Both lateral control spoiler actuators were recovered. [redacted]. 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.

[redacted]

[redacted]

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.

[redacted]

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.

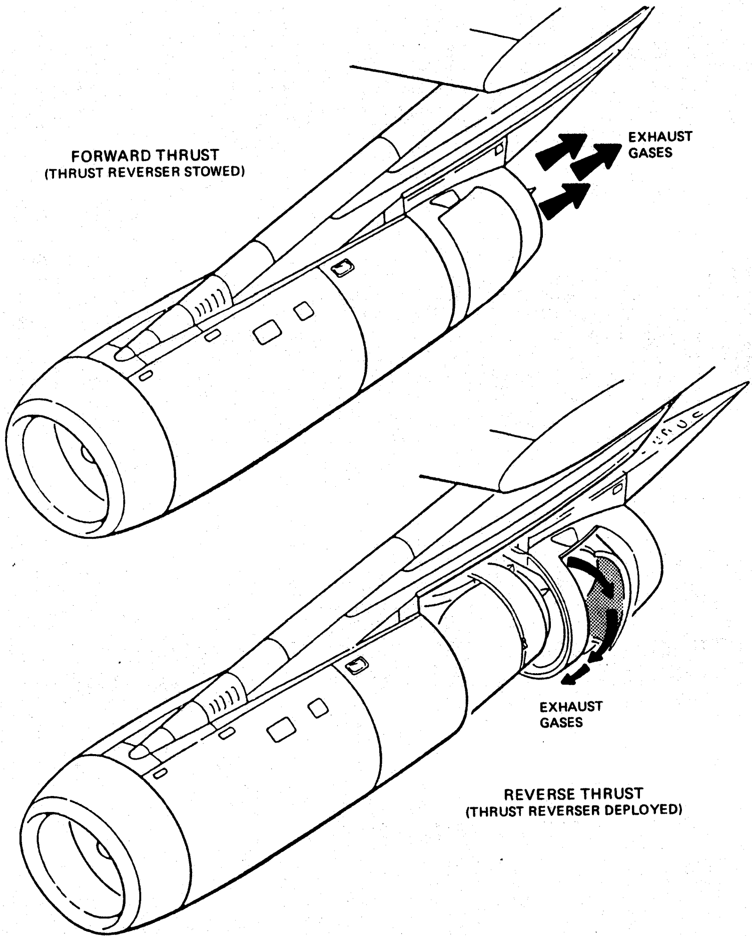
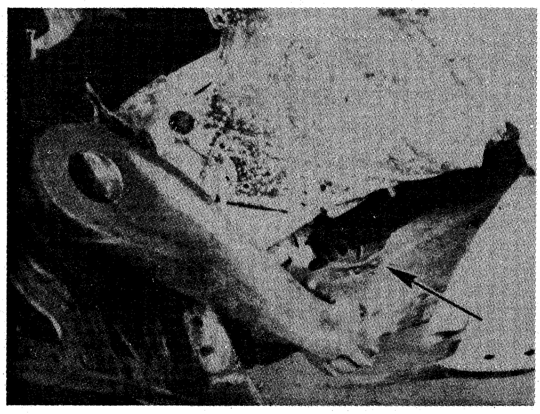
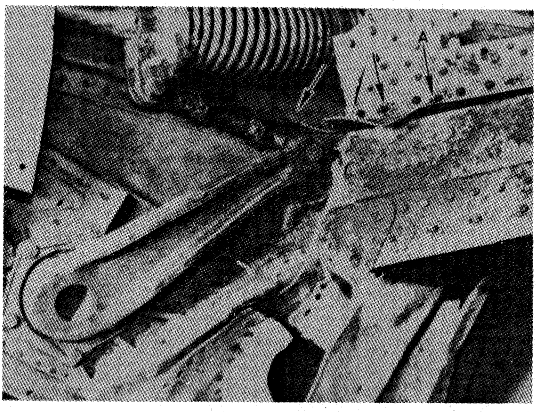


Figure 1.7. Schematic of Thrust Reverser Assembly



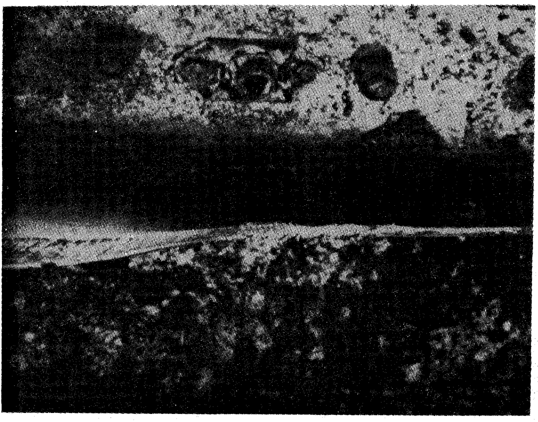
OUTBOARD DEFLECTOR DOOR UPPER ACTUATING ARM AREA OF NO. 4 REVERSER. ARM HAS BEEN PULLED OUT OF SLOT BY CRASH DAMAGE. NOTE DAMAGE IN AFT END OF SLOT AT ARROW.

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



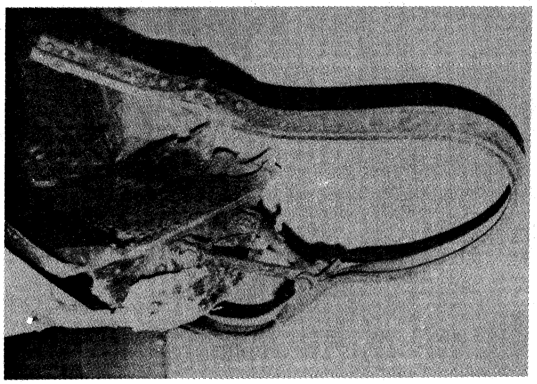
THRUST REVERSER NO. 4 INBOARD DOOR LOWER ACTUATING ARM. SKIN HAS BEEN CUT AND FOLDED BACK TO SHOW DEFORMATION IN EDGES OF SLOT (ARROWS). NOTE THAT ARM IS IN THE DOOR DEPLOYED POSITION.

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



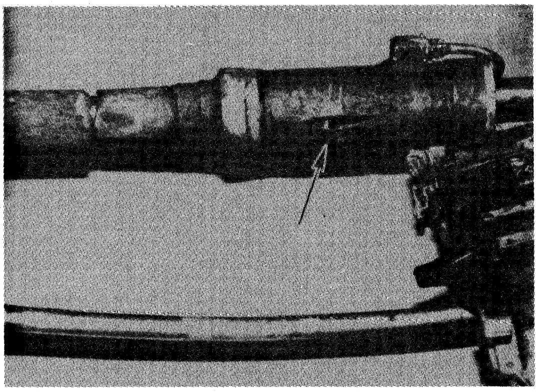
VIEW OF DAMAGE TO EDGE OF SLOT AS SHOWN IN FIGURE 1.9. AT A. DAMAGE PATTERN SHOWS ARM MOVED FROM THE DOOR FAIRED TO THE DOOR DEPLOYED POSITION AFTER INITIAL IMPACT.

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

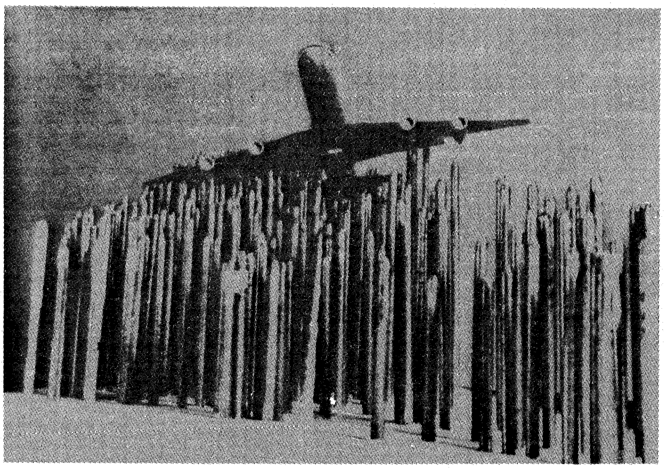


Figure 1.14. Reconstruction of Impact Attitude

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 t
ing were obtained from the remains of three flight attendants. Toxicological tests
of CO were positive in the case of two flight attendants. Measured levels of (
cent and 5 per cent saturation. Toxicological tests for the presence of HCN reveal
HCN level in the blood of the flight attendant with the 21 per cent CO level, the ı
for HCN were negative. Tests for common drugs were positive for caffeine in all tl 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.

