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**PART FOUR**

**AIRCRAFT INVESTIGATION  
PROCESS AND ANALYSIS**

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# 10

# TECHNICAL INVESTIGATION

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## The Aircraft and Its Systems

### Conduct of the Investigation

This chapter is based on reports prepared for the Commission by Canadian Aviation Safety Board (CASB) investigators, by interested-party participants, and, where indicated, by other investigators working independently. It also draws on the evidence given at the Commission hearings.

Upon receipt of notification of the Air Ontario F-28 crash at Dryden, the director of investigations of CASB, following the normal procedures for major aircraft accidents, mobilized the pre-designated investigation response team (Go-Team). The Go-Team comprised the following: the investigator in charge, a head office coordinator, a deputy investigator in charge, an administration officer, a regional coordinator, and 12 group chairpersons. The groups were: aircraft powerplants; aircraft structures; aircraft systems; flight data recorder and cockpit voice recorder; human factors and survivability; operations; photo and video; public affairs; records and documents; site security and survey; weather/air traffic control and airports; and witnesses. A special performance subgroup, formed shortly after the accident, worked with the operations group. Ten additional CASB investigators worked within the group system.

Arrangements for accommodation, expenses, and travel were completed by CASB administration staff while the investigators carried out preparatory duties for their areas of responsibility. A briefing held in the late afternoon and evening of March 10, 1989, brought everyone up to date on the known facts surrounding the accident and ensured that the investigators were prepared. Most of the team members departed Ottawa airport early the next morning on a de Havilland Dash-8 operated by Transport Canada, arriving at Dryden at approximately 11 a.m. local time. The balance of the team travelled in a Beech King Air, also operated by Transport Canada, and on commercial airlines. All investigators were in Dryden by the evening of March 11, 1989. The investigation headquarters were set up in a Ministry of Natural Resources building on Dryden Municipal Airport property.

The investigation was conducted in accordance with established procedures, applicable legislation, and regulations in effect at the time:

- *The Canadian Aviation Safety Board Act and Regulations, R.S.C. 1985, c-12*
- CASB's Manual of Investigation Operations
- The International Civil Aviation Organization (ICAO) Manual of Aircraft Accident Investigation
- Annex 13 to the Convention on International Civil Aviation (*International Standards and Recommended Practices, Air Accident Investigation*)

Observers representing parties with direct interest in the accident assisted the CASB investigators in appropriate areas of investigation and made their own observations in all phases of the field investigation. There were observers from Air Ontario, Transport Canada, the Canadian Air Line Pilots Association (CALPA), the Canadian Union of Public Employees (CUPE, representing flight attendants), Fokker Aircraft, Rolls-Royce (manufacturer of the aircraft's engines), and insurance companies. An aircraft-accident investigator from the Department of National Defence assisted in the investigation as part of his own training.

Pursuant to Order in Council P.C. 1989-532, passed on March 29, 1989, a public inquiry was ordered, and the investigation of this accident was turned over to this Commission of Inquiry. The responsibility of CASB in this investigation was terminated. At my request, the CASB team of investigators already involved in the investigation of the accident, including the investigator in charge, Mr Joseph Jackson, and three aviation technical experts, Messrs David Rohrer, David Adams, and Reginald Lanthier, were seconded to my Commission and thereafter reported directly to me. Representatives from interested parties having expertise in areas of interest to the CASB investigation team were assigned to work as full participants with particular CASB groups. As an example, CALPA provided the operations group with representatives offering expertise as pilots and performance engineers, and Air Ontario provided the aircraft structures group with those knowledgeable about the F-28 aircraft. In some instances, these individuals had initially served as observers on the CASB investigation teams. These participants were given access to all investigation information gathered prior to their having joined the investigation and had more investigative responsibility than that enjoyed by the observers. The participants were of great value to the investigation and were able to offer information of a highly specific nature in relation to their organizations.

At the end of the active investigation phase, the participants helped prepare their group's factual report. Each participant either signed his or her group's report as an indication of agreement with its contents or provided a written explanation of why he or she could not agree. The few differences of view that arose were resolved before the final

investigative group reports were submitted to this Commission. Various group chairpersons thereafter appeared on the witness stand at the Commission hearings and were questioned on the contents of their reports.

## **Initial Investigative Activity and Observations**

Members of the CASB investigation team arrived at the accident site at approximately noon on March 11, 1989. At that time, members of the Ontario Provincial Police (OPP) were controlling access to the site, and fire-fighters had extinguished the fire. In order to ensure that evidence was not lost, none of the bodies and no part of the wreckage, other than as necessary during the rescue and fire-fighting operations, had been moved. CASB photographers photographed and videotaped the entire accident scene, and other CASB investigators made a cursory inspection of the area. Over the next days the OPP removed bodies and belongings.

An OPP district search and rescue team, together with CASB personnel, searched the area from the end of runway 29 to the crash site out to 100 m on either side of the wreckage trail. The locations of all the debris from the aircraft were subsequently plotted on a diagram, with information obtained from surveying results, ground plots, and photographs taken from the air. The accuracy of the survey is estimated to be within 10 cm in horizontal and vertical positioning with reference to the elevation of the Dryden airport. Before being removed, each piece of wreckage was photographed with a 35 mm camera.

The site security and survey group determined that the aircraft first contacted a single tree 127 m off the end of runway 29, 3° to the left of the runway centre line. The treetop was broken off at an elevation of 413.1 m above sea level (asl); the west end of the runway is 413 m asl. The aircraft struck 18 more trees in the next 600 m, all at an elevation of 413 m asl, plus or minus 1.5 m. The aircraft then contacted a more heavily wooded area at the top of a knoll and started to descend. It struck the ground and slid about 80 m before coming to rest. The knoll elevation was 404 m asl and sloped downwards to 390 m asl, where the aircraft came to rest.

Vertical colour and infrared photography and subsequent evaluation using photogrammetric techniques established the exact position and height of the cut-off trees. It is estimated that this technique registered the tree heights within a standard deviation of 10 cm.

The first piece of wreckage located on the wreckage trail was the broken red lens cap from the rotating beacon on the lower fuselage of the aircraft. Lens pieces were found in the vicinity of the first tree strike. The left wing tip, the main landing-gear doors, and pieces of the radome were found in the heavily wooded area on the knoll where the aircraft



started to break up from striking the trees. As the aircraft entered the heavily wooded area, the wings were relatively level; however, as it travelled through the trees, it rolled some 10 to 20° to the left. Most of the left wing broke away in pieces before the fuselage struck the ground. The wreckage along the trail consisted primarily of parts of the left wing, the main landing-gear doors, and the underside of the fuselage.

The main wreckage came to rest upright and consisted of three relatively intact major pieces, joined on the left side and in the form of a U, with the tail and nose sections pointing backwards, towards the airport. There were two large breaks in the fuselage, one just aft of the main passenger door and one through the fuselage at approximately seat row 12. The centre fuselage section came to rest approximately perpendicular to the flight path, the tail section was oriented about 50° off the centre line of the fuselage, and the cockpit was about 90° to the fuselage.

Fire broke out coincident with the rupturing of the left-wing fuel tank, approximately 50 m beyond where the aircraft entered the heavily wooded area. The fire along the wreckage trail superficially burned the trees but was not sustained after the sprayed fuel had burned. After the aircraft came to rest, the fire continued to burn until it was extinguished by fire-fighters, about two hours after the crash. The cockpit and fuselage aft to the rear pressure bulkhead were almost totally destroyed by fire. The empennage (tail section) and engines were lightly sooted and relatively unburned. There was no evidence that the aircraft was on fire prior to the main tree strikes.

