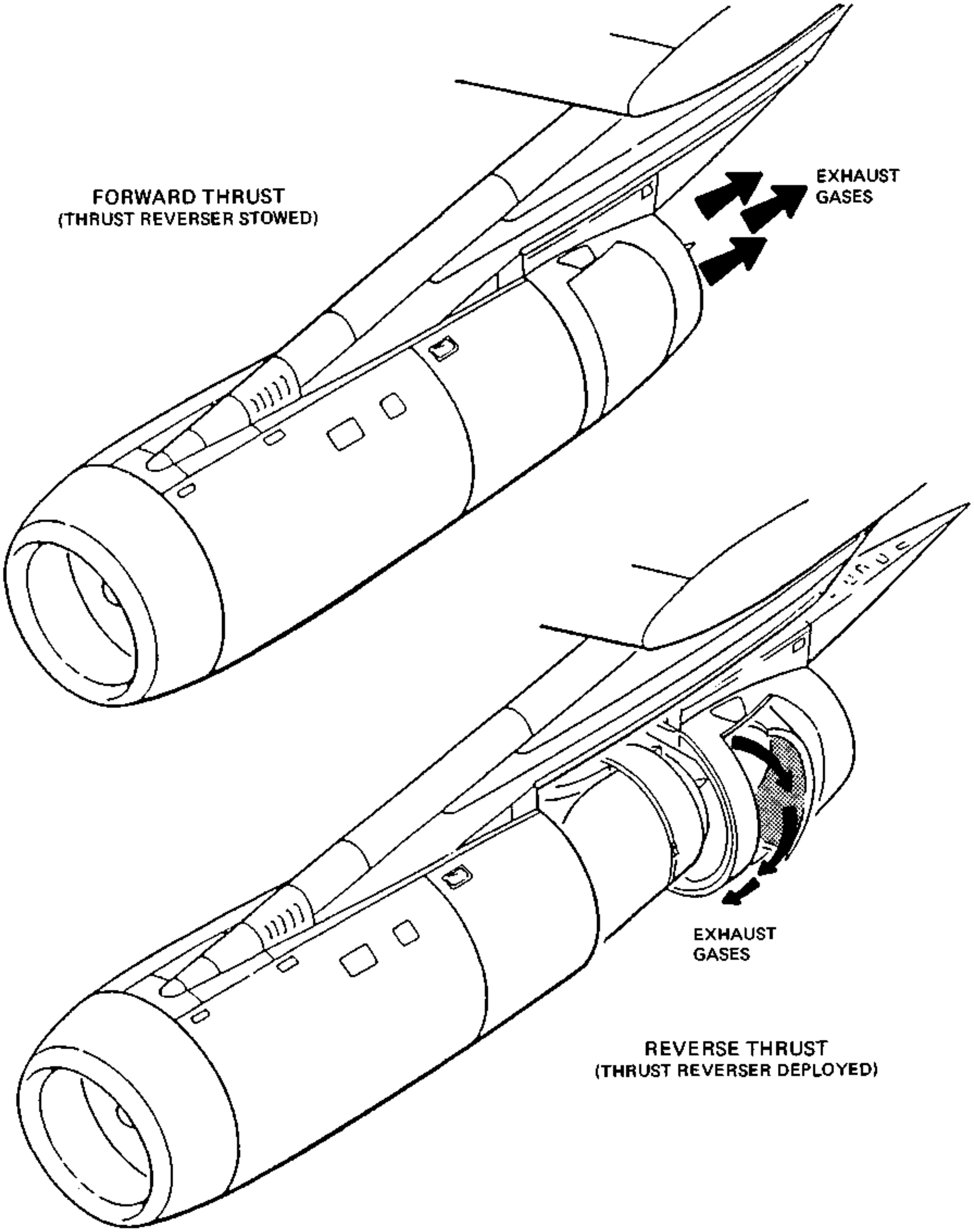
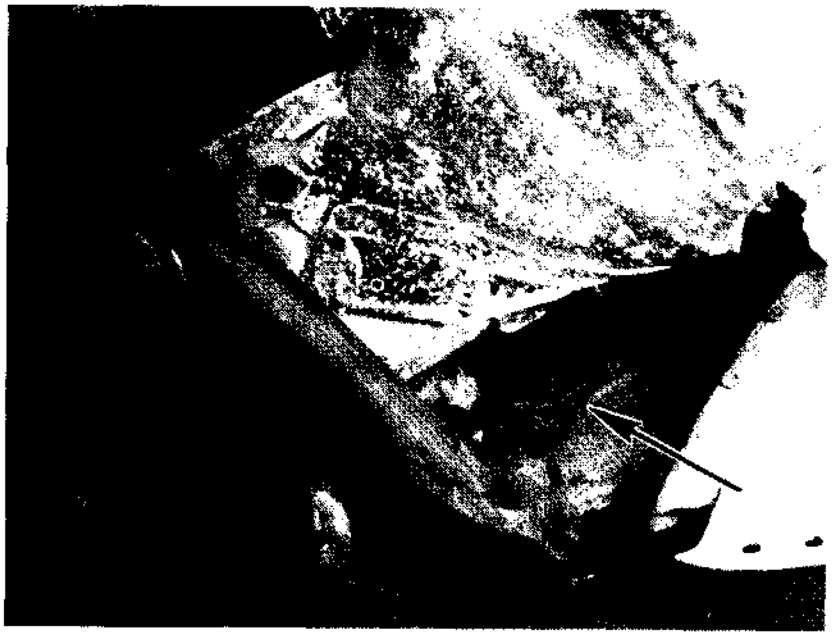
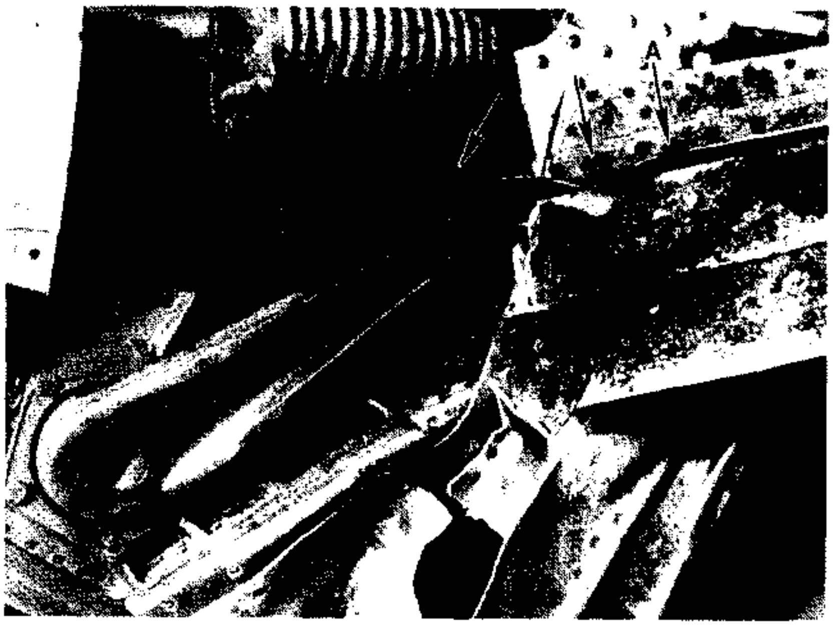

FORWARD THRUST
(THRUST REVERSER STOWED)
EXHAUST GASES
EXHAUST GASES
REVERSE THRUST
(THRUST REVERSER DEPLOYED)

Figure 1.7. Schematic of Thrust Reverser Assembly



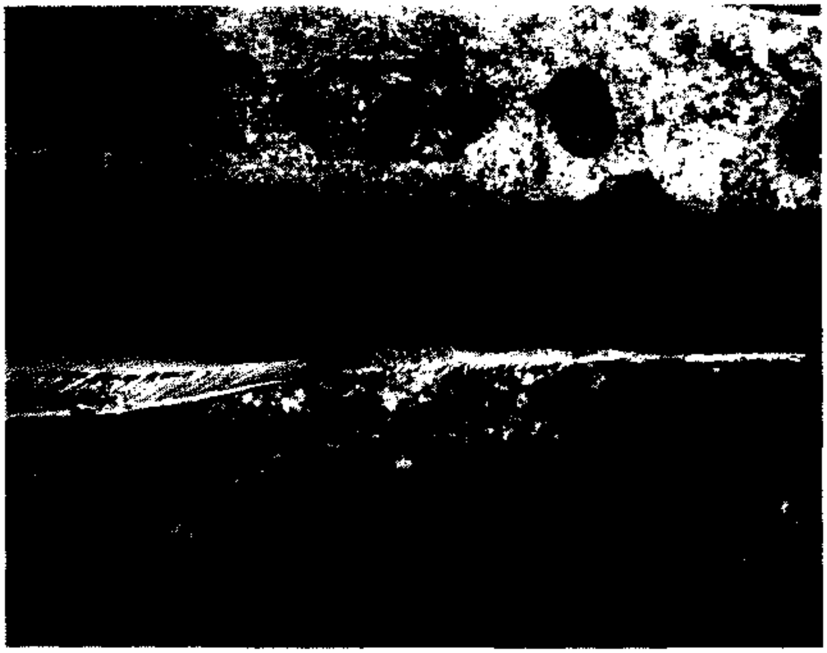
OUTBOARD DEFLECTOR DOOR UPPER ACTUATING ARM AREA OF NO. 4 REVERSER. ARM HAS BEEN PULLED OUT OF SLOT BY CRASH DAMAGE. NOTE DAMAGE IN AFT END OF SLOT AT ARROW.

Figure 1.8. Number Four Thrust Reverser Outboard Deflector Door Upper Actuating Arm Area



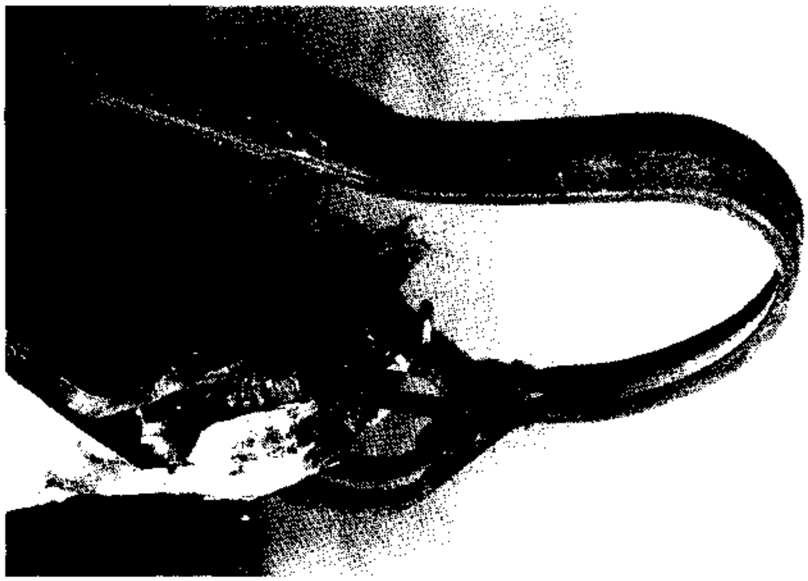
THRUST REVERSER NO. 4 INBOARD DOOR LOWER ACTUATING ARM. SKIN HAS BEEN CUT AND FOLDED BACK TO SHOW DEFORMATION IN EDGES OF SLOT (ARROWS). NOTE THAT ARM IS IN THE DOOR DEPLOYED POSITION.

Figure 1.9. Number Four Thrust Reverser Inboard Deflector Door Lower Actuating Arm Area



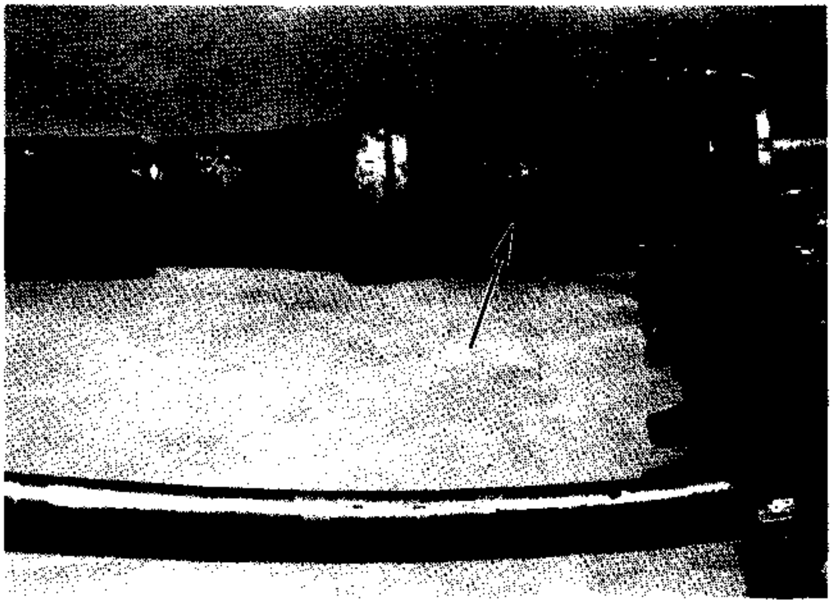
VIEW OF DAMAGE TO EDGE OF SLOT AS SHOWN IN FIGURE 1.9. AT A. DAMAGE PATTERN SHOWS ARM MOVED FROM THE DOOR FAIRED TO THE DOOR DEPLOYED POSITION AFTER INITIAL IMPACT.

Figure 1.10. Number Four Thrust Reverser Inboard Deflector Door Lower Actuating Arm Area



THRUST REVERSER NO. 4 LOWER TRACK. AFT END OF TRACK IS AT TOP IN PHOTOGRAPH.

Figure 1.11. Number Four Thrust Reverser Lower Track



THRUST REVERSER NO. 4 HYDRAULIC ACTUATOR. NOTE SPLIT IN OUTER CYLINDER.

Figure 1.12. Number Four Thrust Reverser Hydraulic Actuator

1.12.5 Impact Attitude Determination

Using analytical plotters, three dimensional measurements were made of 378 trees which had been cut by the aircraft prior to ground impact (See Figure 1.13.). A 1/100 scale model of the tree-cut zone was then constructed, and a detailed 1/100 scale die cast model of a Douglas DC-8-63 aircraft was mated to the tree pattern (See Figure 1.14.). Flaps were placed on the model at an 18-degree configuration to match post-crash investigation findings. By accurately measuring the orientation of the aircraft model in the tree pattern at increments along its flight path, the attitude of the aircraft and the flight path angle were determined. Measurements indicated that the aircraft first contacted the tree canopy in a seven-degree right bank, nine-degree pitch (the angle between the longitudinal axis of the fuselage and the horizontal), and a 10-degree yaw right attitude, on a descending, 12-degree flight path angle (the angle between the flight path and the horizontal).

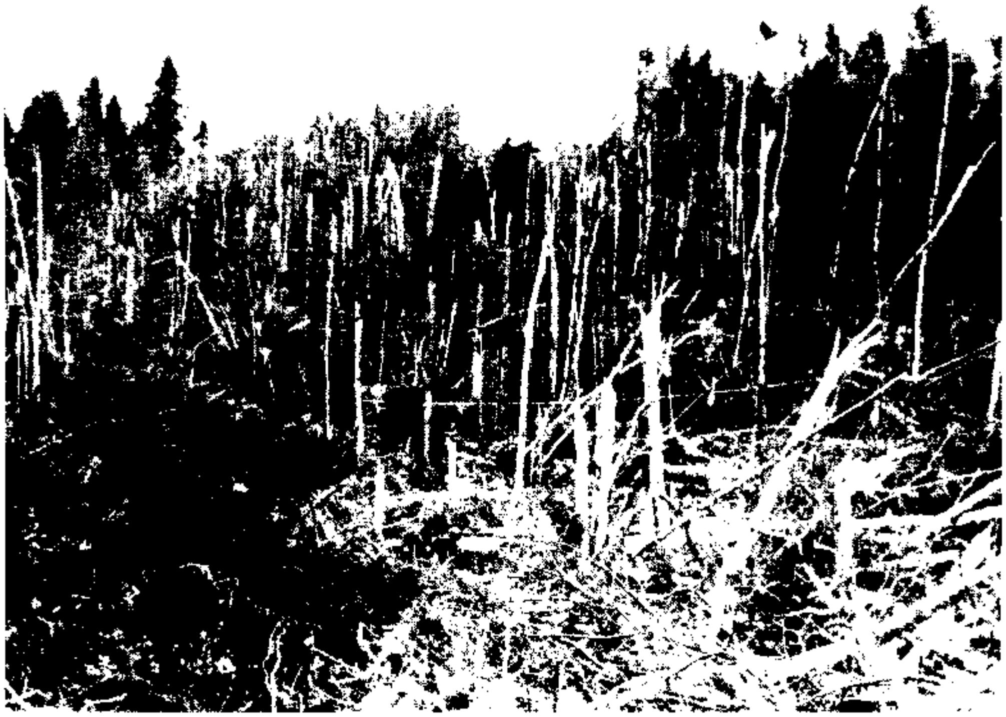


Figure 1.13. Photo of Tree Swath Cut by Aircraft

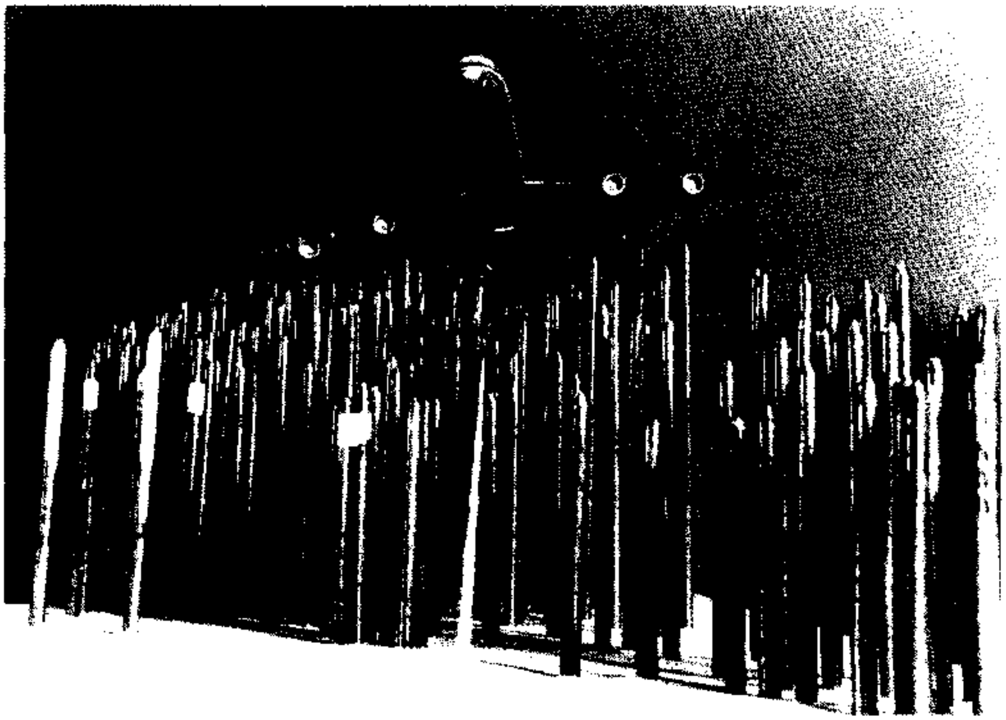


Figure 1.14. Reconstruction of Impact Attitude

1.12.6 Weapons and Military Equipment Recovered

A variety of military weapons and weapon components was found scattered throughout the accident site. A list of recovered items which were identifiable follows.

Weapon Type	*Number Recovered*
Pistols	25
M16 (complete or components)	202
M203	24
M60	2
Rifle	1

There was no evidence found of any military ammunition or explosive device. Several practice-type devices and training aids were recovered. All were inert and contained no explosives.

1.13 Medical Information

Post-mortem examinations of all occupants of the aircraft were conducted by the United States Armed Forces Institute of Pathology (AFIP) under the control and supervision of CASB investigators. In addition, toxicology testing for the presence of carbon monoxide (CO), hydrogen cyanide (HCN) and common drugs was conducted on tissue and fluid specimens obtained during autopsy. Blood samples were obtained from thoracic vessels or the heart where possible. When these vessels were disrupted and blood unavailable elsewhere, specimens were obtained from pooled thoracic blood. The toxicology testing was conducted at the Civil Aviation Medical Unit (CAMU) of the Department of National Health and Welfare located in Toronto, Ontario.

Prior to autopsy, all accident victims were radiographed and examined carefully for injuries indicative of explosive blast effects and/or fragmentation associated with the detonation of an explosive device. The radiographs and bodies were specifically examined for trace evidence such as scrapnel and/or identifiable portions of an explosive device. No characteristic injury patterns, trace evidence, or portions of an explosive device were detected.

All three flight crew members sustained multiple fatal injuries on impact. No evidence of causal or contributory pre-existent disease or other physical problems that would affect the flight crew's judgement or performance was detected through autopsy of the three flight crew members.

Toxicological test results were negative for the presence of CO in the case of the captain and flight engineer. Toxicological test results for the presence of HCN were negative in the case of the captain and, in the case of the flight engineer, revealed an HCN level in the blood of 0.01 milligrams per 100 millilitres (mg%). Both the captain and flight engineer tested positive for caffeine and salicylic acid (ASA/Aspirin). In the case of the first officer, insufficient fluid samples were available to test for the presence of CO and HCN. Test results for the presence of common drugs were negative.

Complete autopsies were performed on three of the five flight attendants. The remaining two flight attendants were not autopsied in deference to family requests made on religious grounds. However, both remains were radiographed and external observations made.

The five flight attendants sustained multiple traumatic injuries. Specimens for toxicological testing were obtained from the remains of three flight attendants. Toxicological tests for the presence of CO were positive in the case of two flight attendants. Measured levels of CO were 21 per cent and 5 per cent saturation. Toxicological tests for the presence of HCN revealed a 0.12 mg% HCN level in the blood of the flight attendant with the 21 per cent CO level, the remaining tests for HCN were negative. Tests for common drugs were positive for caffeine in all three cases and positive for salicylic acid (ASA/Aspirin) in two cases.

All 248 passengers sustained fatal injuries as a result of impact and/or the result of fire. Toxicological tests determined positive values of CO in 69 of the 189 passenger samples available for testing. Toxicological tests determined positive values of HCN in 158 of the 187 passengers where measures of HCN were available.

All but two of the blood samples in which a positive CO value was detected also gave evidence of positive HCN findings. However, there was no correlation between level of CO and level of HCN.

An extensive analysis of lung tissue was undertaken to identify possible evidence of explosive blast effects and/or evidence of inhalation of hot air, toxic gases and/or soot. The results of this analysis were inconclusive. The effects of an explosive blast wave were considered indistinguishable from the effects of trauma due to decelerative forces, flying debris, and structural collapse of the aircraft. Similarly, it was not possible to distinguish between the pulmonary effects of a pre-impact or post-impact fire.

To use respiration of products of combustion as indicators of the timing of a fire, it is necessary to assess the likelihood of a victim surviving the impact. Where a significant number of victims unlikely to have survived an impact show evidence of respiration of the products of combustion, this would indicate there was a fire before impact. Where a significant number of victims likely to have survived an impact show evidence of respiration of combustion products and very few of those unlikely to have survived the impact exhibit traces of the respiration of combustion products, this would be a strong indication of a post-impact fire only.

A complete review of pathological examination results was undertaken for the CASB by forensic pathologists from the University of British Columbia and University of Toronto, and AFIP representatives. The primary purpose of this review was to estimate the time interval from injury to death for each victim. Injuries were coded according to severity using a modification of the approach taken by the Abbreviated Injury Scale, a commonly used injury severity index developed by the American Association of Automotive Medicine. Injury pattern coding was completed without reference to CO or HCN levels. The time intervals from injury to death were estimated as follows:

Time Interval From Injury to Death	*Number of Cases*
zero seconds	41
less than 30 seconds	51
30 seconds to 5 minutes	158

In six cases, it was not possible to estimate the time interval from injury to death.

The high numbers of victims with positive levels of HCN detected in toxicological examinations caused CASB investigators to conduct an examination of the HCN phenomenon. An extensive literature review revealed that conflicting opinions exist among forensic experts with respect to the mechanisms whereby measurable levels of HCN can enter the blood of an accident victim. Bacteria action, physical decay, freeze-thaw cycles, and direct contamination have all been cited as factors that can cause elevation of HCN levels in blood samples. As a result of this review, CASB investigators conclude that four primary mechanisms leading to measurable levels of HCN must be considered when assessing levels of HCN in accident victims.

1. Background

   HCN may be found in low concentrations in the blood of normal people. Smokers can have levels as much as twice the "normal" level.

2. Neo-formation

   A number of processes can produce HCN in the body. These processes are very complex and their impact is not well understood. They include bacterial activity, the breakdown of thyocyanate, and the production of HCN as a result of the burning and subsequent freezing of the body. It appears that, under certain conditions, these processes can result in wide variations in HCN levels.

3. Contamination

   In victims who suffer penetrating chest wounds, HCN can be directly introduced into blood in the chest cavity through direct contact with combustion products. HCN does not combine with haemoglobin to form a virtually impermeable barrier at the blood/air interface as does CO. Rather, it continues to diffuse into the pooled blood until a point of equilibrium is reached.

4. Respiration of Combustion Products

   HCN is given off as a product of combustion of many of the materials found in aircraft interiors. Victims who breath in air contaminated with HCN will show elevated levels of HCN in the blood. Depending on the concentration of HCN in the air and the amount of contaminate air breathed in, levels of HCN in the blood can be quite high.

The role that factors other than respiration of products of combustion play in elevating HCN levels in accident victims' blood is illustrated by new procedures adopted by CAMU. Prior to this accident, the threshold level used by CAMU when reporting the presence of HCN was 0.01 mg%. However, since the accident, CAMU has revised this threshold upward to 0.02 mg% in response to the common detection of HCN in accident victim blood samples where no exposure to fire occurred. Application of this new threshold value in blood sample analyses from this accident would result in 30 fewer cases of positively reported HCN levels.

A statistical analysis was performed to identify and correlate the mechanisms involved in production of the HCN levels observed in the victims of this accident and to correlate the evidence regarding the possibility of a pre-impact fire as illustrated by CO and HCN levels, and soot traces found below the trachea in micropathological examinations. The statistical analysis indicated that more than one mechanism was involved in the production of the observed HCN levels. The most important mechanism was determined to be inhalation of products of combustion. Contamination of the blood through direct entry via chest wounds and the production of HCN through exposure to tobacco were also determined to have significant effects, both singly, and in combination.

In the 27 cases where survival for any time was considered to be unlikely and blood samples were available for toxicological testing, 24 cases showed a zero level of CO. The three cases which showed non-zero levels of CO were all below 25 per cent saturation. Where survival was estimated to be less than 30 seconds, 36 of 41 cases where blood samples were available showed zero levels of CO. In the 125 cases where survival was estimated at between 30 seconds and five minutes and blood samples were available, CO was found in 62 cases.

In the 39 cases where soot was found below the trachea, 38 were among victims where the estimated survival time was between 30 seconds and 5 minutes. In the remaining case, survival time was estimated at less than 30 seconds. There were no cases of soot found below the trachea where survival time was estimated to be zero.

In the 160 cases where measurable HCN was detected, 51 cases involved an estimated survival of less than 30 seconds and/or zero. However, 45 of these cases showed evidence of severe chest wounds and/or exposure to tobacco products. The remaining six cases were victims for which the survival time was estimated to be less than 30 seconds but not zero. There were no cases of positive HCN levels where survival time was estimated to be zero, and the confounding factors of chest wound and/or exposure to tobacco products were not also present.

The statistical analysis concluded that the comparison of survival time estimates with evidence of respiration of combustion products strongly supported the proposition that a number of accident victims survived the initial impact and died in the post-impact fire and that the comparison did not support a pre-impact fire scenario.

Mechanism of death was determined in 247 of the 256 cases. In the remaining nine cases, post-mortem disruption prevented determination of the mechanism of death. Mechanisms of death were determined as follows:

1. One hundred and seventy-five victims died as a direct result of injuries sustained in the impact.
2. Thirty-one victims died as a direct result of the inhalation of products of combustion. Impact injuries played no material role in their deaths.
3. Forty-one victims died as a result of the combined effects of the inhalation of products of combustion together with the injuries sustained in the impact.

1.14 Fire

An intense fuel-fed post-crash fire developed. Substantial portions of the aircraft were consumed in the fire. As a result, it was impossible to account for and examine all the aircraft. The most intense area of the fire occurred in the lower half of the wreckage trail. The upper portions of the wreckage trail were also subjected to the post-crash fire but to a lesser extent.

Airport Crash Fire Fighting Rescue (CFR) vehicles arrived at the site approximately 10 minutes after the accident. Fire suppression activities commenced immediately using dry chemical and foam. Additional fire vehicles and personnel were dispatched from the town of Gander. With the exception of a few stubborn spot fires, the fire was extinguished within 45 minutes of the arrival of rescue vehicles. These spot fires were extinguished within four hours, except for one which continued to burn for 23 hours.

CFR personnel reported that there were a number of explosions seen and heard throughout the burning wreckage area. Some were strong enough to lift mounds of rubble several feet into the air.

Three eyewitnesses reported an orange or yellow glow emanating from the underside of the aircraft. All three were travelling in separate vehicles on the Trans-Canada Highway which crosses the extended centre line of the runway, 900 feet beyond the departure end. Two of these witnesses observed the aircraft through their left side windows just before the aircraft passed directly overhead at low altitude. Both reported a steady orange/yellow glow that was bright enough to illuminate the interior of the truck cabs in which they were travelling. They were unable to make any precise determination about the location of the glow. One of these witnesses thought the glow might have been a fire but could not be sure.

The third of these witnesses observed the aircraft, from a distance of about one-half mile, crossing the highway from right to left. He also described the phenomenon as a steady orange glow emanating from the underside of the aircraft. He attributed the glow to the reflection of the runway 04 approach lights on the underside of the aircraft. A passenger in this vehicle also observed the aircraft crossing over the highway but did not report the glow.

A fourth eyewitness travelling along the Trans-Canada Highway observed the aircraft from a distance of about one-quarter mile, crossing the highway from left to right. He estimated that the aircraft was about 70 feet above the highway. He stated that, although he could not see the right-hand side of the aircraft, he could tell it was very bright on that side. He could not see any flames but thought that it was brighter than it should have been.

A fifth eyewitness travelling along the Trans-Canada Highway observed the aircraft lights from a position two and one-half miles west of the accident site, as the aircraft passed over the highway from left to right. He described a yellow light which appeared to be on the wing.

Several other witnesses observed portions of the take-off roll and brief flight which followed. None described observations consistent with a glow or fire. One of these witnesses was the air traffic controller on duty in the control tower. He observed the take-off of the aircraft until it descended below trees beyond the departure end of the runway. He did not observe any sign of fire or glow other than appropriate aircraft lighting. A second witness observed the take-off of the aircraft from a vantage point on the airport ramp, south of the main terminal building. He also observed the take-off until the aircraft descended below trees beyond the departure end of the runway and reported seeing no fire or anything else unusual other than the aircraft's failure to continue to climb.

1.15 Survival Aspects

Immediately following the accident, ATC personnel initiated the airport emergency response in accordance with published off-airport crash procedures. Direct telephone contact was established with airport CFR services and the RCMP. The location of the accident site could not be immediately determined. Although the aircraft struck terrain only about one and one-half miles from the control tower, the impact point was at an elevation significantly lower than that of the airport and was thus not visible to airport personnel. The exact position of the accident was established with the assistance of an arriving aircraft.

Airport CFR vehicles arrived at the site about 10 minutes after the accident. A severe fuel-fed fire was still in progress. Fire suppression activities commenced immediately, following which an initial search for survivors was begun, without success. A second search for survivors was conducted about 45 minutes after the accident, also without success.

The accident was considered to be non-survivable due to the magnitude of the deceleration forces and the severity of the fire.

1.16 Tests and Research

1.16.1 Computer Performance Simulations

The University of Dayton Research Institute (UDRI), Dayton, Ohio, was contracted to conduct an independent analysis of the take-off performance of the aircraft using previously developed computer simulation techniques (DSS Contract No. 4M012-6-0005/01-FR). Data used in the analysis included that derived from the FDR and aerodynamic performance information provided by Douglas Aircraft Co.

A two-part study was conducted. A take-off sensitivity analysis was performed using a digital, fixed-stick simulation program to establish the relative performance degradation resulting from a variety of factors which were identified as having potential to adversely affect take-off performance. The second approach was to reconstruct the accident trajectory by solving the airplane equations of motion.

The take-off sensitivity analysis used a two-dimensional, three degrees of freedom digital take-off program to simulate various take-off scenarios. A normal take-off trajectory was simulated, and then various abnormal trajectories were generated under assumed conditions or events that might have degraded take-off performance.

For this analysis, a normal take-off consisted of initiating rotation one second after V_R and rotating to a pitch attitude of about 13 degrees at a rate of just under two degrees per second. This rate of rotation took into account the geometry-limited properties of the aircraft by ensuring that the aircraft was airborne before a pitch angle of 8.6 degrees was achieved. This resulted in the aircraft rotating to a pitch attitude of 12.6 degrees at a rotation rate slightly less than two degrees per second. An airspeed of $V_2 + 10$ was achieved at 35 feet above ground level and then maintained during the climb-out. The take-off weight used for the normal take-off simulation was 344,500 pounds. The corresponding take-off reference speeds were V_R - 154 KIAS; V_2 - 166 KIAS. Ground effect was considered in the simulation.

The abnormal conditions and events evaluated in the sensitivity analysis were early rotation; reduced thrust in one engine; failure of one engine; failure of two engines; and ice-contaminated wings. The individual effect of each factor on a normal take-off, as well as the combined effect of several factors, was evaluated.

The sensitivity analysis concluded that, of all the factors and events considered, the lift and drag penalties associated with ice-contaminated wings were necessary to result in a flight profile that resembled the accident trajectory.