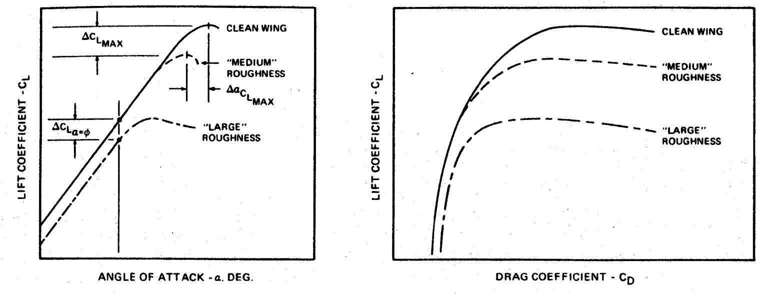


Figure 1.15. Typical Effect of Surface Roughness at the Leading Edge on Aerodynamic Characteristics

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.

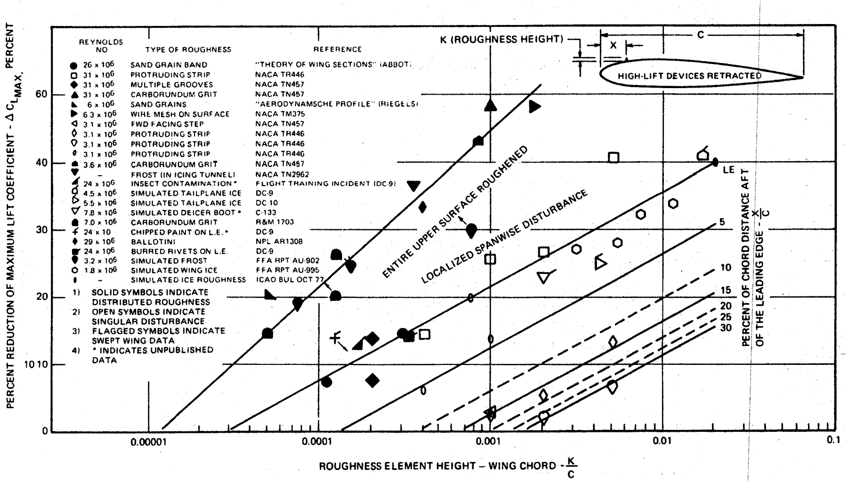


Figure 1.16. Reduction of Maximum Lift Coefficient Due to Wing Surface Roughness

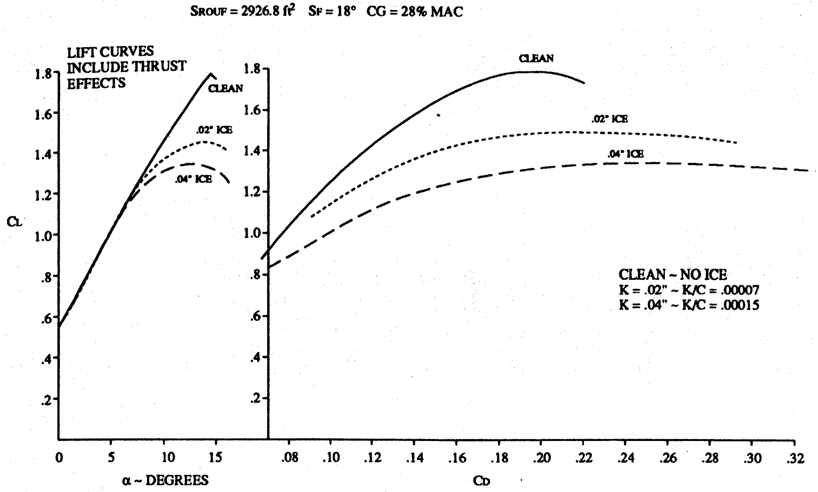


Figure 1.17. Model DC-8-63 Effect of Wing Upper Surface Distributed Roughness on Aircraft Lift and Drag

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.

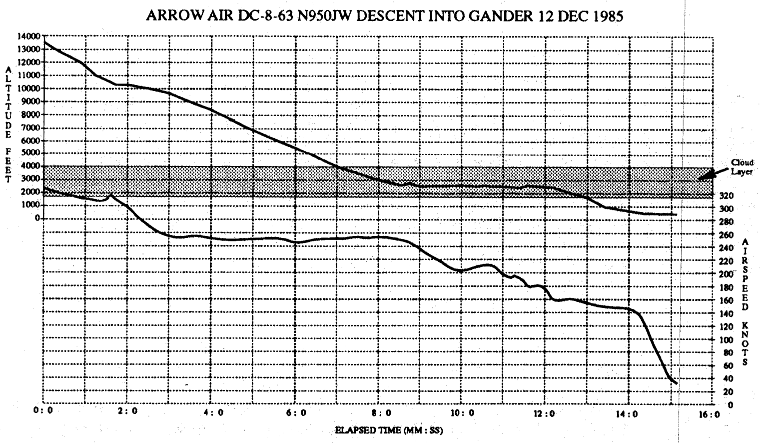


Figure 1.18. FDR Plot of Approach to Gander

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 . Board's public inquiry. Flight crew scheduling at Arrow Air is his responsibility. He test that applicable FARs were the primary parameters used to establish individual flight c 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. [redacted] 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. [redacted] 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.

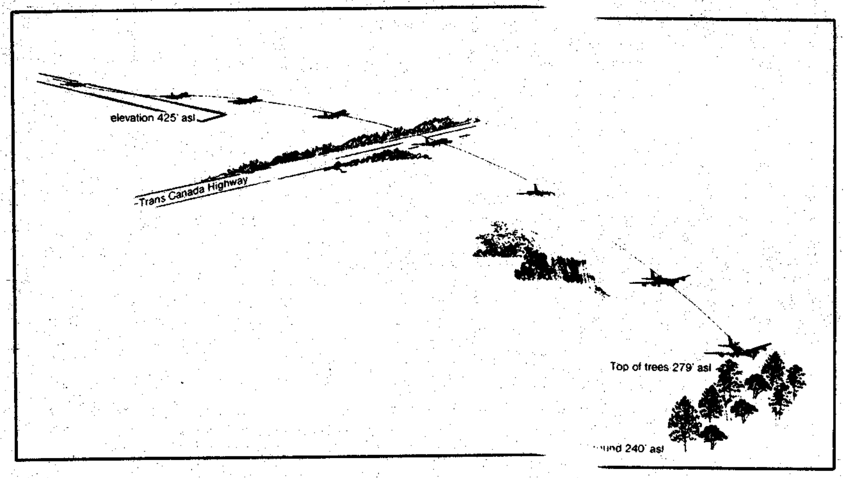
This report and the safety action therein has been adopted by the Chairman, K.J. Thorneycroft, and Board Members:

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



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.

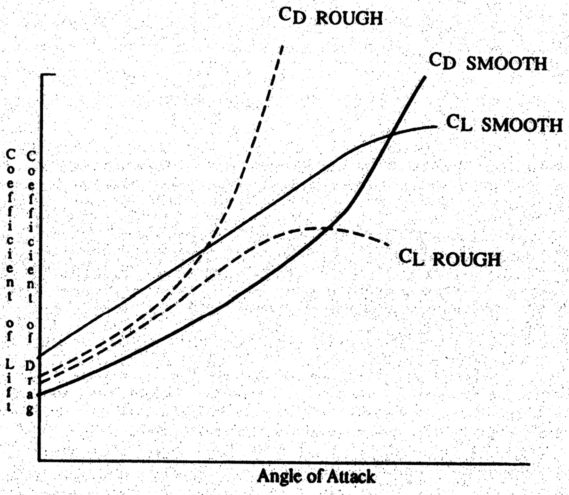
3.9.4 Intensity by Visibility Criteria.