Following documentation of the wreckage *in situ* and subsequent on-scene examination, all wreckage that could be found was either locked in trunks/crates or guarded by security personnel, before being moved by air, truck, and rail to the CASB engineering laboratory in Ottawa. Detailed examination of all pieces of the wreckage was then carried out by CASB investigators as well as by others under their supervision. After the snow had melted at the accident site, another search was conducted. Further pieces of wreckage were found; these too were documented, sent to the laboratory in Ottawa, and examined.

Reconstruction and examination of the wreckage and of the breakup patterns showed that all aircraft damage was consistent with collision with trees or the ground.

The aircraft flight path and wreckage location were pictorially reconstructed, and the results are reproduced in the report of the aircraft structures and the site security and survey groups. (This detailed report, which graphically describes the actual flight path and resulting crash, is included in its entirety as technical appendix 1 to my Report.)

## Engines

Aircraft C-FONF was equipped with two Rolls-Royce Spey RB 183-2 Mk555-15 jet engines, one attached to each side of the rear fuselage. When viewed from the rear, the engine on the left side is designated number 1 and that on the right side is designated number 2. The engines provide thrust; power to drive accessories connected to the engines; and hot air from the engine compressor for, among other things, air-conditioning, pressurization, and airframe anti-icing.

On-site examination of the wreckage revealed that the engines were still securely mounted to the aircraft and had suffered minimal damage. The left engine was damaged as follows: the engine was still cowled, but the bottom of the cowling was impact damaged; the hinged portion of the cowling was severely damaged; the gearbox was fractured; the engine nose cowl and tailpipe were dented upwards and the cowl was forced against the compressor; and all components from the left engine appeared to be contained within the engine cowlings. The right engine was found completely cowled and had been subjected to only minor impact damage. The low pressure (LP) compressor was free to rotate and was still coupled to the LP turbine, and the LP compressor blades showed damage from foreign objects.

To detach the engines from the aircraft, the engine pylons (stubwings) were cut from the aircraft structure with the engines still attached. The units were then shipped in a sealed trailer to the engineering laboratory of the Canadian Aviation Safety Board in Ottawa. The engines were subsequently shipped to the Rolls-Royce (Canada) facility in Montreal for disassembly and examination under the supervision of CASB investigator William Taylor. Following the examinations at the Rolls-Royce (Canada) facility, all components from the stubwings and engines were shipped back to the CASB engineering laboratory for further study and analysis both by CASB investigators and by an independent engine-management consultant retained by this Commission, Mr Peter Clay.

### Number 1 (Left) Engine

The number 1 (left) engine (serial number 9130) was generally intact, although the lower and aft cowling panels were torn and partially burned. The lower portion of the compressor's intermediate case was split adjacent to the rear flange, and the gearbox case was broken. The accessory units were externally damaged, with most of them separated at their mounting flanges. The engine power controls were broken and twisted. The emergency fuel shutoff mechanism had been shifted to the off position by the breakup, and the low-pressure shaft failure system had not been actuated. This was demonstrated by an intact shear pin in

the cable quadrant on the side of the engine. If the low-pressure shaft disconnects from the turbine while the engine is running, the failure system causes a cable to actuate the emergency fuel shutoff, thus shutting down the engine to prevent further damage.

The engine anti-ice valves were found in the closed position. When selected ON (open), and there is both electrical power and air pressure available, these valves open – and they are held open – by the electrical power and the air pressure. With failure of either electrical power or air pressure, the valves move to the closed position. The internal area of the engine anti-ice ducting was examined for ingested vegetation. Small amounts of vegetation were found, but it could not be established if the vegetation entered via the engine compressor, which would indicate that the anti-ice was on, through breaks in the structure, or through normal air exit points. An examination and a basic electrical test of the anti-ice shutoff valves showed that the valves were serviceable. Equipment for a full functional check was not readily available; however, there was no reason to suspect that the valves would not operate as required. The anti-ice gauge-pressure transmitter was serviceable.

The fuel spray nozzles were heavily sooted but were not damaged. Testing of the nozzles showed some streakiness during low-pressure flow, but, except for a marginally low flow rate on several nozzles, the nozzle set was serviceable under combined flow conditions, as is the case at high engine-power settings. There was much discussion about the serviceability of the fuel nozzles because the Rolls-Royce test data showed that most or all of the nozzles tested out of limits. In the opinion of the powerplants group's chairman, Mr Joseph Bajada, there was nothing in the reports regarding the nozzles or other fuel control components to alarm him or indicate any inability of the fuel delivery systems.

In an attempt to establish the relative position of the torque shaft of the compressor bleed valve at the time vegetation and other foreign material was passing through the engine, investigators examined the debris pattern on the torque shaft. No identifiable pattern was found. The position of the torque shaft would indicate the position of the bleed valve, which in turn would give an indication of engine power. The valve is closed when the engine operates at high power.

The LP compressor was damaged by debris: five first-stage blades (one near the root) and one second-stage blade were broken. Other blades in the compressor were gouged and bent. All the breaks were the result of overload at impact. Some blades in the high pressure (HP) compressor showed minor damage in the form of nicks, rubs, and minor bends. The turbine sections were in generally good condition, but there were extensive metal deposits throughout the entire HP and LP turbines and, especially, on the HP nozzle guide vanes.

All bearings were in good condition, with no evidence of a distress or other lubrication problem. The oil tank was ruptured; no oil sample was available, but the filters appeared clean on visual inspection. The magnetic plugs were clean.

### **Number 2 (Right) Engine**

There was little external damage to the number 2 right engine (serial number 9187). There was some post-crash fire damage to the pylon, but the engine was not affected.

The fuel HP shutoff valve arm was at mid-travel, and the LP shaft failure system had not been actuated. The power lever linkage to the fuel regulator unit was found at the MAX position. Normally, this would indicate that the engine had been selected to full power; however, the linkage could have been moved to MAX as a result of the breaking up of the linkage during the crash.

The observation and conclusions about the engine anti-ice valves for the left engine apply to the right-engine valves, except that the gauge-pressure transmitter, although functioning acceptably, leaked a small amount.

Functional tests of all fuel system components were performed, with the results much the same as for the left engine. A fuel sample was obtained from the engine fuel lines. The fuel sample was straw coloured and contained no visible free water or suspended matter. The sample did contain traces of fine black particles and several other small pieces of particulate matter; National Research Council Canada (NRC) concluded that the amount was not excessive. The simulated distillation characteristics of the sample indicated a mixture of fuel types.

Examination of the bleed-valve torque shaft for fan duct debris showed that, when ingested vegetation collected on the shaft, the valve was in the bleed-valve-closed position. The bleed valve is closed when the engine is operating at high power.

The T6 thermocouples, which measure turbine gas temperature, were checked for continuity. One was internally shorted, but it was not determined whether the short was in the controlling or the indicating section; either system will continue to function acceptably with one probe unserviceable.

The adjustment of the rod that actuates the switch to control the selection of seventh- or twelfth-stage air was found to be incorrect, with the clearance being less than specified. The function of this switch is to match bleed-air output to the airframe pneumatic system requirements. Incorrect adjustment would have had no effect on engine operation.

The interior of the right engine showed a greater accumulation of tree debris, in finely chopped form, than was found in the left engine. In the fan duct there was vegetation packed in the exhaust collector's support

struts and at flanges, and there was a collection of charred vegetation around the inlet areas of the burner cans.

The LP compressor had one broken blade, broken in overload, with others moderately gouged and bent. The overall condition was good relative to the amount of debris ingested. The HP compressor suffered light damage. A heavy coating of soot appeared throughout much of the engine, especially in the HP compressor area. A sample of the soot was analysed by NRC's chemistry division, and the soot was found to be organic material related to tree fragments and other objects ingested during the crash. The turbines were also sooted, and there was metal spatter throughout the engine to the number 2 LP turbine. The metal deposits were not as heavy as in the left engine.