The reconstruction of the accident trajectory used a technique developed by UDRI for an analysis of a previous take-off accident involving a Boeing 727. Several changes to the original equations were made as well as slight modifications to the solution method. Aerodynamic and thrust data provided by Douglas Aircraft Co. were curve fitted and interpolated for insertion into the computer program. A moment equation was incorporated into the program in order to calculate elevator deflections. An algorithm was used to calculate pitch rate and rotational acceleration from the assumed pitch history profile. Terrain elevation was explicitly included in the take-off run and used for the calculation of the ground effect during the airborne segment of the accident flight.

The equations of motion were solved iteratively with known conditions as constraints. The solution of the equations of motion of the aircraft determines the lift coefficient (C_L). The derived lift coefficient is largely insensitive to the assumed pitch history. The drag coefficient (C_D) derived from solving the equations of motion is not as accurate as the C_L, since, in this case, it was dependent upon assumed thrust. For example, loss of thrust from one engine cannot be distinguished from a 0.05 increase in C_D. The UDRI accident reconstruction study concluded that the only acceptable solutions to the aircraft equation of motion required a significant loss of lift and a significant increase in drag. The calculated reduction in lift was approximately 30 per cent, the increase in drag at least 100 per cent.

At the request of the Board, a second independent series of computer performance simulations was performed. This work was conducted by a flight dynamics specialist of the Department of National Defence (DND). The primary purpose of these simulations was to further analyse the performance of the aircraft with varying amounts of thrust and of ice contamination on the wings.

Performance estimations were made using lift and drag data for the DC-8-63 provided by Douglas Aircraft in conjunction with the following additional assumptions: aircraft weight - 344,500 pounds; pitch angle at lift-off - 8 degrees; field ambient conditions - temperature -4.2 degrees C, altitude 425 feet asl. For reference purposes, lift-off was considered to occur 8,000 feet after the start of the take-off roll. Ground effect increments to lift and drag coefficients were eliminated if the aircraft height above ground was greater than that of the aircraft wing span or if the distance from start of take-off was greater than 10,500 feet (this distance corresponds to the location where the ground slopes steeply away at the end of the runway). Douglas Aircraft lift and drag data were extrapolated from 16 to 18 degrees angle of attack to obtain data over the angle of attack range 0 to 18 degrees.

The computer program written for the simulation calculated the aircraft post-lift-off performance at the desired time increments for a total of 20 seconds. The performance calculations were based on accelerated climbing/descending equations of motion.

The performance calculations were separated into two groups: cases with surface contamination and four engines operating normally; and, cases with surface contamination and a single engine failure at a specified time. In addition, several cases without surface contamination were run as test cases to validate the program and provide a basis for comparison. These test cases demonstrated that the program accurately estimated the normal climb performance of the DC-8-63 predicted by Douglas Aircraft.

Program options for individual simulation runs were as follows:

1. Time increment
2. Equivalent surface roughness - 0, 0.02, or 0.04 inch elements
3. Engine failure - failure time and degree of thrust loss
4. Acceleration - sets initial acceleration
5. Climb-out speed - target speed for steady climb-out
6. Maximum pitch attitude
7. Overrotate - allows rotation to pitch attitude higher than optimum for the degraded aerodynamic properties
8. Pitch rate start - specifies time for overrotation if allowed
9. Pitch-up - forces angle of attack to 18 degrees if speed decreases to stall in order to simulate high drag associated with the stall

The program was limited in that it could not duplicate the dynamic control inputs of the pilot at the controls, and, since an accurate pitch history was not available, it is unlikely that any predicted performance would exactly match the complete flight trajectory of the accident take-off. However, assuming that the aircraft was flown using normal procedures (ie. normal pitch limits, pitch rates and airspeeds), the first portion of the trajectory could be estimated with reasonable accuracy. Once the aircraft performance began to degrade below normal, the predictions become less accurate because pilot inputs have a significant influence.

The cases of surface contamination with four engines operating showed that the aircraft was capable of a safe climb-out with either contamination with surface roughness elements of 0.02 or 0.04 inches if the aircraft was flown at the optimum pitch attitude (which was lower than the normal pitch attitude for climb-out with a clean airfoil). Small changes in pitch angles or airspeed had a significant effect on aircraft performance for both 0.02 and 0.04 inch surface roughness elements. Increasing pitch angle from 12.5 to 15 degrees with 0.02 inch contamination elements was sufficient to degrade the climb performance so that a successful climb-out was not possible.

With surface roughness contamination elements of 0.04 inches, the aircraft was more sensitive to pitch angle increases. A successful take-off with four engines operating and with surface roughness contamination elements of 0.04 inches was only possible if the pitch angle was maintained at or below 11.7 degrees.

For those cases which included an engine failure along with contamination of the wing surface, even lower pitch angles were necessary to ensure a successful take-off. When contamination with surface roughness elements of 0.02 inches was combined with an engine failure, a successful take-off was possible only if pitch angle was maintained at or below 11 degrees; with surface roughness elements of 0.04 inches and an engine failure, a successful take-off was not possible.

In all, 44 different simulations were conducted (including those which were conducted to validate the program). The simulations which resulted in the best "match" to the accident flight were those with lift and drag penalties associated with wing contamination with the equivalent of full surface roughness elements of 0.02 inches and the loss of thrust from one engine, and those with lift and drag penalties associated with wing contamination with the equivalent of full surface roughness elements of 0.04 inches, with or without a loss of thrust from one engine.

1.16.2 Simulator Tests

As part of its investigation, the Board conducted a series of simulator tests using a DC-8-63 training simulator located at the Sterling Airways Flight Training Centre, Kastrup, Denmark. Representatives of Arrow Air, Douglas Aircraft Co., Pratt & Whitney, the FAA, and the NTSB were present and observed the tests.

The aim of the simulator testing was to duplicate the situation faced by the crew in Gander on 12 December 1985. Various scenarios generated by technical concerns arising from the investigation, performance predictions by the aircraft manufacturer, the computer simulations performed by UDRI, and the Board's own performance analysis were "flown" by pilots from Arrow Air, Douglas Aircraft Co., and Sterling Airways.

The simulator was manufactured by Canadian Aviation Electronics (CAE) of Montreal, Quebec. For the purposes of the tests, it was programmed to reflect, as closely as possible, the ambient conditions at Gander at the time of the accident.

Prior to conducting the test "flights", the fidelity of the simulator was checked, both quantitatively and qualitatively. It was concluded by all who attended the tests that the simulator had reasonable lift, drag, and thrust fidelity in the flight regime of interest. Handling qualities were determined to be acceptable.

The test scenarios included the use of low take-off reference speeds, failure of the number four engine, extension of the pitch trim compensator (PTC), deployment of the number four engine thrust reverser, and ice-contaminated wings. The scenarios were "flown" individually and in various combinations. All tests were flown by the pilot in the right seat. Various recovery techniques were utilized by the pilot when abnormalities occurred.

For those tests which simulated ice contamination of the wing, the simulator computer was reprogrammed with modified coefficient of lift and drag values derived from data provided by Douglas Aircraft Co. and UDRI. The changes in C_L and C_D were consistent with that occurring with upper wing surface contamination with roughness elements of 0.04 inches. The C_L maximum value was achieved at 10 degrees angle of attack, which conformed to the value predicted in the UDRI performance study. The 10-degree value also provided a compromise fit for lift coefficient value imposed by the existing software description of the coeffficient of lift curve. Reprogramming was performed by the engineering staff of the Sterling Airways Training Centre.

The only scenarios flown which came close to duplicating the actual performance of the aircraft during the accident take-off were those that included the altered coefficients of lift and drag. Any attempt to fly the simulator at normal climb-out angles with these C_L and C_D values resulted in a stall just after passing the runway end. The stall occurred at 168 KIAS at a pitch angle of about 12 degrees.

Rotating at a higher airspeed, reducing the pitch angle used to angles below the normal climb-out angle, and using full power after lift-off enabled a successful take-off to be conducted. It should be noted, however, that the detrimental effects on pitch stability associated with ice contamination could not be simulated.

After the stall occurred, the simulator "nose" would drop, and post-stall angles of attack could not be achieved. Because the simulator stall and post-stall qualities did not accurately reflect the manner in which the aircraft would respond during and after a stall, the drag values had limited value in the simulation with regard to trajectory prediction.

The tests also demonstrated that it was possible to maintain aircraft control with an outboard engine in idle reverse.

Additional simulator testing was conducted using a DC-8-63 training simulator located at the Flying Tigers Training Centre, Los Angeles, California. Representatives of Arrow Air, Douglas Aircraft Co., Pratt & Whitney, and the FAA were again present and observed the tests. As in the previous testing, the simulator was programmed to reflect as closely as possible the ambient conditions at Gander at the time of the accident, and the fidelity of the simulator was verified, both quantitatively and qualitatively.

The purpose of this second series of tests was to examine several accident scenarios which involved aircraft system malfunctions deemed by the Board to require further scrutiny. The scenarios examined included PTC runaway, full reverse thrust on the number four engine, in-flight deployment of the ground spoilers, asymmetric flap conditions, take-off with closed slots, jamming of the elevator, and a complete hydraulic system failure.

Similarities with the accident flight profile were observed in several of the scenarios tested. Application of full reverse thrust on the number four engine, a jammed elevator, severe flap asymmetry and attempting take-off with flaps retracted all resulted in marginal aircraft control. Although in some instances the pilot was able to complete a take-off successfully, the margin of control was such that, under actual flight conditions and without any prior warning, successful completion of a take-off would be doubtful.

Airspeed and altitude values similar to those of the accident take-off were observed in the test runs that simulated application of full reverse thrust at or shortly after lift-off, take-off with asymmetric flaps (0 and 18 degrees) and slots closed, and take-off with flaps retracted and slots closed. Attempting take-off with either the left or right wing flaps in the retracted (0 degrees) position resulted in the sounding of the take-off warning horn.

In each case that simulated a jammed elevator, the pitch angles that were achieved prior to lift-off would have resulted in a tail strike.

Test scenarios which simulated extension of the PTC, complete hydraulic failure, and take-off with the slots closed all resulted in successful take-offs. In each case, the take-off was completed without significant difficulties being experienced by the pilot at the controls.

It proved impossible to simulate in-flight deployment of the ground spoilers. Although cockpit indications of spoiler deployment were obtained (illumination of spoiler deployed light), no change in aircraft performance was observed.

It was also noted that, when faced with a situation involving degraded climb performance or control difficulties, a gear-up selection was rarely completed.

1.16.3 Flight Crew Fatigue

Considerable research has been conducted in the past two decades concerning the subject of flight crew fatigue. As a result of this research, fatigue-inducing factors and the consequences of fatigue on human performance have been identified.

Fatigue can be described as either "acute" or "chronic." The former refers to fatigue of short-term origin usually brought on by intensive and repeated activities and is often influenced by a short-term irregular sleep pattern; the latter refers to fatigue of long-term origin, is usually characterized by extended accumulation of flight and/or duty time, and sometimes may be accompanied by long-term sleep degradation.

Key-fatigue producing elements have been identified as extended accumulation of flight and/or duty time; inadequate rest prior to flight; multiple time-zone travel; flights which span the normal sleep period; short layovers; flights in an easterly direction; seven-day-plus flight patterns; and exposure to noise, vibration, and the aircraft microclimate which produces low humidity and cabin altitudes as high as 7,000 feet.

The effects of fatigue have been identified as judgement deterioration, alertness deterioration, an increase in error rate, irritability increase, and the development of sleep hunger, all of which have detrimental effects on the performance of flight crews.

Recent research has concentrated on quantifying fatigue-producing work patterns so that the likelihood of fatigue can be predicted. Several fatigue-rating indexes have been developed to be applied in the analysis of flight crew schedules.

Dr. Stanley Mohler, the Director of Aerospace Medicine, Wright State University School of Medicine, testified at the Board's public inquiry, regarding a fatigue-rating index he had developed in conjunction with other aerospace medicine researchers.

The index scores each of the flight segments of a schedule in accordance with a number of known fatigue-inducing factors. The cumulative fatigue potential of a given schedule is then calculated and compared against a Physiologic Fatigue Index which reflects a range of physiologic demands.

At the request of the Board, Dr. Mohler applied his fatigue-rating index to the December schedule of the accident flight crew up to the time of the accident. The physiological index for each flight segment was determined to fall into the category of "may dangerously deplete physiological reserves."

1.17 Additional Information

1.17.1 Arrow Air Procedures

1.17.1.1 DC-8-63 Take-off Procedures

Normal take-off procedures are described in the *Arrow Air Inc. DC-8 Airplane Operating Manual.* Pertinent extracts from the manual follow:

a) "With a smooth positive back pressure, initiate rotation of the airplane at the scheduled V_R speed. Adjust the rate of rotation [of 2 degrees per second. Do not allow the pitch attitude on the runway to exceed] maximum 8 degrees, so as to attain the V_2 speed at a height of 35 feet above the runway surface." *

b) "Retract gear as soon as a definite climb is established...."

c) "After gear is up accelerate to $V_2 + 10$."

d) "WARNING: Failure to remove snow and ice accumulated on aircraft while on the ground can result in serious aerodynamic disturbances and structural damage when flight is attempted. Take-off distance and climb-out performance can be adversely affected to a dangerous degree, depending on weight and distribution of the snow and ice. Structural damage has also resulted from vibrations induced in flight by unbalanced loads of unremoved accumulations. These hazards must be avoided by removing the snow and ice from the wings, fuselage and tail before flight is attempted."

1.17.1.2 Take-off With Engine Failure

The *Arrow Air Inc. DC-8 Ground/Flight Training Manual*, under the general heading "Take-off with Engine Failure" states the following:

> Maintain V2 until attaining 1000 ft AFE [above field elevation]. Always ensure complete control of the airplane and attain a safe altitude before dealing with specific problems. The nature of the emergency will be a determining factor but 1000 feet is generally recommended as a safe minimum altitude for dealing with engine failures, fires, etc. This altitude (1000 feet) will ONLY be used when obstacle clearance criteria is not a problem.

1.17.1.3 Cold Weather Operating Procedures

The *Arrow Air Inc. DC-8 Airplane Operating Manual*, under the general heading "DC-8-63 Cold Weather Procedures" states the following:

D. Snow, Ice and Frost Removal

(1) Snow removal from the control surfaces must be complete to ensure proper balance and travel. Control surface movements can be seriously affected by freezing of hinge points. Aircraft should not be dispatched unless a careful visual check has been made of aircraft wings, control surfaces and hinge points, and it has been definitely determined that frost or snow deposits are cleared from these areas. At any time de-icing is performed, all slush or snow accumulations will be removed from all areas by use of glycol de-icing equipment.

N. Airfoil (De-Icing and Anti-Icing)

(1) When airfoil de-icing is necessary, observe the RAT [Ram air temperature] and set timer number one or timer number two to the observed RAT. When icing conditions no longer exist, leave timer turning and set to long cycle and allow it to run through

*According to Douglas Aircraft, normal pitch attitude during climb is between 11 and 15 degrees depending upon ambient conditions and the aircraft gross weight.

one complete cycle. Momentarily push Tail De-Ice Button to De-Ice Tail for 2.5 minutes. Turn Airfoil De-Ice Switch Off after Tail De-Icing Cycle is completed.

NOTE: When in icing conditions and while using the Airfoil De-Icing System, the Tail De-Ice Button should be momentarily pressed approximately every 20 minutes. When landing in icing conditions using the Airfoil De-Icing System, the Tail De-Ice Button should be pressed approximately 10 minutes before landing but not less than 5 minutes prior to landing.

1.17.1.4 Standard Average Passenger Weight

The Weight and Balance section of the *Arrow Air Inc. DC-8 Operating Manual* identifies the standard average adult passenger weight, including five pounds of carry-on baggage, for use between 01 November and 30 April as 170 pounds. This section also states that actual passenger weights should be used when large groups of passengers are carried whose average weight does not conform to the normal standard weight. Examples are given as a group of large athletes or a planeload of men.

1.17.1.5 Arrow Air Adjusted Weight Units Loading System DC-8-62 and DC-8-63 Aircraft

On 31 October 1985, Arrow Air published Bulletin 85-22 which introduced a new system for calculating the weight and centre of gravity position of its DC-8 aircraft. This new system, entitled *Arrow Air's Adjusted Weight Unit Loading System*, was designed to simplify and give greater accuracy to the development of the loading system analysis prior to the dispatch of each flight.

Instructions for the operational use of the loading system were contained in the bulletin. To determine passenger weight, flight crews were instructed to enter on the load sheet the number of passengers to be boarded and then enter the adjusted weight units from the loading table which corresponded to the number of passengers. The weight units found in the loading tables were based on an average passenger weight of 165 pounds in summer and 170 pounds in winter. There were no instructions or guidance concerning the requirement or method to determine total passenger weight using actual passenger weights when the average value was not considered representative of actual passenger weights.

After Bulletin 85-22 had been developed, the FAA principal operations inspector (POI) assigned to Arrow Air was consulted, and he concurred with its contents.

1.17.2 Basic Operating Weight

The *Douglas Aircraft DC-8-63 Weight and Balance Manual* defines operational empty weight as the basic empty weight plus operational items. Operational items are identified as those items of personnel equipment and supplies that are necessary on a particular operation unless already included in the basic empty weight. Examples of items normally included in the operational empty weight are flight crew, removable cabin and galley equipment, and usable drinking and washing water.

The Arrow Air weight derivation report for N950JW indicated that the aircraft was last weighed on 04 August 1985. The basic empty weight was determined to be 159,399 pounds. Examination of the pre-weighing check-list determined that this weight did not include removable galley equipment, cabin items such as pillows and blankets, or disposable water. The derivation of operational empty weight (basic operating weight) included only the weight of the flight crew and their personal baggage.

Although the weight of the flight attendants and meals was included in the determination of the aircraft weight and centre of gravity, no consideration was given to removable galley equipment, removable cabin items, and potable water.

By contrast, the previous weight derivation performed by Union des Transports Aériens in 1981 included 1,250 pounds in the basic operating weight to account for these items.

In consideration of the above, the Board estimates that the basic operating weight of the aircraft was underestimated by at least 1,000 pounds.

1.17.3 Zero Fuel Weight

The *Douglas Aircraft DC-8-63 Weight and Balance Manual* defines maximum design ZFW as "the maximum weight of an aircraft less the weight of all usable fuel and other consumable propulsive agents in particular sections of the aircraft that are limited structurally to this condition. This is a weight at which the subsequent addition of fuel and other consumable propulsive agents (as limited by other design gross weights) will not exceed the aircraft design strength." The *Douglas Aircraft DC-8-63 Weight and Balance Manual* states that the actual ZFW must never exceed the maximum design ZFW.

The maximum design ZFW of N950JW was 230,000 pounds. In 1985, Arrow Air explored the possibility of increasing the maximum design ZFW of the aircraft. A Supplementary Type Certificate (STC) was available that would have raised the maximum design ZFW of the aircraft by 14,000 pounds. No structural modifications to the aircraft were required; however, certain modifications to the airspeed indicating system were necessary to provide maximum airspeed warnings for a reduced flight envelope. The maximum allowable airspeed would have been reduced, but this speed, 352 KIAS versus 373 KIAS, would not normally be exceeded during normal operation. Although action to obtain the STC had been contemplated, it was not being actively pursued.

1.17.4 Aircraft Weight and Balance

1.17.4.1 Operator's Weight and Balance Calculations

Weight and balance calculations were performed by the crew using the Arrow Air Adjusted Weight Units Loading System for DC-8-62 and DC-8-63 passenger aircraft.

The load sheet completed at Gander showed a 330,625-pound gross take-off weight which was comprised of the following:

Basic Operating Weight (includes pilots and baggage)	160,022.8 lb*
Flight Attendants and Meals	1,599.9 lb
Passenger Weight	42,499.2 lb
Cargo pit #1	8,791.8 lb
Cargo pit #2	1,299.3 lb
Cargo pit #3	10,404.5 lb
Cargo pit #4	5,004.2 lb
ZFW	229,621.7 lb
Take-off Fuel	101,003.7 lb
Total	330,625.4 lb

* Decimal values reflect units for the purpose of determining centre of gravity position.

The calculated centre of gravity position was 25.4 per cent Mean Aerodynamic Chord (MAC), well within the allowable range of 14.0 to 32.3 per cent MAC.

With the exception of the take-off fuel weight, all weight values had been determined at Cairo by the Cairo/Cologne flight sector crew. Because the passenger and cargo loads did not change at Cologne, these same values were used for the subsequent take-offs from Cologne and Gander. Weight and balance calculations in Cairo were performed by the first officer.

The passenger weight used was the winter-adjusted weight unit which corresponded with 250 passengers. This represented an average passenger weight of 170 pounds. Although the load had changed in Cairo, the cargo pit weights used were the same weights used to perform weight and balance calculations for the flights from McChord AFB to Cairo. The first officer and flight engineer who operated the flight testified at the Board's public inquiry that they believed the actual take-off weight at Cairo to be about 10,000 pounds greater than that calculated on the load sheet. Although they increased take-off reference speeds accordingly, the calculations on the load sheet were not amended, nor was this information passed to the crew who assumed responsibility for the aircraft at Cologne. The captain of the aircraft on the Cologne/Cairo flight sector testified that he did not recall either the first officer or flight engineer informing him that take-off reference speeds had been increased.

Weight and balance calculations for the first series of rotation flights on 03 to 05 December were reviewed by investigators. These calculations were performed using the same adjusted weight units loading system by the same flight crew who performed the calculations for the 10 to 12 December series of flights.

The passenger weight indicated on the load sheets for this first series of flights was 8,000 pounds greater than that used on the 10 to 12 December flights. The total weight of cargo indicated was 8,000 pounds less than that of the 10 to 12 December flights. The weight used on the flight to Cairo was identical to those used on the flights to Fort Campbell.

1.17.4.2 Cargo Weight

In preparation for the 12 December flight from Cairo to Fort Campbell, all cargo which was to be placed in the aircraft cargo pits was weighed. The weighing was performed by MFO personnel, prior to departure from their base of operations in the Sinai. The weight of the cargo was determined to be 27,950 pounds and consisted of 481 duffle bags and 48 foot lockers of miscellaneous military goods.

At Cairo, it proved impossible to fit all the cargo into the aircraft. Despite extraordinary efforts and to the expressed consternation of MFO personnel, 41 duffle bags were left behind in Cairo. After the accident, MFO personnel estimated the weight of the items left behind to be 2,870 pounds. This figure was determined by MFO personnel who estimated the average weight of each duffle bag to be 70 pounds.

It could not be determined if the scaled weight determined by the MFO was passed to Arrow Air personnel at Cairo. The total cargo weight indicated on the load sheet was 2,400 pounds less than the scaled weight determined by MFO personnel. The cargo weight indicated on the load sheet also included 1,300 pounds of catering equipment and aircraft spares not included in the MFO scaled weight. Thus, even if the estimated 2,870 pounds of duffle bags which were not loaded on the aircraft were considered by the crew, the cargo weight was about 1,000 pounds heavier than that indicated on the load sheet.

1.17.4.3 Passenger Weight

The weight of the passengers was not determined on departure from Cairo. For flight planning purposes, an average weight of 170 pounds was used to determine the total passenger weight. This average weight includes an allowance of five pounds for carry-on baggage. Information from several sources indicates that the total weight of passengers and their carry-on baggage was considerably in excess of the weight calculated by the crew using the 170-pound average value. Ante-mortem weights of the 248 passengers were determined through the examination of U.S. army personnel records. The average weight of each passenger without uniform was 164 pounds. Each passenger carried with him personal gear which included a weapon, miscellaneous military equipment, web belt, clothing, and souvenirs. The carry-on baggage boarded on the aircraft in Cairo nearly filled the baggage holds of two B-737 aircraft which ferried the passengers from their base at Ras Nasrani to Cairo. Numerous witnesses indicated that a large quantity of carry-on baggage was stowed in the cabin on departure from Cairo. The quantity of cabin baggage was the subject of concern to MFO personnel and the cabin crew.

In an effort to determine the total weight of passengers and cabin baggage, the passenger weights of MFO flights inbound to Cairo were examined. In accordance with procedures established by the U.S. Army, each passenger travelling from McChord AFB to Cairo for duty with the MFO was weighed with his or her carry-on baggage.

On 03 December 1985, the total scaled weight including carry-on baggage of the passengers who flew from McChord AFB to Cairo was 54,726 pounds or about 219 pounds per passenger. This value was passed to Arrow Air personnel at McChord. Personnel who dealt with the flight inbound to Cairo on 10 December and the flight outbound to Fort Campbell on 12 December reported that the cabin baggage on the outbound flight exceeded that on the inbound flight.

In consideration of the points enumerated above, the Board estimates that the average weight of each passenger on the accident flight was about 220 pounds. The total weight of the 248 passengers was thus about 54,560 pounds, that is, about 12,000 pounds higher than the weight indicated on the load sheet.

1.17.4.4 Take-off Weight Estimated by the Board

Based on the findings of its investigation, the CASB estimated the take-off weight of the aircraft to be about 344,500 pounds comprised of the following:

Basic Operating Weight	161,000 lb
Flight Attendants and Meals	1,600 lb
Cargo Loaded at Cairo	25,080 lb
Catering Equipment and Spares	1,300 lb
Passenger Weight	54,560 lb
ZFW	243,540 lb
Take-off Fuel	101,000 lb
Total	344,540 lb

1.17.4.5 Load Planning, Procedures, and Documentation

The movement of MFO troops to and from Egypt was governed by a contract between Arrow Air and the MFO, entered into in 1984 and renewed in 1985.

The contract specified that, for each flight, 250 passengers were to be carried and each passenger was entitled to a baggage allowance of 154 pounds. No passenger weight was specified in the contract, nor was there any requirement for the MFO to provide weight information to Arrow Air for individual flights.

In preparation for this series of flights, planning meetings were held involving U.S. Army personnel and representatives of Arrow Air. At those meetings, Arrow Air representatives informed U.S. Army personnel that the payload capacity of the DC-8 was 72,000 pounds. It was the consensus among all concerned that, on these flights, the aircraft would "bulk-out" before the maximum weight capacity was reached.

Various directions and instructions were proposed by the U.S. Army pertaining to the movement of their personnel to MFO duties in the Sinai. A standard operating procedure, promulgated by the U.S. Army for the use of units deploying to duty with the MFO, identified the payload capacity of the deployment aircraft as 75,000 pounds. The individual baggage allowance established by the U.S. Army for MFO members was 150 pounds. For certain personnel, the baggage allowance was 175 pounds. For planning purposes, the U.S. Army considered 170 pounds to be the average weight of each soldier. When planning for a tactical deployment, 220 pounds was used as an average weight to account for web gear and weapons.

A U.S. Military Command pamphlet designed for use by U.S. military organizations when planning airlift requirements identified the allowable payload of a DC-8-63 as 90,000 pounds.

No manifests which contained weight information were prepared by MFO or U.S. Army personnel either at Cairo or at McChord AFB, nor were they requested to do so by Arrow Air. In all cases, where weight information was passed on, it was done via miscellaneous slips of paper.

According to an operation order prepared by U.S. Army personnel which described the procedures governing this deployment of troops to the Sinai, the officer-in-charge was to have on paper the total weight of all personnel and baggage to be loaded on the aircraft. Three copies were to be prepared. One was to go to the aircraft captain and one to the MFO representative. The only documents recovered during the investigation pertained to the weight of the baggage boarded at Cairo.

The only U.S. military records recovered which pertained to the payload carried on this series of MFO rotation flights were records and audit documents prepared by U.S. Air Force personnel at McChord AFB to account for the use of ramp space and ground equipment at McChord.

The recorded payload on 03 December was 40,000 pounds passengers and 14,760 pounds cargo. On 10 December, the recorded payload was 50,000 pounds passengers and 37,500 pounds cargo.

The only reference to the aircraft load found in Arrow Air documents was in the flight message addressed to the flight crew in Cologne from Arrow Air dispatch personnel in Miami. The message contained a note to plan for 250 passengers with 100 pounds of baggage each.

The original passenger load planned for this rotation flight was 250. However, in the days immediately preceding the flight, several adjustments to the passenger manifest were made, and the planned load was reduced to 249 passengers. The actual passenger load was reduced to 248 because one passenger, who was to have been on board the aircraft, misplaced his passport and was not permitted to board the aircraft at Cairo. However, his personal baggage remained on the aircraft. The load sheet prepared by the flight crew in Cairo and carried over to the departures from Cologne and Gander showed a load of 250 passengers.

1.17.4.6 Military Equipment/Weapons Carried On Board

In addition to their own personal effects, the military personnel on board the aircraft carried personal issue military equipment which included a variety of weapon types. The United States Army provided the following list of weapons believed to be on board the aircraft at the time of the accident:

Weapon Type	*Number Onboard*
Pistol (.45 cal)	21
M16 (light assault rifle)	121
M203 (machine gun)	24
M60 (grenade launcher)	2
Sniper Rifle	3
M16/M203/Pistol (specific type not specified)	75

Other miscellaneous military equipment belonging to the unit was also on board the aircraft. However, with the exception of one clip each of .45 calibre ammunition reported to have been carried by a Criminal Investigation Division (CID) inspector and the Batallion Commander, this equipment did not include military ordnance, ammunition, or other explosive material.

All personal effects carried on board the aircraft were subject to a rigorous pre-flight inspection by United States Military Customs Inspectors and Egyptian Customs officials. Approximately 60 per cent of the baggage placed in the cargo pits of the aircraft was inspected. Bags were selected at random, emptied and the contents examined. One hundred per cent of the carry-on baggage was inspected. No unauthorized military equipment, ordnance, explosives, or military devices of any kind were found during this inspection procedure, nor had any such items been found in similar inspections conducted prior to the first flight of this rotation and prior to the three flights in the preceding rotation.

The baggage that belonged to the passenger who was not boarded at Cairo had been subjected to this inspection procedure.

1.17.5 DC-8-63 Performance Information

1.17.5.1 Flight Manual Performance Information

The FAA approved *DC-8-63 Airplane Flight Manual* defines the minimum take-off field length as the greatest of:

1. The distance from start of takeoff to a point 35 feet above the runway at the V_2 speed, assuming an engine to fail at a speed corresponding to the decision speed, V_1.

2. The distance to accelerate to the decision speed, V_1, and to bring the airplane to a stop. The stopping performance is based on maximum braking on a dry, hard surface runway, anti-skid operative, with spoiler extension initiated after the throttles are moved to the idle position.

3. The all-engines-operating takeoff field length which is 115% of the four-engine distance from start of takeoff to the 35 foot height.

The take-off run available was 9,900 feet because runway 22 was entered from a right turn from runway 13. The field-length limited take-off weight for the accident flight, as determined from the Flight Manual, was 352,000 pounds.

The following take-off reference speeds are utilized in DC-8 flight operations:

1. V_1 - Critical Engine Failure Speed.

2. V_R - Take-off Rotation Speed. The speed at which rotation is initiated during the take-off to achieve the V_2 climb speed at 35 feet.

3. V_2 - Take-off Climb Speed. The V_2 value is equal to the actual speed at the 35-foot height, as demonstrated in flight tests and must be equal or greater than 120 per cent of the stall speed.

4. V_F - Flap Retraction Speed. The minimum flap retraction speed. It is equal to V_2 + 25 knots.

The take-off reference speeds are normally determined by the flight engineer and by reference to tables found in the *DC-8-63 Airplane Flight Manual.* They are then reviewed by the captain and first officer and are set using movable "bugs" located in the circumferential ring of each pilot's airspeed indicator, with the exception of the V_2 value which is set using a rotary knob which moves a cursor behind the glass face of each indicator.

Take-off reference speeds and corresponding stabilizer angles vary depending on the take-off weight and centre of gravity position of the aircraft and the flap setting used for take-off. The take-off reference speed data card calculated by the crew for the take-off at Gander was not found. Applicable take-off reference speeds and corresponding stabilizer angles for take-off weights of 310,000, 330,600, 344,500 and 355,000 pounds and the applicable centre of gravity position, as published in the *DC-8-63 Airplane Flight Manual*, are as follows:

	310,000 lb*	330,600 lb**	344,500 lb***	355,000 lb****
V_1	130 KIAS	135 KIAS	140 KIAS	144 KIAS
V_R	145 KIAS	150 KIAS	154 KIAS	158 KIAS
V_2	158 KIAS	163 KIAS	166 KIAS	169 KIAS
V_F	183 KIAS	188 KIAS	191 KIAS	194 KIAS
Corresponding stabilizer angle for take-off:	4.3 ANU	4.8 ANU	5.3 ANU	5.5 ANU

* Weight which corresponds to the internal bug setting (V_2) found on the co-pilot's airspeed indicator.
** Crew-calculated weight.
*** Take-off weight estimated by the Board.
**** Maximum allowable take-off weight.

The 172 knots indicated on the captain's airspeed indicator internal bug did not correspond with any V_2 value published in the *DC-8-63 Airplane Flight Manual*.

Based on a take-off weight of 344,500 pounds (estimated by the Board) and a V_2 speed of 158 KIAS (V_2 that corresponded with the internal bug setting on the co-pilot's airspeed indicator) the corresponding stabilizer angle for take-off would be 5.8 ANU.

1.17.5.2 Manufacturer's Performance Information

Douglas Aircraft Co. supplied a considerable amount of information pertaining to the aerodynamic performance of a DC-8-63. This performance information took into account the aircraft configuration and ambient conditions at Gander and included data for a normal take-off and data applicable to certain abnormal conditions.

According to information supplied by Douglas Aircraft Co., under the ambient conditions at Gander, a DC-8-63 with a take-off weight representative of that estimated by the Board should have lifted off 47 seconds after brake release at 165 KIAS, following a ground roll of 6,700 feet, assuming that rotation was initiated at 153 KIAS and the time from rotation to lift-off was 3.5 seconds. The take-off distance (to 35 feet agl) would have been 7,800 feet. An engine failure at V_R would have increased the take-off distance by about 200 feet.

Further information was supplied which pertained to changes in the coefficient of lift generated by the lift-producing surfaces of the aircraft under the following conditions: leading edge slots closed; ground spoilers deployed; and ice-contaminated wings.