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

APPENDIX 47.—FINDINGS OF THE SUBCOMMITTEE ON CRIME IN ITS INVESTIGATION OF THE DECEMBER 12, 1985, AIRPLANE CRASH WHICH CLAIMED THE LIVES OF 248 MEMBERS OF THE U.S. ARMY, 101ST AIRBORNE, AND 8 CREWMEMBERS

EXECUTIVE SUMMARY

On December 12, 1985, a DC-8 Arrow Air international charter with 248 members of the U.S. Army's 101st Airborne and eight Arrow Air crew members crashed approximately 20 seconds after takeoff (approximately one-half mile from the runway) from the Gander International Airport, Gander, Newfoundland. The charter flight departed Cairo, Egypt on December 11, 1985 with planned stops in Cologne, Germany and Gander, Newfoundland prior to its scheduled arrival in Ft. Campbell, KY.

According to the International Civil Aviation Organization (ICAO) treaty, to which the United States is a signatory, the Canadian Government was responsible for the investigation and reporting of the fatal plane crash since the accident occurred in Canada. The role of the United States was limited to being advisors in the investigation. The United States was allowed to review and make comments to the draft report prepared by the Canadians.

The Canadian investigation took almost four years to complete and report. There was considerable controversy within Canada and the United States over the management of the investigation, and the conclusions and findings that were the result of the investigation. During those years, four separate reports (the Majority Report, the Dissenting Opinion, the Aviation Group of Canada Report and the Justice Estey Report) were issued in Canada before the Canadian Government determined that no further inquiry into the crash was warranted.

Immediately following the crash, allegations were made that the crash was the result of an act of international terrorism. Two U.S. embassies abroad received communications concerning alleged claims of responsiblity for the fatal plane crash.

Allegations of terrorist involvement persisted following the completion of Canadian investigation and the subsidiary reports which that investigation generated. Additionally, concern in the United States, particularly among family members of the victims of the Gander disaster, regarding the role of the United States Government in investigating the disaster persisted, and in fact grew rather than subsided.

For these reasons and the fact that the Subcommittee has responsibility for matters relating to extraterritorial criminal jurisdiction of the United States, the Subcommittee on Crime initiated an oversight investigation of the role of the United

States Government in the investigation of the Gander disaster. The purpose of this investigation was to review the role of the U.S. Government and not to criticize or discredit the Canadian investigation.

The Subcommittee's investigation disclosed a near total absence of United States Government participation in the investigation of the fatal crash.

Though the Subcommittee found no evidence in the record that terrorism was involved in the accident, we do not believe that concerned Americans can find any comfort in this fact. We say this because we found no evidence that there was an investigation of possible terrorism.

In this regard, it concerns the Subcommittee that no one in the United States Government had detailed information on what was done by the Canadians, or by the United States Government itself, to determine that terrorism was not the cause. When the National Transportation Safety Board (NTSB), the lead U.S. agency, was questioned about terrorism, the Subcommittee was referred to Canadian authorities for a response.

Because there was no investigation of possible terrorism, there is no opportunity to reconstruct, review, and reevaluate that investigation.

Additionally, the Subcommittee is disturbed that the NTSB expressed complete satisfaction with the factual information in the Majority Report. It did so after maintaining a "laissez-faire" attitude while the Canadians spent four years mired in controversy over the facts in the Majority Report.

Justice Estey's Report (the final report in Canada on the Gander investigation), concluded there was no evidence in the Majority Report to support its conclusion as to the cause of the accident. Meanwhile, after reviewing the draft report, the NTSB submitted a letter to the CASB which stated, "The National Transportation Safety Board staff has reviewed the draft report and has no comments to suggest. They find the report thorough and complete, and the conclusions logically supported by the text."[1]

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[1] Burnett, Jim, Letter from the NTSB to the Chairman of the CASB, dated January 22, 1988 (See Exhibit 38)

The Subcommittee believes the NTSB was grossly negligent and was not acting in the public's interest for taking such a position. A layman, after reviewing the Canadian reports, could determine that there were obvious flaws in the CASB investigation and conclusions. From the information collected by the Subcommittee, it appears that the NTSB was predisposed to not find fault with the content of the CASB draft report.

The United States Government owes a great deal to the 248 members of the U.S. Army who were returning from a peacekeeping mission in the Middle East who tragically gave their lives in the fatal crash. For the NTSB to "sit back" while the controversy over the results of the investigation were drawn out over a number of years was not fair to the victims or their families, nor in the best interest of the United States. The Subcommittee believes the NTSB should have been more aggressive during the investigation and should not have taken such a "hands off" approach after the CASB Majority Report was released.

As mentioned previously, this investigation was not intended to criticize the Canadian investigation. The Subcommittee believes that it would be remiss if it did not comment on the CASB investigation. The Subcommittee respects the sovereignty of Canada and understands the provisions in the ICAO treaty. Nonetheless, there comes a point at which politics and "turf battles" should be put aside for the best interests of the victims, their families and this country.

BACKGROUND ON THE MULTINATIONAL FORCE AND OBSERVERS (MFO)

The MFO was created on August 3, 1981 as a result of a protocol entered into between Egypt and Israel and witnessed by the United States. The Protocol established the MFO to replace the United Nations forces and observers that were established as a result of the 1979 Egyptian-Israeli Treaty of Peace (the result of the Camp David Accord). The United States agreed to participate in the MFO along with approximately 10 other countries. The MFO was established as a separate international organization which would not be affiliated with the United Nations.[2] The MFO is headed by the Director-General who is domiciled in Rome, Italy. The Director-General is an American who is nominated by the United States and agreed upon by Egypt and Israel. The MFO is funded by the United States, Egypt and Israel. The U.S. State Department oversees the entire MFO program.

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[2] U.S. Army Information Paper--Multinational Force and Observers. (See Exhibit 4)

The U.S. Army is the only branch of the United States military that participates in the MFO. The U.S. Army rotates different divisions of U.S. soldiers every six months to the Sinai. The U.S. soldiers are responsible for operating checkpoints, reconnaissance patrols, observation points and ensuring the freedom of navigation through the Strait of Tiran. They are also responsible for reporting violations of the Egyptian-Israeli Peace Treaty, and ensuring that the parties correct any violations.[3]

At the time of the Gander crash, approximately 95% of the Department of Defense international passenger flights were contracted out to commercial carriers under the responsibility of the Military Airlift Command (MAC) within the Department of the Air Force. Military aircraft was used for movement of cargo. During Fiscal Year 1985, Arrow Air charters accounted for $33,674,000.00 of the $422.7 million spent on Department of Defense charters.[4] Arrow Air's primary purpose was to move military personnel.

CANADIAN INVESTIGATION

Since the fatal plane crash occurred in Canadian territory, the investigation was conducted by the Canadian Aviation Safety Board (CASB) in accordance with the ICAO treaty. The United States participated as advisors to the Canadians. The majority members of the CASB issued their report, which was endorsed as the official report of the Canadian Government, approximately three years after the fatal crash. The dissenting members of the CASB issued a separate report expressing their dissatisfaction with the investigation and the conclusions in the Majority Report.

In keeping with standard procedure, the Aviation Group of Transport Canada (a Canadian Government agency comparable to the Federal Aviation Administration (FAA) in the United States) issued their own report after reviewing the majority and minority reports. The Aviation Group's report was highly critical of the Majority Report. As a result of the controversy, the Transport Minister of Canada requested that Justice Willard Estey, a former member of the Supreme Court of Canada, review the entire Gander investigation. Justice Estey issued his report in July 1989 in which he concluded there was evidence to support some of the majority's conclusions, but not the ultimate conclusion of the cause of the accident.

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[3] Id.