The oil tank had ruptured, and only a small oil sample was recovered for analysis. From visual inspection, all bearings and filters were in good condition and there was no indication of a lubrication problem. The magnetic plugs were clean.

### **Engine Accessories**

The engine accessories from both engines, including the constant speed drives, were delivered to the appropriate manufacturer's facilities and were functionally tested under the supervision of CASB investigators. Accessories that were damaged and could not be tested were disassembled and examined. No discrepancies that could adversely affect engine operation were found in the components tested and examined.

The airflow control unit and the fuel flow regulator of the right engine were bench tested and found to be slightly out of specified limits on some points. The airflow control unit controls the position of the compressor inlet guide vanes, and at takeoff power the guide vanes are in the full open position. Both the engine and the aircraft manufacturers commented that the out-of-limits condition existed at a point where the inlet guide vanes would already be fully open and, therefore, would have no effect on engine power at takeoff. At takeoff power, the fuel flow regulator condition would result in a slight thrust increase above normal.

### **Oil Analysis**

The oil sample recovered from the oil filter housing of the right engine was analysed by National Research Council Canada (NRC). The analysis showed the oil to be typical of synthetic ester-type aviation turbine oil. Approximately 75 mg of particulate material was filtered from the 75 mL sample. The material was identified as mostly silicious matter plus a few fibres and bits of vegetation. The sample did not include any other type of contamination, and there was no indication that the oil had been subjected to undue oxidation.

### **Fuel Analysis**

Fuel samples were collected from the fuel delivery vehicles in Dryden (Jet B) and Thunder Bay (Jet A), and a small sample was recovered from a fuel line on the right engine. The samples were analysed at the NRC.

The Jet B and Jet A samples were clear, water white, and contained no visible free water, suspended matter, or sediment. The Jet B sample contained 0.13 and the Jet A sample 0.31 mg/L of particulate matter; the maximum allowable particulate matter at time of delivery to an aircraft is 0.44 mg/L. Both samples met all the specification requirements for which they were analysed, including the distillation characteristics.

### **Metal Spatter Analysis and Engine Power**

Samples of the metal spatter deposited on the turbine blades of each engine were collected. Dr Kenneth Pickwick, CASB's chief of physical analysis, examined the samples at the CASB laboratory in Ottawa, using a scanning electron microscope and subjecting the samples to energy-dispersive X-ray analysis. Dr Pickwick has a doctorate in metallurgy from the University of Manchester. He served two years as a postdoctoral fellow in the NRC's applied chemistry division before joining CASB.

CASB's physical analysis section is charged with two general areas of concern: fractographic analysis, the examination of fracture surfaces with a view to determining modes of failure and causes of failure, for which electron optic machines are used; and the determination of the chemical compositions of materials, for which a full range of X-ray spectrometric equipment is used. The spatter material from the blades was found to be the same aluminum alloy used in the LP compressor blades.

It has been the experience of the manufacturer, Rolls-Royce, that extensive diffusion within the limited time available during engine failure from ground contact can occur only if the turbine's operating temperatures are sufficient to sustain the aluminum-based component of the spatter in the molten state. The blade material has solidus and liquidus temperatures of 549 and 638°C, respectively. Thus, over an operating range of 550 to 640°C, some proportion of liquid aluminum would be present in the spattered deposits.

During the developmental stage of this engine type, the manufacturer conducted thermal-indicator paint studies of the temperature distribution in various locations of the turbine assembly of the engine. The paint used is colour sensitive to temperature and duration at temperature. These studies indicated that the temperature of the LP2 turbine, especially on the midspan range of the turbine blades, approached and exceeded the range of 550 to 640°C for all engine operating levels above cruise power. The temperatures existing in the LP turbine areas of both engines during the failure sequence were sufficient to allow aluminum

diffusion into the blade surfaces (that is, they were in the 550–640°C range). Accordingly, it can be concluded that both engines were operating at or above the cruise power range at the time of failure of the LP compressor blades.

During Dr Pickwick's testimony it was pointed out that there were some variables which the investigators did not take into account in their temperature and power determinations:

- 1 All 20 burners on these engines were out of specification.
- 2 The combined flow rates from 16 of the 20 engine fuel nozzles were out of specification.
- 3 Two of the engine burners were leaking at 1500 pounds per square inch (psi).
- 4 Some of the fuel nozzles exhibited very streaky spray patterns.
- 5 The fuel nozzles from the burners were very heavily sooted.
- 6 Jet B fuel may burn at a different temperature from Jet A fuel. (The fuel in C-FONF was a mixture of Jet A and Jet B, and the manufacturer used Jet A during the temperature tests.)
- 7 The fuel/air mixture of the engines is affected by the sooted fuel nozzles.
- 8 An engine malfunction such as a compressor stall may have affected engine power.

Dr Pickwick agreed in testimony that, in determining the power level of the engines, he had assumed the engines were functioning properly just prior to the time that the metal diffusion occurred. His conclusions were based on the premise that none of the variables mentioned above would affect the evaluation of the engines. At the end of his testimony, Dr Pickwick agreed that, to the best of his knowledge, the temperatures were consistent with cruise power or better at the time of the incident.

Mr Clay commented in his testimony on the variables mentioned above. He was contracted by the Commission to participate in this investigation as an independent engine analyst who would provide another opinion about the engines of C-FONF. He is a fellow of the Institution of Mechanical Engineers, a fellow of the Institution of Production Engineers, and a member of the Royal Aeronautical Society; while he resided in Quebec, he was a member of the Corporation of Professional Engineers of that province. Mr Clay started working at Rolls-Royce, United Kingdom, in 1943, at the same time studying at the College of Technology in Darby. Graduating in 1949, he continued his postgraduate studies for about another 10 years while working with Rolls-Royce, where he trained in all aspects of engine repair and overhaul. Throughout his career with Rolls-Royce, Mr Clay specialized in engine design, development, manufacturing, and product support. At

the time of his retirement from Rolls-Royce in 1982, Mr Clay was working in Montreal as the director of product support responsible for Rolls-Royce products in service in Canada, the United States, Central America, and Venezuela. He has been involved as an investigator in other aircraft accidents where Rolls-Royce engines powered the aircraft and where engine teardowns were required.

Mr Clay provided insight into the variables mentioned above. Variables 1, 2, 5, and 7 pertain to the nozzles. Mr Clay's evidence was that the noted variations in the nozzles would have no effect on engine operation. The fuel control system is flow sensitive, and the fuel flow regulator ensures that the proper flow is achieved for a set (requested) engine condition by varying the fuel pressure to the nozzles. Mr Clay also stated that he "wouldn't expect, on flows and angles, any burners [nozzles] taken from service to differ to these" (Transcript, vol. 62, p. 15). In response to a question regarding the nozzles, Mr Clay stated:

- A. ...The condition of these fuel nozzles was such that it would not have had any effect on combustion. The fact that they are outside the new or fully overhauled limits, those limits are established to ensure that, with the normal deterioration and sooting which occurs throughout the life of the engine, they will still be serviceable, not new, but they will still be serviceable at the end of that life.

(Transcript, vol. 62, p. 63)

Regarding variable 3, the normal combined flow-nozzle operating pressure is 500 psi. Mr Clay placed no significance on the fact that two of the nozzles leaked slightly, at 1500 psi.

Variable 4 pertains to the nozzles and the primary fuel flow. The primary flow is active alone (that is, not in conjunction with secondary flow) only during engine startup to approximately 20 per cent  $N_2$ . Above 20 per cent  $N_2$ , there is both primary and secondary fuel flow. In Mr Clay's view, there was no significance in the fact that the flow was streaky.