The lift penalty which results from closed wing slot doors is a 0.2 reduction in maximum coefficient of lift. Ground spoiler deployment results in a 0.4 reduction in coefficient of lift at zero degrees angle of attack. This reduction increases as angle of attack increases. Douglas Aircraft Co. was unable to provide exact data for higher angles of attack. With respect to ice contamination, Douglas Aircraft Co. supplied information which indicated that, with wings contaminated by surface roughness elements of 0.04 inches, maximum coefficient of lift would be reduced by about 25 per cent. The coefficient of drag at or beyond the stall angle of attack (which would be a lower than normal angle) would increase by greater than 100 per cent relative to an uncontaminated wing operating at the same angle of attack, below the stall. (See Figure 1.17.)

1.17.5.3 Lift-off Speed

An aircraft will not lift-off until the lift produced exceeds the aircraft weight. Because the DC-8-63 is geometry-limited to a pitch angle of approximately 8.6 degrees on the ground, crews have been trained not to allow the pitch angle to exceed eight degrees while the aircraft is still on the ground. Thus, for the DC-8-63 to become airborne, the aircraft must accelerate to a speed where sufficient lift will be generated at the limiting angle of attack.

Experience has shown that the DC-8-63 begins to rotate approximately one to two seconds after the "rotate" call is made, assuming normal crew and aircraft response times. If the aircraft is rotated early but at a normal rate of two degrees per second, the DC-8-63 will reach a pitch angle of eight degrees before reaching a speed that will produce sufficient speed for lift-off. If the eight-degree pitch angle is held, lift-off would occur at about 161 KIAS at an aircraft weight representative of that estimated by the Board.

1.17.5.4 Climb Performance

For small angles of climb at a given aircraft weight, the rate of climb depends on the difference between thrust and drag. When the total thrust is greater than the total drag, the aircraft is able to climb at a steady or increasing speed. When the aircraft climbs at an angle greater than allowed by the available excess thrust, the airspeed will decrease.

If airspeed, climb gradient, and thrust are known, the total aircraft drag can be calculated for the climb after lift-off. The total drag can be used to calculate a coefficient of drag required to produce the climb profile. Using FDR data, the coefficient of drag required to produce the climb profile of the accident flight was calculated. In the absence of reliable FDR altitude data, maximum and minimum climb profiles for the accident flight were determined using witness observations and the JETS Mode C altitude readout. In this manner, the peak altitude achieved during the brief climb after take-off was determined to be no more than 125 feet above the runway. Similarly, thrust was assumed to be normal four-engine take-off thrust for the ambient conditions at Gander.

From 54 seconds to 61 seconds after brake release, the airspeed decreased at a rate of 1.3 knots per second. Three calculations were performed to assess the coefficient of drag necessary to account for the observed deceleration. These calculations assumed altitude gains after take-off of 70 feet, 100 feet and 125 feet respectively. The results of these "snapshot" calculations suggested that coefficients of drag of 0.29, 0.281, and 0.267 would be required to explain the performance, assuming that all four engines were developing take-off thrust and respective altitude gains of 70 feet, 100 feet, and 125 feet occurred.

The loss of thrust from one engine is equivalent to a change of 0.05 in coefficient of drag. Thus, if an engine failure is considered in these calculations, the coefficients of drag that would be required to explain the performance of the aircraft are 0.24, 0.231, and 0.217 respectively.

The manufacturer's data indicated that the expected coefficient of drag would be approximately 0.13 for a normal climb following lift-off.

1.17.6 Aircraft Stall

The lift produced by an airfoil (wing) is primarily dependent on three variables: airfoil geometry, angle of attack, and airspeed. Airfoil geometry on any given aircraft is altered through the use of trailing edge and/or leading edge flaps. Typically, extension of flaps increases the lift-producing capability (coefficient of lift) of a wing. For a specific flap setting, the only other way of changing the coefficient of lift is to change the angle of attack.

Angle of attack is the relative angle between the air impinging on the wing and the wing chord. As the angle of attack increases so does the coefficient of lift. The coefficient of lift continues to increase with increases in angle of attack as long as the airflow over the wing remains smooth and adheres to the contour surface of the wing. However, at a certain angle of attack, the airflow begins to separate from the upper surface of the wing. Initial separation usually occurs near the trailing edge of the wing. As the angle of attack increases further, the separation points move forward until the critical angle of attack is reached. Beyond this critical angle, any further increase in angle of attack results in a decrease in coefficient of lift, and a stall is said to have occurred. Near the stall, drag increases significantly.

The point at which an aircraft will stall is dependent upon angle of attack. However, due to the interrelation of angle of attack and airspeed in the production of lift, stalling and the point at which an aircraft will stall are usually expressed in terms of airspeed. For a given flap angle, factors which affect stall speed are thrust, angle of bank, load factor (vertical acceleration, 'G'), weight, and centre of gravity position.

Stall onset is the flight regime that precedes a full stall. In this regime, the aircraft is subjected to ever increasing buffet, pitch, and roll activity. Typical stages of stall onset, in order of occurrence, include activation of the artificial stall warning; momentary separation of the airflow on the wing as airspeed is reduced toward stall; buffeting which increases in intensity as speed decreases further (and angle of attack increases); the movement forward of the centre of lift as the separated flow region expands, resulting in less pilot control force necessary to cause the nose to raise; an increase in roll activity and lateral control difficulties caused by asymmetries in the fluctuating separation regions of each wing and which typically result in aircraft heading change during stall.

The stall characteristics of the DC-8 series of aircraft are described in the *DC-8 Flight Study Guide* in the following manner. "The stall characteristics of all DC-8 series aircraft are excellent and straightforward in every respect throughout the entire operating weight and C.G. range. All aircraft possess a crisp, clean break with no pitch-up tendencies or adverse roll characteristics. This is basically achieved through care in wing design. On the DC-8, as angle of attack is increased in the approach to stall, the inboard section of the wing, which already has been flying at a greater angle of attack than the outboard because of airfoil design, will stall first. The center of lift of the wing will then move aft with respect to the aircraft's center of gravity, thus causing the nose to pitch down in a positive manner while good lateral control is retained."

According to aerodynamicists from Douglas Aircraft and published material from the Boeing Commercial Aircraft Company (*Jet Transport Performance Methods*), swept wing jet transport aircraft like the DC-8-63 will yaw at the stall, particularly if pilots are trying to control wing drop with aileron inputs. An examination by the Board of several other accidents in which a DC-8 aircraft stalled shortly after lift-off determined that it was common for the aircraft heading to deviate significantly when the aircraft stalled.

Stall speeds for the DC-8-63 are published in the FAA approved Airplane Flight Manual. The speeds are predicated on idle thrust and a forward centre of gravity. They represent the minimum speed reached during aircraft certification stall recovery tests. With 18 degrees of flap and an aircraft gross weight of 344,500 pounds, the FAA certified stall speed is 144 KIAS.

Actual stall speed, that is, the speed at which the stall occurs, is higher than the FAA certified stall speed. Calculations using aerodynamic data provided by Douglas Aircraft Co. produced a 1G stall speed for a gross weight of 344,500 pounds that was about 11 knots higher than the FAA stall speed. A centre of gravity position which corresponded with the take-off from Gander would result in a stall speed decrease of three knots. Take-off thrust would reduce the stall speed by a further four knots. Because of the limitations of the FDR, the effects of load factor and angle of bank could not be estimated. Accordingly, the 1G clean wing stall speed on take-off from Gander, determined from data provided by Douglas Aircraft Co., was about 148 KIAS.

1.17.7 Stall Warning Systems

Most jet transport aircraft are equipped with a stick shaker or some other type of warning device to alert the pilot that the aircraft is approaching a stall. In the DC-8, the stick shaker is activated by a sensing mechanism (a lift transducer) in the wing leading edge.

The vane of the lift transducer protrudes through the lower surface of the wing leading edge so that, during flight, aerodynamic forces on the vane activate the stick shaker when a preset angle of attack is reached. According to Douglas Aircraft Co., the DC-8-63 stick shaker will activate approximately 13 knots above the FAA stall speed and six knots above the 1G stall speed.

1.17.8 Ground Effect

Any airplane operating near the ground will experience changes in the aerodynamic characteristics of its wing. The ground will cause a restriction to the local airflow and alter the wing upwash, downwash, and tip vortices. These effects are referred to as ground effect.

In ground effect, the induced flow velocities will be reduced, and the wing will experience a lower induced drag coefficient and a higher coefficient of lift for any specific angle of attack. In other words, the wing will require a lower angle of attack to produce the same lift coefficient and the corresponding drag coefficient will also be lower.

Ground effect is most pronounced when the aircraft is within one quarter of a wing span (37 feet for the DC-8-63) of the ground. All ground effect benefits are lost when the aircraft is more than one wing span above the ground. Typically, induced drag is reduced by about 20 per cent at one-quarter wing span from the ground and by about 45 per cent at one-tenth wing span from the ground.

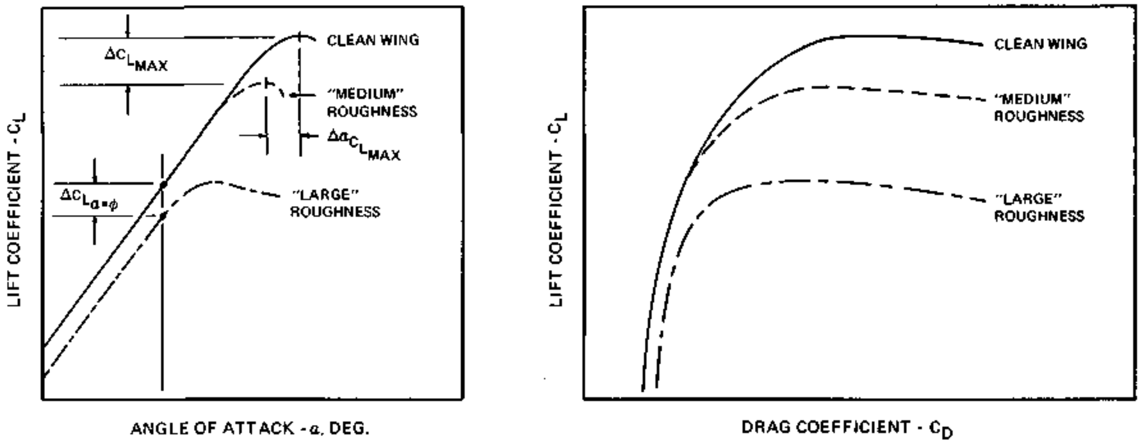


Figure 1.15. Typical Effect of Surface Roughness at the Leading Edge on Aerodynamic Characteristics

1.17.9 Aircraft Icing

Considerable research has been conducted into the effects of ice contamination on airfoil performance. As a result of this research, it is accepted that, in general, ice accretion on the leading edge or upper surface of an aircraft wing results in an increase in stalling speed, decrease in the stall angle of attack, and rapid drag increase near the stall. (See Figure 1.15.)

These effects and the inherent hazards have been documented and described in numerous aerodynamic tests and papers, aviation periodicals, and cold weather operations manuals. (See Appendix C for general information on the aerodynamic effects of ice contamination).

Recent research has shown that seemingly insignificant amounts of wing ice can be sufficient to significantly degrade an aircraft's performance and flight characteristics. Surface roughness caused by ice, frost, snow, or even large accumulations of insect debris or badly chipped paint can be sufficient to cause significant decreases in lift production and increases in drag.

Research has demonstrated that distributed roughness elements having a height of only 1/10,000 of the wing chord can adversely affect performance by increasing stall speeds. This height corresponds to about 0.030 inches on a DC-8-type aircraft - about the roughness of medium to coarse grit sandpaper.

On a wing contaminated with surface roughness, the normal stall progression of a swept wing is altered. The normal nose-down pitching moment in the direction of stall recovery which accompanies a stall is reduced when the wing is contaminated. The effects of the degraded pitching moment characteristics can range from an out-of-trim condition that can result in a different than normal response to control column inputs, to a severe pitch-up as the angle of attack is increased.

The leading edge portion of the wing is the most sensitive to contamination. Localized ridges, grooves, or narrow bands of roughness near the leading edge of the wing can cause a detrimental effect equivalent to that caused by some lessor degree of roughness elements distributed over the entire surface of the wing. The relative effects of such localized ridges, grooves, or narrow bands of roughness as a function of the location of the roughness expressed in percentage of chord can be seen in Figure 1.16.

Because ice contamination results in a lower than normal stall angle of attack, angle-of-attack-dependent stall warning systems, such as that installed in the DC-8, may not provide warning prior to actual stall.

In 1981 and 1982, the Boeing Commercial Airplane Company conducted wind tunnel, flight, and simulator tests with a Boeing 737 to better understand the effects of wing and horizontal tail contamination on airplane performance and flight characteristics. The results of these studies indicated that contamination significantly reduces wing lift capability, increases stall speeds, and decreases climb performance.

When the wing was contaminated, stall onset flight characteristics occurred within the clean airplane normal manoeuvring envelope, before stall warning system activation.

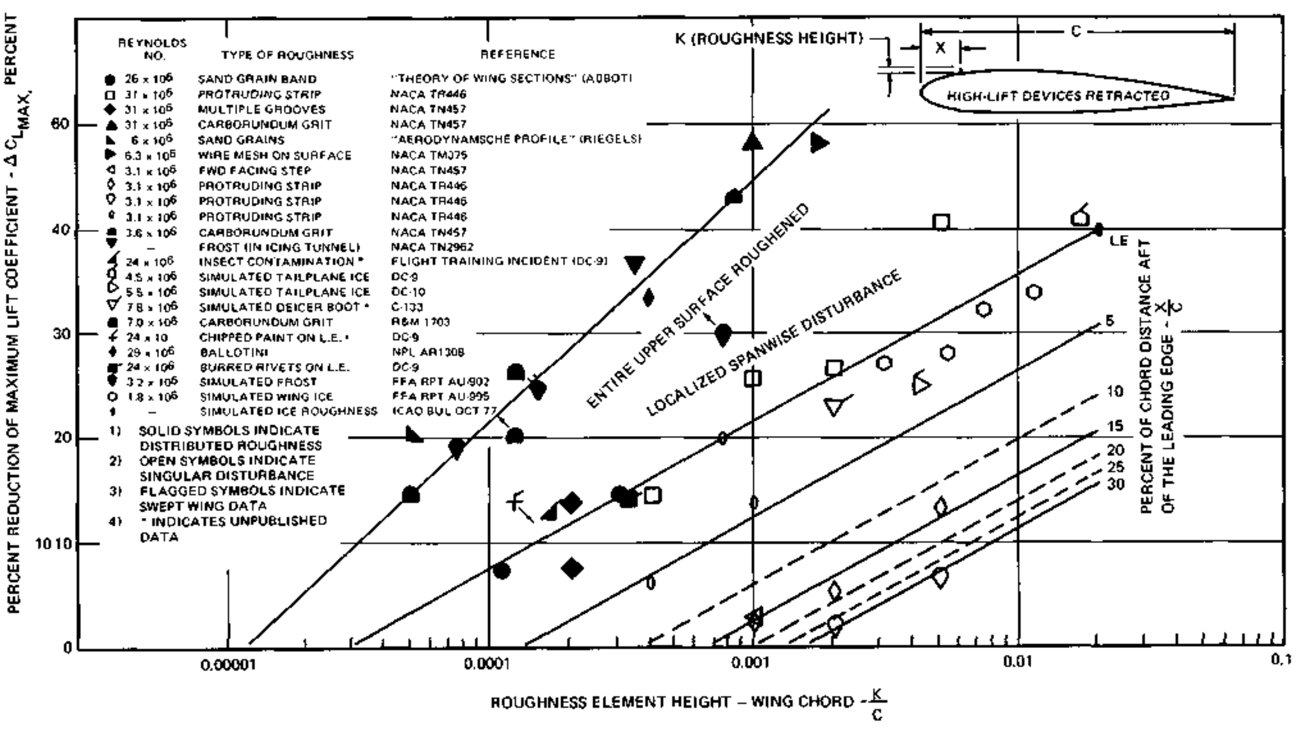


Figure 1.16. Reduction of Maximum Lift Coefficient Due to Wing Surface Roughness

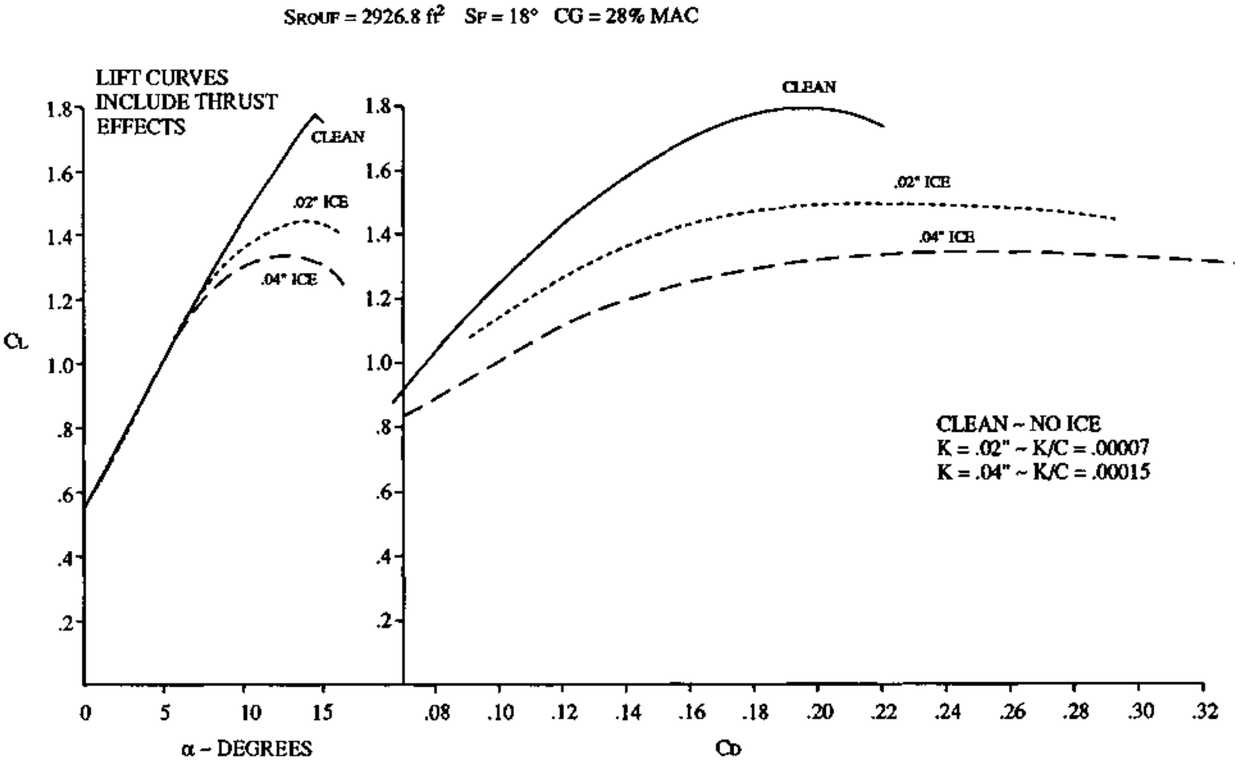


Figure 1.17. Model DC-8-63 Effect of Wing Upper Surface Distributed Roughness on Aircraft Lift and Drag

Flight tests, conducted on a Boeing 737 aircraft with wing surfaces roughened by the application of epoxy potting compound and safety-walk finish with a textured paint roller, demonstrated an 18 per cent loss of maximum lift capacity, which results in a 13-knot increase in stall speed.

Tests in the Engineering Flight Simulator indicated that pilots could encounter stall onset flight characteristics during a normal take-off rotation manoeuvre when the simulator was programmed with contaminated airplane aerodynamic characteristics.

Aircraft without leading edge high-lift devices are particularly sensitive to wing surface roughness. Extension of the leading edge devices on aircraft so equipped will generally recover most of the performance degradation resulting from low levels of roughness.

Unlike the Boeing 737, the Douglas DC-8-63 is not equipped with wing leading edge devices. Douglas Aircraft Co. confirmed that the performance degradation experienced by the DC-8-63 with small amounts of contamination is significantly greater than that encountered by other aircraft types equipped with leading edge devices. Information provided by the Douglas Aircraft Co. indicated that significant reduction in the maximum coefficient of lift and significant increase in the coefficient of drag would be experienced with surface roughness elements of 0.04 inches. (See Figure 1.17.)

According to the Douglas Aircraft Co. data, in an 18-degree flap configuration, the maximum coefficient of lift for the DC-8-63 would be reduced by 25 per cent with wings contaminated by surface roughness elements of 0.04 inches.

1.17.10 Ice Accretion on Approach

In the recent past, considerable research has been conducted into the subject of in-flight ice accretion on airfoils. This research has resulted in the development of several models which can predict the amount of ice that would accrete on a specific airfoil shape under certain conditions. In order to make such predictions, the conditions that must be known include the true airspeed and altitude of the aircraft, static air temperature, liquid water content of the cloud through which the aircraft is flying, and the radius of the water droplets in the cloud.

Several such calculations were performed by CASB investigators and by research officers of the National Research Council (NRC) of Canada. This agency has conducted recent research into icing through experiments undertaken in the high speed icing wind tunnel of the Low Temperature Laboratory. All calculations performed used the airspeeds and altitudes determined from the aircraft FDR recording of the descent into Gander (Figure 1.18.), static temperatures determined from the Atmospheric Environment Service's (AES) rawinsonde released near St. John's Newfoundland approximately two hours after the accident, and liquid water content and droplet size values obtained from AES. The altitude of the top and base of the cloud layer through which the aircraft flew while on approach to Gander was determined from pilot reports made by pilots who either arrived at or departed from Gander both before and after the accident.

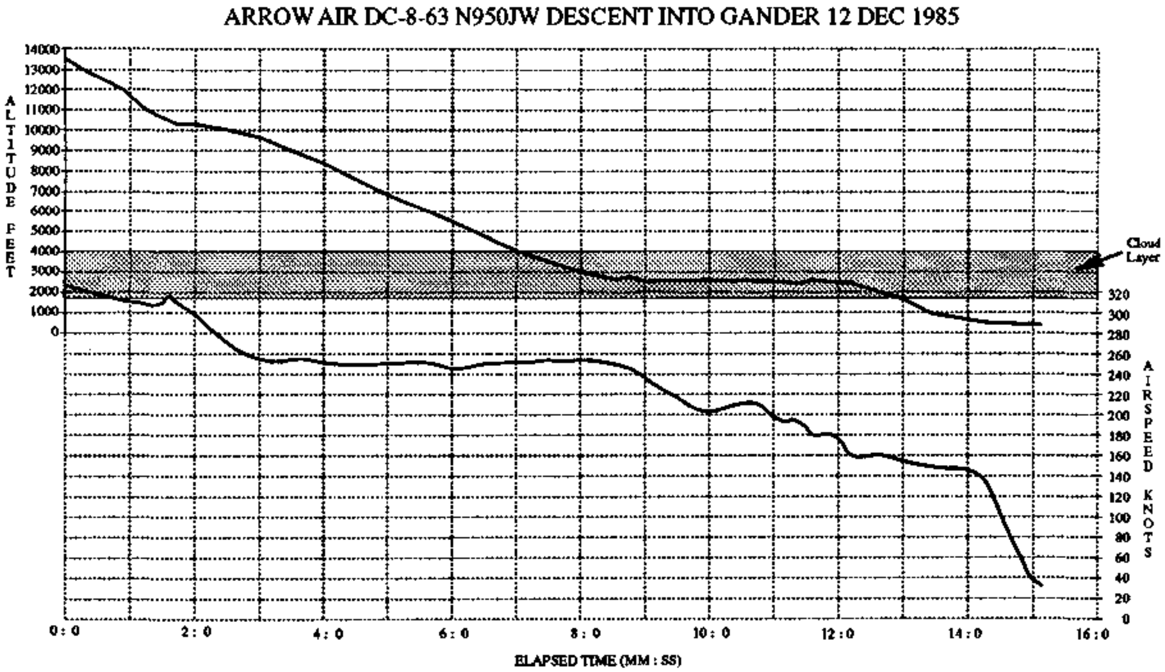


Figure 1.18. FDR Plot of Approach to Gander

One calculation used a method described in the *United States Federal Aviation Agency Technical Report*: "Engineering Summary of Airframe Icing Technical Data." This calculation resulted in a predicted ice accretion on approach of about 0.25 inch on the outboard portion of the wing.

A second method involved estimating the ice accretion on the wing utilizing a numerical model of rime ice accretion on two dimensional airfoils of arbitrary shape in potential flow. The model was suitable only to provide an estimate of the collision efficiency of the wing and an estimate of the thickness of the accretion which could have occurred at a sufficiently cold temperature. The model predicted that the total collision efficiency of the wing under the assumed conditions would be 0.14, resulting in an ice accretion rate of about 3.8 kilograms per hour per metre of span. The maximum local efficiency was about 0.65 near the leading edge of the wing. Assuming no runback, the local collision efficiency of the wing would have produced an ice thickness of about 0.3 inch.

Both of these methods were limited in value because they assumed a rime ice type accretion on the wing. However, the air temperature during the approach was sufficiently warm that the supercooled drops which struck near the leading edge of the wing would not have frozen immediately on impact, but rather would have run back along the wing surface, freezing at some distance back from their location on inital impact. The resulting horn-shaped, glaze ice formation would produce a much less streamlined profile than that predicted in the first two calculations.

In an attempt to refine estimates of the probable thickness and shape of wing ice accretion during the approach to land at Gander, a further series of calculations was performed using a method which enables calculation of the thickness of glaze ice formations on a non-rotating cylinder. Since the model was able to simulate icing only upon cylinders, various cylinder diameters were chosen because they approximated the curvature of the upper and lower surfaces of the DC-8-63 wing profile at various semi-span stations between 26 per cent and 85 per cent.

This series of calculations determined that the most probable estimate of maximum ice accretion expected during the aircraft's approach to land at Gander would vary from 8.7 millimetres (0.34 inches) at 85 per cent semi-span through 6.5 millimetres (0.26 inches) at 53 per cent semi-span to 5.0 millimetres (0.20 inches) at 26 per cent semi-span.

While slight variations between the local collision efficiencies on the cylinder and the DC-8-63 wing would lead to slightly different forms of ice accretion on the wing than on the cylinder, the calculated values were considered to be an accurate approximation of the ice which would have accreted on the wing of the aircraft during the approach to land at Gander.

Interviews with pilots from Arrow Air and other operators indicated that airfoil de-ice is rarely used. For weather conditions similar to those at Gander on the morning of 12 December 1985, it was the consensus of those interviewed that it would be unusual for airfoil de-ice to be used on approach to land.

1.17.11 Aircraft Ground De-Icing

To comply with the "clean aircraft concept" and minimize the hazards associated with ice contamination, it is common practice in the aviation industry to de-ice an aircraft prior to take-off when conditions warrant. Various techniques of ground de-icing have been developed over the years. Current practice involves the use of Freezing Point Depressant (FPD) ground de-icing and anti-icing fluids which have the capability to remove ice contamination and provide a protective film to delay further formations of frost, snow or ice.

Ground de-icing facilities using FPD fluids were available in Gander on the morning of 12 December 1985. The crew of MF1285R did not indicate that de-icing was required during their station stop.

Two other aircraft departed Gander in the three hours immediately preceding the accident. A Boeing 737, which departed about 30 minutes before the accident, was de-iced on the ground prior to departure. This aircraft landed at Gander at 0645. During the last two hours of its three-hour station stop at Gander, precipitation in the form of very light freezing drizzle and light snow grains was reported. The individual who de-iced the aircraft reported that ice was present on the leading edge of the aircraft wing prior to de-icing.

A British Aerospace VC-10, which departed about three hours before the accident, was not de-iced prior to take-off. This aircraft spent 50 minutes on the ground at Gander. During that time, no freezing drizzle was reported.

1.17.12 Ground Service Personnel Observations

Six ground service personnel attended the aircraft during its technical stop at Gander. All were interviewed by CASB investigators in the days following the accident.

The individual who marshalled the aircraft into position on the ramp and assisted in the placement of the passenger stairs did not observe ice on the aircraft. However, he reported that he did not inspect the aircraft for ice, nor did he at any time go up on the passenger stairs. In response to detailed questioning, he stated that he was not sure if there was, or was not, ice on the aircraft.

Two other individuals positioned the passenger stairs at the aircraft, loaded catering supplies and removed trash from the aircraft. Both indicated that they did not observe the wings of the aircraft and could not say whether ice was present on the wings or not.

A fourth individual serviced the lavatories of the aircraft during the station stop. He reported that he did not specifically look at the aircraft because immediately upon completion of his duties he was required to assist with departure preparations for another aircraft.

One of two refuellers reported that he did not see any obvious need for de-icing but qualified his response to investigators by stating that he could not see the top of the wing and that the top of the wing might have had ice.

The second refueller reported that he did see ice on the edge of the windscreen while he was on the flight deck conversing with the flight engineer. He further reported that the flight engineer had said that the flight had picked up a little ice on descent into Gander. With respect to his observations made while outside the aircraft, this refueller stated that he was unable to see the top of the wing and, thus, could not comment on what ice may have been present.

All six ground service personnel were re-interviewed by CASB investigators later in the investigation. Their recollections of observations made during the aircraft's station stop at Gander were unchanged.

1.17.13 Arrow Air Flight Crew Scheduling

Arrow Air's policy pertaining to flight crew member scheduling is found in the Arrow Air General Operations Manual. The manual states that all Arrow Air flight crew members will be scheduled in accordance with appliable FARs. Arrow Air's Director of Flight Operations testified at the Board's public inquiry. Flight crew scheduling at Arrow Air is his responsibility. He testified that applicable FARs were the primary parameters used to establish individual flight crew schedules. Although no written policy existed with respect to maximum duty day, he considered a duty day of 16 hours to be the upper limit used when developing schedules. He further testified that it was normal to allow a two-hour extension to the maximum crew duty day in the event of unanticipated delays and that it was within the discretionary power of a captain to extend the duty day in excess of 18 hours. He also testified that fatigue-inducing factors such as time-zone changes and night departures were not considered in developing crew schedules. The company employed no medical officer or adviser. Pilots were expected to self-monitor for fatigue. Interviews with Arrow Air personnel indicated that, on occasion, pressure was exerted by flight dispatch to complete planned itineraries.

1.17.14 Recovered Documentation

A work book containing a listing of the captain's previous flights was recovered from the wreckage.

One entry pertained to an Arrow Air MFO cargo flight in a DC-8-63, N6161A, to Ras Nasrani, Egypt on 23 February 1983. The entry indicated that the aircraft's main hydraulic system had failed on the flight inbound to Ras Nasrani.

The subsequent entry pertained to a flight to Cairo after a brief stop at Ras Nasrani. The entry indicated that, in order to get the aircraft out of Ras Nasrani, it was necessary to use the auxiliary hydraulic system to raise the landing gear and flaps. The process was described as slow but successful. Some difficulty was experienced getting the gear doors latched.

The next entry pertained to the departure from Cairo following a fuel stop. It indicated that the aircraft was nursed out of Cairo and that the company diverted the flight to Amsterdam for maintenance. The entry described the approach and landing at Amsterdam and the difficulties encountered (manual reversion of ailerons, cross-wind, and turbulence).

1.17.15 Pertinent United States Federal Aviation Regulations

Arrow Air is a certificated air carrier operating under domestic and flag carrier rules of FAR Part 121.

1.17.15.1 Flight Recorder Requirements

FAR 121.343 requires that large turbine-engine-powered aircraft certificated for flight above 25,000 feet be equipped with one or more approved flight recorders. For aircraft having an original type certificate issued before 30 September 1969, the recorder must record the following information: time, altitude, airspeed, vertical acceleration, and heading.

FAR 121.349 requires that large turbine-engine-powered aircraft be equipped with a CVR. Current regulations do not require that a CVR be functionally tested by flight crews prior to flight.

The Arrow Air, FAA Approved DC-8 Minimum Equipment List permits dispatch of an aircraft with an inoperative FDR and with an inoperative CVR. This is consistent with the FAA Master Minimum Equipment List for the DC-8 and other transport-category aircraft.

1.17.15.2 Flight Crew Flight-Time Limitations

The U.S. FAR 121.521 outlines the flight-time limitations for aircraft operated overseas and internationally by a crew of two pilots and one additional airman. It states:

> (a) No supplemental air carrier or commercial operator may schedule an airman to be aloft as a member of a flight crew of two pilots and at least one additional flight crew member for more than 12 hours during any 24 consecutive hours.
>
> (b) If an airman has been aloft as a member of a flight crew for 20 or more hours during any 48 consecutive hours or 24 or more hours during any 72 consecutive hours, he must be given at least 18 hours of rest before being assigned to any duty with the air carrier or commercial operator. In any case, he must be relieved of all duty for at least 24 consecutive hours during any seven consecutive days.

There are no flight crew duty day time limits included in FAR Part 121.

The provisions of FAR Part 121 do not apply when a specific flight does not involve the carriage of persons or property in air commerce for compensation or hire, such as a ferry flight to a maintenance base. Such non-revenue flights operate under the provisions of FAR 91, General Operating and Flight Rules. Under FAR Part 91, there are no flight crew flight-time limitations.

1.17.16 FAA Surveillance

In March 1984, as part of special two-phase National Air Transportation Inspection (NATI), the FAA conducted concentrated inspection and surveillance of air carriers throughout the United States. Findings of the first phase of the inspection were reviewed by regional coordinators who analysed them for trends and potential problem areas. If deficiencies were noted during the phase one inspection of a particular carrier, a second, more detailed inspection of the specific air carrier was immediately initiated. On completion of its phase one inspection of Arrow Air, the FAA conducted a second phase inspection of Arrow Air between 19 March 1984 and 29 March 1984.

The inspection team carried out an in depth review to ensure that Arrow Air operations were conducted in accordance with applicable FARs. The inspection involved the review of records, interviews with company personnel, en route inspections, ramp inspections, and facility inspections.