[4] U.S. Army Information Paper--DOD Use of Civil Aircraft for Movement of Passengers and Cargo. (See Exhibit 3)

However, Justice Estey believed that no further investigation of the Gander crash was warranted. A more detailed review of each report issued in Canada appears in the following pages.

MAJORITY REPORT

At the conclusion of the CASB investigation, five members of the CASB (the majority members) issued Aviation Occurrence Report No. 85-H50902, dated October 28, 1988. In the Majority Report, under the section entitled "Causes", the majority reported, "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."[5]

The majority members of the CASB published 32 separate findings that were part of the conclusions reached as a result of their investigation. The majority members did not find any evidence of an explosion or fire on board the plane prior to impact.

DISSENTING OPINION

On November 14, 1988, four members of the CASB issued their Dissenting Opinion to the report filed by the majority members. In the Dissenting Opinion Report, under the "Causes" section, the dissenting members concluded "an in-flight fire may have resulted from detonation of undetermined origin brought about catastrophic system failures."[6] The dissenting members issued several findings that included "ice contamination was not a factor in this accident"; and "a fire broke out on board while the aircraft was in flight; possibly due to a detonation in a cargo compartment."[7]

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[5] CASB Aviation Occurrence Report No. 85-H50902, Oct. 28, 1988, p. 95.

[6] CASB Dissenting Opinion Report No. 85-H50902, Nov. 14, 1988, p. 14.

[7] Id.

In addition, the dissenting members were not satisfied with the manner in which the Canadian investigation was conducted and the information that was made available to them. During their interviews with the Subcommittee the dissenting members claimed they were not allowed to go to the crash site; they did not know about witnesses' statements prior to the public inquiry; and when they formed a special committee to review the evidence of the crash, the committee was dissolved later by the Chairman of the CASB.

AVIATION GROUP REPORT

The Aviation Group of Transport Canada reviewed the majority and dissenting members reports and documents to ensure that the safety of the Canadian aviation system was addressed and to identify preventative methods that the CASB did not address.

After reviewing the majority report the Aviation Group determined that ". . . some of the assumptions are based on inaccurate data and some significant factors have not been given appropriate attention."[8] The Aviation Group evaluated the 32 findings of the Majority Report and concluded that 16 of the findings were statements of fact; 6 findings were considered to be substantiated and the remaining 10 findings could not be substantiated by the evidence and analysis contained in the report. Some of the findings that could not be substantiated were that "a thrust reverser could not have deployed, that the aircraft stalled, and that ice could have accreted on the aircraft while it was on the ground at Gander."[9] However, the Aviation Group recognized that ice on the wings could have been a possible cause.

The Aviation Group concluded that the exact cause of the crash could not be determined by the evidence available to them. They also concluded that the findings by the dissenting members were not supported by the evidence.

The Aviation Group was highly critical of the management of the investigation as well. Some of the major criticism's were that " . . . the Board has occasionally interchanged factual information with analysis and allowed unsubstantiated assumption to be repeated as conclusions. In addition, the report is written in such a way

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[8] Aviation Group Report of Transport Canada, Executive Summary, p. i.

[9] Id.

that assumptions are seen to imply factual information."[10] The Aviation Group further concluded that "The emphasis of the factual data almost totally on the icing theory suggests that there were other aspects of the occurrence which were allowed to go relatively untouched."[11] The Aviation Group believed, "the fascination with computer results is an indication of a mismanaged investigation; and "the data appears to have been gathered to prove a preconceived concept of why the accident occurred not to investigate and evaluate all the possibilities."[12]

JUSTICE ESTEY'S REPORT

Due to the controversy within Canada over the conclusions reached as a result of the Gander investigation, the Transport Minister of Canada requested on March 29, 1989 that Justice Estey review the Gander investigation to determine if any further review of the accident was necessary.

In July 1989, Justice Estey concluded his review of the Gander investigation and determined no further inquiry into the crash was warranted. Justice Estey concluded in his report that, "The testimony and material gathered by the Board does not show that ice contamination of the leading edge or upper surface of the wing was the cause of the accident. Furthermore, nothing in the material placed before the Board reveals the cause of the accident."[13] Justice Estey concluded that ice contamination was not a cause nor even a probable cause of the accident. He also concluded that "there is almost no evidence which supports any of the conclusions of the minority."[14]

SCOPE OF INVESTIGATION

The purpose of the Subcommittee's investigation was to examine the role of the U.S. Government concerning the Gander crash and address numerous allegations that have been made concerning the crash and the investigation of the crash. These include allegations that the

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[10] Id. at p. 44

[11] Id.

[12] Id.

[13] Report of Justice Willard Estey, former Justice of the Supreme Court of Canada, July 21, 1989, p. 34.

[14] Id. at p. 36.

crash was the result of a terrorist act, and that there was a conspiracy within the U.S. Government to cover up this fact.

The Subcommittee determined that, due to the lapse of time since the fatal crash and the absence of an investigative record by the U.S. Government, it would be impossible to determine the cause of the crash. In addition, such an undertaking would be outside the jurisdiction of the Subcommittee.

During the oversight investigation, the Subcommittee reviewed volumes of documents maintained by the U.S. agencies involved with the Gander investigation, and interviewed current and former employees of the U.S. Government who were directly involved with the Gander investigation.

In addition, the Subcommittee interviewed three of the CASB dissenting members, Canadian citizens, relatives of the victims in the crash, members of the U.S. Army who were with the 101st in the Sinai, and American aviation experts. The following pages address the role of the U.S. Government and the more significant allegations and the findings disclosed as a result of this investigation.

U.S. GOVERNMENT INVOLVEMENT

During the oversight investigation by the Subcommittee, documents and/or briefings were provided to the Subcommittee by the National Transportation Safety Board (NTSB), U.S. Army, Defense Intelligence Agency (DIA), Armed Forces Institute of Pathology (AFIP), Department of State, Federal Bureau of Investigation (FBI), and the Federal Aviation Administration (FAA).

NATIONAL TRANSPORTATION SAFETY BOARD

The NTSB was the lead U.S. agency for the investigation and participated as advisors to the Canadians. The NTSB was responsible for providing technical advisors from all the U.S. organizations that had an interest in the fatal crash (i.e. U.S. Army, the Federal Aviation Administration (FAA), McDonnell Douglas, Pratt & Whitney and Arrow Air).

Mr. George Seidlein was the NTSB accident investigator in charge of the U.S. team in Gander.

In interviews with the Subcommittee, Mr. Seidlein, who is now retired, explained he was responsible for coordinating all the representatives from the U.S. organizations to assist the CASB. Mr. Seidlein stated that his team participated, as advisors, with the CASB in the technical investigation of the crash. No one from the NTSB assisted the RCMP with their investigation. Mr. Seidlein added that the CASB did not ask his opinion on the cause of the crash nor was he in the position to offer his opinion. Mr. Seidlein emphasized during the various interviews with the Subcommittee that his role was limited to being an advisor and that he had to follow the laws and regulations of Canada.

According to Mr. Seidlein, he never saw the CASB draft report or the NTSB response to the report. Mr. Seidlein expressed the opinion that his analysis of the CASB draft report would not have made it through the NTSB because he did not agree with the icing theory.

The CASB draft report was reviewed by Ronald L. Schleede, Chief, Aviation Accident Division for the NTSB. Mr. Schleede was Mr. Seidlein's supervisor and was in Gander as the senior representative from the NTSB. In his interview with the Subcommittee, Mr. Schleede explained that he reviewed the CASB draft report in Canada and made some verbal comments and suggestions to the CASB.

Mr. Schleede also represented the NTSB at the public inquiry in Canada on April 8, 1986 concerning the fatal plane crash. Mr. Schleede explained during his Subcommittee interview that Mr. Seidlein did not appear at the Canadian public inquiry because he could be a "public relations problem" for the NTSB.

The NTSB deferred all questions concerning sabotage/terrorism to the Canadians. One of the primary concerns of the Subcommittee is that no one in the U.S. Government was able to provide the Subcommittee with detailed information on the RCMP investigation that determined terrorism was not involved with the fatal crash.