Regarding variable 6, Mr Clay could not even conceive that the type of fuel being burned in the engine would make any difference, even going outside the range of normal fuels. There is virtually no difference in calorific value among fuels variously called Jet A, Jet B, JP1, JP4, Avtur, or Avtag.

In a letter dated December 1989, the powerplants chairman, Mr Bajada, requested information from Rolls-Royce regarding compressor stalls. Among several questions, he asked whether, during compressor stall or air disruption as may have been encountered while the aircraft was going through the trees, the LP2 blade temperature rises. Rolls-Royce replied:



During compressor stall or air disruption a rise in turbine gas temperature can occur. The effect of this on the L.P.2 turbine blades, however, is not immediate and depends on the duration of the temperature increase. Small increases in gas temperature over a few seconds do not necessarily result in an increase in L.P.2 blade temperature. If the increase in gas temperature is maintained, this will, of course, produce an increase in the temperature of the L.P.2 blades.

(Exhibit 452, appendix Q)

Mr Bajada also asked Rolls-Royce whether, in the event of compressor stall or air disruption, the airflow within the engine is sufficient to carry the aluminum material to diffusion on the LP2 blades. Rolls-Royce responded:

During a compressor stall condition air continues to flow through the engine and would therefore be capable of carrying pieces of aluminium debris to the L.P.2 blades.

A compressor stall we define as an unstable airflow in some of the stages.

(Ibid.)

### **Engine Assessment by Rolls-Royce**

The engines were disassembled and examined, under the control of CASB, at the Rolls-Royce (Canada) facility during the period April 24–28, 1989. Rolls-Royce engine experts personally provided technical assistance as required. A report was compiled by Rolls-Royce to record the condition of both engines at disassembly. The conclusions drawn in the report are as follows:

#### **2.0 CONCLUSIONS**

- 2.1 Examination of Spey Mark 555-15 Engine Numbers 9130 and 9187 at Rolls-Royce (Canada) Ltd, revealed no evidence of a pre-impact mechanical failure or malfunction.
- 2.2 Examination and testing of accessory units from both engines revealed no evidence of any malfunction or mechanical failure which could have affected engine operation.

(Exhibit 504, p. 2)

### **Engine Assessment by Mr Peter Clay**

Mr Peter Clay, the independent engine consultant, visited the CASB engineering laboratory, where he viewed the disassembled engines and related data and talked to CASB staff. Drawing on his observations and knowledge, he came to the following conclusions, which are taken from both his testimony and his report for the Commission (Exhibit 466).

- 1 There was no evidence of any failure or unserviceability being present prior to initial ingestion/impact.
- 2 All damage observed was consequent upon foreign-object ingestion and tree and ground impact.
- 3 The low-pressure compressor damage resulted from ingestion and impact of and with trees, aircraft material, and the ground.
- 4 There was no evidence to suggest any impediment to achievement of the full power range of the engines. In fact, the evidence supports the fact that the engines were at high power beyond the points of debris ingestion and through to major external impact.
- 5 The anti-icing systems on both engines were operating beyond the point of initial foliage ingestion. Since the valving was fully operational on post-accident bench test, it is correct to conclude the system was operating throughout.
- 6 The material temperatures in the later stages of the high-pressure compressor of the right engine were of the order of 400°C at the time of final impact and cessation of engine rotation. These HP compressor components would be in the 400°C temperature range with the engine at takeoff power at the ambients present at the time of the accident. This conclusion is evidenced by sooting, and by the form and texture of the sooting, found on these components.
- 7 All oil and fuel filters and oil scavenge strainers were clean. The magnetic plugs sampling the total oil system had the usual minor amounts of sludge around their periphery, with no trace of metal particles. All bearings, air and oil seals, and oil passages were in good condition.

Mr Clay in his report also commented on the diffusion of aluminum throughout the turbines of both engines, the position of the bleed valves, and the anti-ice selection. His conclusions are summarized below:

- 1 Examination of sections taken from the LP2 turbine blades from both engines reveals the initiation of grain-boundary penetration of molten aluminum into the Nimonic of the blade, in the active area with the aluminum coating. This evidence confirms that the aluminum remained molten and that the host blade remained at a suitable temperature to promote the conditions found. For the turbine to be at this temperature requires a high engine-power setting. It is clear from this evidence that both engines were operating at high power when material from the LP compressors was in the system (following the initial impact and ingestion, which caused the release of such material). Penetration and diffusion were more advanced on the right engine because, although the blade temperatures at onset were comparable, the operating time was less on the left engine.

- 2 Debris deposited on the bleed-valve quill shafts established that the bleed valves were closed, as they ought to be at the higher operating condition (high power).
- 3 The engine anti-icing system was free and clear and capable of operation, and the valves were operative on bench check. That the system was operating at the time of ingestion/impact is evidenced by the presence of pine needles and other foliage debris in the piping, in the nose fairing (the bullet), and in the nose cowl. The nose fairing on either engine had not been penetrated by external impact; therefore, since the nose-cowl flow is downstream of the fairing, the debris had to come through the system.

### **Engine Sounds at Takeoff from Dryden**

*Witness Description* Witnesses who were in the aircraft or on the ground described their recollections of the sounds of the engines during the takeoff roll at Dryden and while the aircraft was airborne.

Mr Norbert Altmann, a commercial pilot, was in the terminal building and saw the aircraft near the departure end of runway 29. He was walking through the terminal building and heard a "muffled roar" of the engines of the F-28 on the takeoff roll (Transcript, vol. 22, p. 189).

Mr David Berezuk, a Dash-8 captain with Air Ontario, was seated in 12A. He described the power application as "smooth," without any "unusual engine noises," as the aircraft accelerated down the runway (Transcript, vol. 14, pp. 82, 86).

Mr John Biro is a retired RCAF technician and was seated in 11E. He did not recall anything unusual about the sound of the engines at any time or any sense of power-on or power-off during rotation. He did remember "quite clearly that the right engine ... was just above and behind" where he was sitting, and "the sound from it didn't change at all" until the aircraft "started hitting the trees" (Transcript, vol. 21, p. 54).

Mr Craig Brown is a commercial pilot and was on the east side of the terminal ramp. To him, the engines "sounded normal. The engines powered up, and there was nothing that I noticed or took note of" (Transcript, vol. 5, p. 245).

Mr Ricardo Campbell was seated in 7D. He heard no change in engine noise, "just loud jets, full force of a jet, now loud and fast ... I heard it." He did not hear "anything unusual" about the engine sound coming out of Dryden (Transcript, vol. 17, pp. 52, 94).

Mr Vaughan Cochrane was the general manager of the Dryden Flight Centre and is a pilot. He was on the tarmac by the fuel cabinets. During the takeoff, he was looking directly at the aircraft. He did not hear

“anything at all unusual about the engine noise” (Transcript, vol. 53, p. 237).

Mr Donald Crawshaw was seated in 13B. During the initial part of the takeoff roll there was nothing unusual that caught his attention. However, on rotation the aircraft “just seemed to lose a little bit of power – or a lot of power, actually, and it came back down, and power was again put to the engines, it went back up a little bit, then came back down again” (Transcript, vol. 17, p. 308). He noted that “where we were sitting was right by the left engine, and, on our – on the initial takeoff, it was whining pretty good like one of those engines do, and then there was nothing and the plane flattened out. And then there was a lot of power put back to it again” (ibid.). Mr Crawshaw equated the sound as the aircraft was rolling down the runway to that of “a DC-9” (Transcript, vol. 17, p. 319). The aircraft was in the air when the decrease and increase in sound occurred.

Mr James Esh worked for Dryden Air Services as a baggage handler and is also a private pilot. At the time of the accident he was near the fuel cabinets. He did not describe the engine sounds he may have heard as the aircraft was taking off, but he stated that, as the aircraft disappeared behind the trees, he heard the engines “still screaming away” with no unusual noises (Transcript, vol. 24, p. 204).