The inspection followed a period of rapid growth at Arrow Air. Inspectors noted that, in many cases, Arrow Air operating policies and procedures had not kept pace with this growth. Numerous company manuals were found to be out of date, and, in some cases, manuals did not meet the requirements of FARs.

Arrow Air aircrew training records were judged to be unsatisfactory. Many examples of incomplete and unsupported training records were observed. Weak record keeping was a trend found throughout the Arrow Air organization. The inspection team noted that there was no formal maintenance training program in place.

It was determined by the inspection team that Arrow Air operated their fleet of aircraft with many DMIs and that, in some cases, DMIs were carried for months without corrective action.

Inspection of Arrow Air spare parts held in stock at one of their facilities determined that many parts contained serviceable parts tags from unapproved foreign sources. Arrow Air personnel were immediately advised that use of these parts was unacceptable. In response, Arrow Air removed all the parts from stock and shipped them to its Miami base to ensure the parts were properly certified by FAA approved sources.

With respect to FAA surveillance activities, the inspection team noted several cases where routine surveillance had identified discrepancies which appeared to be violations of FARs, and where the inspection results were recorded as satisfactory.

There were also instances where no follow-up action had taken place after unsatisfactory surveillance observations had been made. There were other instances where the inspection team determined that the carrier itself had been asked to investigate alleged violations of FARs.

As a result of its observations, the inspection team made a number of recommendations. Many pertained to increased surveillance on the part of the local FAA office and the assigned principal inspectors. They recommended that operations and maintenance units increase their surveillance and inspections of the carrier; that all discrepancies or unsatisfactory findings noted be followed up to ensure that corrective action was taken; that, where deemed appropriate, violation action was taken; and that, in general, a more firm stance be taken with respect to company activities and practices found to be inappropriate or contrary to regulations.

Specific areas identified as requiring increased surveillance activity and follow-up were company manuals, training, DMIs, and the use of parts from unapproved foreign sources.

The FAA conducts ongoing surveillance of air carriers to ensure compliance with FARs and approved FAA procedures. The responsibility for this ongoing surveillance is primarily that of the assigned POI and principal maintenance inspector (PMI).

The FAA inspectors who were the assigned POI and PMI at the time of the accident testified at the Board's public inquiry into the accident.

The assigned POI had assumed his responsibilities at Arrow Air in June 1985, six months before the accident. He testified that about 75 per cent of his duties related to activities at Arrow Air. Of that time, only 30 per cent was devoted to inspection and surveillance, the remainder to providing technical advice to the carrier. Although an assistant operations inspector position existed, it had been vacant since the POI was assigned to Arrow Air.

In the opinion of the POI, Arrow Air's operations met the requirements of FARs and approved FAA procedures. He further testified that he believed the manpower resources available to him for surveillance of Arrow Air were inadequate.

The assigned PMI had assumed his responsibilities at Arrow Air in April 1985, eight months before the accident. He testified that it was his responsibility to ensure that Arrow Air maintenance and inspection programs were in accordance with FAA standards. Surveillance activities would include spot inspections, en route inspections, facility inspections, review of various manuals and aircraft technical logs as well as aircraft inspection. He further testified that, in addition to his duties at Arrow Air, he was also the PMI for two other air carriers and five repair stations. He estimated that about 40 per cent of his time was devoted to surveillance of Arrow Air. To assist him in his responsibilities were two other FAA inspectors.

During his eight months of surveillance at Arrow Air, the PMI did not identify any deficiencies in Arrow Air's maintenance and inspection programs. He considered Arrow Air's operations to be in accordance with required standards. He further indicated that, in his role as PMI at Arrow Air, he did not in any way use the report of the 1984 NATI of Arrow Air.

In January 1986, one month after the accident, the U.S. Secretary of Transportation directed the FAA to conduct in depth inspections of airlines operating under military charter. Arrow Air was subject to such an inspection between 21 January 1986 and 21 February 1986.

The inspection team made numerous observations which were, in the opinion of inspectors, instances of non-compliance with FARs or accepted FAA procedures. In several cases, findings were similar to those determined in the 1984 NATI of Arrow Air. Inadequacies and examples of non-compliance with FARs were noted in almost all areas of Arrow Air's operations. Specific observations included out-dated manuals, procedures not in accordance with FARs, unsatisfactory training files, non-compliance with established Arrow Air procedures, use of aircraft parts and components from unapproved foreign sources, and non-compliance with FAR maximum flight-time limitations and minimum crew-rest provisions. Although no overall conclusions were drawn as a result of this inspection, the FAA inspector in charge testified at the Board's public inquiry that, in some areas, Arrow Air did not meet the minimum standards required by the FAA. He further testified that he considered some of the observations made to be significant and that, in some cases, the safety of operations was questionable.

Subsequent to the public inquiry, the FAA informed the Board that, after an in depth review by the FAA's Miami Flight Standards District Office, many of the inspection team's findings were found to be invalid for a variety of reasons. Specifically, many of the findings were considered to be of a minor nature, and, of the 19 findings considered by the FAA to be major, that is, worthy of formal enforcement proceedings, further investigation determined that eight were not violations, and they were subsequently dismissed without further action. Ten of the major findings were determined to be violations which resulted in assessment of a civil penalty or issuance of a warning/correction letter.

The FAA further indicated that, when compared against in depth inspections carried out at other carriers, the magnitude of Arrow Air noncompliance was no worse than "average", indicative of violations in limited areas of their operation.

The FAA also asserted that, in the months preceding the accident, their surveillance and follow-up of Arrow Air was executed to a greater degree, both in quality and quantity, than ever before in the company's history.

1.17.17 Public Inquiry

The CASB conducted a seven-day public inquiry into this accident in Hull, Quebec, beginning 08 April 1986 (See List of Witnesses - Appendix D). Participants in the inquiry were the CASB technical panel; Douglas Aircraft Co.; Pratt & Whitney United Technologies; the Flight Crew Next of Kin; Arrow Air Inc.; Multinational Force and Observers; Department of Transport, Canada; United States Federal Aviation Administration; United States National Transportation Safety Board; United States Army; and the Department of Justice, Province of Newfoundland.

2.0 ANALYSIS

2.1 Introduction

Analysis of all available information from the FDR, witness observations, and radar data indicates that, following an apparently normal ground roll, the aircraft failed to achieve a normal rate of climb. Within a few seconds of rotation, the airspeed began to decrease, and, at an altitude of no more than 125 feet above the runway, the aircraft stalled. A rapid descent ensued, and, about 20 seconds after lift-off, the aircraft struck trees on downsloping terrain about 2,900 feet beyond the departure end of the runway. Aircraft pitch attitude and the flight path angle at impact were indicative of an angle of attack of 21 degrees, well beyond the normal stall angle of attack.

The major objective of the investigation was to determine the cause of the significant degradation in normal take-off performance. The investigation and analysis were directed toward the pre-impact serviceability of the aircraft, the take-off weight of the aircraft, and the weather factors. In the absence of a useful cockpit voice recording and because of the limited number of parameters measured by the FDR, it was also necessary to conduct a detailed theoretical analysis of the aircraft's performance. In addition, flight crew performance, load planning and control, company maintenance procedures, flight crew fatigue, flight recorder requirements, and FAA surveillance activities were examined.

2.2 Performance Analysis

Characteristic changes in the pressure altitude and vertical acceleration traces of the FDR recording indicate that lift-off occurred 51 seconds after brake release at an airspeed of about 167 KIAS. Following lift-off, the airspeed continued to increase for a further two seconds until a peak airspeed of 172 KIAS was attained. The aircraft crossed the departure end of the runway six seconds after lift-off, at about 170 KIAS. Thereafter, the airspeed continued to decrease until a stall occurred.

It proved impossible to determine an altitude profile of the flight from the pressure altitude trace of the FDR because of static pressure errors associated with the occurrence of the stall. However, eyewitness observations and the radar controller's observations of the radar Mode C readout suggest the aircraft gained a maximum altitude of 125 feet. The Mode C readout as observed by the radar controller did not change from the 500 feet asl readout that was indicating at the commencement of the take-off roll. The readout indicates in 100-foot increments, thus it is possible that the aircraft could have climbed a maximum of 100 feet above the start of take-off roll altitude (125 feet above the runway departure end) before the altitude readout would have changed to 600 feet. Eyewitness observations were consistent with a maximum altitude gain of 125 feet, although in all likelihood the altitude gain was less than that.

The vertical acceleration trace proved to be unsuitable for estimating a flight path; nevertheless, the rapid fluctuations in acceleration values immediately after take-off indicate the aircraft was in a stalled condition. Further evidence of this condition are the extreme oscillations of the pressure altitude trace which are the result of the rapid pressure changes experienced in the stall regime. The fluctuations in both vertical acceleration and pressure altitude values were in marked contrast to those of previous take-offs. The alteration in heading which commenced about five seconds after lift-off was not inconsistent with control difficulties experienced during stall onset and is typical of swept wing aircraft accidents where aircraft stall was a factor.

Because of the unreliable time sequence associated with the vertical acceleration trace of the FDR, it was not possible to determine precisely when the stall occurred. Nevertheless, when viewed together, the vertical acceleration, airspeed, and heading traces indicate that the aircraft was in a stalled condition within 10 seconds of lift-off.

Early rotation would normally result in aircraft lift-off at about 161 KIAS, if the crew used a pitch angle of eight degrees while on the runway. Analysis indicates that the aircraft lifted off at about 167 KIAS, six knots above the predicted speed. However, since the actual pitch history of the take-off and brief flight is not known, it is not possible to conclude with certainty that the lift-off speed was abnormal.

The performance of the aircraft during the take-off was compared closely with the theoretical performance data provided by Douglas Aircraft Co. A normal DC-8-63 at the calculated weight of the accident aircraft and under the existing environmental conditions should accelerate to lift-off in about 47 seconds, using 6,700 feet of runway. After lift-off, the aircraft should climb and accelerate while transitioning to the climb configuration.

The performance of the aircraft during the take-off was below that predicted. Although acceleration corresponded well with that expected to rotation, lift-off occurred four seconds later than predicted assuming normal take-off reference speeds were used. Over 1,000 feet of additional runway were used. Nevertheless, sufficient flying speed was achieved, and the aircraft lifted off well before the end of the runway. The later than normal lift-off should not have had any adverse effect on the remainder of the take-off.

The performance of the aircraft after lift-off was significantly below predicted values. The evidence is conclusive that, following lift-off, both the climb rate and acceleration were well below normal. Although an initial climb was established, it was maintained for less than 10 seconds, and no more than 125 feet was gained during this brief climb. Similarly, the aircraft continued to accelerate for only two seconds following lift-off. Thereafter, the aircraft began to decelerate until the stall occurred.

Based on the data provided by Douglas Aircraft Co. and from the *DC-8-63 Aircraft Flight Manual*, the 1G stall speed, at the weight calculated by the Board and for the configuration of the accident aircraft, is 148 knots. As determined from the FDR, the aircraft stalled within 10 seconds of lift-off. Airspeed during this 10-second period varied between a peak of 172 knots, which was achieved two seconds after lift-off, and a low of 163 knots, which was the recorded airspeed 10 seconds after lift-off. Thus, the aircraft stalled at an airspeed between 15 and 24 knots above the predicted stall speed. Application of the estimated error bounds of the FDR airspeed trace results in a stall speed range between 10 and 29 knots above the predicted stall speed. It should, however, be noted that the recorded airspeed during the take-off roll agreed closely with that predicted by the Douglas Aircraft Co., evidence that the recorded airspeed values were substantially correct.

Further analysis was conducted to determine the theoretical lift and drag penalties necessary to result in the observed differences between predicted performance and the actual performance of the aircraft during the accident take-off.

Theoretical analysis demonstrated that the performance of the aircraft after lift-off was indicative of a significantly decreased value in coefficient of lift and a significantly increased value in coefficient of drag. During the brief climb which followed lift-off, the aircraft decelerated. Assuming an altitude gain of 125 feet, the coefficient of drag value necessary to produce the deceleration was calculated to be 0.267, well above the normal coefficient of drag value of 0.13 provided by Douglas Aircraft Co. for the conditions and aircraft configuration during take-off. The calculated coefficient of drag was about 100 per cent higher than the normal value.

An altitude gain after lift-off of less than 125 feet would require an even higher value in coefficient of drag to produce the observed deceleration. The calculated coefficient of drag values that corresponded to altitude gains of 100 feet and 70 feet were 0.281 and 0.29 respectively.

Although the recorded airspeed could have been subject to a maximum error of five knots, any error would have been constant, and thus would have no effect on the validity of the deceleration used to calculate the coefficient of drag.

The increase in both lift-off speed and stall speed is indicative of decreased lift-producing capability of the wing (i.e., coefficient of lift). The calculated decrease in C_L maximum necessary to account for the magnitude of the increase in stall speed was at least 0.38. According to data provided by Douglas Aircraft Co., this corresponds to about a 22 per cent decrease in maximum coefficient of lift.

The conclusions of the computer simulations conducted by UDRI agreed closely with this analysis. Their solution of the aircraft's equations of motion determined that an approximate 30 per cent loss in coefficient of lift had occurred accompanied by at least a 100 per cent increase in coefficient of drag.

2.3 Pre-Impact Condition of the Aircraft

2.3.1 Introduction

Serious consideration was given to the possibility that the significant changes in aircraft performance were the result of a pre-impact failure or malfunction of the aircraft. Extensive and detailed examinations were conducted on all the recovered wreckage. Although much of the aircraft was consumed in the post-crash fire and the complete integrity of most of the aircraft systems could not be determined, the Board was unable to identify any physical evidence of such a failure or malfunction. All damage to the aircraft and its components was assessed to be the result of impact and the post-crash fire. The aircraft configuration at impact was determined to be normal for the planned take-off.

There was, however, considerable information in the form of witness statements which suggested that problems with the aircraft were present before the accident. Specifically, these related to the flight control system, the hydraulic system, the number four engine, and the thrust reversers. In addition, there were the reports of the yellow/orange glow emanating from the underside of the aircraft and the evidence of a lower rpm of the number four engine at impact.

In the absence of FDR information pertaining to aircraft system operation and because of the extensive destruction of the aircraft which precluded a complete examination of all aircraft components, several possible malfunctions were analysed to determine their likelihood and what impact, if any, they would have had upon the accident flight.

2.3.2 Flight Controls

The reported binding and ratchetting of the co-pilot's control column suggested the possibility that control of the aircraft could have been lost because of a binding or jamming of the elevator. No conclusive evidence of such an event was found in examinations of the wreckage, nor was the source of the reported binding identified.

It is possible that the binding was the result of an unserviceable PTC. The description of the binding was similar to that encountered with a previous PTC problem. Under normal circumstances, the PTC is deactivated for take-off, and any irregularities in its operation would not affect take-off. Nevertheless, had it been inadvertently in operation, and malfunctioning, it is remotely possible that abnormal inputs could have occurred as a result of PTC extension. However, had there been such a malfunction, it would be expected that the PTC EXTEND/FAIL light would have been illuminated. Examination of the wreckage determined that the light was not illuminated at impact. Furthermore, extension of the PTC could not explain the significant changes to coefficients of lift and drag.

Testing in the simulator further demonstrated that a runaway PTC during take-off was a situation that was readily overcome by the pilot, resulting in a successful take-off.

Detailed examination of the elevator leading edge revealed the presence of a chordwise scratch on the elevator that corresponded with a mark on the rear spar of the stabilizer. It could not be determined if the marks were the result of impact damage or if they existed before the accident. If these marks were not the result of impact, their presence may be indicative of interference between the elevator and stabilizer caused by a foreign object. Such interference could have resulted in the reported binding. Had this been the case, it is also remotely possible that the interference between the elevator and stabilizer progressed to the point that the elevator jammed during the take-off.

Examination of the wreckage determined that the elevator was in the full-trailing-edge-up position at impact. Faced with the imminent impact with the terrain, it is likely that the flight crew would have reacted with control inputs that would have resulted in this position. The position of the elevator thus suggests that full-up movement was available to the pilots. Alternatively, the impact position of the elevator suggests that, if jamming occurred, it resulted in a full-up deflection, or the jamming was of a transient nature, and the pilots regained authority prior to impact. Had the elevator jammed in the full-up position at rotation, the pitch angle would have exceeded the 8.6 degree geometry limit of the aircraft, and the tail would have struck the runway prior to lift-off. There was no evidence of a tail strike on either the runway or aircraft tail. No scrape marks were observed on the tail skid or on the runway surface. Furthermore, neither of these cases is supported by the analysis of the aircraft's performance during take-off. Neither case would result in the significant changes to coefficients of lift and drag evidenced by the magnitude of the deceleration during the slight climb and the premature stall. Testing in the simulator further demonstrated that jamming of the elevator resulted in pitch angles before lift-off that would result in a tail strike.

2.3.3 Hydraulic System

Some flight control systems of the aircraft are hydraulically operated. So too are the landing gear and engine thrust reversers. There was evidence to suggest that the hydraulic system of the aircraft was leaking; replenishment of hydraulic fluid was a recurring event. In the two days prior to the accident, a total of 13 quarts of fluid was added to the system. According to Douglas Aircraft

Co., leakage is the only explanation that can account for such a fluid replenishment rate. Representatives of the operator suggested that the recorded rate of replenishment had been inflated by vendors and did not reflect the actual replenishment rate. The Board could find no evidence to support this.

Examination of the aircraft wreckage did not reveal any evidence of a hydraulic system failure; however, examination of the hydraulic system was limited to two engine-driven pumps. In view of the significant rate of leakage of hydraulic fluid, it is possible that a hydraulic system failure could have occurred as a result of insufficient fluid. The recovered documentation provided evidence that, on a previous occasion, the pilot had initiated two flights with an inoperative hydraulic system.

Evidence obtained through examination of recovered light bulbs was inconclusive with respect to the status of the main system hydraulic power and services during the take-off. However, the impact status of the hydraulic reservoir low pressure light (not illuminated) would indicate that a rapid depletion of fluid in the main reservoir had not occurred. Furthermore, the impact status of the rudder control manual indicating light (not illuminated) indicates that the rudder was hydraulically powered through either the main system or rudder standby hydraulic power pump.

Testing in the simulator demonstrated that take-off with an inoperative hydraulic system could be accomplished without significant difficulty. Similarly, failure of the hydraulic system during take-off did not result in an unsuccessful take-off. Both the ailerons and rudder automatically revert to manual (aerodynamically boosted) in the event of hydraulic system failure. The horizontal stabilizer is equipped with an alternate electrically powered trim system, and the elevators are operated by a conventional cable system and by an aerodynamic boost tab. The captain's previous take-offs performed with an inoperative hydraulic system further demonstrated that such a take-off could be accomplished without significant difficulty and cannot explain the observed performance degradation during the accident take-off.

2.3.4 Engines

EGT indications of the number four engine were approximately 40 degrees hotter than the other three engines. As a result, the Cologne/Cairo sector crew was retarding the throttle slightly on take-off to keep the temperature under limiting values. It is reasonable to assume that the accident crew was doing the same. Information supplied by the engine manufacturer demonstrated that such an action would reduce total engine thrust by about 2.5 per cent. Such an event would have an insignificant effect on take-off performance.

Engines one, two, and three were determined to be operating at high-power settings at ground impact. The number four engine was determined to be operating at a lower rpm than the other three engines when it struck the ground. It could not be conclusively determined how much lower the impact rpm was although the position of the bleed valve strongly suggests that, prior to impact with the ground, engine rpm fell below 53 per cent. It could not be determined if this lower ground impact rpm was the result of the ingestion of debris as the engine passed through trees immediately prior to ground impact, or if the lower rpm was a condition which occurred prior to descent into the trees. With the exception of the possible pre-impact rupture of the pressure regulator diaphragm in the FCU, there was no evidence of any mechanical failure of the engine. Metallization in the transition duct provided positive evidence that the engine was operating at tree impact and had not flamed out.

Independent examination of the number four engine confirmed the assessment of CASB investigators that, with the exception of the possible pre-impact rupture of the pressure regulator diaphragm in the FCU, there was no evidence of any component failure or malfunction involving the number four engine prior to impact with trees and that the engine was operating at the time of tree impact. Similarly, this independent examination could not establish with certainty the engine power output at the time of initial tree impact. However, the independent consultant did conclude that the observed engine damage caused by tree ingestion and resulting deceleration was consistent with a high power output.

It is possible that the rupture of the pressure regulator valve diaphragm of the FCU believed to have been installed on the number four engine occurred prior to impact, although the overall good condition of the diaphragm and previous accident investigation experience suggest that the rupture was impact related and occurred as a result of a pressure spike. Tests with the ruptured diaphragm indicated that, had it occurred prior to impact, no adverse effects would have resulted. However, the FCU bench flow tests were limited to assessing steady state conditions. Thus, the possible effects, such as compressor stalling or surging, a ruptured diaphragm could have had under other conditions, such as a rapid advancement of the throttle lever beyond the take-off thrust position, are not known.

The impact readings of the number one, three, and four engine EPR gauges were consistent with a high power setting. The number two engine EPR gauge reading was consistent with a significantly lower power setting. These gauges are a servo motor type, with no return spring mechanism. Indicators of this type will tend to remain at the position of last reading when electrical power to the system is cut; however, when contacted, the manufacturer of the gauges indicated that, because there is no return spring mechanism, the pointer can move when a gauge is rotated. Thus, it is quite possible that none of the EPR gauges accurately reflected engine power output at impact.

Nevertheless, since three of four EPR gauge impact readings were at or near the take-off thrust setting, their possible significance was examined. In assessing the significance of any individual reading, it is necessary to know when power was removed from the indicator. The impact reading of the number four engine, if reliable, suggests that, when power was removed from the indicator, the engine was operating at high power. Assuming that power was not removed from the indicator until aircraft breakup began to occur, the reading suggests that this engine was operating at high power until at least initial tree impact.

Although the impact reading of the number two engine indicator was well below take-off EPR, it is possible that the reading, if reliable, indicates that power was removed from the indicator later in the impact sequence, after the engine rpm and EPR had decreased as a result of impact and breakup. This assessment is supported by the examination of the engine which indicated that the engine was operating at high rpm at ground impact.

Although there was no definitive evidence to indicate that the number four engine was not operating at a high power setting when the aircraft entered the trees, the possibility that the lower ground impact rpm indicated that an interruption of number four engine power occurred at or after rotation could not be completely ruled out through examination of the engine. Furthermore, witness accounts of the yellow/orange glow could be considered consistent with flames emanating from an engine experiencing compressor stalls and surges. Also considered consistent with an interruption of engine power of the number four engine was the heading change to the right which occurred shortly after lift-off.

Engine performance was not recorded on the FDR. Thus, in the analysis of aircraft performance, it was necessary to assume normal engine operation. Therefore, had there been a power interruption in the number four engine, it could not be distinguished from an increase in drag. However, the thrust penalty associated with the failure of one engine is equivalent to an increase of about 0.05 in the coefficient of drag. The theoretical performance analysis determined that the combined effects of thrust loss or drag increase, necessary to result in the actual performance of the aircraft, were equivalent to a coefficient of drag increase of at least 0.13, well in excess of the value associated with the failure of one engine. Additionally, the failure of one engine cannot explain the significant decrease in coefficient of lift determined in the performance analysis.

Previous accidents involving DC-8 aircraft have demonstrated that, at high angles of attack, it is possible for an engine to experience power fluctuations accompanied by flames emanating from the engine as a result of surging caused by disruptions in the intake airflow. Thus, it is also possible that the lower ground impact rpm of the number four engine and yellow/orange glow observed by witnesses was a consequence of the stall and a subsequent compressor surge that occurred shortly after take-off.

In conclusion, although the possibility of the number four engine operating at less than full power cannot be eliminated, such an event, on its own, should not have caused the accident. Performance simulations conducted on behalf of the Board by UDRI and DND indicated that the performance of the aircraft could be explained by the loss of thrust from one engine, coupled with the performance degradation that results from ice-contaminated wings.

2.3.5 Potable Water System

There was evidence to indicate that the potable water system was leaking. Although the system had been subject to maintenance actions in Oakland prior to the initiation of this series of rotation flights, it was again leaking on arrival at McChord, and water leakage was reported by the captain to Arrow dispatch in Miami during a telephone call made from Gander, on the morning of the accident. The Board considered the possible effects that this water leakage could have had on aircraft control either as a result of changes in weight and centre of gravity position or through disruption to critical aircraft systems.

Water leaking from the aircraft's potable water system drains by gravity to the space between the cargo compartment liner and the aircraft skin. The lower fuselage is equipped with fuselage drains; however, when the aircraft is pressurized, these drains close and water can accumulate in the belly of the aircraft. During a long duration flight, this water can freeze due to the low ambient temperatures at high altitudes. This ice will melt and slowly drain away during ground stops where the ambient temperature is above freezing.

Discussions with other DC-8 operators indicated that, on occasion, water leakage directly into the cargo pits is a problem. The problem is not, however, one of aircraft control, but rather one of wet baggage and water damage to the insulation in the cargo pits. There are no aircraft control systems in the lower portion of the cargo pits which would be affected by water leakage, nor could water accumulate in a quantity sufficient to cause significant changes in the aircraft weight or centre of gravity.

2.3.6 Aircraft Configuration

There was no evidence found during the examination of the wreckage to suggest that the aircraft configuration was abnormal at impact.

To assess the position of the flaps at impact, the Board examined evidence gathered through examination of the flap actuators, flap lockout cylinders, flap position indicator, and the flap tracks.

Impact marks inside the flap actuators were consistent with a flap setting of less than 25 degrees. Roller imprints on three of the eight flap tracks recovered were consistent with a flap setting of 18 degrees. Although there were conflicting imprint marks on the other flap tracks recovered, with only two exceptions, these marks were within a corresponding flap setting range of between 12 and 25 degrees. Because of the multiple roller imprints on some flap tracks, the most distinct marks were assumed to be those that occurred at impact. With flaps partially extended, tree contact would tend to pull the flaps and rollers rearward. However, tree contact would not likely produce sufficient shock loading to result in witness marks on the tracks. As a result, witness marks on the tracks could equate to a greater flap angle than the actual position prior to tree impact. Thus, it is possible that secondary impacts occurred during breakup, which may have been of greater magnitude, thus accounting for the range of flap positions determined through interpretation of the most distinct marks. With respect to the remaining two roller imprints, one was clearly unreliable due to the significant difference between imprint positions on the left and right side of the same track (i.e., 50 and 23 degrees). The other imprint, which corresponded to a flap position of 32 degrees, was also considered unreliable because of the significant difference in the interpreted flap setting and the flap setting determined for adjacent flap tracks on the same flap.

No useful information was gained through examination of the flap lockout cylinders or the flap position indicator.

Flap asymmetries have been experienced with the DC-8-63. In these cases, the asymmetric condition was caused by failure of a flap-link assembly initiated by fatigue pre-cracking. The flap-link assemblies were recovered from the wreckage and examined. There was no evidence of pre-impact failure. No fatigue pre-cracking was detected.

In conclusion, although testing in the simulator demonstrated that severe flap asymmetry could result in a flight profile similar to that of the accident flight, the Board found no evidence to suggest that such an asymmetry had occurred. Based on its examination of the flap system components, the Board concluded that the flaps were extended to the planned 18-degree setting.

The stabilizer angle determined from the wreckage was close to that applicable to the take-off weight and centre of gravity position calculated by the crew and the corresponding V_2 speed. It was within the flight-deck indicator's 1 ANU margin of error. Because of indications that the flight crew had underestimated the take-off weight and may have inadvertently used a V_2 speed applicable to 310,000 pounds, the corresponding take-off stabilizer angle was calculated. This value (5.8 ANU) was also close to the value determined from the wreckage. It too was within the flight-deck indicator's 1 ANU margin of error. Thus, the Board concludes that an inappropriate stabilizer setting did not contribute to this accident.

Examination of the recovered wing slot hydraulic actuators suggested that the wing slot doors were in the appropriate (open) position at impact. This conclusion was supported by the determination that the wing slot door light was not illuminated at impact. This light will illuminate when the wing flaps are not in the UP position and any one or none of the slot doors is not fully open.

The results of the performance analysis and simulator testing further indicated that closed slots could not explain the accident. The lift penalty which results from closed slots is a 0.2 reduction in maximum coefficient of lift. The performance analyses calculated that a minimum 0.38 decrease in maximum coefficient of lift is necessary to result in an increase in stall speed of the magnitude indicated through analysis of the FDR recording. Testing in the simulator demonstrated that take-off with wing slots closed could be completed without significant difficulty.

There was no evidence to suggest that an inadvertent extension of the ground spoilers had occurred. Examination of the ground spoiler system hydraulic actuator determined that it was in the extended position at impact, consistent with spoilers retracted. The lift and drag penalties associated with their deployment exceed the values determined in the performance analysis. Although the Board was unable to successfully simulate the in-flight deployment of the ground spoilers, it has no doubt that such an event, if it were to occur immediately after take-off, would result in catastrophic consequences not dissimilar to those which occurred on the morning of 12 December 1985. Nevertheless, there was no physical evidence to suggest that such an event had occurred. Furthermore, the operation of the spoiler system through a ground shift mechanism and nose gear oleo extension prevents the spoiler lever from being inadvertently moved to the EXTEND position when the aircraft is in the air.

The landing gear was extended at impact. Normally, retraction of the landing gear is initiated within three seconds of lift-off, once a positive climb rate has been established. In view of the severely degraded climb performance after lift-off and the abnormal flight characteristics associated with the stall onset, flight management problems likely precluded an up selection of the landing gear. Tests in the simulator confirmed that, when faced with a situation involving degraded climb performance, a gear-up selection was rarely completed.

2.3.7 Thrust Reversers

Initial examination of the number four thrust reverser at the accident site raised the possibility that the reverser had deployed in flight. When found, the translating ring of the reverser system had been turned inside out, giving the appearance that the reverser had been open at ground impact. This possibility was further supported by the aircraft's slight turn to the right shortly after lift-off. As a result, all four engine thrust reversers were subjected to close scrutiny by investigators. In the case of engines one, three and four, the translating rings were determined to be in the forward position and the deflector doors faired. In the case of the number two engine, the translating ring may have been aft of the forward stop but was at least some 16 inches forward of the rear stop and the deflector doors were faired. The Board considers this to be clear physical evidence that all four reverser assemblies were in the forward thrust position at impact.

No pre-impact faults with the reversers were identified.

Consideration was given to the possibility that a reverser had deployed in flight and, as a result of crew actions, had been stowed prior to impact. The performance penalties associated with deployment in flight are considerable. Simulator testing showed that application of full reverse thrust on the number four engine at or near lift-off could result in a flight profile similar to that of the accident flight.

The aircraft is equipped with an emergency "dump" capacity which, when selected, instantly returns the reverser doors to the faired position, thus eliminating reverse thrust. In the accident aircraft, the emergency dump switch was located on the overhead console above the captain's (left-hand) seat. The dump switch can not, however, move the translating ring forward to the stowed position. Thus, if a reverser had deployed in flight and the dump switch activated, only the doors would fair and the translating ring would have remained in the aft position.

Therefore, when the position of all four reverser assembly translating rings is considered, uncommanded deployment of a thrust reverser could not have occurred.

2.3.8 Explosion or Fire

There was considerable speculation that the accident occurred as a result of the detonation, either accidental or through sabotage, of some explosive device. This speculation was fuelled by the fact that military personnel and equipment were aboard the flight and by the increasing worldwide incidence of terrorist activity. Also contributing to this speculation were a reported claim of responsibility by a terrorist group, the point of origin of the flight, and the reports by three witnesses of a yellow/orange glow emanating from the lower surface of the aircraft. The observations of the yellow/orange glow also raised the possibility of a pre-impact fire.

Detailed examination of the wreckage with the assistance of forensic experts of the RCMP, including examinations at the RCMP Central Forensic Laboratory, revealed no evidence of an explosion or pre-impact fire. All damage to the aircraft and its components was considered to be the result of impact with terrain and the post-crash fire.

The Board believes there is sufficient evidence to conclude that two side panels were missing in the number three cargo pit. The absence of these panels would compromise the integrity of the Class D classification of this compartment. A Class D cargo or baggage compartment is one in which: a fire occurring in it will be completely confined without endangering the safety of the airplane or occupants; there are means to exclude hazardous quantities of smoke, flames, or other noxious gases from any compartment occupied by the crew or passengers; and ventilation and drafts are controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits. Thus, although the Board found no evidence to suggest that a fire had occurred in the number three cargo pit, the missing side panels would permit ventilation of the compartment and, in turn, possible propagation of a fire, if one had originated in this compartment.

Examination of the engine fire extinguishing agent containers indicated that it was possible that agent had been released into the number three engine as a result of crew actions; the explosive charge had fired while agent was still in the container. This and witness observations of the yellow-orange glow raised the possibility of a pre-impact fire in the number three engine. However, other evidence indicates that this did not occur. Intentional discharge of the fire extinguishing agent into an engine through operation of the fire extinguishing agent discharge switches first requires movement of the appropriate engine fire shut-off lever. One of the functions of this lever is to close the fuel shut-off valve, thereby shutting down the engine. The number three engine was determined to be operating and at high rpm at ground impact. This indicates that the engine had not been shut down prior to ground impact. The evidence also indicates that the Master Fire Warning light was not illuminated at impact. Activation of the fire extinguisher would also be contrary to Arrow Air published emergency procedures and training which specify that, in the event of an emergency during take-off, flight crews are to wait until a safe altitude (1,000 feet AFE) is attained before dealing with specific problems.

Discussions with the manufacturer of the fire extinguishing agent containers indicated that it is possible for the the explosive cartridge in the container to activate as a result of exposure to the high temperatures associated with a post-crash fire or through energizing of the actuating circuit during aircraft breakup. In consideration of all of the available evidence, the Board concludes that the discharge of the fire extinguishing agent was the result of either impact or the post-crash fire and not the result of an intentional action on the part of the flight crew.