According to the NTSB, they did not have any documents pertaining to the fatal crash because under the ICAO treaty the Canadians maintained all the documents.

U.S. ARMY

The Army reported that its role in the events following the fatal crash was in the areas of recovery and identification of the remains of the deceased and assisting the victim's families. The Army did not get involved with the technical or criminal investigation of the accident. The Army relied on the expertise of the NTSB. Through the Office of the General Counsel, the Army provided the Subcommittee volumes of documents, including the autopsy reports from the AFIP, and arranged for numerous interviews of active duty personnel during this investigation.

Major General John S. Crosby, who was Assistant Deputy Chief of Staff for Personnel, U.S. Army, at the time of the crash, was the senior military official in Gander, and was in charge of the recovery of all the victims in the crash.

Approximately 45 U.S. Navy personnel stationed in Argentia (approximately 200 miles from Gander) assisted the Army for a brief period immediately after the crash. The search for the remains of the deceased was carried out by over 30 U.S. Army personnel under the command of General Crosby.

In order to provide assistance to the families of the victims, the U.S. Army's Casualty and Memorial Affairs Operations Center located in Alexandria, VA assumed responsibility for coordinating the support effort for the families. One aspect of the program involved appointing a Survival Assistance Officer to the families in order to assist them in obtaining benefits and services to which they were entitled.

In addition, the Army assigned Legal Assistance Officers to provide legal advice for the primary next of kin. In an interview with the Subcommittee, Major General Hugh Overholt, retired Judge Advocate General for the U.S. Army, explained that legal assistance was provided to the families to protect them from individuals who would try to take advantage of them for financial gain. The significant documents pertaining to the Army's role in the Gander investigation are included in the Exhibits section of this report.

ARMED FORCES INSTITUTE OF PATHOLOGY

The identification of the body remains was the responsibility of the Armed Forces Institute of Pathology (AFIP) in accordance with a Memorandum of Understanding (MOU) that was agreed to by the CASB, Department of Justice of the Province of Newfoundland, Royal Canadian Mounted Police (RCMP), NTSB and the Army.[15] As outlined in the MOU, the toxicology analysis was performed by the Canadians. Colonel Robert R. McMeekin, M.D., Director of the AFIP certified the identification of each individual on the plane. The AFIP identified 100% of the bodies on board the plane, and determined there was no evidence of an explosive device.[16]

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[15] Memorandum of Understanding, Dec. 14, 1985. (See Exhibit 8)

[16] U.S. Army Identification Paper. (See Exhibit 2)

In a letter dated June 21, 1988 from the AFIP addressed to the CASB, the AFIP stated, "There was no evidence of inflight explosion or fire. At autopsy, all bodies were radiographed and carefully examined for injuries compatible with blast or fragmentation associated with an explosive device. The radiographs and bodies were also examined specifically for trace evidence and/or identifiable portions of an explosive device. No characteristic injury patterns, trace evidence, or explosive device fragments were identified. An inflight fire would probably have resulted in at least a few bodies in demonstrable instantly fatal injuries in association with significantly elevated carboxyhemoglobin and/or prominent soot deposition on mucosal surfaces of the trachea, bronchi, and other airways. None of the 256 bodies examined had this combination of findings."[17]

DEFENSE INTELLIGENCE AGENCY

The Defense Intelligence Agency did not participate in the Gander investigation. DIA received copies of interviews pertaining to the fatal crash which were conducted by the FBI in the United States at the request of the RCMP. Colonel Thomas C. Rauter, former Branch Chief of the Office of Security, Counter-Intelligence Division, was responsible for maintaining liaison with the FBI in the areas of espionage, terrorism and defectors. Standard procedure was that Colonel Rauter would receive reports from the FBI and then he would disseminate the report to the proper section within DIA. In the Gander case Colonel Rauter said the report probably went to the Counter-Terrorism section. A former analyst in the Counter-Terrorism section could not recall the specific report, but thought it was probably destroyed since there was no evidence of terrorism.

FEDERAL AVIATION ADMINISTRATION

The Federal Aviation Administration assisted in the Gander investigation by participating in the maintenance review, systems review and engine teardown. At the time of the crash, Robert D. Cook, former Branch Manager of the Accident Coordination Branch, was the agencies's representative for the Gander investigation. Mr. Cook believed the FAA should have participated in various interviews during the investigation in which they were excluded. Mr. Cook said that he disseminated the CASB draft report to the FAA employees who participated in the investigation; compiled the responses; and drafted the FAA's letter of response to the Canadians.

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[17] Gormley, Colonel William T., M.D., and Wagner, Captain Glenn, D.O., Letter regarding the autopsies of the victims, dated June 21, 1988. (See Exhibit 14)

In the response to the CASB draft report, the FAA's South Florida Flight Standards District Office and Regional Staff concluded that the presence of ice accumulation during ground time was arguable and suspect. However, "since conclusive evidence of ice, or lack of ice, will never be available, we accept the possibility of its presence."[18]

Mr. Cook and William R. Hendricks, Director, Office of Accident Investigations for the FAA, both agreed, during their interview with the Subcommittee, the NTSB should have been more forceful which would have enhanced the investigation. The FAA did not receive any information during the investigation concerning sabotage/terrorism. At the request of the Subcommittee, the FAA provided various documents pertaining to the Gander accident. The significant documents are included in the Exhibits section of this report.

FEDERAL BUREAU OF INVESTIGATION

The Federal Bureau of Investigation (FBI) did not conduct a separate criminal investigation concerning the Gander crash. In a letter from John E. Collingwood, Inspector-in-Charge, Congressional Affairs Office for the FBI, addressed to Subcommittee Chairman Hughes, dated April 10, 1990, the FBI advised the Subcommittee that the Canadians did not allow the FBI to participate in the investigation.[19]

Immediately after the crash, the FBI dispatched a forensics team to Gander, however, the FBI team was not permitted by the Canadians to go to the crash site. On December 14, 1985, the FBI departed Gander after they notified FBI Headquarters "it was established that terrorism most probably was not involved in the crash and the decision was made to return the crash victims to the Armed Forces Institute of Pathology."[20] According to the FBI, the information that there was no evidence of terrorism was told to them by the Canadians; it was not determined by their own investigation.

The Subcommittee can not understand how the Canadians could determine so quickly that terrorism was not involved in the crash.

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[18] Berry, William M., Jr., FAA Memorandum regarding CASB Draft Aviation. (See Exhibit 21)

[19] Collingwood, John E., Letter to the Honorable William J. Hughes. (See Exhibit 28)

[20] FBI Teletype, December 1985. (Exhibit 27)

The wreckage of the plane may not have been scattered as if there was an explosion on board, but the Subcommittee has learned from previous investigations, that terrorists have more sophisticated methods of disabling a plane than through the use of an explosive device.

The FBI provided all their documents pertaining to the fatal plane crash to the Subcommittee. The significant documents are included in the Exhibits section of this report. Included with these documents is the report from the FBI's Identification Division pertaining to the identification of the victims.

STATE DEPARTMENT

The State Department's role in the Gander crash consisted of collecting information and performing their diplomatic duties. The State Department did not get involved with the investigation. The State Department provided classified and unclassified documents to the Subcommittee. The significant unclassified documents are included in the Exhibits section of this report.

The following pages contain the allegations of the fatal plane crash and the findings which are the result of the oversight investigation.

ALLEGATION: The U.S. Army wanted to cover-up what the Special Agent from the Criminal Investigation Division (CID) was carrying on board the flight that crashed in Gander. Part of the basis for this allegation was that the U.S. Army provided conflicting statements to the Canadian Government and the Director General of the MFO on what the CID agent was transporting on the plane.

FINDING

In a Memorandum, dated March 26, 1990, the U.S. Army Criminal Investigation Command reported to the Subcommittee that their records indicated that Special Agent Dirk Miller was carrying 66 grams of hashish as evidence that was seized from a soldier in the Sinai on December 2, 1985.[21] The evidence was not recovered at the crash site. In addition, Special Agent Miller was carrying a file containing unsubstantiated information about the battalion commander taking a personally owned weapon to the Sinai. This file was also destroyed.