Mr Jerry Fillier worked for Dryden Flight Centre and was by the fuel cabinets. He observed the takeoff run but did not hear “any unusual sounds coming from the engines” (Transcript, vol. 25, p. 46).

Mr Michael Gatto was seated in 11A. To Mr Gatto, the engines sounded sluggish as the aircraft proceeded down the runway. They did not have that high-pitched sound. He recalled the high-pitched sound as the aircraft took off at Thunder Bay, but in Dryden that sound was not there. “It just didn’t feel that they had full steam. It didn’t feel like it was going to its full max” (Transcript, vol. 13, p. 128).

Mr Raymond Gibbs is a commercial pilot and was in the airport manager’s office. He neither saw nor heard anything unusual as the aircraft took off. He heard the engine noise, and it “sounded like a typical jet engine” (Transcript, vol. 23, p. 39).

Mr Daniel Godin was seated in 9B. He heard nothing abnormal and remembered hearing “the engines seemingly at full power with no noises” that would have been alarming to him. He also “distinctly remember[ed]” the engines running while the aircraft was in the crash sequence (Transcript, vol. 17, pp. 189, 193).

Mr Murray Haines, a DC-9 captain with Air Canada, was seated in 13D, between the engines. To him, the engines were “running perfectly,” and they “both made a lot of noise.” Based on his experience flying jets, “those engines sounded good” (Transcript, vol. 19, p. 39).

Mr Thomas Harris was seated in 8A. To Mr Harris, everything appeared to be normal until about half to three-quarters of the way down the runway, when he heard what appeared to be "a momentary change in pitch of the engines," which he likened to "a throttle-off, throttle-on instantaneous type engine noise" (Transcript, vol. 12, p. 173).

Mrs Sonia Hartwick, a flight attendant on the flight, was seated in 8D. She heard "nothing" that she "noticed that was unusual" during the takeoff (Transcript, vol. 10, p. 238).

Mr Roscoe Hodgins is a commercial pilot who observed the F-28 take off while he was standing near the Ministry of Natural Resources building. He described the acceleration of the aircraft as slow, and

A. ...as the engines spooled up and came up to full throttle, there wasn't a steady whine or crackling noise of a jet engine.

Normally on jet engines, any that I have heard, have a steady whine or swish to them, a high-pitched, ear-piercing noise. This had an intermittent burping noise to it which was happening maybe every three to four seconds.

(Transcript, vol. 22, p. 144)

According to Mr Hodgins, the intermittent burping noise came at regular intervals and continued throughout the takeoff sequence. At rotation, the engine noise seemed to die off, which Mr Hodgins attributed to the fact that the jet blast was pointed down at the runway; however, as the aircraft started to fly, he could again hear the intermittent burping noise. Mr Hodgins had observed the F-28 take off from Dryden approximately 12 to 15 times in the two-and-one-half weeks prior to the crash. At those times he heard only "the normal high-pitch scream of a jet engine" (Transcript, vol. 22, p. 146).

Mr Gary Jackson was seated in 13A. He recalled the engines being powered up, and they sounded normal. He stated that there was "a slight wavering to the pitch, but that's all" (Transcript, vol. 16, p. 144). When the aircraft was at about 15 or 20 feet, he then heard what he thought was "extra power going to the engines. They increased in intensity, and we got a little bit more altitude" (Transcript, vol. 16, p. 132).

Mr Stanley Kruger, the crew chief of the Dryden crash fire rescue unit, was in a fire truck near the fire hall. He did not hear "anything unusual about the sounds of the engines" during the takeoff of the aircraft (Transcript, vol. 27, p. 67).

Mr Peter Louttit, the Dryden Municipal Airport manager, was in his office in the terminal; he is a former military pilot with about one thousand hours' experience flying the CF-100 jet aircraft. He saw the aircraft for a very short time during its takeoff, his impressions gained as it went by the intersection of taxiway Alpha and the runway. When

he observed the aircraft, it was at a point on the runway where, in Mr Louttit's opinion, the aircraft would normally already have been airborne. The aircraft was in a rotated attitude, with the main wheels still on the runway. When Mr Louttit saw the aircraft, its sound caught his attention. He described the sound as

- A. ... an intake noise. It was not the exhaust noise. The jet engine has an intake noise when it is approaching. It has an exhaust noise when it is going away. And it was an intake noise that I heard and it was a descending noise.  
... It was quite – quite a sharp noise, explosive I guess would be a good word for the description of it.

(Transcript, vol. 5, p. 23)

To Mr Louttit, the noise meant a malfunction in the engine, probably a flame-out, which is an engine failure. (He has experienced a flame-out while flying the CF-100 aircraft.) Mr Louttit stated that the noise was "very quick. It came, it went to high pitch, and was gone" (Transcript, vol. 5, p. 44).

Mr Ronald Mandich, of Green Bay, Wisconsin, who holds a master's degree in mechanical engineering from the Massachusetts Institute of Technology, was seated in 8C. He has a work history with Hughes Aircraft, involving the management of flight test programs and vibration testing. He testified that he has done extensive work in vibration analysis and testing. His evidence was that the aircraft left the runway and came back down. When the wheels hit the runway he noticed that, assuming both engines were going the same speed initially, the sound of one of the engines "decreased in pitch ... about a half an octave ... about four, five, six times." Just before the aircraft left the runway the second time, he heard the pitch of both engines "increase somewhere between 3 to 5 per cent, as if someone in the cockpit had advanced the thrust levers" (Transcript, vol. 17, p. 358). The engine noise that he heard was definitely not a "synchronization" noise; it was a "step function ... not a beat frequency phenomenon" (Transcript, vol. 17, pp. 375–76).

Mr Richard Waller was seated in 3D. Compared with the sound of the engines during takeoff from Thunder Bay, at Dryden the engines had a higher-pitched sound, "as if he had more throttle to the engines ... the engines were very, very loud, as if they were at full throttle" (Transcript, vol. 18, p. 149).

The following is a summary of the witness testimony regarding engine sounds. Of the 21 people who discussed engine sounds during testimony, 14 said that the engines sounded normal, were screaming away, were running perfectly, or that there was nothing unusual in the sound. The 7 other witnesses gave inconsistent testimony regarding the sounds of the engines. Two of these thought the engines were operating

normally, and one described a musical step-function sound; these three witnesses then heard power being added as or after the aircraft became airborne. Another thought the engines sounded sluggish and did not have full power; another described the sound as if the throttles had been moved instantaneously off then on, three-quarters of the way down the runway; another thought the engines were not making the normal steady whine or crackling noise of a jet and made burping sounds from the start of the takeoff until becoming airborne; and another heard a sharp, explosive noise like the sound of an engine flame-out as the aircraft passed taxiway Alpha: the noise came, went to a high pitch, then was gone.

*Analysis of Engine Sounds* Investigators who had examined the engines after the crash testified with respect to the question of whether the engine sounds described by the witnesses indicated possible engine malfunctions, specifically, engine compressor stall or engine flame-out.

Mr Joseph Bajada, the CASB powerplants group chairman, stated that there was no evidence of damage in the high-pressure compressor that would indicate there had been a severe compressor stall. Such evidence would include, for example, bent compressor blades, and none were found. (Compressor stalls create back pressure in the compressor area, which causes the blades to bend.) As well, Mr Bajada found no evidence from his examination of the engines of a flame-out having occurred on the takeoff roll.

Mr Bajada agreed that there can be "less severe" compressor stalls that do not damage the engines, but said these will result in bangs, or "a series of bangs," as the compressor stall goes through the engine (Transcript, vol. 60, pp. 143, 144).