Despite an extensive search of the area between the departure end of the runway and the initial impact point, no components or debris was found that originated from the aircraft, evidence that the aircraft was intact until initial impact with the terrain.

There was no evidence found of any ammunition or military ordnance in the wreckage. A thorough inspection of personal baggage loaded on board the aircraft had been carried out prior to departure from Cairo. No explosive materials or otherwise hazardous items were discovered. The Board noted no significant difference between the weapons recovered and those reported to have been on board.

Several small post-impact explosions occurred in the burning wreckage. Although some of these explosions were reportedly large enough to cause mounds of rubble to lift several feet into the air, none were considered of sufficient magnitude to be the result of detonation of explosive devices. The Board attributes these explosions to the normal bursting of pressure vessels (accumulators, fire extinguishers, aerosol cans, etc.) due to the heat of the fire. It is also likely that some of the reported explosions may have been firing of up to ten .45 calibre small arms rounds reported to have been carried on the aircraft by the Batallion Commander and the CID inspector.

The occurrence of a pre-impact fire or explosion was also not supported by the autopsy evidence and the blood carboxyhemoglobin levels of the aircraft occupants.

No evidence was found of shrapnel wounds and/or the identifiable portions of an explosive device, nor were injury patterns deemed to be characteristic of a pre-impact explosion.

All of the pathologists involved in the assessment of the pathological/toxicological evidence agreed that pathological examinations and toxicological analyses yielded no evidence of pre-impact inhalation of the products of combustion and that, when these findings were combined with evidence from the accident site, injury patterns and mechanisms and timings of death, pre-impact inhalation of products of combustion could be excluded beyond any reasonable doubt.

Although there was some level of HCN detected in the remains of the majority of aircraft occupants, it was the conclusion of all pathologists involved in the assessment of the pathological and toxicological findings that the HCN values were unreliable as an indicator of pre-impact fire and, at best, only indicative of exposure to fire. A high correlation with exposed chest cavities and hemothorax was noted in the cases with very high HCN concentration. In the 20 cases with the highest HCN concentration, 17 cases had exposed chest cavities and 16 had either documented hemothorax or multiple rib fractures which was accepted as evidence of hemothorax. This represented a highly significant correlation between high HCN levels and hemothorax. Almost all the blood samples were retrieved from the body cavities, and, thus, it was the agreement of all pathologists involved that much of the HCN in the blood was the result of post-mortem exposure to fire. The effects of neo-formation on the HCN levels, if any, could not be identified.

CO values were considered to be a reliable indicator of the inhalation of the products of combustion. In this regard, all cases of elevated CO levels were considered to be the result of post-impact inhalation of the products of combustion.

In summary, it was concluded that all aircraft occupants died as a direct result of impact and/or the post-crash fire. Some of the victims sustained injuries compatible with short-term survival and died as a result of inhalation of the products of combustion, either primarily or in combination with severe injuries sustained during impact. No evidence of any pre-impact fire or explosion was found as a result of the pathological examinations and toxicological testing.

Finally, the performance of the aircraft was not consistent with a sudden and catastrophic event such as an explosion.

Considerable interest was generated by the yellow/orange glow reported by some witnesses. However, in the absence of corroborating physical evidence, the Board was unable to determine the source of the illumination described by these witnesses. In assessing the significance of this evidence, the Board took into account that each saw the aircraft for only a brief period of time, and, since all were driving vehicles when they made their observations, they could not fully direct their attention to the aircraft. As a result, none was able to precisely describe the phenomenon, nor fix its position on the aircraft. Although at least one of these witnesses thought that the glow might have been a fire, he was not certain. Experience has shown that, when an accident is followed by a post-impact fire, witnesses often tend to associate fire with pre-impact observations.

The Board also noted that other witnesses who observed the aircraft during its brief flight did not report observing this glow or any other observation consistent with a fire. Two of these witnesses observed the take-off of the aircraft until after it began to descend below trees beyond the departure end of the runway.

It is possible that the glow observed by some witnesses was the illumination from normal light sources on the aircraft such as landing lights. One of these witnesses attributed the phenomenon to the reflection, on the bottom of the aircraft, of approach lights for runway 04 located on the extended centre line of runway 22. It could not be determined if the approach lights to runway 04 were illuminated at the time of the accident. It is also possible that the phenomenon observed by these witnesses was caused by compressor surging of one or more engines, resulting from disruptions in intake airflow. Compressor surges accompanied by flame emanating from the engine have been observed in other DC-8 accidents where angles of attack at or beyond the stall were achieved.

2.4 Aircraft Weight

There was considerable evidence to suggest that the crew-calculated take-off weight (330,625 pounds) at Gander was less than the actual take-off weight. Determination of the actual weight was difficult due to inconsistent load documentation and, in some cases, an absence of adequate load documentation. Nevertheless, the Board estimates that the actual take-off weight exceeded that calculated by the crew by about 14,000 pounds. The most significant contributing factor to this underestimation was the use of an average passenger weight that was significantly less than the actual weight of a U.S. Army soldier with web gear, weapon, and the quantity of other carry-on baggage described by witnesses. Also contributing to this underestimation was the use of a basic operating weight and cargo weight that were each about 1,000 pounds in error. However, despite this underestimation, it is clear that the maximum authorized take-off weight was not exceeded for the accident flight, nor did the take-off weight exceed that allowable for the runway length available for take-off. Nor was the centre of gravity position altered significantly because of the relatively even distribution of the higher weight values.

This underestimation of weight would have, however, resulted in the use of take-off reference speeds below those appropriate for the actual take-off weight. The take-off reference speeds for the crew-calculated weight are between three and five knots lower than the reference speeds for the Board's estimate of the actual weight, that is, 344,500 pounds. According to information provided by Douglas Aircraft Co., the use of these lower speeds would have had little effect on the take-off performance of the aircraft. Early rotation would have resulted in a slight increase in take-off distance and time to take off. A slight decrease in initial climb rate would have also occurred. The stall margin would have been reduced by three knots if the 330,625-pound V_2 value was used as a reference speed by the crew.

Rotation results in a slight decrease in the rate of acceleration because of the normal increase in induced drag associated with lift production. When rotation is initiated too early, this decrease in acceleration rate occurs earlier in the take-off and results in slightly lower acceleration to lift-off speed, hence a slightly longer take-off roll, in both time and distance. With the exception of this slight lengthening of the take-off roll, there are no other adverse effects.

Other evidence suggests that the crew may have inadvertently used take-off reference speeds for a take-off weight about 35,000 pounds below the actual take-off weight. Examination of the wreckage suggested that the reference bugs on the co-pilot's airspeed indicator may have been set at the reference speeds appropriate for a take-off weight of 310,000 pounds. It is possible that the reference bugs moved during the breakup sequence and that their positions as found were not those set by the flight crew prior to take-off. Furthermore, parallax errors could account for small differences between the reference bug positions found on the face of the instrument and the positions observed and set by the first officer. Tests indicated that the possible parallax error was as much as three knots for the bug found at 144 knots and two knots for the bug found at 185 knots. There was no parallax error for the internal bug found at 158 knots. Nevertheless, with parallax errors considered, all three reference bugs were found at speed values less than those appropriate for the take-off weight calculated by the crew, and two of three were found at speed values appropriate for a take-off weight of 310,000 pounds. The positions of the three bugs at speed values less than those which corresponded to the take-off weight calculated by the crew may have been more than coincidental.

Although use of speeds applicable to a take-off weight of 310,000 pounds would result in an even longer take-off roll, slower time to lift-off, and slightly reduced climb rate, a successful take-off would follow. In certification testing, the aircraft manufacturer was required to demonstrate the aircraft's ability to perform a successful take-off when rotated 10 knots below normal rotation speed. The occurrence of a successful take-off under these conditions was further demonstrated in the computer simulations conducted by UDRI and the simulator testing conducted by the Board.

The post-accident position of the internal bug on the co-pilot's airpseed indicator was eight knots lower than the corresponding V_2 speed predicated by the actual take-off weight. If the lower V_2 speed is used as a reference, the 18-knot stall margin that would be available under normal conditions would be reduced by eight knots. If, for whatever reason, the stall speed was increased, the stall margin could be reduced to zero if lower than normal reference speeds were selected and flown.

The post-accident position of the internal bug on the captain's airspeed indicator did not correspond with any published V_2 speed for the DC-8-63. It was suggested by a colleague of the captain that it was common practice for pilots to set this bug at a position that corresponded with V_2 plus 10 knots. If in fact this bug had been set to a position that corresponded to V_2 plus 10 knots, the corresponding V_2 speed is 162 knots, the V_2 value appropriate for the crew-calculated take-off weight. Representatives of Arrow Air could not confirm that setting the bug to V_2 plus 10 knots was common practice among their pilots. Nevertheless, it is possible that the internal bug on the captain's airspeed indicator had been set to V_2 plus 10 knots. If such was the case, it would indicate that the captain had set the bug with reference to the speeds appropriate to the crew-calculated weight.

2.5 Weather Factors

The weather conditions at the time of the accident and the similarity of this accident to others involving aircraft with ice-contaminated wings caused the Board to examine, in detail, the possibility that the accident was the result of ice accretion. The Board's analysis determined that the performance of the aircraft was consistent with the known effects of wing icing. The theoretical performance analysis conducted by the Board determined that a reduction in lift production and increase in drag were necessary to produce the performance of the aircraft observed during the accident take-off. Furthermore, the Board determined that the aircraft stalled at an airspeed above the stall speed calculated for the applicable weight and configuration.

As demonstrated in previous research and by previous accidents, seemingly insignificant amounts of ice can be sufficient to significantly degrade an aircraft's performance and flight characteristics. This performance degradation is the result of reduced lift production and increased drag. Of particular significance is the increase in stall speed and decrease in stall angle of attack caused by changes in the leading edge shape of the wing and surface roughness. The Board believes that the failure of the aircraft to accelerate following lift-off, its failure to achieve a sustained climb, and the stall at a higher than normal airspeed exemplify the known effects of ice-contaminated wings.

Calculations performed by the Board during its analysis determined that the increase in drag and decrease in lift production were consistent with that demonstrated to occur with wing surface roughness elements of about 0.03 inches or an amount of leading edge ice contamination with equivalent effects.

The fact that the aircraft did initially achieve a climb and continued to accelerate for a very brief period after rotation could be attributed to the enhanced aerodynamic efficiency (increased lift and reduced drag) provided in ground effect. However, as the aircraft climbed away, the benefit of ground effect would have been quickly reduced. As the aircraft crossed the departure end of the runway, ground effect would have been lost because of the rough, downsloping terrain. Analysis of the aircraft flight profile indicated that the aircraft entered stall buffet and stalled soon after it crossed the departure end of the runway.

The conclusions based on the computer simulations conducted by UDRI and the simulator tests conducted by the Board were consistent with those of the theoretical analysis. Both demonstrated that lift and drag values consistent with ice accretion on the aircraft wings duplicated the take-off performance of the aircraft.

The performance simulations conducted by DND, on behalf of the Board, also confirmed that the performance of the aircraft was consistent with that which results from ice-contaminated wings. Although the simulations were limited in that the aircraft pitch history of the brief flight and inputs by the pilots were not known and thus could not be considered, there was close similarity between the observed performance of the aircraft and simulations of take-offs with the wings contaminated with surface roughness elements of 0.04 inches or an amount of leading edge icing with equivalent effects, or with wings contaminated with surface roughness elements of 0.02 inches, or an amount of leading edge ice with equivalent effects, compounded by the loss of thrust from one engine. Furthermore, the simulations demonstrated that, with ice contamination present, aircraft take-off performance is very sensitive to small changes in aircraft pitch and airspeed. The differences between a successful take-off and an unsuccessful take-off were only one degree and two to three knots respectively.

The simulator tests showed that it was possible to complete a take-off successfully with C_L and C_D values consistent with ice-contaminated wings. However, to be successful, it was necessary to use significantly lower than normal pitch angles during rotation and initial climb in order to maintain the angle of attack below the lower than usual angle of attack at which a stall would occur. Such an action would require advanced knowledge of the degraded performance. In this regard, the simulator tests confirmed the sensitivity of aircraft performance to changes in aircraft pitch demonstrated in the computer performance simulations.

The precise amount, type, and location of any ice adhering to the surfaces of the aircraft during the take-off could not be determined. Nevertheless, based on the prevailing weather conditions, the Board believes that some ice would have accreted on the leading edge of the wing. Under the prevailing conditions for the aircraft's approach to Gander, it was calculated that the most probable maximum amount of ice accretion on the leading edge of the wing would vary from about 8.7 millimetres (0.34 inches) at 85 per cent span, through 6.5 millimetres (0.26 inches) at 53 per cent span, to 5.0 millimetres (0.20 inches) at 26 per cent span. This accretion would represent a full span, narrow ridge, or disturbance on the leading edge of the wing with the greatest accretion on the outboard section of the wing. This calculation did not include any ice that would have accumulated below cloud in the approximate one and one-half minutes of additional flight to touchdown. In view of the freezing precipitation occurring when the aircraft landed, it is probable that additional ice would have accreted on the leading edge during the approach, although the quantity could not be calculated.

The calculated ice accretion was consistent with the pilot reports made by the captain of the Boeing 737 which departed Gander about 45 minutes after MF1285R had landed and the pilot of the PA-31 which landed just after the accident. During his brief climb through the same cloud layer, the 737 captain reported moderate icing. He estimated that approximately one-quarter inch of ice accumulated on the centre post of the windscreen. The PA-31 pilot reported icing on approach sufficient to significantly obscure visibility through the cockpit windshield.

With the exception of the one refueller who reported seeing ice on the edge of the windscreen, none of the ground service personnel who assisted in servicing the aircraft reported observing ice on the aircraft. However, the Board notes that most of these personnel were not in position to observe, at close range, the aircraft wings. Further, in their interviews with CASB investigators, those personnel who did approach the wings of the aircraft reported that they did not specifically inspect the aircraft for ice and that ice may have been present. In considering the lack of witness reports of ice on the aircraft wing, the Board also notes that the leading edge of the wing is between approximately 10 and 16 feet above ground and that the station stop was made during the hours of darkness. Both of these factors would have made it difficult to detect small amounts of glaze ice on the leading edge, particularly on the outboard sections of the wing, when no specific effort was being made to look for ice. None of the ground service personnel were in position to observe any ice contamination that may have been on the upper surface of the wings.

The quantity of ice which would have accreted on the leading edge of the wing would be dependent on the use of wing ice protection. Although the Board cannot conclude with absolute certainty that ice protection was not used during the approach, normal industry practice suggests that it would not be usual for the crew to employ ice protection for such a brief descent through cloud. Pilots who were interviewed from Arrow Air and other operators concurred that it would be unusual for airframe ice protection to be used on approach in the prevailing circumstances.

As a result, the Board considers it likely that ice was present on the leading edge of the wings when the aircraft landed at Gander. The greatest quantity of leading edge ice would have been on the outboard section of the wings. The approach and landing at Gander would have been completed without incident because they were flown at angles of attack below those used for takeoff and because of the aerodynamic benefits of ground effect experienced during the landing flare.

Data provided by Douglas Aircraft enabled the Board to estimate the decrease in coefficient of lift maximum which would result from the calculated leading edge accretion amounts. As seen in Figure 1.16., the per cent reduction of maximum lift coefficient which results from a localized, spanwise disturbance or narrow band of roughness located at the leading edge is a function of the roughness height divided by chord length.

At 85 per cent semi-span, the chord length is 125.5 inches, thus the 0.34-inch calculated accretion divided by the chord length is 0.00271, which, according to the Douglas data, results in a maximum lift coefficient reduction of about 27 per cent.

At 53 per cent semi-span, the chord length is 226.4 inches, thus the 0.26-inch calculated accretion divided by the chord length is 0.00115, which, according to the Douglas data, results in a maximum lift coefficient reduction of about 23 per cent.

At 26 per cent semi-span, the chord length is 312.9 inches, thus the 0.20-inch calculated accretion divided by the chord length is 0.00064, which, according to the Douglas data, results in a maximum lift coefficient reduction of about 18 percent.

From Figure 1.16. it can be seen that the reduction of maximum lift coefficient determined at the 85, 53, and 26 per cent semi-spans equates to full upper surface contamination with roughness elements of 0.052 inches, 0.033 inches, and 0.022 inches respectively.

The weather conditions during the technical stop at Gander were conducive to the accumulation of additional ice on the wings of the aircraft. Freezing precipitation in the form of very light freezing drizzle and snow grains was reported between 0900 and 0945. At 0930, the observer noted freezing drizzle and snow grains adhering to the accretion indicator. He described the precipitation as a thin, rough layer, covering less than 30 per cent of the indicator's surface. After 0945, no further freezing drizzle was noted; however, snow grains continued to be observed on the indicator until after the accident. The time of the aircraft's landing at Gander corresponded closely with the 0900 surface observation taken by the weather observer. Thus, the Board believes that the type and quantity of ice which accumulated on the aircraft would be closely reflected by the freezing precipitation observed on the ice accretion indicators at 0930, 0945, and 1000.

Based on these observations, the Board concludes that the upper surface of the wings would have been roughened by the cumulative effects of the freezing drizzle and snow grains. The texture of the precipitation which adhered to the indicators was further described by the meteorological observer as resembling medium grit sandpaper. This description is often used in the research documentation to describe the magnitude of roughness necessary to significantly degrade an aircraft's performance and flight characteristics.

In addition, it is considered possible that some frost may have formed on the upper surface of the wing as a result of interaction between the cold wing surface and the near saturated atmosphere. Although the amount of frost that may have formed is not considered large, it could have resulted in further roughening of the upper wing surface.

The Board concludes that the combination of leading edge ice, which accreted during the approach, and upper surface roughening, which occurred during the station stop, was probably sufficient to result in aircraft performance degradation equivalent to that which occurs with the entire wing upper surface roughened with roughness elements of between 0.03 and 0.04 inches.

The flight engineer was observed to conduct a visual inspection of some portions of the aircraft while at Gander. It is not known if he observed any ice on the wings of the aircraft. From his vantage point on the ground, it should have been possible to see ice left on the wing leading edge from the approach to land. However, it was dark at the time, and, although the ramp area was lighted, without close inspection, the darkness would have made such an observation more difficult, particularly on the outboard sections of the wings. Furthermore, it is possible that his inspection was confined to areas of the aircraft under the wings such as the landing gear and engines. If this was the case, ice on the leading edge would not have been detected. Alternatively, it is possible that he did observe ice on the wing leading edge but considered its effects insignificant. The Board could not determine whether the crew knowingly, or unknowingly, attempted the take-off with ice contamination on the wings.

The freezing precipitation which fell during the station stop at Gander was a signal that there was a high potential for ice accretion on the upper surface of the wings. Unfortunately, the absence of a useful cockpit voice recording precluded the Board from establishing what, if any, discussion took place between the flight crew members regarding ice on the aircraft.

Although regulatory requirements, company procedures, training, and advisory material stressed the importance of the clean wing concept, experience has shown that some pilots do not fully appreciate the extent to which small amounts of contaminant can degrade an aircraft's performance, especially swept wing aircraft and, in particular, those not equipped with leading edge devices. Thus, it is possible that the flight crew was aware of the ice contamination and underestimated its effects. Had the crew determined that de-icing was necessary, suitable equipment and facilities were available at Gander. A review of records determined that Arrow Air flights had utilized these facilities on previous occasions.

2.6 Sequence of Events

The Board was unable to determine the *exact* sequence of events which led to this tragic accident. The significant destruction of the aircraft at impact and during the post-crash fire, the limited flight data recorder information, and the lack of cockpit voice recorder information were all factors which prevented the determination of the exact causal sequence. Nevertheless, no pre-impact failures or malfunctions which could account for the accident were identified. Thus, the following scenarios were not considered consistent with the evidence gathered during the investigation: uncommanded deployment of a thrust reverser; pre-impact fire; pre-impact explosion; inappropriate aircraft configuration; hydraulic system failure; flight control malfunction; potable water system leakage; and physical failure of one or more engines.

Furthermore, the Board believes that there is sufficient evidence to conclude that ice contamination of the wing and the resulting degradation in aircraft performance was a significant factor.

There is significant evidence in the form of ice accretion calculations, pilot reports, and weather observations to suggest that, during the approach to land, ice accreted on the leading edge of the wing and that, while the aircraft was on the ground, additional roughening of the upper surface of the wings occurred because of the freezing precipitation and possibly frost. Since the aircraft was not de-iced, the contamination which accumulated during the approach and station stop remained on the aircraft for the take-off. The performance calculations, computer simulations, and flight simulator testing all demonstrated that the performance of the aircraft was consistent with the reduced aerodynamic efficiency and resultant high drag associated with wing ice contamination.

It is possible that other factors such as an engine compressor surge and the use of an inappropriate take-off reference speed contributed to this occurrence; however, their precise contribution could not be determined. The Board considers the following to be the probable sequence of events which occurred during the attempted take-off.

The take-off roll proceeded normally, and rotation was commenced at or about the speed calculated by the crew. The calculated rotation speed was at least four knots below that appropriate for the aircraft weight and may have been as much as nine knots below that appropriate for the aircraft weight. This lower rotation speed probably resulted in a delayed lift-off and extended take-off roll. Nevertheless, the aircraft lifted off and commenced climbing. The simulator tests did, however, demonstrate that the use of lower than normal take-off reference speeds reduced the chance of a successful take-off with ice-contaminated wings. Lower than normal take-off reference speeds would reduce the already limited speed margins above the stall.

At lift-off, rotation was probably continued towards the expected pitch attitude necessary to achieve a normal climb schedule. After lift-off, and, as the benefits of ground effect decreased, the aircraft's degraded aerodynamic characteristics would have become apparent to the crew. These degraded characteristics would initially have resulted in a lower than normal rate of climb for the pitch attitude set. In response, it is probable that the pitch attitude was increased to achieve the desired rate of climb. However, simultaneously, the drag effects of the contamination would have caused the rate of acceleration to decrease, followed rapidly by a decrease in airspeed. The extended position of the landing gear indicates that a normal climb rate was never acheived.

Further performance degradation may have occurred as a result of a compressor surge in the number four engine. Although there was no definitive evidence to indicate that the number four engine was not operating at high power at initial tree impact, this possibility could not be eliminated. Computer simulations demonstrated that lessor amounts of ice contamination were required to result in the observed performance degradation, if coupled with a loss of thrust in one engine.

Soon after the airspeed began to decrease, the aircraft stalled. Computer simulations and tests in the flight simulator demonstrated that, with ice contamination present, a stall would occur at normal climb-out pitch attitudes. The crew would have received very little warning of the impending stall: the stall occurred at a significantly higher than normal airspeed, and, because the angle of attack at which it occurred was lower than normal, it is probable that there was little or no advanced warning from the artificial stall warning.

The heading change to the right was typical of other jet transport aircraft stall accidents and thus could be directly attributable to the stall. It is also possible that the heading change reflects a loss of thrust involving the number four engine.

Once the stall had occurred, there was insufficient altitude available to effect a recovery. Furthermore, the change in aircraft pitch characteristics caused by the ice contamination could well have made aircraft pitch control more difficult. The normal nose-down pitching moments which occur at stall would likely have been changed to a nose-up pitching moment.

Previous stall accidents involving DC-8 aircraft have shown that compressor surging at the high angle of attack associated with stall is not uncommon. Thus it is also possible that the lower ground impact rpm of the number four engine reflects surging in the engine after the stall had occurred. The angle of attack at initial tree impact was determined to be about 21 degrees. Witness observations of the yellow/orange glow could have been the result of flame emanating from the engine which accompanied a compressor surge.

The full trailing-edge-up elevator position suggests that, when impact with the terrain became imminent, the pilot applied full-aft control in an instinctive effort to avoid ground contact. Despite this effort, the aircraft struck trees, while in a severe stalled condition about 20 seconds after lift-off. Breakup of the aircraft commenced immediately, and, upon impact with the ground, an extensive fuel-fed fire commenced.

2.7 Load Planning and Control

The weight and balance calculations performed by the crew underestimated the actual take-off weight of the aircraft at Gander by about 14,000 pounds. The underestimation of the take-off weight was primarily due to the use of a standard average weight that did not take into account the nature of the passengers being carried. Contributing to the underestimation was the lower cargo weight used by the Cologne/Cairo crew and the company's use of a basic operating weight that did not take into account the weight of removable galley and cabin equipment and potable water.

The standard weight used was applicable to an average civilian adult with five pounds of carry-on baggage. The Board determined that the average weight of the passengers carried on MF1285R was approximately 220 pounds, 30 per cent higher than the 170-pound average used for flight planning purposes.

The original incorrect figures continued to be used for the flights to Gander, and the planned flight from Gander to Fort Campbell. As a result of the underestimation of the weight of the aircraft load, the Board believes that the maximum authorized take-off weight was exceeded by 8,000 pounds on take-off from Cologne.

Although the use of actual passenger weights was required by the Arrow Air Operations Manual, the system employed by the company for determining weight and centre of gravity did not provide specific direction on how to use actual weights. It was evident that weights on previous flights had been used in actual passenger weight and balance calculations; thus, it is apparent that crews were familiar with a method to adjust passenger weights to reflect a more accurate weight. The actual weight of individual passengers was not determined in Cairo by either MFO personnel or Arrow Air. It should have been apparent to the crew who completed the initial weight and balance calculations that an average weight of 170 pounds was considerably less than the actual weight, and the load sheet should have reflected this higher weight.

There was further evidence to indicate that Arrow Air flight crews were not determining the weight and centre of gravity for every flight. A review of weight and centre of gravity documentation for the series of MFO rotation flights which commenced on 03 December 1985 and the series of flights which commenced on 10 December 1985 determined that the passenger and cargo weights used on the flights from Cairo to Fort Campbell were identical to the weights used on the inbound flights from McChord AFB to Cairo. Despite the fact that a different load was being boarded at Cairo, it is apparent that the flight crew was copying the load figures for the inbound flight.

The Board also noted significant inconsistencies in documentation regarding loads being carried on the two series of rotation flights. The Board obtained considerable evidence that suggested the loads carried from McChord AFB to Cairo on 03 December 1985 and 10 December 1985 were substantially the same. Despite this similarity, the passenger weight as indicated on load sheets prepared by the same flight crew differed by 8,000 pounds. The cargo loads carried on these flights were reportedly also similar in weight; nonetheless, on the load sheets, the indicated weights were again 8,000 pounds different. Because new weight and balance calculations were not performed for the return flight to the United States, these same inconsistencies were present in the load documentation for the flights originating in Cairo. In addition, the Board notes that the number of passengers indicated on the load sheets prepared on departure from Cairo, Cologne, and Gander was incorrect.

These inconsistencies are further evidence that the weight of loads being carried on Arrow Air aircraft was not being determined accurately.

Contributing to this situation were inadequate load documentation and record keeping. Throughout its investigation, the Board experienced difficulties in obtaining accurate documentation regarding the weight of passengers and cargo carried on the MFO chartered flights both to and from Cairo.

Although the cargo was being weighed prior to departure from both Cairo and McChord AFB, no manifests or records of the scaled weights were being kept. Nor were such records kept of the scaled weight of passengers departing McChord AFB. The only U.S. military load records recovered that pertained to the series of flights were the McChord AFB Records/Audit manifests which did not agree with either the scaled weights or the figures used on the Arrow Air load sheets. Weight information prepared by U.S. military and MFO personnel was passed to Arrow Air personnel on slips of paper. It could not be determined what, if any, use was made by the Arrow Air personnel of this weight information. None of the load sheets prepared prior to flight reflected the weights calculated by U.S. Army or MFO personnel.

The Board also noted numerous inconsistencies regarding load weights in the load planning guidance material available to personnel from Arrow Air, the U.S. Army, and the MFO. These inconsistencies added to what the Board believes was considerable uncertainty regarding the actual weight of the loads carried on the MFO flights.

In calculating the actual weights of loads carried on the two series of rotation flights, the Board determined that, on each flight, the maximum authorized ZFW was exceeded. Furthermore, it is the conclusion of the Board that Arrow Air flight crews and management were aware that the maximum ZFW was being exceeded on a regular basis.

The flight crew members who were responsible for the calculation of the weight and centre of gravity in Cairo acknowledged that they believed the load to be about 10,000 pounds heavier than that indicated on the load sheet. The ZFW indicated on the load sheet was 229,621 pounds, less than 400 pounds under the maximum authorized ZFW. Therefore, the crew operated the aircraft almost 10,000 pounds over the maximum authorized ZFW. On those occasions where the passenger weights on the load sheets were higher than the standard average weight, the Board noted that the cargo weight was always less than the cargo weight shown on the load sheets where a lower passenger weight was used. The reduction in cargo weight corresponded closely to the increase in passenger weight. In every case, the ZFW was just under the maximum allowable. It is the opinion of the Board that the load sheet calculations performed by the flight crew were planned to demonstrate adherence to the maximum allowable ZFW. It further believes that the standard average passenger weight, although it did not accurately reflect the weight of passengers being carried, was being used in an effort to keep the ZFW indicated on the load sheet below the maximum authorized.

Arrow Air management was concerned about the ability of the aircraft to carry the MFO contracted loads within its ZFW limits. In 1985, they had contemplated action to raise the ZFW limit of the aircraft, although this action was not actively pursued. In discussions with Arrow Air management personnel following the accident, it was evident they were aware that, in order to conduct MFO flights, the maximum design ZFW of the aircraft was a problem. The contract between Arrow Air and the MFO specified a baggage allowance of 154 pounds per passenger. Assuming an average passenger weight of 170 pounds, Arrow Air had contracted to carry payloads of up to 81,000 pounds on the MFO flights. This value was approximately 13,500 pounds in excess of the payload capability of the aircraft used for the MFO flights. This discrepancy between contractual obligations and the payload capacity of the aircraft was known to management; however, action to increase the maximum design ZFW was not being pursued.

2.8 Arrow Air Maintenance and Operating Practices

The Board found no reason to conclude that the accident was the result of an aircraft unserviceability or malfunction. Nevertheless, during its investigation of the accident, the Board did observe certain maintenance-related practices and methods of operation that were not in accordance with approved and recommended procedures and which had the potential to adversely affect safety.

In the two December 1985 series of rotation flights between the United States and Cairo, there were at least four occasions when the Board believes maintenance entries should have been made in the technical log of the aircraft. These relate to the ratchetting of the co-pilot's control column, the illumination of the thrust reverser unlocked light in flight, the missing panel in the cargo hold, and the abnormally high number four engine exhaust temperature indication. In each case, the problem should have been entered in the technical log and the situation either rectified or, if possible, deferred within the guidelines of the company's DMI policy. In none of the four cases was this action taken.

The Board is particularly concerned with the decision of Arrow Air aircrews to accept an aircraft that exhibited anomalies in the operation of the flight control system. Further evidence of this attitude and the willingness on the part of flight crews to accept for flight aircraft with known unserviceabilities are the two separate flights operated by the captain, with an unserviceable main hydraulic system.

The Board considers that these actions were those of well-meaning flight crews who believed that the flights could be undertaken without jeopardizing the safety of passengers or crew. Among the factors likely considered by flight crew in making such decisions were the logistical problems that would arise by delaying a flight at an en route station and the probable domino effect on company operations caused by a significant delay in one of its flights.

Nonetheless, the Board considers that this practice represents non-compliance with established airworthiness standards and an unnecessary reduction in flight operations safety margins.

Problems were being experienced with the aircraft potable water system. Despite repeated repair action, maintenance personnel were unable to rectify the problems and keep the system in a serviceable state. Although repairs to the system had been carried out in Oakland prior to the rotation flights which commenced on 10 December 1985, it is evident that leaks were present during the flight to and from Cairo. Despite the leaks and the knowledge that water was leaking into the aircraft, Arrow Air personnel continued to have the system replenished.

Similarly, the frequency of the replenishment of hydraulic fluid indicates that the aircraft's hydraulic system was leaking fluid at an abnormally high rate. Although this problem had been occurring for at least six months prior to the accident, it was not apparent that Arrow maintenance personnel had taken definite action to identify the source of the leakage and rectify the problem.

In addition, Arrow Air maintenance personnel did not identify the requirements for inspection and replacement of some of the repairs made to the aircraft following the 1981 accident in Casablanca. The life-limit on one of the repairs had expired without action being taken to replace the repair.

2.9 Flight Crew Fatigue

2.9.1 Flight Crew Scheduling Practices

Daily flight-time limits and minimum crew-rest requirements have been established to reduce the potential for aircrew fatigue. Examination of the flight crew's flight time records for the month of December 1985 determined that the flight-time limitations of FAR 121.521 had been exceeded twice. In the 24-hour period commencing 0206 GMT, 05 December 1985, the flight crew's flying time was recorded as 13 hours 22 minutes, that is, 1 hour 22 minutes in excess of the 12-hour maximum. In the 48-hour period commencing 1018 GMT, 03 December 1985, the flying time recorded was 22 hours 24 minutes. Following this, only seven hours elapsed before the crew initiated its next flight. FAR 121.521 requires that a minimum of 18 hours crew rest be given when a flight crew member has been aloft for more than 20 hours during any consecutive 48 hours.

A review of FAA special surveillance reports determined that, on other occasions, Arrow Air flight crew had exceeded the requirements of FAR 121.521 with respect to flight-time limitations and crew rest.

It was the stated intent of the flight crew to ferry the aircraft to Oakland, California on completion of the flight to Fort Campbell. The Board estimates that, at the completion of this flight, the crew would have accumulated about 15 flight hours in the 24 hours commencing with departure from Cologne. The crew's duty day would have approached 20 hours. Because the flight to Oakland was to be conducted without passengers, it was not considered an FAR 121 flight. Rather, it was to be conducted under the provisions of FAR 91. FAR 91 does not include any flight-time limitations or minimum crew-rest requirements. Thus, the flight could be conducted within the provisions of applicable FARs.

By scheduling non-revenue ferry flights under the provisions of FAR 91 at the completion of a series of FAR 121 flights, flight-time limitations and crew-rest requirements designed to reduce the potential for aircrew fatigue can be circumvented. The Board can find no reason to justify the absence of such limits and requirements for flights conducted by FAR 121 certificated air carriers under FAR 91.