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[21] Memorandum from the U.S. Army Criminal Investigation Command, March 26, 1990. (See Exhibit 17)

Special Agent Miller was assigned a .38 calibre pistol and 12 rounds of ammunition for use with his official duties in the Sinai. Special Agent Miller's pistol and ammunition were confiscated from him on December 11, 1985 by the Egyptian Air Security prior to his flight from the Sinai to Cairo. According to U.S. Army Major Ronald W. Carpenter, Jr., U.S. Army Liaison Officer for the MFO, he retained the ammunition but returned the pistol to Special Agent Miller in Cairo. The pistol was not recovered at the crash site. The ammunition was retained by Major Carpenter because of an agreement with the Egyptians that the MFO would not transport ammunition during the rotation through Cairo.

ALLEGATION: In an Arrow Air Memo, dated February 24, 1986, Michael Mendez, Director of Maintenance for Arrow Air, alleged that on December 13, 1985, George Seidlein said General Crosby wanted to immediately bulldoze the crash site to prevent pilferage.

FINDING

The Subcommittee interviewed George Seidlein, Robert Cook, the FAA representative at Gander, and General Crosby, who was in charge of the U.S. Army's recovery operation.

Mr. Cook stated he attended a meeting (date unknown) with General Crosby and three or four others (names unknown) regarding what to do with the crash site to prevent souvenir hunters. Mr. Cook said General Crosby mentioned bulldozing the crash site as an alternative. Mr. Cook stated General Crosby did not mention bulldozing at the beginning of the investigation.

Mr. George Seidlein explained that General Crosby never mentioned to him about bulldozing the site. Mr. Seidlein thought the subject of bulldozing the site came up later in the investigation when they were deciding what to do with the crash site at the conclusion of the investigation.

General Crosby stated he thought the subject of bulldozing the crash site was the idea of the Airport Manager at the Gander airport. General Crosby said he thought it was a good idea.

A review of the U.S. Army's documents disclosed that the Operation Control Center Duty Officer's Log, dated December 18, 1985, annotated the possibility of bulldozing the crash site by Canada became an issue.

From the interviews conducted, the Subcommittee determined that the discussion of bulldozing the site took place in the context of steps which might be taken after the investigation was completed.

The Subcommittee believes there is no evidence that the idea of bulldozing the crash site was intended to be immediately after the accident.

ALLEGATION: The FBI conducted an independent investigation which included a 200-page report that the FBI would not release under the Freedom of Information Act (FOIA).

FINDING

The FBI did not conduct an independent investigation regarding the Gander crash. After the crash, the FBI sent their legal attache (LEGAT) from Ottawa and forensic experts from FBI Headquarters to Gander. According to the FBI, the Canadians would not allow the FBI to participate in the investigation and prevented them from going to the crash site.

A review of the FBI documents disclosed the FBI's participation was limited to providing disaster identification services and conducting interviews in the United States for the RCMP. The "mysterious" 200-page report consists of worksheets and other documents prepared by the FBI's Latent Fingerprint Section Identification Division as a result of the identification process for the victims in the crash.

The interviews conducted by the FBI were requested by the RCMP in a letter dated December 31, 1985.[22] The RCMP requested the FBI to interview Captain Schoppaul, First Officer Bertelson and Flight Engineer Alonso, all employees of Arrow Air who flew the Cologne to Cairo leg of the trip. The FBI was asked to focus their questions on the condition of the aircraft, the maintenance of the aircraft, flight schedules and security of the aircraft on their trip. The RCMP did not ask the FBI to inquire about sabotage, terrorism or explosive devices. The FBI provided to the Subcommittee the memorandums of interviews they submitted to the RCMP.

The one puzzling area is that a former Arrow Air pilot , Stephen Saunders, claims he was interviewed at his home by FBI Special Agent Wilbur Scarborough. Mr. Saunders stated that after he was interviewed at his home, he escorted Agent Scarborough to the Miami Airport where he showed Scarborough a plane similar to the one that crashed. Mr. Saunders stated some of the questions asked by Scarborough included whether a person could survive in the belly

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[22] Letter from the Royal Canadian Mounted Police, Dec. 31, 1985. (See Exhibit 22)

of the plane, and what effects an explosion would have in certain areas of the plane. Mr. Saunders' wife confirmed her husband was interviewed by Agent Scarborough.

Agent Scarborough, who is now retired, denied he interviewed Saunders. Agent Scarborough stated he interviewed Captain Schoppaul. The FBI provided the memorandum of interview of the Schoppaul interview. They did not have any documents concerning an interview with Saunders.

ALLEGATION: The dissenting members of the CASB concluded that there was evidence to show that the Arrow Air plane experienced an on board fire and massive loss of power prior to impact. The dissenters believed the fire may have been associated with an in-flight detonation from an explosive or incendiary device that may have been the work of terrorists.

FINDING

In December 1985, the U.S. Embassy in Algiers informed the Secretary of State via telegram that on December 16, 1985, the U.S. Consul General in Oran received a telephone call in which the caller claimed responsibility for the fatal crash in Gander on behalf of the Islamic Jihad.[23]

In January 1986, the U.S. Embassy in Port Louis advised the Secretary of State via telegram that they had received a letter, dated January 17, 1986, in which a group claiming to be the "Sons of Zion" informed them that the fatal plane crash in Gander was a "cold blooded premeditated act which involved an expert sabotage of the aircraft a few hours before take-off, with the complicity of several Egyptian and Libyan mechanics and other Anti-U.S. and Anti-Israeli individuals."[24]

From the documents reviewed by the Subcommittee, there was no evidence of any investigation to follow up these allegations. All the government agencies deferred to the NTSB. The NTSB deferred the question of terrorism to the Canadians. The NTSB pointed out that they receive claims of responsibility by terrorist groups for every plane crash.

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[23] Department of State Incoming Telegram, Dec. 1985. (See Exhibit 33)

[24] Department of State Telegram, Jan. 1986. (See Exhibit 34)

ALLEGATION: It was alleged that duffle bags belonging to the members of the 101st were removed from the Arrow Air plane in Cairo in order to load six boxes onto the plane. The contents of these boxes were related to attempts to release the hostages in the Middle East. In addition, it was alleged that a blackout occurred while the plane was being loaded and a fight broke out among the baggage handlers which would have had an impact on the security of the plane.

FINDING

Prior to the 101st Airborne leaving the Sinai, all their personal duffle bags and unit equipment were subject to a customs inspection by U.S./Egyptian officials. According to Mark Brady, a former Military Policeman who participated in the customs inspection in the Sinai, a high percentage of the bags and unit equipment were randomly inspected. Mr. Brady stated there was definitely small arms ammunition (M16 and .45 calibre) in the boxes he checked. He said there was nothing unusual about the items he inspected, and there were no high explosives.

After the baggage and equipment passed customs, it was loaded and sealed on trucks and driven to Cairo by U.S. soldiers. In Cairo, the trucks were met by Major Carpenter and parked in the customs holding area. Major Carpenter, who was in Cairo the entire time the 101st Airborne was there, said the trucks were guarded by U.S. soldiers. Major Carpenter added that he was not aware of any blackouts or fights during the loading of the Arrow Air plane. He stated the plane was parked in the VIP landing area where planes of foreign dignitaries are parked when they arrive in Cairo. Major Carpenter said security at the airport was very tight. The movement of the MFO troops was top priority that involved negotiations and special arrangements with high ranking Egyptian officials with terrorism always a concern.

According to Major Carpenter, the items on the trucks consisted of duffle bags, aviator kits and unit equipment. The unit equipment included medical/dental records, night vision equipment, and other pieces of equipment that was assigned to the 101st.