Mr Bajada stated that he had reviewed testimony of a few witnesses with regard to the abnormal engine sounds they heard and discussed with Rolls-Royce personnel these sounds and their possible origins. Neither Mr Bajada nor Rolls-Royce could come to any conclusions over the source or cause of the abnormal sounds.

Mr Clay, the independent engine consultant, discussed the evidence that would have indicated a compressor stall had occurred. He stated that if there had been a very severe compressor stall, then, as the offloading and onloading of the HP compressor blades occurred, there would likely have been a "woof" sound. A severe compressor stall would also result in physical evidence, namely contact between the rotating blades and the static blades, since the blades, during onloading and offloading pressures, moved forward and rearward as they rotated. During his examination of both engines, Mr Clay did not find any such physical evidence in the HP compressor section.

Mr Clay commented on the engine sounds described by Mr Mandich. Mr Clay's theory was that when the pilot tried to rotate the aircraft, he found he was unable to do so, and the "first normal self-preservation reaction was to firewall the engine or engines" (Transcript, vol. 62, p. 27). To Mr Clay, this meant pushing the throttles forward just as fast as the pilot possibly could.

During cross-examination, Mr Clay stated that it is possible to have a compressor stall occur without any evidence being left within the engine. He also stated that if the stall is so minor as to leave no physical evidence, it is doubtful there would be any loss of power.

When questioned about whether the ingestion of ice, slush, or water into an engine could possibly cause a compressor stall, Mr Clay replied: "In sufficient quantity." He further described "sufficient quantity" as an "alarming amount." He explained that Rolls-Royce does tests where fire hoses are directed full bore into intakes of engines, and "all kinds of things" are shovelled into the engines. He was quite proud to say that "Rolls-Royce probably has the best record on their engines of exceeding all regulations in that regard" (Transcript, vol. 62, p. 55). In summary, the engine experts could give no explanation for the engine sounds heard by the witnesses, except for the sound of an increase in power at or after liftoff. It would be a natural reaction for the pilots to advance the throttles to maximum when it became apparent the aircraft was not flying properly.

Apart from the abnormal sounds described by some witnesses, there is no evidence that the engines were not operating normally throughout the takeoff and flight. Indications that the engines were operating normally are as follows: the flight crew did not reject the takeoff, so it can be assumed that the engine indications as seen and heard in the cockpit were normal up to the time the aircraft reached  $V_1$  (the takeoff-decision speed); as demonstrated in the performance analysis, both engines had to have been operating to achieve the flight profile flown; and the physical examination and tests conducted on the engines and accessories did not reveal any reason why the engines could not have produced full power up to the time they started ingesting tree material. Although some witnesses heard abnormal engine sounds, it is considered that the conditions which produced those sounds were transient and did not affect the performance of the engines.

### **Engine Smoke on Startup at Winnipeg**

*Description of Occurrence* On March 8, 1989, an Air Canada ground handler, Mr William O'Connell, worked on the turnaround of an Air Ontario F-28 aircraft in Winnipeg and observed the startup of the engines when the aircraft was ready to depart. According to his testimony, the engines were started using the aircraft's auxiliary power



unit. The number 2 (right) engine was started first, and it was a normal start. When the number 1 (left) engine was started, "excessive black smoke" came from the rear of that engine for a "good five minutes" before the engine stabilized (the smoke stopped) (Transcript, vol. 58, p. 55). The captain "opened the cockpit window and looked back at that number 1 engine at least three times" (ibid.). The wind was from the left, perpendicular to the aircraft fuselage. After the left engine stopped smoking, the aircraft taxied out for takeoff.

During the start, Mr O'Connell gave no signs to the crew to indicate that the engine was smoking; he was certain they were aware of the problem. Mr O'Connell described a "wet start" as a blast of flames out of the engine tailpipe that lasts only a few seconds, and he stated that what he saw was not a wet start. He described the smoke as being four or five times the normal volume one would get from an F-28 engine, and, although he had been working around jet aircraft for 21 years and had seen thousands of engine starts, he had never seen anything like this from a jet engine. Mr O'Connell did not know the registration of the aircraft, but it was later shown to have been C-FONF.

*Analysis of the Engine Smoke* The engine experts were asked to comment about why the engine smoked during startup.

Mr Bajada, the CASB powerplants group chairman, stated that, based on his experience with jet engines, he could not come to any conclusion as to why the smoke to which Mr O'Connell attested would have appeared. Mr Bajada talked to Rolls-Royce many times about the smoke, and the company could not provide an answer either. Mr Bajada did say that fuel pooling could cause "a little bit of black smoke on startup" (Transcript, vol. 60, p. 139), but he knew of no other reason for a jet to produce black smoke. Mr Clay, the independent engine consultant, stated:

- A. With no action in between and, as I say, 12 to probably, I don't know, 12 to 14 starts satisfactory subsequently, if indeed the black smoke occurred, then a possible explanation is that the start sequence, for whatever reason, either human or mechanically or any other reason was not followed; such that he would get an overage start which, traditionally, on all kinds of engines creates a black smoke or a very dark smoke with the potential for some yellow flame, which is incomplete combustion where you have more fuel or you either have more fuel or less air ... it is the only explanation that I can arrive at on this particular system.

I am somewhat incredulous – in fact, not somewhat, I am totally incredulous, with due respect, to the five minutes. In some training that I do, I ask people to understand ten seconds

and so frequently they think it is five minutes. It depends on the circumstances as to your understanding of time.

But I am also encouraged in this interpretation by the fact that although ... I believe, the captain on that particular occasion in the left-hand seat was reputed to have looked out three times, which in and of itself is most unusual, has no recollection of this occurrence.

(Transcript, vol. 62, pp. 29–30)

Mr O'Connell's description is the only known report of an engine of the F-28 emitting an unusual amount of smoke during startup. The incident was not reported by the pilot, who, when questioned on the matter by Commission investigators, did not recall it. Engine experts could give no explanation as to why a jet engine would smoke for five minutes during startup. At times, jet engines will smoke for a few seconds during startup because of fuel pooling or incorrect startup procedures. It is considered that this incident was, at best, an isolated case and had no bearing on the serviceability of the engines and, therefore, no bearing on the accident.

### **Evaluation of Engine Condition**

There was no material evidence of any pre-impact malfunction or failure of either engine. The left engine sustained impact damage because it struck the ground; the right engine did not strike the ground and did not sustain impact damage. Both engines exhibited similar foreign-object damage related to ingestion of tree material, and both engines exhibited similar metal spatter on internal components in the air path. This evidence indicates that the engines were subjected to approximately the same conditions at approximately the same power level during the descent into the trees.

*Engine Power* It was concluded by the investigators and engine experts that the engines were capable of producing full power beyond the point at which they started ingesting tree material. Indicators used by the investigators to determine the amount of power being produced by the engines are as follows:

- 1 The crew did not reject the takeoff. This indicates that takeoff power had been achieved and was sustained until the aircraft reached at least  $V_1$  speed.
- 2 When the engines were ingesting vegetation, the bleed valves in the engines were closed, as is the case when an engine is operating at high power.

- 3 The metal spatter indicated, if one assumes the engines were operating normally when the compressors started to break up, that the engines were operating at or above cruise power.
- 4 The material temperatures in the later stages of the right engine's HP compressor were, at the time of final impact, approximately 400°C, which is the temperature of the compressor with the engine at takeoff power.
- 5 Although some witnesses said the engines were screaming away, or were very, very loud, or were increased to full power, none of the witnesses suggested that the engines were operating in an abnormal manner after the aircraft was airborne.

It is concluded that the engines were operating at normal takeoff power until the aircraft became airborne. After the aircraft became airborne, it is probable that the power was increased to full power.