To a large extent, the prevention of flight crew fatigue is dependent on the scheduling practices and policies of the air carrier. In the United States, the FARs provide a framework within which the carrier must operate; however, it is incumbent on the carrier to devise workable policies that meet the operational needs.

The pilot-scheduling policy developed by Arrow Air makes no reference to flight-time limits, duty-day limits or minimum crew rest. It was determined by the Board that company scheduling procedures did not address flight crew fatigue factors. No maximum duty-day limit was established.

2.9.2 Fatigue Assessment

A detailed analysis of available information pertaining to each flight crew member's vulnerability to fatigue was undertaken. Consideration was also given to identifying behavioural evidence that could be attributed to fatigue, and the causal sequence of events leading up to the accident.

It was the opinion of the medical expert who testified at the Board's public inquiry that, in the 12 days leading up to the accident, the flight crew had been consistently exposed to work patterns and fatigue-inducing factors which were highly conducive to the development of chronic fatigue. These factors included short layovers, night departures, multiple time-zone travel, and a flight-hour accumulation of almost 57 hours in the previous 10 days.

There are no accepted toxicological tests which can verify the presence of, or quantify the influence of, fatigue. However, research has empirically identified certain fatigue-induced behaviours and associated performance decrements.

An analysis of what was known of the flight crew's behaviour while in Cologne, during the flight, and while on the ground in Gander indicated no clear behavioural pattern that could be associated with fatigue. As a result, the Board could not determine whether any individual flight crew member was in fact fatigued nor establish any cause and effect relationship between probable fatigue and the accident sequence.

2.10 Flight Recorder Requirements

The investigation into the causes and factors that led to this accident was hampered by the minimal amount of accurate information provided by the accident aircraft's five-parameter foil-type FDR and the partially unserviceable CVR. The FDR provided only gross indications of the aircraft's performance during take-off. There were no indications of engine performance or systems operation. In the absence of such information, the Board had to use other, less reliable and more time-consuming methods in an effort to determine the sequence of events leading up to the accident.

The CVR apparently had an unserviceable cockpit area microphone. Consequently, there was no recording of flight crew conversation from the time pre-flight checks were commenced until the aircraft crashed. Had such information been available, the Board would have obtained greater insight into crew actions and flight management problems.

The Board notes with concern that the DC-8 Minimum Equipment List approved by the FAA permits operation of a DC-8 aircraft when both the FDR and CVR are unserviceable and that current regulations do not require CVRs to be functionally checked by flight crews before flight.

2.11 FAA Surveillance

The normal ongoing surveillance of Arrow Air by the FAA did not identify any deficiencies in Arrow Air's ability to comply with applicable FARs or established FAA procedures. Both assigned principal inspectors testified at the Board's public inquiry that, during their surveillance, they noted no significant discrepancies in Arrow Air's methods of operation.

In contrast, the special inspection conducted in January and February 1986 noted numerous examples of non-compliance with FARs and established FAA procedures in certain areas of Arrow Air operations. In some cases, findings of the 1986 inspection were similar to those made during the NATI conducted in 1984. Although, according to the FAA, many of the findings were later determined to be of a minor nature and enforcement action resulted in civil penalties or warning/correction letters in only 10 cases, the Board is concerned that routine surveillance, characterized by the FAA to be the most thorough in the company's history, was unable to identify these deficiencies.

As a result of the 1984 inspection, numerous recommendations had been made with respect to increased surveillance and follow-up. According to the FAA, in the months preceding the accident, their surveillance and follow-up of Arrow Air was executed to a greater degree, both in quality and quantity, than ever before in the company's history. Nevertheless, the Board notes that, in the months preceding the accident, the assistant operations inspector position at Arrow Air had been vacant and that the POI assigned to Arrow Air testified at the Board's public inquiry that the resources available to him for surveillance of Arrow Air were inadequate.

3.0 CONCLUSIONS

3.1 Findings

1. During the approach to land at Gander, the existing meteorological conditions were conductive to ice accretion on the leading edge of the wing.
2. While on the ground at Gander, the aircraft was exposed to freezing and frozen precipitation capable of producing roughening on the wing upper surface.
3. While the aircraft was on the ground at Gander, the difference between the wing surface temperature and the outside temperature was conducive to the formation of frost on the surface of the wing.
4. The aircraft was not de-iced prior to take-off.
5. The aircraft stalled at a higher than normal airspeed after leaving ground effect.
6. There was insufficient altitude available to effect a recovery from the stall.
7. The performance of the aircraft after lift-off was below that expected and was consistent with the reduced aerodynamic efficiency and resultant high drag associated with wing ice contamination. It was also consistent with the effects of wing ice contamination combined with a partial loss in engine thrust.
8. The ground impact rpm of the number four engine was lower than that of the other three engines.
9. No evidence was found of a pre-impact mechanical failure of the number four engine.
10. It could not be determined if the lower ground impact rpm of the number four engine was the result of an in-flight power loss, either before or after the stall, or was the result of tree fragment ingestion prior to ground impact.
11. The integrity of a Class D cargo compartment was compromised because flight was undertaken with two missing side panels in the number three cargo pit.
12. The take-off weight at Gander calculated by the crew was about 14,000 pounds less than the actual take-off weight of the aircraft.
13. The take-off reference speeds believed to have been used by the crew during the accident take-off were applicable to a take-off weight at least 14,000 pounds less than the actual take-off weight and may have been applicable to a take-off weight as much as 35,000 pounds less than the actual take-off weight.
14. Although the use of actual passenger weights was required by the *Arrow Air Operations Manual*, the crew used a standard average weight to calculate the weight of passengers. This average passenger weight did not accurately reflect the actual weight of the passengers carried on the flight.

15. Guidance material available to Arrow Air flight crew did not include direction concerning the requirement or method to determine total passenger weight using actual passenger weights when calculating weight and centre of gravity.

16. Accurate weight and centre of gravity calculations were not being performed by Arrow Air flight crew for every flight.

17. Inconsistencies existed in the load-planning material that was available to Arrow Air personnel, MFO personnel, and U.S. Army personnel.

18. The quantity and accuracy of documentation regarding the number and weight of passengers and weight of cargo carried on the MFO rotation flights were inadequate.

19. The maximum design zero fuel weight of the aircraft was exceeded on each of the MFO rotation flights conducted in December 1985.

20. Arrow Air's contractual obligations with respect to allowable payload exceeded the authorized payload capability (maximum design zero fuel weight) of the aircraft being used.

21. Arrow Air flight crews were not recording all aircraft unserviceabilities in the aircraft journey log and on occasion were accepting for flight aircraft with known defects.

22. A life-limited repair resulting from a previous occurrence had not been replaced in accordance with the recommendations of the aircraft manufacturer.

23. The potential of the flight crew's December flight schedule to produce fatigue was high.

24. There are no flight-time and crew-rest limitations for United States FAR Part 121 air carrier operations conducted under FAR Part 91.

25. The accident investigation into the causes and factors that led to this occurrence was severely hampered by the lack of information that a serviceable cockpit voice recorder and enhanced-capability digital flight data recorder could have provided.

26. The United States Federal Aviation Administration Master Minimum Equipment List for aircraft such as the DC-8 allowed aircraft to be released for flight with an unserviceable cockpit voice recorder and flight data recorder.

27. Routine FAA surveillance of Arrow Air did not identify existing deficiencies with respect to Arrow Air's ability to comply with applicable FARs and FAA approved procedures. These deficiencies were identified in a special inspection conducted in January 1986, one month after the accident.

28. The balance of evidence did not support the occurrence of a pre-impact fire or explosion either accidental or as a result of sabotage.

29. The evidence did not support the occurrence of an uncommanded deployment of a thrust reverser.

30. The flight crew was certified and qualified for the flight in accordance with existing regulations.

31. The aircraft was certified in accordance with existing regulations.

32. The take-off weight and centre of gravity position were within prescribed limits.

3.2 Causes

The Canadian Aviation Safety Board was unable to determine the exact sequence of events which led to this accident. The Board believes, however, that the weight of evidence supports the conclusion that, shortly after lift-off, the aircraft experienced an increase in drag and reduction in lift which resulted in a stall at low altitude from which recovery was not possible. The most probable cause of the stall was determined to be ice contamination on the leading edge and upper surface of the wing. Other possible factors such as a loss of thrust from the number four engine and inappropriate take-off reference speeds may have compounded the effects of the contamination.

4.0 SAFETY ACTION

4.1 Action Taken

4.1.1 Weight and Balance Calculations - Use of Standard Average Weights for Atypical Passenger Loads

In the initial phase of the investigation into the causes and factors that led to this occurrence, a safety deficiency was identified in the methods used by Arrow Air flight crews for determining the take-off weight of the aircraft.

On 13 February 1986, as a consequence of these initial concerns, the CASB recommended that:

> The Department of Transport review company documentation for Canadian air carriers to confirm the adequacy of provisions for the use of actual weights (versus standard average weights) and that the associated load calculation forms reflect the basis for the load determinations; and
>
> CASB 86-01
>
> The Department of Transport re-emphasize to each carrier the need to use actual weights for passengers, if the passenger load is likely to deviate from standard weights.
>
> CASB 86-02

In addition, the CASB recommended that:

> The National Transportation Safety Board consider issuing parallel recommendations to CASB 86-01 and 86-02 above, requiring similar action for American-registered air carriers.
>
> CASB 86-03

These three recommendations have been fully implemented to the Board's satisfaction.

4.1.2 U.S. Operations With Unserviceable Flight Data and Cockpit Voice Recorders.

At the time of the accident, the U.S. Master Minimum Equipment List permitted certain aircraft types such as the DC-8 to be released for flight with an unserviceable flight data recorder and cockpit voice recorder. NTSB and FAA involvement in this investigation led to FAA action to rectify this deficiency, and, on 15 December 1987, the FAA adopted a policy that the U.S. Master Minimum Equipment List require those previously exempted aircraft types to be equipped with at least one serviceable and functioning recorder.

4.2 Action Required

4.2.1 Loss of Performance - Leading Edge and Wing Upper Surface Contamination

4.2.1.1 Flight Crew Knowledge of Performance Impacts

The loss of performance due to ice or snow contamination of leading edges and wing upper surfaces, particularly during the take-off phase of flight where high angles of attack are present, has been known to aircraft manufacturers, regulatory and accident investigation authorities, and operators for many years.

For almost four decades, United States Federal Aviation Regulations have prohibited take-off of aircraft when frost, snow, or ice adheres to the wings, propellers, or control surfaces of an aircraft. These regulations are known collectively as the "clean wing regulations." Additionally, in 1982 the Federal Aviation Administration issued Advisory Circular (AC) 20-117 to address frequent misconceptions concerning the effects of slight surface roughness on aircraft performance caused by ice accumulation. The circular outlines the aerodynamic principles of changes in lift and drag due to wing surface roughness and emphasizes that take-off is not to be attempted unless it has been confirmed that all critical components are free of adhering snow, frost, or other ice formations. AC 20-117 states that close inspection is the only known method of ensuring clean wings and flight control surfaces before flight.

In Canada, legislation contained in Air Navigation Order Series VII, Number 2 governing air carrier operations using large aircraft, repeats the U.S. clean wing regulations, and a section of the Aeronautical Information Publication cautions pilots against the hazards of attempting flight with wing or control surfaces contaminated by snow, ice, or frost.

In spite of existing regulations and promotional material, numerous aircraft occurrences bear witness to the fact that flight is sometimes attempted when wing surface contamination due to ice, snow, or frost is present. Accident investigations and analyses of aircraft occurrences concerning aircraft such as the Boeing 737-200 series, the McDonnell-Douglas DC-9 Series 10, and this occurrence involving a Douglas DC-8-63 series aircraft all confirm that leading edge and wing surface contamination due to ice and snow can degrade aircraft performance during the take-off phase of flight to the point where there is little to no margin of safety. This loss of performance is particularly severe in aircraft like the DC-8 which do not have leading edge devices to augment lift and to allow the aircraft to attain a higher angle of attack before the wings stall.

The Board has no doubt that flight crews understand the aerodynamic principles concerning loss of performance due to readily visible amounts of ice, snow, or frost contamination of leading edges. However, the Board believes that many flight crews do not fully comprehend the magnitude of performance penalties attributable to small amounts of ice contamination. Aircraft operating manuals and other aircraft performance documents contain little or no information on the magnitude of performance penalties possible with relatively minor amounts of surface roughness. Therefore, the CASB recommends that:

> The Department of Transport initiate a national safety campaign to ensure that all pilots are aware of the potential consequences of attempting take-off with even minor amounts of contamination on the wings.

CASB 88-07

4.2.1.2 Wing Ice Detection

As a consequence of an investigation into an accident of a McDonnell-Douglas DC-9-10 series aircraft at Denver Colorado on 15 November 1987, the NTSB recently issued two recommendations to the FAA to address the hazards of conducting a take-off in the DC-9-10 with undetected ice on the upper wing surfaces. The recommendations call for operators of this aircraft type, which is not equipped with wing leading edge high lift devices, to establish detailed procedures for detecting upper wing ice prior to take-off and, until such time as the procedures have been implemented, to anti-ice these aircraft with maximum effective strength glycol solution when icing conditions exist.

The Board notes that Canadian companies operating DC-9 aircraft currently use only the DC-9-30 series, which are equipped with leading edge high lift devices and which are thus less susceptible to performance degradation from wing ice contamination. However, the deficiency identified by the NTSB is applicable to DC-8 aircraft which are operated in Canada. The Board believes that the circumstances of the accidents involving the DC-9-10 at Denver and the DC-8 at Gander confirm the need for Canadian flight crew operating aircraft not equipped with wing leading edge high lift devices to be able to detect the presence of ice on the wings. Accordingly, the CASB recommends that:

> The Department of Transport require all Canadian operators of McDonnell-Douglas DC-8 aircraft, and such other aircraft types which the Department deems appropriate, to establish detailed procedures for detecting ice on the wings prior to take-off.
>
> CASB 88-08

4.2.2 Operating With Unserviceable Cockpit Voice Recorders

The CASB believes that the lack of useful cockpit voice recorder (CVR) information in combination with the inaccurate and minimal flight data recorder (FDR) information provided by five-parameter foil-type flight recorders contributed significantly to the difficulty in determining the causes and factors that led to this accident. In particular, the Board's understanding of any contributing flight crew human factors is incomplete. The Board is pleased that regulatory revisions to improve the capabilities of FDRs, in keeping with the International Civil Aviation Organization (ICAO) standards and recommended practices, have been undertaken or proposed in both Canada and the United States; however, the Board believes that easily implementable procedures ensuring the serviceability of CVRs should be introduced.

For a number of years, CVRs have had the capability for flight crews to test the cockpit area microphone channel; this feature is part of the Technical Standards Order requirement for such equipment. This self-test feature allows flight crews to functionally check the cockpit area microphone channel before flight and quickly detect an unserviceability. Canadian and U.S. regulations specify that flights must be conducted with a serviceable and functioning CVR. However, there are no prescribed procedures with respect to the nature or frequency of CVR tests. It is understood that some operators' procedures include a test prior to each flight, some require only one test daily, and others include tests on a less frequent schedule. As a result, there is potential for unserviceabilities to remain undetected through a number of flights conducted between functional tests.

The Board believes that, in the event of an occurrence, recorded cockpit communications can be vitally important in understanding the sequence of events and in assessing the influence of human factors. Accordingly, the CASB recommends that:

> The Department of Transport review the procedures currently in place with respect to functional checks of cockpit voice recorders with a view to ensuring that the serviceability of the equipment is being tested adequately.
>
> CASB 88-09

and

> The National Transportation Safety Board consider seeking parallel action in the United States to that outlined for Canada in CASB 88-09.

CASB 88-10

4.2.3 Flight Crew Fatigue - Inadequacies in Regulations and Their Application

The CASB accident investigation into this occurrence determined that, in the 11 days leading up to the accident, the flight crew had exceeded specified flight-time limitations twice and had less than minimum crew rest on at least one occasion. Thus, there was a potential for the development of fatigue, with its concomitant potential for adversely affecting pilot judgement and crew coordination. Furthermore, on the day of the accident, the crew's planned ferry flight to Oakland, California after the flight to Fort Campbell would have resulted in the accumulation of about 15 flight hours in less than a 24-hour period and a duty period of almost 20 hours. Nevertheless, this would not have contravened U.S. regulations.

In 1986, the CASB identified several safety deficiencies in current Canadian legislation regarding maximum crew-flight and duty-time limitations and minimum crew-rest provisions. Three of six related recommendations issued by the Board to Transport Canada suggested that there be more stringent regulations governing crew-duty hours and crew-rest cycles for crews of large transport-category aircraft.

The Board notes that, in general, the U.S. FARs prescribe more stringent controls to prevent fatigue-related accidents than are applicable in Canada today. However, while FAR Part 121 (applicable to air carriers and commercial operators of large aircraft) specifies flight-time limitations and minimum crew-rest periods, these restrictions do not always apply. Ferry flights and other non-revenue operations can be conducted under the provisions of FAR Part 91 (general operating and flight rules) which do not include any limitations on flight time nor prescribe minimum crew-rest periods. The Board believes that the flight crews of FAR Part 121 air carriers require the same degree of vigilance, judgement, and ability to react whether they are conducting a revenue-generating or non-revenue operation. Therefore, the CASB recommends that:

> The National Transportation Safety Board consider recommending a change in U.S. Federal Aviation Regulations such that the flight-time, duty-time, and crew-rest provisions of FAR Part 121 would apply to all operations of Part 121 air carriers, including non-revenue flights.

CASB 88-11

4.3 Other Safety Concerns

4.3.1 Air Carrier Maintenance and Operating Procedures - Inadequate Regulatory Control

The investigation of this occurrence revealed numerous instances of long-standing inadequacies in the air carrier's maintenance and operating procedures. In 1984, the Federal Aviation Administration, under the National Air Transportation Inspection, completed an extensive review of U.S. air carrier practices and procedures, including Arrow Air. Despite this close inspection by the regulatory authority, inadequacies continued to exist.

The CASB is concerned that such a lack of effective regulatory control and its effect upon the margin of safety may also be present in other air carrier operations.

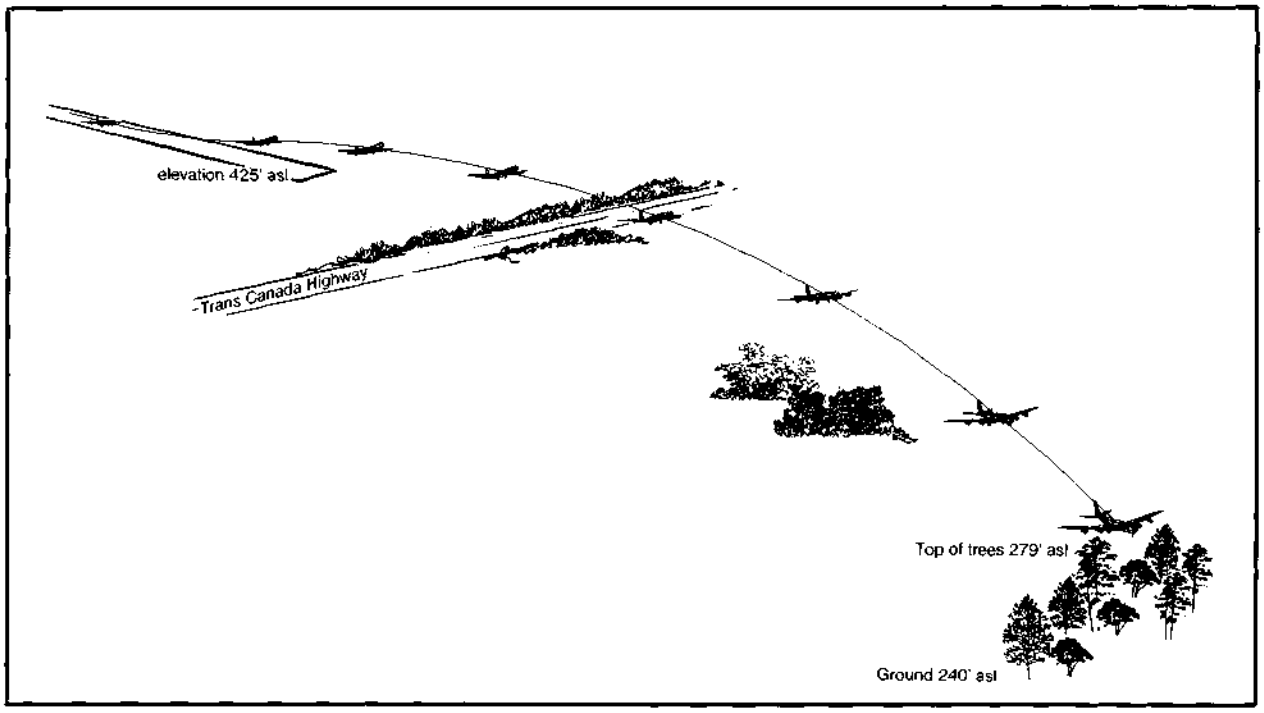
This report and the safety action therein has been adopted by the Chairman, K.J. Thorneycroft, and Board Members:

W. MacEachern
A. Portelance
B. Pultz
F. Thurston

Members N. Bobbitt, L. Filotas, D. Mussallem, and R. Stevenson dissented. A report of their dissent is available on request from the Canadian Aviation Safety Board.

APPENDIX A

ESTIMATED FLIGHT PROFILE


elevation 425' asl
Trans Canada Highway
Top of trees 279' asl
Ground 240' asl

APPENDIX B

EXTRACTS FROM ATMOSPHERIC ENVIRONMENT SERVICE MANUAL OF SURFACE OBSERVATIONS

3.4.2 Freezing Precipitation.

3.4.2.1 Freezing Drizzle. Drizzle, the drops of which freeze on impact with the ground or with other objects at or near the earth's surface.*

3.4.2.2 Freezing Rain. Rain, the drops of which freeze on impact with the ground or with other objects at or near the earth's surface.*

3.4.2.3 Freezing Drizzle or Freezing Rain shall be reported when rain or drizzle is freezing on the Ice Accretion Indicator or on other objects at or near the earth's surface.*

3.4.3 Frozen Precipitation.

3.4.3.1 Snow. Precipitation of mainly hexagonal ice crystals, most of which are branched (star-shaped). The branched crystals are sometimes mixed with unbranched crystals. At temperatures higher than about -5C, the crystals are generally clustered to form snow flakes.

3.4.3.2 Snow Pellets. Precipitation of white and opaque particles of ice. These ice particles are either spheical or conical; their diameter is about 2-5 mm.

3.4.3.2.1 Snow pellets are brittel and easily crushed; when they fall on hard ground, they bounce and often break up. Snow pellets always occur in showers and are often accompanied by snow flakes or rain drops, when the surface temperature is around 0C.

3.4.3.3 Snow Grains. Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is generally less than 1 mm. When the grains hit hard ground, they do not bounce or shatter. They usually fall in very small quantities, mostly from Stratus or from fog, and never in the form of a shower.

3.9 Intensity of Precipitation

3.9.1 The precipitations classified above as Liquid, Freezing and Frozen (with the exception of ice crystals) are always qualified as to intensity, viz., very light, light, moderate or heavy.

3.9.2 VERY LIGHT is used to indicate the intensity when scattered drops, flakes, grains, pellets or stones are occurring at a rate which would not wet or cover a surface, regardless of the duration.

* It is of course assumed that the objects are not artifically heated above or cooled below the temperature of the ambient air.

3.9.3 The intensities LIGHT, MODERATE and HEAVY are determined by considering either the effect on visibility or the rate of fall.

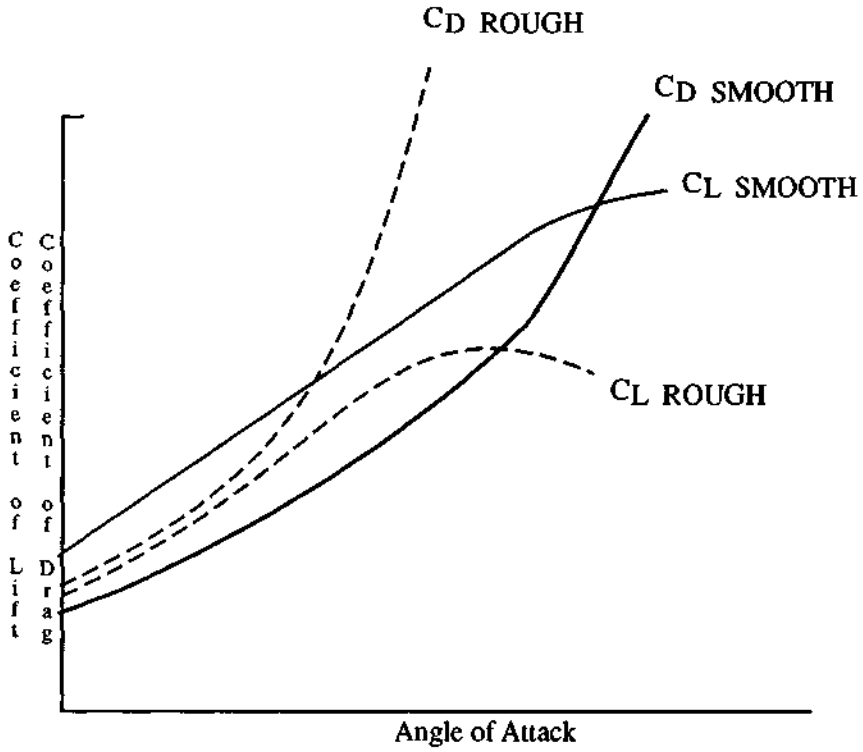
3.9.4 Intensity by Visibility Criteria.

Snow Snow Shower Snow Grains Snow Pellets Drizzle Freezing Drizzle	LIGHT if visibility 5/8 mile or more MODERATE if ALONE* and the visibilty reduced to 1/2 or 3/8 mile HEAVY if ALONE* and visibility reduced to 1/4, 1/8 or 0 mile.

APPENDIX C

AERODYNAMIC EFFECTS OF ICING

The most significant effect of snow or ice on the wing surface is its influence on the smooth flow of air over the surface contour. Changes in the contour shape and roughness of the surface will cause the airflow to begin to separate from the wing at a lower angle of attack than normal and cause a reduction in the lift which will normally be developed by a wing at a given angle of attack and a given airspeed (see figure below). Both the maximum lift which can be developed and the angle of attack at which it will be developed will be reduced significantly. Stall buffet and stall will be encountered at higher than normal airspeeds.



Lift and Drag Effects of Wing Contamination

Ice contamination of an aircraft wing also has a significant detrimental effect on the aircraft's total drag, that is, the force which resists the aircraft's forward motion through the air. The total drag has two components, parasite drag and induced drag. Induced drag is that drag which is produced by the generation of lift. Induced drag increases as the angle of attack increases. Therefore, since a contaminated wing must fly at a higher angle of attack at a given airspeed to produce the required lift, the induced drag generated at that airspeed will be higher than the induced drag of an uncontaminated wing. Furthermore, since ice contamination causes the airflow to separate earlier from the upper surface of the wing, it results in a higher induced drag value at any angle of attack. The increase in parasite drag as a result of ice contamination is small in comparison to the increase in induced drag.

On a wing contaminated by surface roughness, the normal stall progression of a swept wing is altered. The normal nose-down pitching moment in the direction of stall recovery which accompanies a stall is reduced when the wing is contaminated. The effects of the degraded pitching moment characteristics can range from an out-of-trim condition that can have a different than expected response to control column inputs, to a severe pitch-up as the angle of attack is increased.

The leading edge portion of the wing is most sensitive to ice contamination. The effects of the contamination decrease as the forward most extent of the contamination moves farther aft of the leading edge.

Glaze ice accretions which occur at temperatures just below freezing provide the largest aerodynamic penalty.

Ice accumulation, in particular, the detrimental effects on lift and drag associated with wing surface roughness has been identified as a causal factor in a number of take-off accidents involving jet transport aircraft.

On 27 December 1968, Ozark Airline Flight 982, a Douglas DC-9-15, crashed while taking off from the Sioux City Airport, Sioux City, Iowa. The NTSB determined that the probable cause of the accident was a stall near the upper limits of ground effect, with subsequent loss of control as a result of the aerodynamic and weight penalties of airfoil icing. The crew had not deiced before the attempted take-off.

On 27 November 1978, Trans World Airways Flight 505, a Douglas DC-9-10, crashed while taking off from Newark International Airport, Newark, New Jersey. Aircraft control was lost shortly after lift-off at an airspeed of 154 knots and at an altitude of about 65 feet agl. The NTSB identified airframe icing and a failure to de-ice before take-off as causal factors.

On 05 February 1985, an Airborne Express Douglas DC-9-15 crashed while taking off from Philadelphia International Airport, Philadelphia, Pennsylvania. The NTSB determined that airfoil icing and failure to de-ice before take-off were cause factors in the accident.

All three of the above accidents contained several common elements:

1. Each aircraft stalled at a lower than normal angle of attack shortly after take-off;
2. Precipitation was present in the form of freezing rain and/or snow;
3. The aircraft were not de-iced before take-off;
4. None of the aircraft was equipped with leading edge devices.

On 13 January 1977, Japan Airlines Flight 8054, a Douglas DC-8-62-F, crashed while taking off from Anchorage International Airport, Anchorage, Alaska. The aircraft stalled at, or shortly after reaching, V_2 at an altitude of about 60 feet above ground level. The NTSB determined that airframe icing was a contributing factor in the accident. As in the other three cases, the aircraft was not de-iced prior to take-off. Conditions during the approach to land were conducive to the accretion of ice on the wings of the aircraft.

In 1950, the United States established regulations which prohibited take-off of aircraft when frost, snow, or ice was adhering to the wings, propellers, or control surfaces of an aircraft. These regulations remain in effect today as cited under Federal Aviation Regulations (FAR) 121.629, 135.227, and 91.209. These regulations are commonly known as the "clean aircraft concept" and were based on the known degradation of aircraft performance and changes of aircraft flight characteristics when ice formations of any type are present.

In December 1982, in response to a number of accidents involving large transport and small general aviation aircraft resulting from what it believed to be misconceptions that existed regarding the effects of slight surface roughness caused by ice accumulations on aircraft performance and flight characteristics and the effectiveness of ground de-icing fluids, the United States FAA published Advisory Circular (AC) 20-117. Its purpose was to emphasize the clean aircraft concept following ground operations conducive to aircraft icing and to provide information to assist in compliance.

AC 20-117 identifies that the effects of ice formation on an aircraft are wide ranging, unpredictable, and dependent upon individual aircraft design. It states that wind tunnel and flight tests indicate that when ice, frost, or snow, having a thickness and surface roughness similar to medium or coarse sandpaper, accumulates on the leading edge and upper surface of a wing, wing lift can be reduced by as much as 30 per cent and drag can be increased by 40 per cent.

These changes in lift and drag will significantly increase stall speed, reduce controllability, and alter aircraft flight characteristics. It identifies surface roughness as the primary influence in the decrease in lift and increase in drag and emphasizes that take-off not be attempted unless it has been ascertained that all critical components of the aircraft are free of adhering snow, frost, or other ice formations.

AC-20-117 cautions that aircraft certified for flight in icing conditions have only demonstrated the capability of penetrating icing conditions in forward flight regime and that ice, frost, or snow formed on aircraft surfaces on the ground can have a totally different effect on aircraft flight characteristics than ice formed in flight.

AC-20-117 states that the only method currently known of positively ascertaining whether an aircraft is clean prior to take-off is by close inspection. Many factors are identified which influence the accumulation of ice, frost, or snow. Surface roughness results under conditions of precipitation or when moisture is splashed, blown, or sublimated onto aircraft surfaces. The circular states that the pilot-in-command is ultimately responsible for ensuring that the clean wing concept is followed.

APPENDIX D

LIST OF WITNESSES
PUBLIC INQUIRY

Peter Boag	– Chairman, CASB Technical Panel
William Mahoney	– Eyewitness
Cecil Mackie	– Eyewitness
Leonard Loughren	– Eyewitness
Robert Lane	– Eyewitness
Glenn Blandford	– Tower Controller, Transport Canada
William G. Geange	– Allied Aviation Service Company Newfoundland Ltd.
Paul Garrett	– IMP Aviation Services
Raymond Foley	– IMP Aviation Services
Clarence Bowring	– Atmospheric Environment Service/Environment Canada
Walter K. Brown	– Pilot, Canadian Pacific Airlines
John S. Steeves	– Pilot, Canadian Pacific Airlines
Lloyd D. Granter	– Allied Aviation Service Company of Newfoundland Ltd.
Rudy Kiffor	– Chief Pilot, Arrow Air Inc.
L/Col. James M. Kelly	– U.S. Army
Capt. Gerald A. De Porter	– U.S. Army
Maj. Ronald W. Carpenter	– U.S. Army
Charles A. Alonso	– Pilot, Arrow Air Inc.
Hans Bertleson	– Pilot, Arrow Air Inc.
Arthur G. Schoppaul	– Pilot, Arrow Air Inc.
Mona Ogelsby	– U.S. Army
Major Kathlene Kruczek	– U.S. Army
S/Sgt. Charles Hailer	– U.S. Army
Capt. Fred Shambach	– U.S. Army (MFO)
Lt. Bradley G. Clemmer	– U.S. Army (MFO)
Peter Smith	– Arrow Air Inc.
R. Stephens Saunders	– Pilot, Arrow Air Inc.
Michael Mendez	– Director of Maintenance, Arrow Air Inc.
Julius Graber	– European Director, Arrow Air Inc.
Robert E. North	– Pratt & Whitney, United Technologies Corp.
Charles E. Bodemann	– Pratt & Whitney, United Technologies Corp.
Herbert Diehlmann	– Contract Maintenance, Arrow Air Inc.
Kelvin Colbert	– Director of Flight Controller Arrow Air Inc.
John Kempster	– Director of Charter Services, Arrow Air Inc.
Sgt. William R. Fraser	– RCMP Gander
Col. Robert McMeeken, MD	– U.S. Army
Gerald J. Nash	– U.S. Federal Aviation Administration
Anthony Kijek	– U.S. Federal Aviation Administration
Frank P. Giannolla	– U.S. Federal Aviation Administration

Vincent J. Lepera	- U.S. Federal Aviation Administration
Don Ewing	- Director of Operations, Arrow Air Inc.
Ralph Brumby	- Douglas Aircraft Co.
Dr. Stanley Mohler	- Wright State University

APPENDIX E

LIST OF LABORATORY REPORTS AND STUDIES

The following laboratory reports and studies were completed:

LP 287/85 – Fuel Analysis
LP 289/85 – Instruments Analysis
LP 290/85 – Light Bulb Analysis
LP 291/85 – Cockpit Switches
LP 7/86 – Freeze Drying of Documents
LP 180/86 – Identification of Parts
LP 106/88 – Thrust Reverser Position Analysis
LP 139/88 – Engine Fire Extinguisher

Report on Examination of Damaged Pratt & Whitney JT3D-7 Engine S/N 671322 – conducted by Gary J. Fowler, Ph. D., Fowler Inc.