Major Carpenter explained that he assumed ammunition was being carried on board the plane based upon comments made by the battalion commander LTC Marvin Jeffcoat. Major Carpenter stated that he and LTC Jeffcoat had a discussion about ammunition on board the plane after Special Agent Miller's gun and ammunition were confiscated from him. Major Carpenter said LTC Jeffcoat did not see ammunition on board the plane as an issue since the December

4 rotation carried ammunition.[25]

Major Carpenter explained the duffle bags were not removed from the plane in order for boxes to be placed on board. The 41 duffle bags were never loaded onto the plane. He thought the 41 duffle bags could not be loaded onto the plane because there was no more room. This was annotated on the cargo manifest of the plane dated December 9, 1985.[26] Major Carpenter thought this happened because the bags were loaded at night, there were no lights in the cargo compartment, there was an empty pallet in the cargo compartment that took up space, and that the Egyptian cargo handlers were not motivated to squeeze all the luggage into the cargo compartment like American baggage handlers.

ALLEGATION: There were explosive devices on the Arrow Air plane that crashed in Gander. A photograph of three mortar shells recovered at the crash site was sent to the Subcommittee by a family whose son died in the fatal plane crash.

FINDING

The mortar shells in the photograph were either 60mm or 81mm training devices that are used to simulate mortar fire. The exact size of the shells could not be determined from the photograph. The mortar shells are propelled by a 22mm sub-caliber cartridge. A review of U.S. Army records disclosed that 2,000 22mm sub-caliber cartridges were sent to the Sinai in July 1985 (the 101st Airborne was in the Sinai from June through December 1985). The U.S. Army's position was that the mortar shells should not have been on the plane. Speculation is that someone on the plane was taking the shells for souvenirs. According to the CASB majority report, the shells were inert and contained no explosives.

Major David L. Marks, Commander, U.S. Army Technical Detachment, located at the Naval Explosive Ordinance Disposal Technology Center, Indian Head, MD, analyzed the photograph at the request of the Subcommittee. Major Marks stated that it appeared from the photograph that the shells were not armed or expended because the end caps were attached to the shells. Major Marks stated standard procedure is to ship the shells and cartridges separately. When the shells are to be used for training, the procedure is to remove the end cap, screw in the cartridge, and then insert the shell into

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[25] Memorandum from Major Ronald W. Carpenter, Jr., U.S. Army, Dec. 16, 1985. (See Exhibit 10)

[26] Cargo Manifest for the Arrow Air Plane, dated Dec. 9, 1985. (See Exhibit 15)

the mortar tube. Major Marks explained the 22mm cartridge used in the shells is a smoke charge and not an explosive device. When the mortar shell is used with the 22mm cartridge, the 22mm cartridge propels the shell out of the mortar tube; the cartridge continues down range while the shell drops off; when the cartridge strikes the ground a yellow smoke charge is activated and a noise is created to simulate live mortar fire.

In an effort to get detailed information about the mortar shells and the RCMP investigation, the Subcommittee submitted a letter to the Embassy of Canada requesting specific information about the condition in which the shells were found, any live ammunition and spent casings found at the crash site, and detailed information about the scope of the RCMP investigation. The Embassy of Canada has not responded to the request by the Subcommittee.

ALLEGATION: There was an unknown quantity of money on board the plane that was found immediately after the crash and turned over to the U.S. Army. This money was allegedly ransom money to be used for the release of the U.S. hostages in the Middle East.

FINDING

The money on board the plane was the responsibility of the paymaster for the 101st Airborne. At the time of the crash, the paymaster had $118,457.42 in personal checks, U.S. Treasury checks,

U.S. currency and expense vouchers. The money, checks and vouchers were recovered and inventoried by the Canadians at the crash site and returned to Ft. Campbell, KY.[27]

ALLEGATION: A former member of the U.S. Army claimed that he was detailed from his Ranger Unit at Fort Benning, GA to the 101st Airborne in the Sinai in order to participate in a covert mission. The purpose of the mission was to train individuals from other countries on how to fire weapons. Some of the soldiers who participated in this covert mission were allegedly on the plane that crashed in Gander, and the U.S. Government wanted to conceal their identity during the investigation.

FINDING

The Subcommittee reviewed the military record of this soldier and interviewed him on a number of occasions. As a result, the Subcommittee determined there was no factual basis for his allegations. The U.S. Army stated everyone on board the Arrow Air

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[27] U.S. Army records concerning money recovered at crash site. (See Exhibit 16)

flight was assigned to or was a supporting element of the 101st.

CONCLUSION

At the beginning of this investigation there were numerous allegations, some of which included that the fatal plane crash in Gander was linked to an act of terrorism against the United States; that the crash was related to unsuccessful attempts to rescue the hostages in the Middle East; that the plane was sabotaged in retaliation for an arms deal during the Iran Contra affair; and that there were bodies in the six crates that were loaded on the plane in Cairo. The Subcommittee explored each of the allegations, no matter how bizarre, and gathered all the factual information available from the U.S. agencies involved with the Gander investigation, and other sources, in order to resolve these issues.

After evaluating and analyzing all the information obtained during the course of this investigation, the Subcommittee is dismayed and troubled about the failure of the U.S. Government to pursue an active and aggressive role in the investigation of the Gander disaster.

First, no one in the U.S. Government could provide the Subcommittee with any detailed information about investigations to determine if sabotage or terrorism played a role in the crash. The FBI departed Gander two days after the crash because the Canadians indicated they did not need the FBI's assistance and were told that there was no evidence of terrorism.

The Subcommittee believes that this was the first of many shortcomings in the manner in which the government of the United States responded to the Gander crash.

The United States had a strong interest in seeing that a thorough investigation was conducted, including an investigation of the possibility of terrorism as a cause of the crash.

It appears that the FBI agents sent to Gander the day of the crash waited in a Gander motel for whatever reports or conclusions Canadian authorities saw fit to share with them. After a mere 36 hours, they accepted a declaration that "terrorism was not involved" and returned home. From the information available, it does not appear that they were given any evidence in support of this conclusion.

Such a course of conduct on the part of the FBI is, in the view of the Subcommittee, unacceptable if not also unbelievable. It may be that more aggressive efforts by the FBI to assume a role in the investigation would have been unsuccessful. Regrettably, since no such efforts were made, we will never know if they would have been successful.

We note in this regard that this is not the first time the Subcommittee has had occasion to examine the role of the FBI in investigating potential terrorist acts against U.S. citizens outside our borders.

Shortly before undertaking this inquiry, the Subcommittee held a series of hearings on the role of the FBI and other agencies of the U.S. government in the investigation of the August, 1988, airplane crash in Pakistan that took the lives of the Pakistani President Zia, U.S. Ambassador Arnold Raphel, U.S. General Herbert Wassom, and 28 others.

In that case, it can be said that, to its credit, the FBI was very aggressive in seeking a proper role in the investigation, but was thwarted by other elements of the United States government, led by the Department of State.

In the case of the Gander crash, with the possible exception of the U.S. Army in the manner in which it insisted on and obtained a key role in the recovery and identification of the remains of its deceased soldiers, there were no U.S. government agencies who deserve high marks for effective representation of U.S. interests.

The NTSB was directly involved with the technical investigation but could not provide any information about sabotage/terrorism. This was despite the fact that the U.S. accredited representative had the right to have access to all the information collected by the CASB.

The NTSB deferred questions of terrorism to the RCMP. Since the NTSB was the lead U.S. agency, all the other U.S. agencies relied on the NTSB for gathering all the facts to the investigation.

Secondly, the Subcommittee is disappointed that the NTSB did not scrutinize the factual information in the Majority Report in the same manner as it was done in Canada. This raises the concern that the NTSB may have been reluctant to criticize another country and a member of the ICAO treaty.

The manner in which the NTSB utilized--and failed to utilize--the services of its chief investigator, George Seidlein, in the Gander investigation is instructive in this regard.

Mr. Seidlein was selected by the NTSB to lead the U.S. team which took part in the investigation. In this role, he was the point of contact for the United States for all aspects of the Canadian investigation. Nonetheless, he was excluded from participation in critical phases of the investigation.