**Engine Anti-Ice** The engine anti-ice valves, found in the closed position, were not damaged, and limited tests showed no faults with the valves. These valves are held open by electric solenoids when the valves are selected OPEN and if there is air pressure on the valve. When either electric power or air pressure is not available, the valves close. During the crash, the valves would have gone to the closed position; therefore, the position of the valves in flight could not be determined from an examination of the valves. From examination of the mechanical components of the system, it could not be determined whether the system was on or off. However, the presence of minute particles of organic material in the anti-ice ducting of each engine suggests that the anti-ice valves were open and that the system, therefore, was selected ON. The engine anti-ice system should have been selected ON for takeoff in the weather and airport conditions that existed at the time of the takeoff.

## **Auxiliary Power Unit**

The F-28 aircraft is equipped with a gas turbine engine that drives a generator and a hydraulic pump. The complete unit, called an auxiliary power unit (APU), enables some aircraft systems to operate independently of ground-power sources. It is installed in the fuselage behind the rear pressure bulkhead. On the ground, the APU can provide all electrical power to all of the aircraft electrical systems and can supply air for the air-conditioning system and for engine starting. In flight, the APU can be used as a stand-by power source in the event of failure of one or both of the main engine generators.

There is a fire-detection and protection system within the enclosure for the APU. The system is automatic in that if it detects an overheat condition, it will activate the warning system, shut down the APU, and discharge its fire extinguisher. The shutdown of the APU and the firing of the extinguisher can also be accomplished by operating a manual switch in the centre of the glareshield panel. The system can be checked by operating the TEST/RESET switch on the secondary instrument panel.

The APU on C-FONF was not used on the day of the accident because the APU fire-detection circuit did not test satisfactorily. The applicable journey log entry of March 9, 1989, was, "APU will not fire test – Deferred as per MEL 49.04 – Licence ACA 87101" (Exhibit 492, appendix 17). The APU was placarded as inoperative and a main engine had to be kept running while the aircraft was on the ground in Dryden. The cause of the unsatisfactory test had not been determined prior to the accident. After the accident, there was too much crash and fire damage to the aircraft to allow the cause to be determined. The only part of the fire-detection system that remained was the fire-detection loop, housed within the APU container. A continuity check of the sensing loop found it acceptable.

The APU was sent to the manufacturer, Garrett (auxiliary power division), in Phoenix, Arizona, to verify that the unit was in an operable condition and to confirm the reported low bleed pressure during main engine start. Entries had been made in the journey log on March 4, 1989 (air pressure only 14 psi), and on March 9, 1989 (three entries: APU air pressure low, engine starts becoming more and more difficult, APU load control valve u/s), indicating that the APU was not providing adequate air pressure during start.

The APU was visually examined under the supervision of a CASB investigator. There were no abnormalities noted, except that an O-ring on the starter mounting flange was damaged; it had been damaged during removal of the APU from the aircraft. The O-ring was replaced, and the APU was started. The APU accelerated normally to the "no load" operating speed; however, the oil pressure slowly decreased until it stabilized at 30 to 35 psi. The minimum operating pressure is 70 psi, but Garrett elected to continue operating the unit to obtain a performance calibration.

On initial testing, the APU speed dropped excessively when under load, the cause of which was determined to be a malfunctioning fuel control unit. The reported low bleed pressure from the APU was exacerbated by the excessive speed drop. The fuel control unit was replaced, and the APU performance was acceptable in all respects for a unit that was in operational use.

During testing, it was discovered that the APU exhaust overtemperature thermostat either was not functioning or was misadjusted on the unit as tested. Since the malfunctioning of the thermostat did not affect the output of the APU, no troubleshooting was conducted. The oil-pressure regulator was disassembled and inspected, and the setting of the low-oil-pressure switch was verified; the cause of the low oil pressure was not determined.

## **Systems**

The post-crash fire destroyed major portions of the aircraft, including parts of many of the aircraft systems. In general, most of the mechanical items, such as control valves and actuators, survived with limited damage, but almost all the electrical systems and electronic controls located in the area commonly called the radio bay and in the cockpit were severely burned. Although crash and fire damage precluded determining the complete state of serviceability of the aircraft, it should be noted both that critical systems are designed to be fail safe in the event of failure and that there are redundant mechanical systems.

### **Hydraulic System**

Hydraulic power comes from two separate systems, identified in the cockpit as Utility System 1 and Flight Control System 2. Each system is identical to the other in concept and performance; they differ only in capacity, subsystems supplied, and component location. Utility System 1 supplies power to the elevator, horizontal stabilizer, left aileron, rudder, flaps, lift-dumpers, speed brakes, landing gear, normal brakes, and nose-wheel steering. Flight Control System 2 supplies power to the elevator, horizontal stabilizer, right aileron, rudder, and alternate brakes. During flight, both systems operate at 3000 psi at varying flow rates, depending on the demand for services. Each system has two engine-driven pumps and one electrically driven pump (used for maintenance only). Cockpit controls and indicators are located on the secondary instrument panel.

Reservoirs for both systems are located in the rear fuselage section immediately behind the rear pressure bulkhead. The reservoirs were undamaged but were depleted of fluid because of the rupture of the hydraulic lines during the crash.

The connector caps on the hydraulic system ground-service panel were in place, and the fluid-quantity test switch was in the proper off position. Flight-deck indicators and controls were extensively damaged, and determinations of readings and selections could not be made.

The four engine-driven hydraulic pumps were recovered in good condition, were tested, and were found to be serviceable. The electric

hydraulic pumps appeared to be in good condition but were not tested since they are not used in flight operations. The four hydraulic shutoff valves were found in the open position. These valves can be shut off from the cockpit to isolate parts of the hydraulic system in case of fire or malfunction.

The return-line filters were undamaged, and the bypass indicators were in the normal position. Under microscopic examination, an insignificant quantity of solid contaminant was observed on the filter surfaces. Hydraulic-fluid analysis revealed no fault with the fluid.

The redundancies in the hydraulic systems are such that multiple failures would have to occur to affect the operation of the aircraft systems significantly. Although major sections of the hydraulics were destroyed in the crash and fire, examination and testing of the available items provided a good indication that the total system was serviceable.

### **Landing-Gear System**

The landing gear is a tricycle configuration, with the main gear retracting inward and the nose wheel retracting forward. There are two wheel assemblies on each landing-gear strut.

At the crash site, the left main gear was found in the down-and-locked position. The right main gear was partially retracted, and, when the fuselage was lifted during recovery, the right gear dropped to the down-and-locked position. The landing-gear doors were found at the start of the main wreckage trail. The leading edges of the main gear inboard doors showed signs of tree strikes, which indicates that the doors were open when the aircraft was contacting trees. These doors are closed when the landing gear is fully down or fully up, and the doors are open when the landing gear is in transit. The nose gear was found to be near the up position, but the uplock was not engaged.

The landing-gear-selector handle in the cockpit was found in the up position, but the position of its associated valve could not be determined.

The main landing-gear-selector valve, which is located in the hydraulic tunnel in the aircraft, was moderately fire damaged but generally intact. There is a slide within the valve that moves to either of its full travel positions, depending on whether an up or down landing-gear selection is made. The slide is held in the full travel position by the action of two spring-loaded balls. The position of the slide as found equates to an UP selection.

The forward actuator for the left main gear-door was broken away from the aircraft structure at the cylinder-end fitting. Internal examination showed marks on the cylinder wall caused by heavy side-loading of the piston while the actuator was in the fully extended position.

Examination and testing of the landing-gear system and components did not reveal any pre-impact faults.

The fact that the landing-gear-selector handle was found in the up position supports the conclusion that the gear was selected UP, and there is additional evidence for such a conclusion. As well, the lever could have been moved to the up position by the loads placed on the gear-selection linkage during the breakup of the aircraft. The most definitive evidence showing that the gear had been selected UP was the position of the slide in the main gear-selector valve. The design of the ball and detent system is such that the position of the slide should not be affected by crash forces. Accordingly, it is concluded that the gear was moving to the up position at the time of the accident.