Arrow Air DC-8-63 Performance Estimation – conducted by Major M. E. Givins, P. Eng., Flight Dynamics Specialist, Canadian Forces.

Analysis of Arrow Air DC-8-63 Accident – conducted by James K. Luers, M. S., Senior Research Scientist and Mark A. Dietenberger, M. S., Associate Research Physicist, University of Dayton Research Institute.

Supplementary Comments on Questions From the Canadian Aviation Safety Board Regarding Icing as Related to Aviation Occurrence Report 85-H50902 – by Myron M. Oleskiw, Ph. D., Associate Research Officer, Low Temperature Laboratory, Division of Mechanical Engineering, National Research Council.

Post-Mortem Factors: Causal and Survival Aspects – by David D. Elcombe, M.D., Director, Safety Medicine Branch, Canadian Aviation Safety Board.

These reports are available on request from the CASB.

APPENDIX F

GLOSSARY

AC	Advisory Circular
ACC	area control centre
AES	Atmospheric Environment Service
AFB	Air Force Base
AFE	above field elevation
agl	above ground level
ANU	stabilizer angle units aircraft nose up
ASDA	accelerate-stop distance available
asl	above sea level
ATC	air traffic control
C	Celsius
CAE	Canadian Aviation Electronics
Calif.	California
CASB	Canadian Aviation Safety Board
C_D	coefficient of drag
CFR	Crash Fire Fighting Rescue
CID	Criminal Investigation Division
C_L	coefficient of lift
CO	carbon monoxide
CVR	cockpit voice recorder
DMI	deferred maintenance item
DND	Department of National Defence
EGT	exhaust gas temperature
EPR	engine pressure ratio
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FCU	fuel control units
FDR	flight data recorder
ft	feet
FPD	Freezing Point Depressant
Fla.	Florida
FRPC	Flight Recorder Playback Centre
G	load factor
GMT	Greenwich Mean Time
HCN	hydrogen cyanide
hr	hour(s)
ICAO	International Civil Aviation Organization
IFR	instrument flight rules
in. Hg	inches of mercury
JETS	Joint En Route Terminal Systems
KIAS	knots indicated airspeed
Ky.	Kentucky
lat	latitude
lb	pound(s)

long	longitude
M	magnetic
MAC	mean aerodynamic chord
mb	millibar(s)
MFO	Multinational Force and Observers
mg%	milligrams per 100 millilitres
mi	mile(s)
N	north
N_1	Rotational speed of the low pressure compressor of a two-spool engine expressed as a percentage of the maximum value
NAS	Naval Air Station
NATI	National Air Transportation Inspection
Nfld.	Newfoundland
NRC	National Research Council
NTSB	National Transportation Safety Board
PMI	principal maintenance inspector
POI	principal operations inspector
PTC	pitch trim compensator
RCMP	Royal Canadian Mounted Police
STC	Supplementary Type Certificate
T	true
TODA	take-off distance available
TORA	take-off run available
UDRI	University of Dayton Research Institute
V_1	critical engine failure speed
V_2	take-off climb speed
V_F	flap retraction speed
V_R	take-off rotation speed
W	west
Wash.	Washington
Z	Zulu
ZFW	zero fuel weight
°	degree(s)
′	minute(s)
″	second(s)

Bureau canadien
de la sécurité aérienne

Canadian Aviation
Safety Board

ARROW AIR INC.
DOUGLAS DC-8-63 N950JW
GANDER INTERNATIONAL AIRPORT,
NEWFOUNDLAND

12 DECEMBER 1985

REPORT NUMBER 85-H50902

DISSENTING OPINION

Canadä

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DOUGLAS DC-8-63 N950JW
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DISSENTING OPINION

by N. Bobbitt
L. Filotas
D. Mussallem
R. Stevenson

Ce document est également disponible en français. 14 November 1988

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1.0 Introduction/Summary

In our judgement, the wings of the Arrow Air DC-8 were not contaminated by ice — certainly not enough for ice contamination to be a factor in this accident. The aircraft's trajectory and performance differed markedly from that which could plausibly result from ice contamination. The aircraft did not stall. Accordingly, we cannot agree — indeed, we categorically disagree — with the majority findings.

The available evidence convincingly shows that the right outboard engine was producing little power before it contacted trees. The investigation of the other engines was inconclusive with regard to pre-impact status. We believe it possible that these engines were also operating at reduced power. All four thrust reversers may have been deployed.

The evidence shows that the Arrow Air DC-8 suffered an on-board fire and a massive loss of power before it crashed. But, we could not establish a direct link between the fire and the loss of power. The fire may have been associated with an in-flight detonation from an explosive or incendiary device. Consequential damage to various systems precipitated the crash.

2.0 Crew Competent and Alert

Associates of the flight crew unanimously testified that all three members were above average in thoroughness and proficiency.

During the month before their heavy December schedule, all crew members had relatively light flying duties. (The captain, first officer, and flight engineer had 22, 15, and 22 non-flying days respectively in November.) On arrival at Gander, the crew had just completed a flight of 6 hours and 18 minutes after a 17-hour stopover.

The dispatcher and other personnel at Gander International Airport reported that crew members were cheerful, alert, and had carried out duties as expected. This assessment was supported by the Arrow Air dispatcher in Miami who had talked with the captain by telephone. Recorded communications with air traffic controllers indicate normal alert, professional behaviour on part of the crew.

The crew calculated the aircraft's take-off weight according to accepted procedures. Other Arrow Air pilots testified that, conditions permitting, they would increase the margin of safety by using take-off reference speeds appropriate to an aircraft a few per cent heavier than calculated.

We can not agree that the crew may have used take-off reference speeds corresponding to a weight substantially below actual. To us, the post-crash location of the two remaining movable external "bugs" on the first officer's airspeed indicator yields no useful evidence regarding reference speeds. We put more faith in the internal, gear-driven bug on the captain's airspeed indicator which was "burned into position" corresponding to the target airspeed for the weight calculated by the crew. A horizontal stabilizer setting appropriate to the same weight makes our determination conclusive.

We found no basis for supposing that the crew's performance could have been affected by fatigue. In the absence of evidence of abnormal behaviour and in consequence of testimonials to the crew's professional competence, we conclude that no act or failure to act by any member of the crew contributed to this accident.

3.0 No Ice Contamination

3.1 No Ice on Aircraft

The findings of the majority with respect to ice contamination are based on theoretical possibilities. We confuted these in detail in our paper *Critique of the Ice Contamination Hypothesis Presented in Conditional Draft No. 1* (presented to the Board in May 1988).

The majority has adduced no direct evidence of ice on the aerodynamic surfaces of the Arrow Air DC-8. The only evidence of ice anywhere on the aircraft is one reference to a small amount on an unheated edge of a windshield. This reference was made by a refueller who spoke with the flight engineer in the cockpit just before departure. His words were as follows:

> "I noticed some ice buildup around the edges of the cockpit window, and I asked him if they picked up much ice on the way in. He said, "No it wasn't too bad, there's a tiny bit left around the window."

To us, this means that the crew had monitored ice during the approach, had used the airframe de-ice equipment if needed, and that the flight engineer knew from his inspection there was no ice on the lifting surfaces.

The Boeing 737 that took off from Gander shortly before the accident landed in St John's within an hour. This aircraft, which had to descend through the same cloud conditions as the Arrow Air DC-8 on its approach to Gander, did not need de-icing at St John's. The Boeing 737 that landed at Gander shortly after the accident did not pick up any ice during the approach.

The captain of the Arrow Air DC-8, an instructor and check pilot, was universally lauded for his professionalism and meticulous attention to detail. A close professional colleague testified that the captain was aware and wary of the effects of ice contamination, having cited these, for example, in discussions of the 1982 Air Florida crash at Washington.

The *Human Factors Group Factual Report* concluded that the flight engineer was "extremely conscientious and thorough in his approach to his professional duties" and that his "adherence to standards was noted by many sources."

Given the evidence of the crew's professionalism, we conclude that the captain checked the wing as he left the aircraft and that the flight engineer conducted a thorough external inspection. Had there been ice on the leading edge, the crew would have detected it and had the aircraft de-iced.

Two refuellers who could not fail to see the leading edge while connecting the fuel hose to the refuelling panels (see Figure DO1.) testified that they saw no ice. Had de-icing been necessary, it could have been provided on a fee-for-service basis. None of the four ground handlers who would have done the work noticed any ice. Earlier that morning, one of these workers recommended de-icing to the captain of an aircraft that had been at the airport for some time. This witness stated that the Arrow Air DC-8 did not need de-icing because there wasn't any ice on it.

The witness testimony and the detailed meteorological evidence (as presented at the Board's public inquiry and discussed in our previously cited paper) establish that the wing of the Arrow Air DC-8 could not have been contaminated with ice during the take-off run at Gander on 12 December 1985.

3.2 The Aircraft Did Not Stall

The majority based its finding that the aircraft stalled mainly on interpretations of the heading, vertical acceleration, and altitude traces from the flight data recorder. The aircraft's attitude at first contact is cited as supporting evidence. Our paper *Critique of the Ice Contamination Hypothesis ...*, particularizes why both categories of evidence are unconvincing.

We observed, for example, that the alteration in heading is more consistent with a gentle turn than with a stall. We also submitted that the "substandard" vertical acceleration trace (discussed but not reproduced by the majority) provides no support either for or against the notion of a stall.

The majority assessed fluctuations near the end of the altitude trace as an indication of stall buffet. Our paper noted that analogous fluctuations on the trace from the previous take-off disappeared when the aircraft reached about 100 feet above ground. Subsequent analysis by several consultants found: "A study of the altitude stylus marks during take-off going back to twenty flights before the accident ... suggests that such fluctuations tend to be associated with the longer range flights that were made at higher gross weights." That is, fluctuations in the altitude trace near lift-off are characteristic of the installation and not of the accident flight.

The majority cites the high angle of attack at first contact (estimated from the "tree model") as collateral evidence of a stall. Our paper cited a possible estimation error of about six degrees, along with the reduction of apparent angle of attack due to pitch rate, as reasons to be wary of this interpretation. The full upward deflection of the elevator at impact indicates that the pilots may have pulled the control column back in a last ditch effort to reduce speed and delay the crash.

We also note that ground effect could have had no substantive influence on the occurrence or non-occurrence of a stall during the accident flight. This is readily demonstrated by modifying the computer code used for the performance calculations cited by the majority. Recalculation of test cases with no allowance for ground effect produces minor differences (typically: reductions of some 15 feet in maximum altitude and some 350 feet in distance covered) without affecting the presumed stall.

The conclusion that the aircraft *did not* stall can be drawn from evidence of a number of witnesses about the level attitude of the aircraft as it crossed the Trans-Canada Highway. ("It was a normal departure... but that levelling-off effect was abnormal"; "The aircraft's attitude appeared to be level as it crossed the Trans-Canada Highway"; "The plane was levelled off. The plane wasn't nose up or nose down. It was level"; "It looked very flat, just two or three degrees"; "The nose was not pointed up"; "The aircraft was pretty level... Very level.")

In conclusion, the Arrow Air DC-8 did not stall before it crashed.

3.3 Performance Not Consistent with Ice on Wings

Our paper *Critique of the Ice Contamination Hypothesis ...* also points to misinterpretations of the performance calculations reported by the majority.

The computer models (and the flight simulator modifications) extrapolated lift and drag values beyond the range of experimental data. The resulting steeply rising drag curve generated very large increases in drag for modest increments of angle of attack. Thus, the calculations allow minute amounts of "equivalent roughness" to overpower all four engines at take-off power.

Even if we were to accept the assumed effect of ice on lift and drag, we would have to reject the computed results because they depend on unrealistic assumptions about the crew's reactions. To make the computed trajectories "crash" at about the right distance, it was necessary to further assume that, when confronted with decaying airspeed and negative rate of climb, the crew would pull up and hold the aircraft at an angle of attack of 18 degrees. At this angle, aerodynamic buffet would warn the crew to lower the nose — with or without ice on the wings, with or without synthetic stall warning. In any event, corresponding fuselage attitudes of about 10 degrees contradict the observations of the tower controller ("It was a normal departure... but that levelling-off effect was abnormal") and a number of witnesses ("The aircraft's attitude appeared to be level ... "; "The plane was leveled off. The plane wasn't nose up or nose down"; "It looked very flat, just two or three degrees"; etc.).

The calculations cited by the majority take no account of the turn and sideslip which, we feel, are essential features of the accident flight path. The stall presumed in the calculations should at least coincide with the beginning of the turn. Those cases that lead to approximately correct altitude gain and distance show no such coincidence.

We noted in our (previously cited) paper that the flight data recorder indicates a deceleration near the end of the short flight on the order of what would be produced by aerodynamic drag on the standard (i.e., not iced up) aircraft with all engines stopped. The computer program cited by the majority can be used, not only to verify this, but also to find a better fit to the known characteristics of the accident flight — through the assumption that the engines start to spool down shortly after lift-off.

The most natural, tractable assumption for computing the observed performance is that of a massive power loss followed by the expected crew reaction of lowering the nose to try to maintain airspeed. The turn to the right may indicate that the power loss was most severe on that side. It may also indicate additional control problems.

4.0 Pre-Impact System Failures

4.1 Power Lost Before Crash

There is no doubt that all engines were turning just before the crash, nor that the right outboard engine (the number four engine) was turning slower than the others. But air passing through a jet engine keeps it turning even after an in-flight shutdown, so rotational speed does not necessarily equate to power production.

The majority could not determine if the low rotational speed of the number four engine was "the result of an in-flight power loss" or was "the result of tree fragment ingestion prior to ground impact." In our opinion, the evidence is conclusive that engine number four was operating at low power before it contacted trees.

The "tree model" shows the fuselage pitched up about nine degrees and yawed to the right at about 10 degrees when the tail struck the first tree. With this pitch angle, the engines could have ingested "tree fragments" for only part of the time that the aircraft plunged through the trees — for less than one second.

The "tree model" also shows that, when the aircraft first hit trees, it was banked to the right at about seven degrees. Since the wing tips are tilted up at about seven degrees with respect to the roots (6.5 degree dihedral), the two right-hand engines (numbers three and four) entered the tree canopy at virtually the same instant. It follows that "tree fragment ingestion prior to ground impact" cannot account for the vast differences in damage to these engines.

The spare conifers and slender deciduous trees typical of the accident site could not have damaged the number four engine extensively during this short period. We know this from the inlet guide vanes which present the first obstacle to foreign material entering an engine. Seventeen (of 23 total) inlet guide vanes of the number four engine were available for inspection. The leading edges of the inlet guide vanes "generally were in good condition" with no apparent damage from trees or other foreign material.

The bottom of the number four engine case was crushed both front and rear. The fractured blades on the first two (low pressure) compressor stages indicate that the (low pressure) shaft was in fact turning as the front of the engine was crushed; that is, the engine was either windmilling or producing some (unknown amount of) power at this instant. The turbine stages, attached to the same shaft as these compressor stages, were damaged as the back of the case was crushed an instant later. These turbine stages "exhibited relatively little rotational damage." In fact, there is no detectable rotational damage on the final turbine stage. When the engine case was crushed against it, rotation had already ceased.

Low rotational damage to turbine stages at the rear of the engine is consistent with high rotational damage to compressor stages near the front if, and only if, initial impact on the engine was near the front.

Thus, the low pressure spool of the number four engine was stopped during the small interval of time between the instants when the blades were torn from the compressor stages (by crushing at the front) and when the final turbine stage was damaged. Power produced during this time interval would augment the inertial torque tending to twist the hollow shaft. Yet, this shaft remained essentially untwisted on the number four engine.

The low pressure turbine shafts on the other three engines were all twisted in excess of 30 degrees — even though both front and rear stages showed heavy rotational damage. This is clear evidence that the number four engine was rotating substantially slower (and by inference producing substantially less power) than the other engines. This finding is substantiated by the open bleed valve on the number four engine, corresponding to idle power or less. Wood fibres found in this valve also suggest that it was open (hence the engine was not producing power) prior to any ingestion of "tree fragments."

The majority reports that attempts to compare the pre-impact power output of the number four engine to that of the others led to contradictory results. The manufacturer of the engines found little difference between the rotational speeds (and hence between the presumed power) at impact. CASB investigators concluded that this difference was greater than 40 per cent.

We note that large percentage differences in rotational speed would be consistent with small absolute differences if all engines were at low speed. The observation that the bleed valves on engines one, two, and three were closed is based on inference, not conclusive evidence. We believe that the pre-impact power output of these engines remains uncertain.

Both witnesses who observed the "orange/yellow glow" from directly under the flight path believed that the engines were not running (*Witness 1:* "The airplane passed right over my truck ... When it passed right over us, the engines were not running. I did not hear any whine from the engines. I had gone by there hundreds of times when planes were taking off and you could hear the engines. But I could not hear the engines yesterday. There was no whine but there was some type of rumble... I'm certain that when the aircraft passed over us the engines were not working." *Witness 2:* "I heard the noise. I looked, I could see the plane coming over. It didn't sound like engine noise... I live fairly close to the Sydney Airport and I've heard planes taking off before. This one didn't sound right.... There was no roar from him at all"). This "ear witness" testimony is all the more striking since the engines would sound louder than normal as the aircraft flew lower than normal over the trucks.

To us, spooling down of all engines provides a more plausible explanation of the tremendous deceleration than does a massive increase in drag due to 0.03 or 0.04 inches of ice on the wing.

4.2 Thrust Reversers May Have Been Deployed

The sliders on the lower tracks of all four thrust reverser assemblies suggested that the reversers had not been fully forward (that is, not latched in the stowed position) at the time of impact. The position of the number four thrust reverser doors further suggested that they had been deployed prior to impact. The majority concluded that the displacement of all the reverser assemblies (translation rings) and the damage to the number four unit were due to rearward "dragging action during impact." Thus, the majority ruled out in-flight deployment of a thrust reverser as a factor in this accident.

A different appreciation of the evidence may be gained by considering how the rotational damage on all engines establishes the direction of the initial impact force.

We have noted that the engines could not have been in contact with the trees for more than about a second during which the aircraft was pitched up and yawing to the right. Consideration of the possible magnitude and direction of resulting forces shows that tree contact prior to the main ground impact can not account for "dragging action" on the thrust reversers.

The direction of the initial ground impact force can be readily established from the rotational damage on the engines. The direction of twist on the low pressure shafts of the numbers one, two, and three engines indicates that initial impact was at the front of these engines. The low pressure shaft of the number four engine remained essentially untwisted. But, the progressively decreasing rotational damage shows that the number four engine also struck ground first at the front. Thus, the initial axial deceleration would have exerted high forward G-forces on all components of all engines — including all the thrust reversers.

The reversers (translating rings) are normally latched to prevent rearward movement. But, once unlatched, they move relatively easily on their sliders. Had the reversers been stowed in their normal (forward) position when the front of the engine struck the ground, decelerative forces would have tried to drive them even further forward, forcing the latch links even more firmly into the locked position. Under these circumstances, the sliders and witness marks would have been found at extreme forward positions, not "near" the forward positions as observed.

If, however, the reversers had been deployed (that is, positioned at the rear of their tracks) at the moment of initial impact, decelerative forces would have driven them forward. The forward motion of the translating rings would have tended to close the deflector doors. Under such circumstances, the deflector doors could be deployed, stowed, or anywhere in between at the time of subsequent secondary impacts. Witness marks from secondary impacts could correspond to the stowed or nearly stowed positions, or anywhere in between.

Since the cylinders of the hydraulic actuators are double acting, they would split from rapid forward extension as readily as from the rearward extension postulated in the majority report. Detailed examination of scuff marks on the interior of the cylinder walls might have been able to establish which way the pistons were moving at impact.

We also note that the S-shaped bends in the number four thrust reverser lower track (evident in Fig. 1.10.) suggest buckling due to compressive forces. The apparent failure in tension of the attachment links of the deflector door mechanisms also suggests failure during forward movement. These observations support the hypothesis that the reverser was driven forward by decelerative forces.

Similar re-interpretation could be made of the majority findings with respect to the other three reversers. Figures DO2. and DO3. show the deflector doors of the number one reverser, for example. The orientation and lack of continuity of scratches and buckles across the door/housing interfaces suggest that the doors were deployed at initial impact.

At least two of the thrust reverser control valves (which are located in the engine pylons) were apparently recovered. The position of the sliders in these valves may have shed additional light on the pre-impact status of the thrust reversers. Unfortunately, these parts appear to have been discarded without examination.

We believe that all the evidence cited by the majority can be re-interpreted in the light of the large axial decelerative forces at initial ground impact. Such re-interpretation supports the hypothesis that the number four and likely the other three thrust reversers were deployed prior to the crash.

4.3 Multiple Malfunctions

The majority concluded that the Arrow Air DC-8's flaps were extended to the expected 18-degree take-off position even though the wreckage yielded inconclusive and contradictory evidence.

The piston in one of the six recovered flap actuators left a clear imprint corresponding to 25-degree extension. Another had two imprints corresponding to 17- and to 32-degree extension. The remaining four actuators with less clear indications were initially assessed as corresponding to 23, 27, 40, and 43 degrees. Eight of 10 flap track pairs were recovered. Most tracks showed multiple imprints corresponding to a range of settings from 5 to 50 degrees. The flap position indicator read 38 degrees.

All three flap lockout cylinders were recovered, although in severely damaged condition. Two suggested that the flaps were fully extended, while the third suggested a setting near mid-range. These findings could be explained by two simultaneous hydraulic line failures. The majority found this explanation improbable and attributed the contradictory indications to post-impact damage.

To us, this contradictory evidence does not support a determination of a pre-impact flap position of 18 degrees. We are less ready than the majority to rule out improbable multiple failures in such a complex accident.

Multiple failures are also suggested by the landing gear, which remained extended. The captain, an experienced instructor/pilot, would have reacted to declining airspeed after take-off by calling for full power and raising the gear. Disintegration of the cockpit area precluded determination of the position of the landing gear lever. But, if the crew did attempt to raise the gear, the extended landing gear could signal another apparently independent failure.

We believe it unlikely that the contradictory evidence about flaps, spoilers, EPR gauges, N1 tachometers, and other systems can be explained separately through unrelated hypotheses. To us, the extent of the contradictory evidence suggests simultaneous multiple system failures due to a common cause.

5.0 In-Flight Fire/Explosion

5.1 Witnesses Saw Fire

On the day after the accident, one of the witnesses who saw the aircraft pass over his truck testified, "I think the right-hand side of the aircraft was on fire." He later explained that the "yellow/orange glow" seemed to come from the right-hand side "fairly close to the body" and it was so intense that he could see writing on the aircraft's tail. When asked to locate the source of the glow at the Board's public inquiry, he pointed to the cargo compartment at the juncture of the right wing and the fuselage.

The other eyewitness who saw the aircraft pass directly overhead said, "My first impression of the glow was that it was a fire." He could only say that the glow came from the "bottom side" of the aircraft. It was bright enough to illuminate the cab of his truck. This witness also noted that he lived by an airport and this light was not like any other he ever saw on an airplane.

The eyewitness who saw the aircraft pass in front of him from right to left stated, "I couldn't see the right-hand side of the airplane. But I could tell that it was very bright on that side of the plane, like something was on fire."

A witness who is not mentioned by the majority observed the take-off run of the Arrow Air DC-8 from a parking lot near the Gander Airport terminal building. This witness saw the Arrow Air DC-8 taxi out, heard the take-off, and then saw a flash and what appeared to be a "large orange oval object" which then "blew up" and "went into a million pieces." The witness located this "object" low in the sky in a direction that would have placed it on the extension of the runway somewhere close to the Trans-Canada Highway.

The possibility of a fire prior to the main explosion is reinforced by the other witness observations. The crew of an aircraft in the vicinity saw "the sky light up" a few seconds before the fireball of the main explosion. A witness on the ground reported that "there was a second burst of flame that shot up in the air as well. It would appear to me that there was a second explosion."

Thus, a review of the testimony relating to the "orange/yellow glow" reported by eyewitnesses leads us to conclude that this glow may have been a fire burning through the lower right fuselage near the wing root.

5.2 Medical Findings Questioned

Lethal levels of combustion products in toxicological samples show that a large number of victims continued to breath while exposed to fire. Based on the Official Registration of Death certificates, which describe death as instantaneous for all victims, we would have to conclude that there was a fire on board before the crash.

In April 1988, consultants for the Board re-examined injury patterns recorded during the autopsies. They concluded that many of the victims could have survived for up to five minutes. Analysis based on this finding led the majority to impute all evidence of inhaled combustion products to post-impact exposure. This implies that several victims must have been decapitated after surviving the crash and inhaling lethal combustion products.

A consulting pathologist who studied the available information independently advised us that the analysis of the majority does not rule out the possibility of a pre-impact fire. We understand that injury patterns do not provide definitive indication of survival time, or more specifically, of the time the victim continued to breath after injury.

The cause of death may have been clarified by correlating specific injury patterns with carbon monoxide levels. The results are all the more ambiguous since carbon monoxide levels seem uncorrelated with ground fire patterns. In any event, correlations based on location within a grid mean that the conclusions, in so far as they are valid, apply only in some average sense.

To us, the massive destruction of the aircraft suggests unsurvivable decelerative forces. A detailed analysis of these forces could have provided a cross check on the results of the injury pattern analysis.

We also note that the medical examinations found that all injuries consistent with a blast wave or shrapnel from an explosion could also have been sustained during the crash. Nevertheless, the medical report submitted in support of the majority finding indicates that "an explosion within a cargo area might then have its effects on passengers deflected and thus leave no trace on the victims."

5.3 Significant Circumstances

A variety of indirect, circumstantial evidence gives substance to eyewitness testimony suggesting a fire on the lower right-hand side of the fuselage. Such a fire may also explain the evidence of seemingly unrelated systems failures.

The majority explains that "considerable speculation" about an in-flight detonation "was fuelled by the fact that military personnel and equipment were aboard the flight and by the increasing world-wide incidence of terrorist activity. Also contributory to this speculation was the point of origin of the flight ... ."

The point of origin, Cairo, was suspect in that the security arrangements for loading the soldiers and their baggage were not ideal. Previous operations of Arrow Air for the MFO in Egypt had used El-Gorah Airport in the Sinai Desert. Construction at El-Gorah necessitated a last minute switch to Cairo. Troops of the 101st Airborne arrived from the Sinai in two Egyptian Air 737s about five hours before the arrival of the Arrow Air DC-8. Baggage and other equipment were trucked in and parked in a holding area prior to loading. Only a portion of the hold baggage was inspected.

After the first 45 minutes, the ground stay at Cairo was in darkness. Baggage and cargo were loaded without military supervision. Testimony at the Board's public inquiry revealed a chaotic process. The auxiliary power unit failed twice, leaving the aircraft in darkness with only one "semi-uniformed" guard believed to be an Egyptian soldier. It is reported that fighting broke out among the ground handlers beneath the tail of the aircraft, possibly during one of the blackouts.

The security arrangements at Cairo take on added significance in light of the bomb that exploded aboard a TWA 727 in April 1986, tearing a hole in the fuselage and killing four passengers. The bomb was reported to consist of a small amount of plastic explosive about the size of two cigarette packs of a design favoured by Palestinian terrorists. It exploded under the seat of a passenger who had boarded in Cairo and left the aircraft during a stopover in Rome.

The day after the Arrow Air disaster, a group calling itself the "Islamic Jihad" claimed responsibility. We understand that the claim was made to the media and also by means of a telephone call from Lebanon to the CASB headquarters in Hull on 13 December 1985.

The "Islamic Jihad" or "Islamic Holy War", a secretive pro-Iranean terrorist group, had previously claimed responsibility for two separate car bombings of the U.S. embassy in Beirut, murder of the president of the American University of Beirut, laying mines in the Red Sea, and the kidnapping of American, Russian and French nationals. The organization had demonstrated great sophistication in the use of explosives and may have been responsible for the terrorist attack that killed 241 American members of the multinational peacekeeping force at Beirut Airport in October 1983. This attack was a major political setback for the U.S. administration who stood accused of failing to ensure the safety of American peacekeeping forces. Terrorist groups would certainly have been eager to repeat what, from their point of view, was a major success.

In July 1985, five months before the Arrow Air accident, the "Islamic Jihad" claimed responsibility for a bomb attack that killed 27 at Copenhagen, Denmark. Anonymous spokesmen for the organization announced that the attack was in retaliation for raids in Southern Lebanon and warned that terrorist operations would no longer be confined to the middle east.

At the time of the Arrow Air accident, the U.S. government was negotiating with the "Islamic Jihad" for the release of six American hostages.

The remaining factor leading to "considerable speculation" of in-flight detonation noted by the majority concerns "the fact that military personnel and equipment were aboard the flight."

On 26 February 1986, an incident described as a "catastrophe waiting to happen" occurred at Norton Air Force Base near San Bernardino, California. A bag being loaded on a DC-8 military charter broke open, revealing contraband explosive material. A search of the baggage found a variety of detonator cords, machine gun ammunition, blasting caps, slap flares, and other explosive materials.

Another military charter was involved in a similar incident at Oklahoma City on 19 April 1986. A precautionary search after a bomb threat "resulted in the recovery of various items of military ordinance which were being transported without authorization as souvenirs."

A bulletin issued by the Director of Civil Aviation Security noted that "among the items recovered was a trip flare with the triggering pin loosened, rendering it extremely dangerous." It went on to note that "if the trip-flare had been set off a magnesium fire would have resulted." The bulletin also stated that "the U.S. Army Explosive Ordinance Disposal Unit disclosed that the item, if triggered, would have resulted in a severe fire and probable crash of the aircraft."

These incidents, which occurred several months after the Arrow Air DC-8 accident, suggest that clues about the cause might be found in the uninspected baggage. The majority found that "the integrity of Class D cargo compartment was compromised because flight was undertaken with two missing side panels in the number three cargo pit." These panels provide a flame resistant lining and prevent ventilation so as to suffocate any fire that may break out. There are neither alarms nor extinguishing systems. Thus, a fire could propagate undetected in a cargo compartment missing some of these panels.

A magnesium fire resulting from accidental detonation of a "trip flare" in a forward cargo compartment could produce an intense glow with no apparent flames as it burns through the lower fuselage. The intense heat generated by such a fire could destroy control cables and other systems with unpredictable, catastrophic results. In addition to multiple system failures, the consequences could include false cockpit warnings. The crew may be disabled. If not, they may be unable to raise the landing gear, may discharge a fire bottle, and may even attempt to abort the take-off.

In short, a single hypothesis of fire or explosion in a cargo hold can explain many aspects of the accident which need diverse and at times far-fetched assumptions with the ice-contamination hypothesis. These include contradictory evidence about engines, thrust reversers, and flaps; right turn and yaw despite full opposite control; failure to raise the gear despite loss of airspeed; an intentionally discharged fire bottle; inconsistent EPR and N1 tachometer readings.

We would expect much of the evidence of in-flight detonation or fire to be obliterated by the subsequent ground fire. However, we would also expect that meticulous scrutiny of the wreckage might uncover definitive residual signs.

5.4 Incomplete Wreckage Analysis

The section "Fire Investigation" in the International Civil Aviation Organization's *Manual of Accident Investigation* outlines techniques for examining wreckage to determine if a post-crash ground fire could have masked evidence of an earlier in-flight fire.

The most potent technique is to attempt to "reconstruct the aircraft from the remaining parts in order to detect a pattern" in soot deposits or other signs of fire. Patterns in the flight direction would indicate the presence of an in-flight fire, as would continuity of patterns across lines of failure. Lack of soot deposits on fracture surfaces adjacent to a burned surface would indicate that the fracture occurred after the surface had been exposed to fire.

The examination of the wreckage conducted in support of the majority findings was described as follows:

> "All wreckage was recovered from the site and moved to a secure hangar at the Gander Airport, where it was arranged in a grid pattern which matched the grid pattern established at the site. A thorough examination of the wreckage was completed, and further selected components were forwarded to the CASB's Engineering Laboratory in Ottawa."

We understand that the examination of the wreckage in the hangar was completed in several days. There are no records of attempts to "reconstruct the aircraft from the remaining parts" in order to detect or disprove the presence of pre-crash fire. Wreckage not selected for forwarding to Ottawa was bulldozed into piles and later discarded. Accordingly, our efforts to evaluate the evidence for signs of in-flight fire had to be based on an incomplete photographic record.

Hundreds of photographs were taken of the vast destruction at the accident site. Most of the wreckage is unrecognizably fragmented, and the random scatter of the debris seems to belie a sequential breakup. We could not conduct a systematic review since the photographs not needed to support the majority analysis were not organized or labelled. An index relating specific items to the survey grid was not available.

We were particularly interested in the continuity of soot patterns between the edges and frames of doors, emergency exits, and access hatches. As can be seen on Figure DO4., sections of the fuselage with missing doors and windows and evidence of heat discoloration were available for study. We do not know how many doors were recovered, but photographs show that a number were available for analysis. Figure DO5. shows one of the emergency exits. Soot around the edges and blistering of the paint indicate that it had been exposed to severe fire. An attempt to mate this exit with its frame may have helped establish whether the fire occurred in the air or on the ground.