First, he was pushed aside during the public inquiry phase of the Canadian investigation. Second, he was not involved in reviewing and offering comments on the final report of the Canadian investigation on behalf of the United States. In fact, upon being shown findings of the Canadian investigation by Subcommittee staff, Mr. Seidlein indicated that he was seeing them for the first time.

In both of these phases of the investigation--the public inquiry and the formal review of the Canadian report--Seidlein was replaced by his supervisor, Ronald L. Schleede, Chief of the Aviation Accident Division of the NTSB.

In an interview with the Subcommittee, Mr. Schleede indicated that he replaced Mr. Seidlein in the Canadian inquiry because Seidlein was not good at public relations.

We find this suggestion that public relations concerns might be given a higher priority than substantive matters to be very distressing. Our concern is increased by the knowledge that Mr. Seidlein was critical of the inclination of the CASB to conclude that the crash was caused by icing on the airframe of the DC-8.

When interviewed by Subcommittee staff, Mr. Seidlein indicated that he was not asked by NTSB to review the final report of the Canadian investigation. Mr. Seidlein offered the observation that, had he been asked to review the report, it is unlikely his views would have been accepted by the NTSB, since he did not agree with the CASB's conclusion that the crash was caused by icing on the airplane.

We cannot say with certainty that Mr. Seidlein was excluded from critical phases of the investigation because he did not agree with the direction the investigation was going. However, the fact that he did disagree with the icing theory makes it even more disturbing that the NTSB excluded its own point person from the investigation. It did so, according to testimony of the NTSB official who removed him and replaced him, because of his lack of finesse in matters of public relations.

Having done so, the NTSB then proceeded to give its uncritical approval of the CASB majority report, with no indication that it reviewed or considered the storm of controversy that the report generated within the CASB itself and within the aviation community in Canada and the United States.

The Subcommittee is disturbed that the NTSB "sat back and watched" while the Canadian Government spent four years arguing over the causes and findings in the Majority Report. Meanwhile, the families and relatives of the victims were relying on the U.S. Government to protect their interests in the investigation of the fatal crash.

It is the belief of the Subcommittee that the NTSB should have been more forceful in representing the United States interests in this investigation. Granted, the NTSB was working in a foreign country under an international treaty. However, as the Subcommittee has learned in this investigation and previous investigations, each one should be treated differently.

In this particular case, 248 American soldiers lost their lives at a time when terrorism against Americans around the world was widespread. In fact, from June 1985 through November 1985, there were 11 incidents of worldwide terrorism against Americans. The "Achille Lauro" hijacking occurred two months prior to the fatal crash. Therefore, the Subcommittee believes the U.S. Government should have been more assertive in knowing all the facts about the complete investigation as opposed to just the technical aspects of it.

Finally, the Subcommittee is concerned that the Canadians did not utilize all the resources and expertise of the U.S. Government to assist with the investigation. The Subcommittee does not understand how the Canadian Government could turn down the assistance from the U.S. Government (i.e. FBI investigative experts) when the Canadians were facing one of the world's largest aviation catastrophes at a time when terrorism was widespread around the world against Americans.

This is not a matter of second guessing the Canadian investigation, but a realization that when 248 members of the U.S. Army are killed the vast resources and expertise of the United States should have been actively pursuing the cause of the crash. The Subcommittee believes the expertise and resources of the FBI and the U.S. Government would have not only enhanced the investigation but more than likely would have eliminated a lot of the controversy. Instead, it appears the CASB was determined to prove that they had the expertise and resources to conduct their own investigation.

In the end, with all the controversy over the facts of the investigation, the actions and inactions of both the Canadians and U.S. authorities have elevated the concerns of the victim's families concerning the competency of the investigation.

The Subcommittee believes the failure by the Canadians to accept the assistance from the FBI, and the reluctance by the NTSB to be more aggressive with the Canadians during the investigation and after the Majority Report was issued, have left questions that will always remain unanswered.

RECOMMENDATIONS

1. The Departments of Justice and State, and other agencies of the Executive Branch as appropriate, should review our treaty and other international agreements and protocols for consistency with policy reflected in the Anti-terrorism provisions of the United States Code which were enacted in 1986. (18 U.S.C. 2331--Extraterritorial Jurisdiction over Terrorist Acts Abroad against United States Nationals).

By way of explanation for their failure to take a more active role in the investigation of the Gander crash, agencies of the United States government stated that their role was severely limited by the terms of the International Civil Aviation Organization (ICAO) treaty.

The Subcommittee believes that many of the restrictions on U.S. participation in the Gander investigation were self-imposed. Nonetheless, we do believe that provisions of the ICAO and other international agreements should be reviewed to determine any inconsistencies with the policy of the United States as reflected in 18 U.S.C. 2331.

That statute, enacted after the Gander crash and therefore not implicated in that investigation, extends United States criminal jurisdiction over terrorist killings of United States nationals to all such killings, regardless of whether the crime occurred in the United States or abroad.

To the extent existing international agreements prohibit or impede the FBI or other U.S. law enforcement agencies from investigating incidents of possible violations of the "long arm" statute, they should be reviewed for potential renegotiation, and revision.

2. The Departments of Justice and State, and other affected U.S. agencies, should develop procedures and memoranda of understanding relating to the investigation of possible terrorist acts abroad against U.S. citizens and U.S. interests. These agreements should provide mechanisms for problem identification, referral to the appropriate level of government for attention, and resolution.

APPENDIX 48.—ADDITIONAL RECOMMENDATIONS GROWING OUT OF THE INVESTIGATION OF THE SUBCOMMITTEE ON CRIME INTO THE GANDER AIR CRASH

ADDITIONAL RECOMMENDATIONS BY THE SUBCOMMITTEE ON CRIME

1. IN JUNE 1990 THE COMMITTEE SENT A REQUEST TO THE CANADIAN EMBASSY REQUESTING SPECIFIC INFORMATION ABOUT THE RCMP INVESTIGATION INTO POSSIBLE TERRORIST OR OTHER CRIMINAL INVOLVEMENT IN THE GANDER CRASH.

WE RECOMMEND THAT, IN THE 102ND CONGRESS, THIS COMMITTEE CONTINUE TO PURSUE THIS AVENUE OF ADDITIONAL INFORMATION.

INASMUCH AS IT APPEARS THAT INFORMATION DEVELOPED BY THE RCMP CONCERNING POSSIBLE CRIMINAL ORIGINS OF THE GANDER DISASTER HAS NOT BEEN REVIEWED BY U.S. LAW ENFORCEMENT AGENCIES, OUR COMMITTEE SHOULD REQUEST SUCH A REVIEW BY APPROPRIATE LAW ENFORCEMENT AND INTELLIGENCE AGENCIES OF THE UNITED STATES.

2. DUE TO PREOCCUPATION WITH ICING ON THE AIRFRAME AS THE CAUSE OF THE CRASH, INADEQUATE ANALYSIS HAS TAKEN PLACE OF OTHER POSSIBLE CAUSES OF THE CRASH. THIS IS PARTICULARLY TRUE OF MECHANICAL MALFUNCTION, SYSTEMS FAILURE, AND HUMAN ERROR AS POSSIBLE CAUSES.

WE RECOMMEND THAT THIS COMMITTEE FOCUS PARTICULAR ATTENTION ON ADDITIONAL ANALYSIS IN THESE AREAS, AND TO SECURE ADDITIONAL TECHNICAL EXPERTISE (FROM GOVERNMENT AGENCIES WITH EXPERTISE AND FROM INDEPENDENT EXPERTS) IN CARRYING OUR THIS ANALYSIS.

3. WE RECOMMEND THE ATTORNEY GENERAL REVIEW THE HISTORY OF BOTH GANDER AND THE PAKISTANI AIR DISASTER CLAIMING THE LIVES OF OUR AMBASSADOR ARNOLD RAFAEL FOR NEW SAFEGUARDS TO INSURE THAT THERE IS HIGH LEVEL REVIEW AND FULL COORDINATION AT THE EXECUTIVE LEVEL FOR ANY FUTURE EXTRATERRITORIAL DISASTERS OF A POTENTIAL TERRORIST CAUSE.

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