Figure DO6. shows the exterior surface of another door with fire evidence on the edges. This door shows post-crash damage, but no evidence of buckling that might be expected if impact forces had been transferred through the frames. Figure DO7. shows the inner surface of the same door. The burn marks spreading from one edge could suggest that an internal fire may have burned out the seal while the door was still attached. We note that the fire which damaged the upholstery and exposed the frame near the window did not melt the window's outer layer.

Stronger evidence can be observed on Figure DO8. and Figure DO9. which show exterior and interior surfaces of a section of fuselage around a window. Lack of burn evidence on the frames of the adjacent windows indicates a highly localized fire originating on the inside. The soot surrounding the exterior of the empty window opening suggests a flash from an explosion which shattered the window. The relatively light burn marks on the interior also suggest an explosion, since we would expect more severe burning from a fire sufficiently intense to melt both layers of the window. More concrete evidence may have been obtained from detailed microscopic analysis of the window edges.

Figures DO8. and DO9. provide convincing, if not conclusive, evidence that the soot was deposited around the window before the section separated from the fuselage. The fracture surface near the lower edge of the window opening is free of soot deposits or other evidence of exposure to fire. The piece of frame which separated from the top of the window also left a strip clear of soot. Thus, a fire must have occurred before the section separated; that is, before the crash. Since the part in question has been discarded and we could find no other photographs, we were unable to further substantiate this finding.

In the absence of documentation and explanation of apparently anomalous photographic evidence, we were unable to accept the majority's attribution of all burn damage to post-crash fire.

There is also evidence of detonations on the aircraft. Firemen who arrived on the accident scene some 15 minutes after the crash noted some 30 to 40 explosions, some of which were large enough to cause "mounds of rubble to lift several feet into the air." The majority attributes these explosions to "normal bursting of pressure vessels ... due to the heat of the fire." But pressure vessels are equipped with safety valves precisely to prevent explosion. More detailed consideration suggests the possibility of both post-crash and pre-crash detonations from explosive devices.

An explosive expert acting as a consultant for the insurer examined some of the wreckage in the hangar at Gander. He believed he found evidence of an in-flight explosion. This evidence included a roughly circular hole some 11 inches in diameter in a fuselage sidewall. The hole, located just above the floor line in the passenger cabin, seemed to be punched out explosively. The fuselage section showed no damage other than the outward pucker around the hole (Figure DO10.). The partial window frame above the hole seems to be distorted outward as if from an internal blast.

The consultant believed that the hole could not have been formed in the panel after it had separated without other damage to the interior surface. But, an explosion in the passenger cabin while the sidewall was still attached to the floor may well have produced such damage. As would be expected in view of the extensive weathering of the debris, forensic examination found no evidence of explosive residue.

The majority attributes the hole to damage occurring during impact. We believe that such a hole could not have been punched in an unattached section without further damage and without indication of what might have caused it. Accordingly, we hold the consultant's hypothesis credible.

Our own examination of photographs of the wreckage found more evidence of possible explosions. Figure DO11. shows a substantial explosively ripped hole apparently on the underside of the aircraft. Figure DO12. shows an interior view. We could not establish the location on the aircraft, but the wide extent of battered and crushed ribs might be supposed to be the result of impact by material blown about by an explosion. Additional detail shown in Figure DO13. shows chips removed with no apparent local deformation. Such damage suggests high fracture rates typical of explosions.

A host of complex control breakdowns could ensue if the kind of battering illustrated in Figure DO12. were to occur in the ceiling of a forward baggage compartment where cables pass on way to the engines and flight controls. Such common cause failures could account for seemingly improbable simultaneous runaway flaps, in-flight deployment of thrust reversers, along with inability to raise the landing gear.

We accept these and similar photographs as convincing evidence of an in-flight fire and possible evidence of an in-flight explosion. But, in view of the nature of our review, we cannot reasonably speculate on the resulting damage to aircraft systems.

6.0 Conclusions

6.1 Findings

The following findings are further to, or in contrast with, those of the majority:

- Members of the cockpit crew performed their duties without apparent fault.
- Weight and balance considerations were not factors in this accident.
- Ice contamination was not a factor in this accident.
- The right outboard engine (the number four engine) was operating at low power before contacting trees.
- All four thrust reversers may have been deployed prior to impact.
- Fire broke out on board while the aircraft was in flight, possibly due to a detonation in a cargo compartment.
- The determination of the causes and factors that led to this occurrence was severely hampered by the lack of information that could have been provided by a thorough effort to analyze and reconstruct the wreckage.

6.2 Causes

An in-flight fire that may have resulted from detonations of undetermined origin brought about catastrophic system failures.

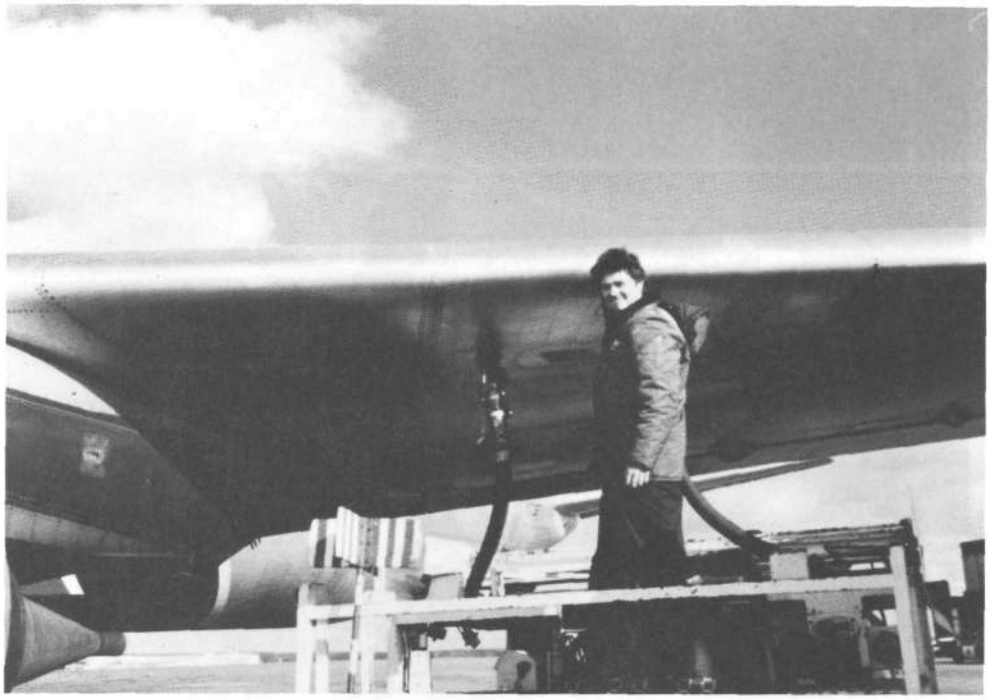

Figure DO1. Refueller's view of DC-8 leading edge

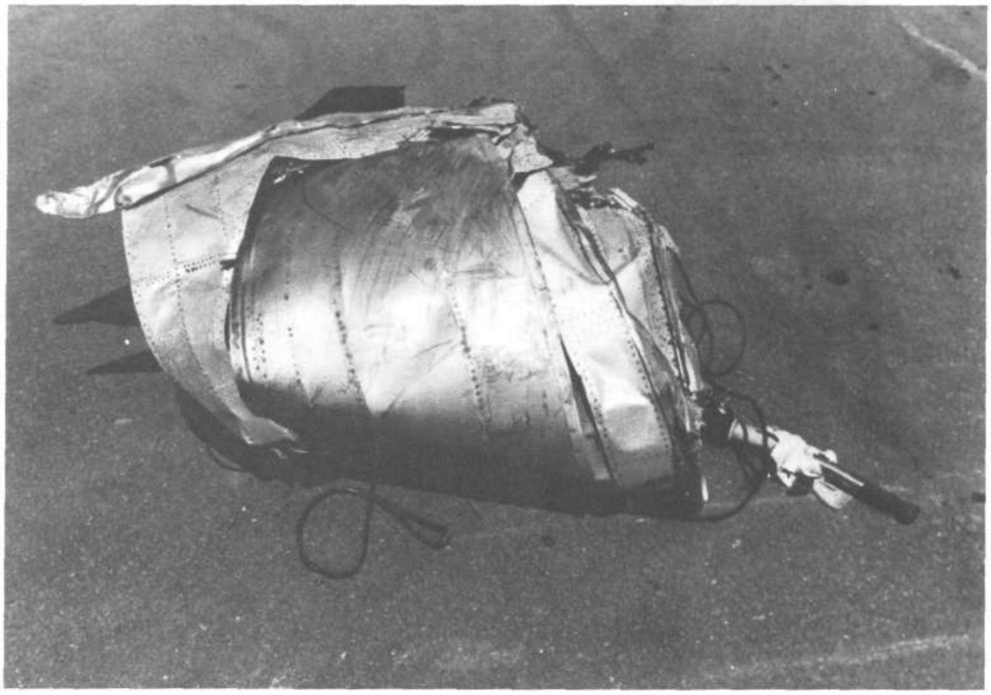

Figure DO2. Thrust reverser #1 — Outboard side

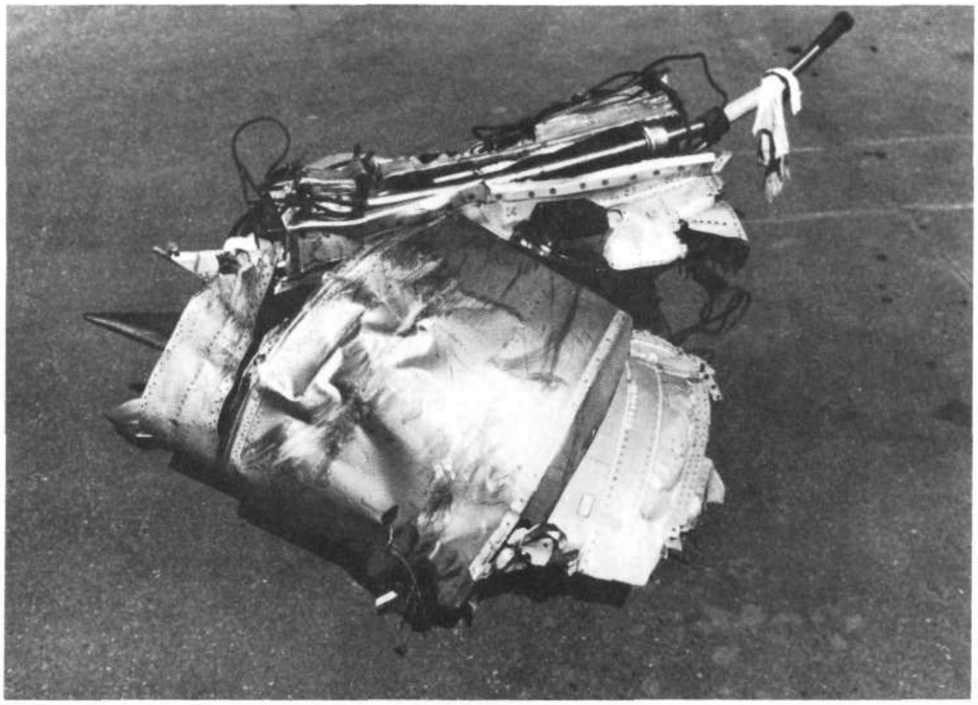

Figure DO3. Thrust reverser #1 — Inboard side

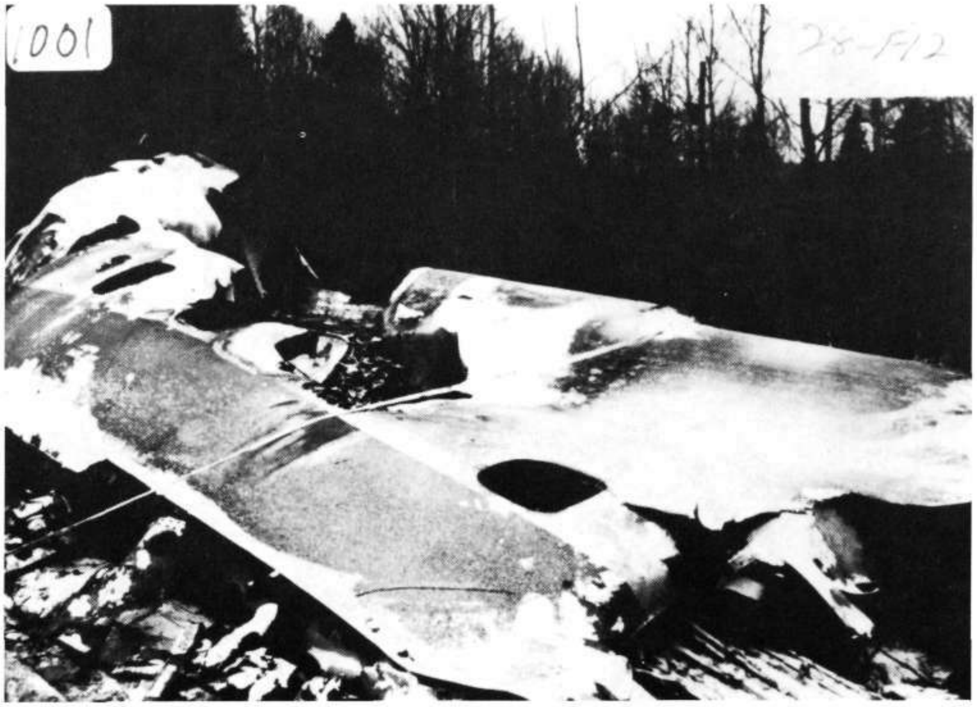

Figure DO4. Fire-damaged fuselage section

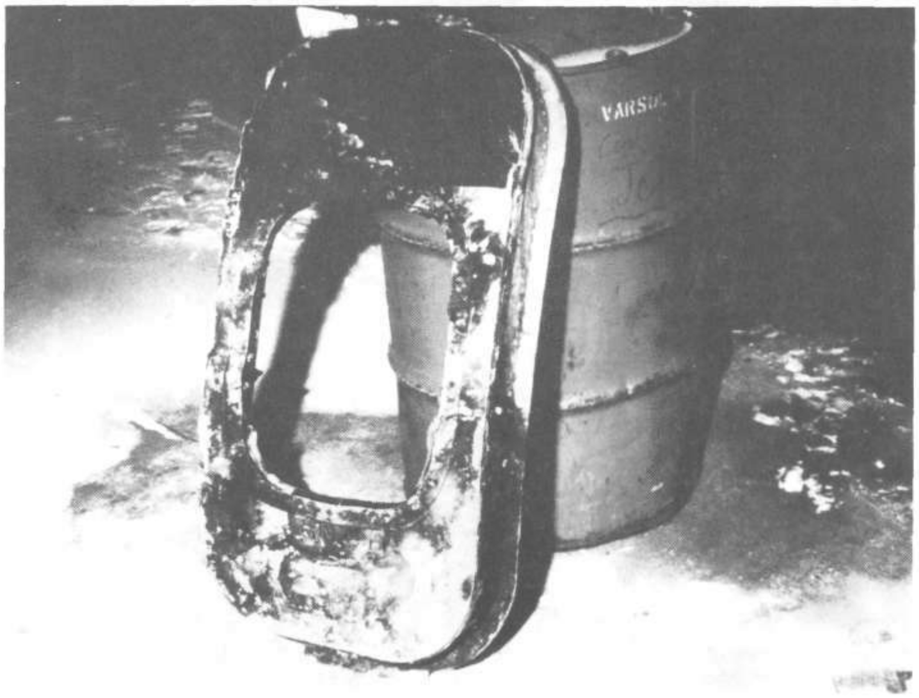

Figure DO5. Emergency exit showing soot deposits around edges

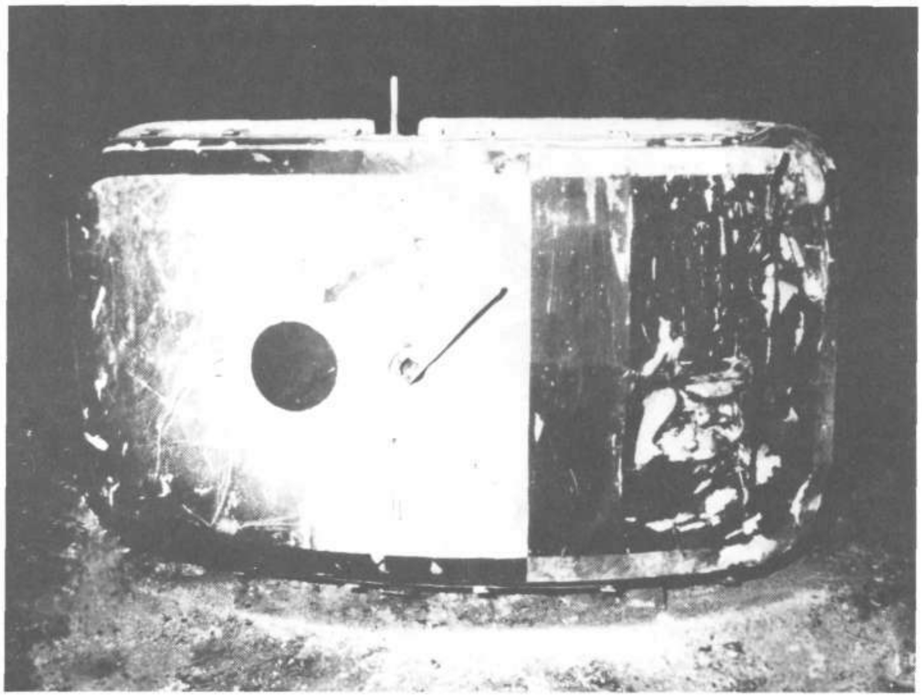

Figure DO6. Exterior of damaged door

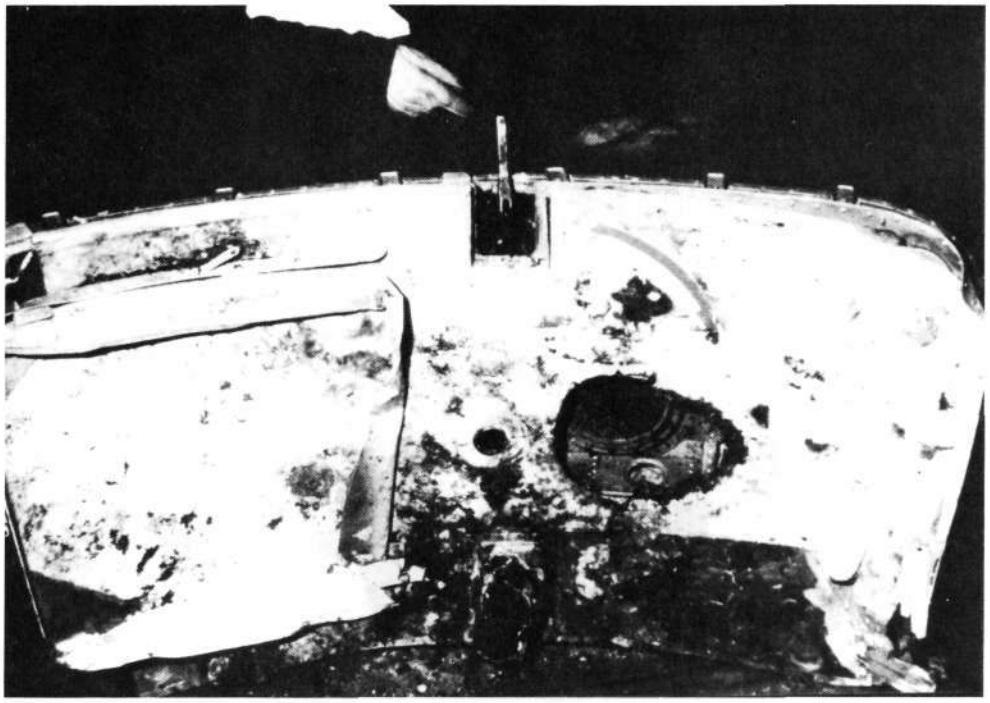

Figure DO7. Inner surface of damaged door

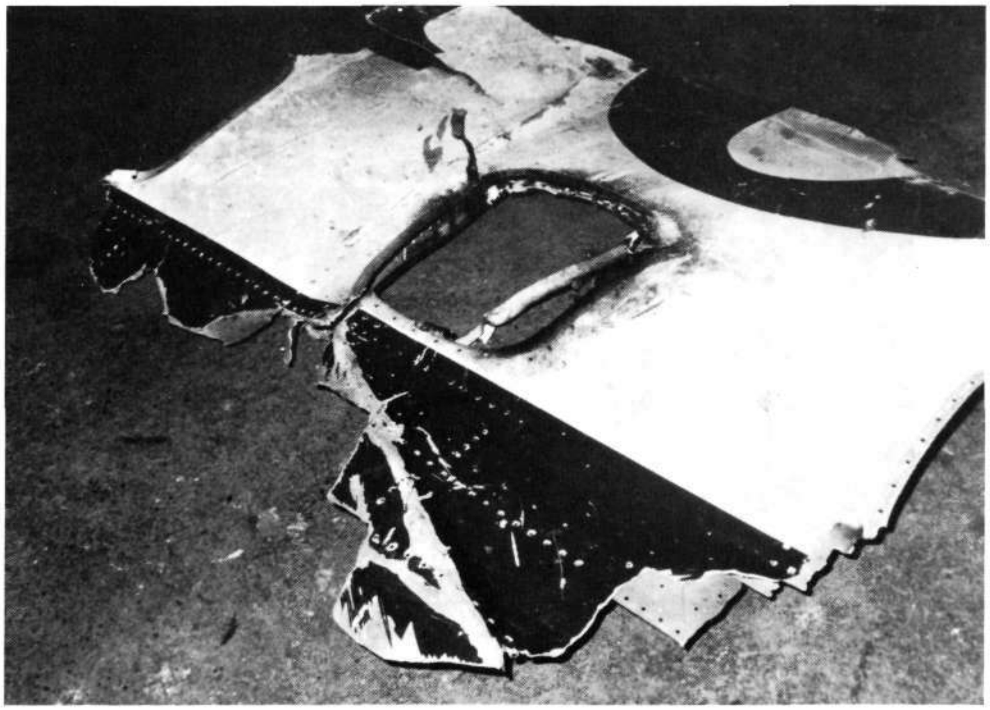

Figure DO8. Exterior surface of fuselage section

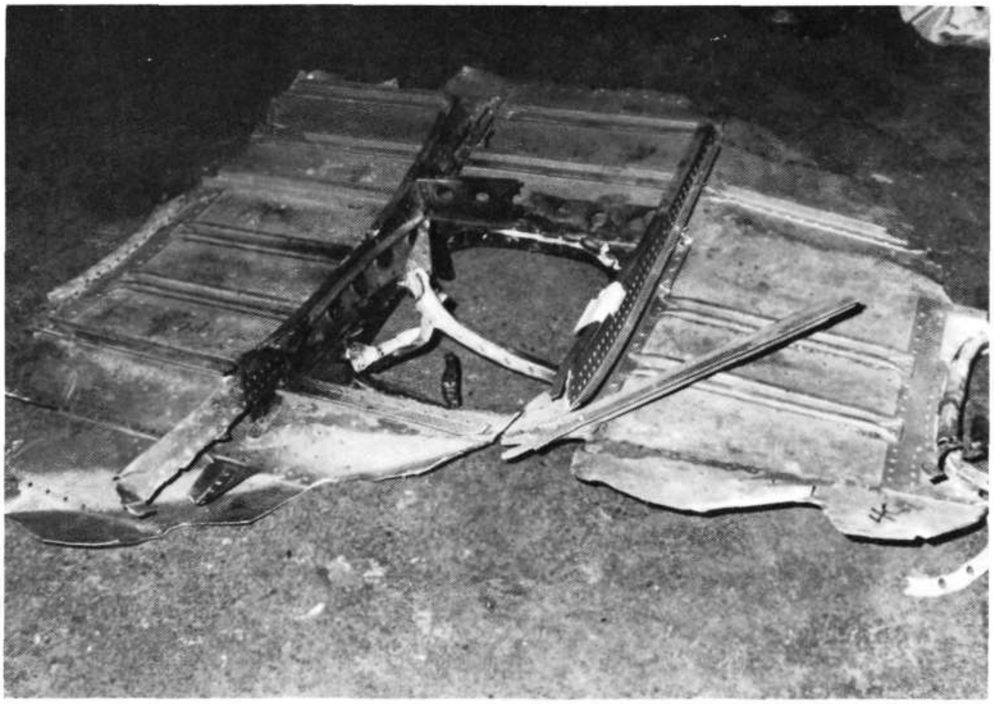

Figure DO9. Interior surface of fuselage section

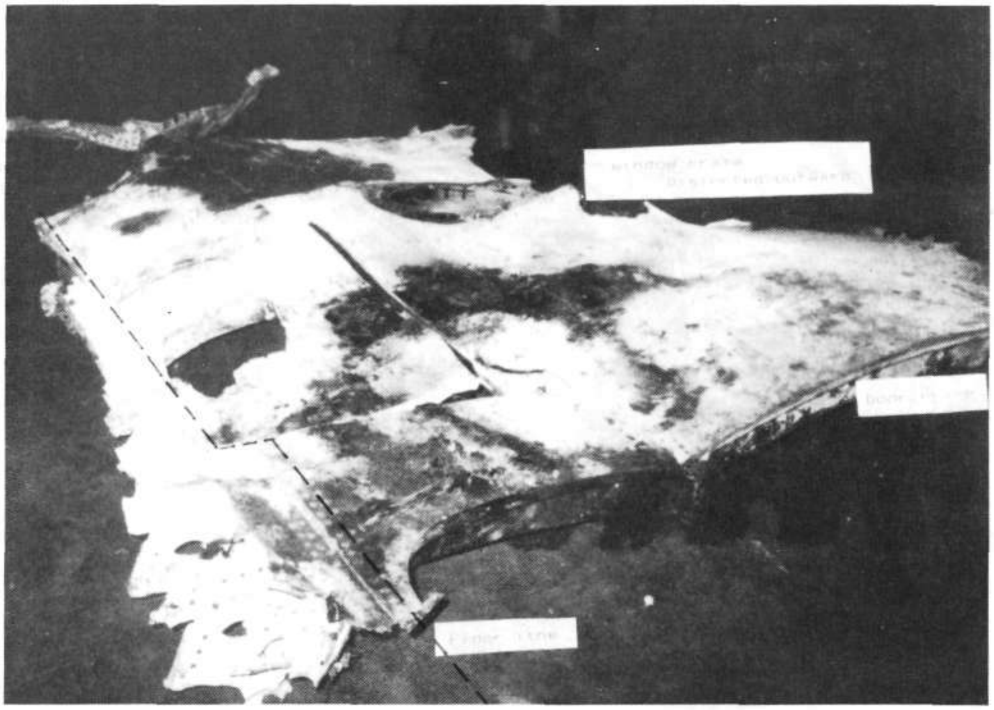

Figure DO10. Explosively punched hole in fuselage panel

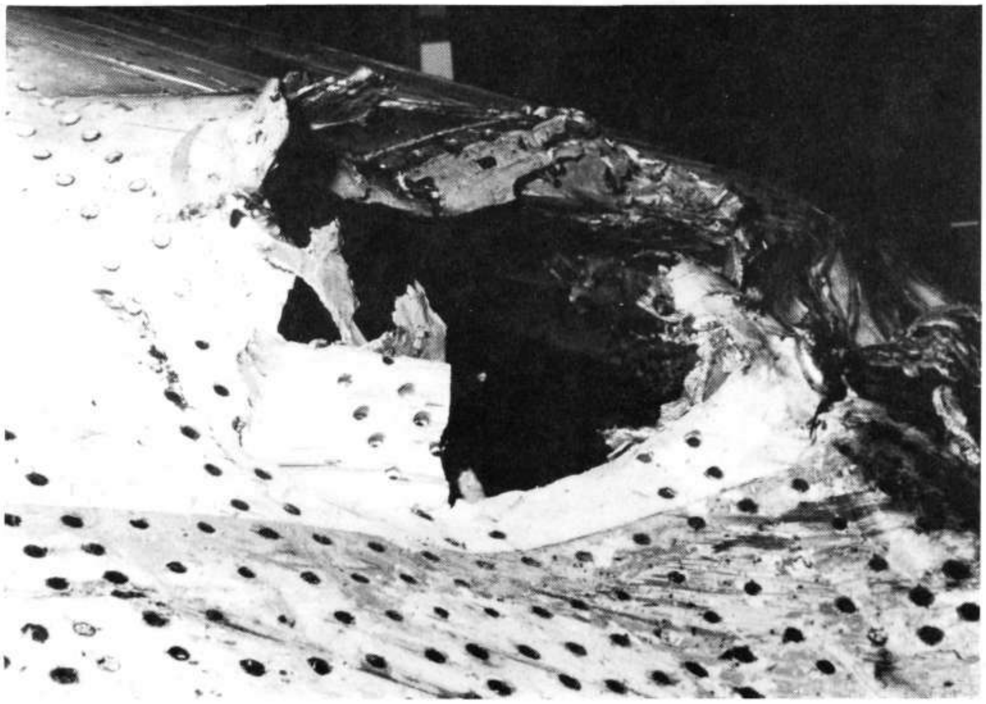

Figure DO11. Hole apparently ripped by explosion

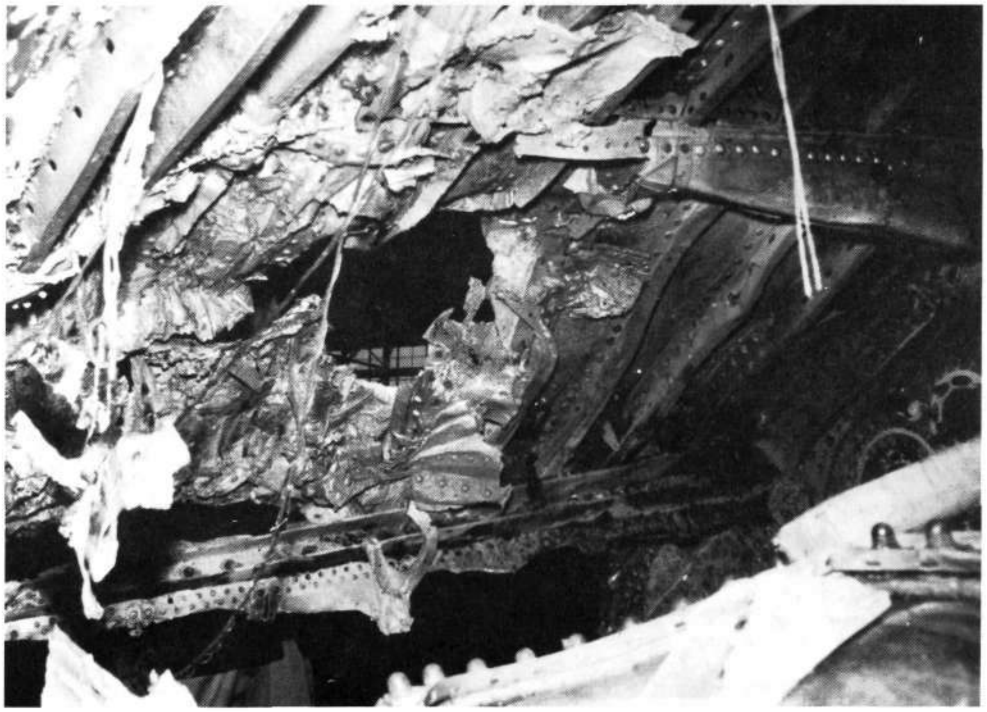

Figure DO12. Interior view showing extensive battering

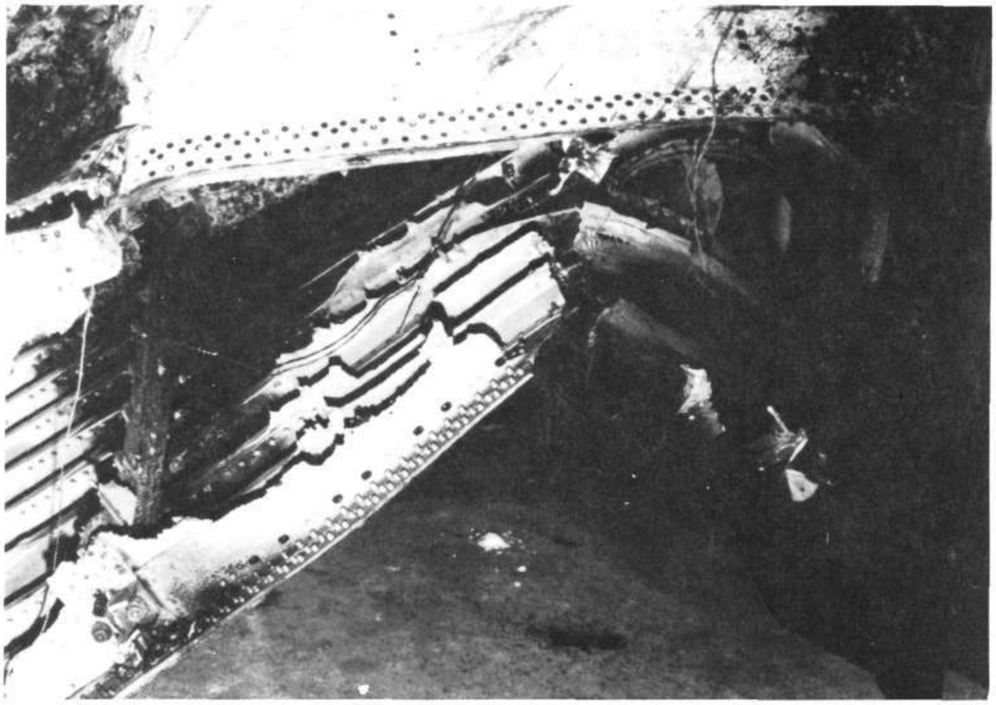

Figure DO13. Possible explosive fracture