### **Wheels and Wheel-Brake System**

The tread on the four main tires was good, and there were no flat spots or evidence of hydroplaning. The wheels showed no signs of overheating, and the fusible plugs in the wheels were in place, with no signs of rupture. There was no evidence that any of the wheel bearings suffered rolling-element distress.

All four brake units remained intact. The right and left outboard brakes were within the in-service wear limits; however, the right and left inboard brakes were worn beyond the specified limit. The Fokker F-28 Engineer's Guide, under the heading "Wear Check for Mounted Brakes," shows a maximum dimension of 0.250 inch from the face of the outer spring-holder to the tip of the return pin, with brakes applied. Both left and right inboard brakes measured 0.290 inch but were assessed as still being operational. Although two sets of brakes were worn beyond specified limits, the CASB investigation team assessed the brakes, tires, and wheels as having been in a serviceable condition at the time of the crash.

### **Electrical System**

The aircraft is equipped with AC- and DC-operated systems, with the electrical power, when required, supplied through electrical buses by a battery, two engine-driven AC generators, an APU-driven generator, and an AC ground-power unit (external power).

The AC bus arrangement is such that one particular bus is supplied by one electrical source at a time. In case the source becomes inoperative, the bus is automatically transferred to another source. The DC buses are supplied by transformer-rectifier units (TRUs), which in turn are supplied from the AC buses. When a TRU becomes inoperative, the DC bus can, in some cases, be transferred to another TRU. The battery is for starting the APU and, in case of an emergency, is the last source of electrical power.

The aircraft electrical system was extensively damaged by the crash and fire, and examination of the wiring and components was therefore limited. From what was found, the only evidence of malfunction in the electrical system was a fault in the left generator.

The main frame of the number 1 (left) generator was cracked, and full functional testing was not possible. Testing confirmed that the rotor windings were in good condition, although there was an open circuit in the rotating rotor assembly. Significantly, two wires from diodes to the main rotating field were broken. Fracture analysis showed that the first wire had been broken for some time; in this condition, the generator would continue to produce power but, short of providing its full-rated load, would break down. There is no indication that an abnormally high load was placed on either generator. Based on the capacity of the generator to continue to operate with one wire broken as long as there is no unusually high load placed on it, and on the fact that the analysis showed that the break was not new, it is probable that the wire was broken prior to the accident flight.

The fracture of the second wire would have resulted in output failure of the generator. The break in this wire showed evidence of arcing. Its fracture surface was not as contaminated as that of the break in the first wire, indicating a more recent failure. It is probable that this break was related to the impact forces which caused the external damage to the generator, but it cannot be stated conclusively that the wire was not broken prior to the crash.

In the event of a generator failure, the relevant GENERATOR INOPERATIVE light will illuminate, and automatic transfer of the load will take place. The operating procedures specify that should a generator fail at some point during the takeoff, no crew action is required prior to establishing a normal climb configuration. Because of redundancy in the electrical system, multiple faults are unlikely and individual faults would have no significant effect on the aircraft's operation. Therefore, it is concluded that electrical failure, even in the improbable event that it did occur, did not likely contribute to the crash.

### **Fuel System**

The fuel system controls in the cockpit and the left-wing fuel system components were not recovered because of the fire and impact damage. The integral fuel tanks were ruptured in the crash, all of them subjected to some degree of fire damage.

The two booster pumps from the right fuel tank were recovered and tested; they operated satisfactorily. The canister shutoff valves and vent valves were open, and the tank internal plumbing in this area was in good condition. Debris found on the surface of the intake screens was typical of miscellaneous contaminants found in fuel tanks, and the



quantity would not have significantly affected fuel entry to the pumps. The fuel system's left and right fire-shutoff valves were open, and both cross-feed valves were closed.

The open fire-shutoff valves and the closed cross-feed valves show that the fuel system was configured as would be a serviceable fuel system. Evidence of proper operation is reflected in the findings that both engines were running at the time of the crash and the cross-feed valves were closed.

### **Fire-Protection System**

An independent fire-detection and protection system is installed in the aircraft for each of the left and right engines and for the APU. Each system consists of a detection system and an extinguishing system. The detection system consists of a sensing element loop in each engine nacelle and in the APU enclosure, and a warning system of lights and audible alarms in the cockpit. Three fire-extinguishing-agent containers installed in the tail section supply extinguishing agent to the two engines and the APU. There are three portable carbon dioxide fire extinguishers in the aircraft, one in the cockpit and two in the cabin, and there is one water/glycol fire extinguisher in the cabin.

The engine fire-protection-system controls in the cockpit were destroyed by the post-crash fire and were not recovered. The sensing element loops in the engine nacelles had been subjected to some impact damage but were generally in good condition, and no pre-crash faults were noted.

The three fire-extinguishing-agent containers were found intact. None of the cartridges from any container had been fired, and all of the outlet discs were intact. The left container safety disc in the thermal discharge fitting was ruptured, and the container was empty; there was evidence of exposure to the fire, but there was no significant damage to the container. The right container and the APU container were still charged with gauge readings of approximately 600 and 575 psi, respectively. It was concluded that the fire-extinguishing system had not been activated by the flight crew.

Impact and fire damage precluded testing of the fire-protection system to determine pre-crash integrity. There was no evidence of fire prior to impact.

### **Bleed-Air Supply System**

Bleed air supplies the following systems: air-conditioning and pressurization, airfoil anti-icing, engine anti-icing, engine starting, and hydraulic reservoir pressure. The air can be supplied from the main engine compressors and, on the ground, by the APU or a pneumatic high-pressure ground-power unit.

The pneumatic system valves and ducting in the engine pylons and in the rear fuselage section were in good condition. The shutoff and pressure-regulating valves and the shutoff and pressure-modulating valves are electropneumatically operated and are spring-loaded to the closed position; all four of the valves were closed.

### **Ice- and Rain-Protection Systems**

To prevent the buildup of ice in the main engine air intakes and on the leading edges of the wings and the horizontal and vertical stabilizers, hot compressed air from the bleed-air supply system can be directed to these areas by cockpit controls. The windshields, the sliding windows in the cockpit, the angle-of-attack vanes of the stall-protection system, the static ports, and the pitot tubes of the air data indicators are electrically heated to prevent ice accumulation. An ice-detect probe under the aircraft's nose section detects ice in flight. The aircraft is equipped with windshield wipers for operation in rain.

All the cockpit controls and indicators for these systems were destroyed in the fire. The ice-detect probe was found in relatively good condition, and both its detection and heating systems tested satisfactorily. The airspeed pitot head from the left side of the aircraft was impact damaged, but the heater circuit was still functional. The pitot head from the right side was not recovered. Both angle-of-attack sensors were recovered, but they were too severely damaged to permit an assessment of the condition of the heaters.

The wing anti-ice valve and the tail anti-ice valve were recovered in good condition. They are motorized butterfly valves, electrically operated, and both were found in the closed position. When tested, the valves operated satisfactorily; the wing valve moved from open to closed or closed to open in approximately 5 seconds, and the tail valve moved in approximately 5.7 seconds.

The finding of the wing and tail anti-ice valves closed is a good indication that the wing and tail anti-ice system was off at the time of the takeoff. As the aircraft takes off or lands, switches on the lower portion of each of the main landing-gear struts direct some aircraft systems, such as touchdown protection for the wheel brakes, landing gear anti-retraction solenoids, and the wing lift-dumpers, to operate in a specific manner. The switches are called "ground/flight switches" by Fokker Aircraft. When the aircraft is on the ground, the ground/flight switch prevents normal opening of the wing and tail anti-ice valves. Thus, if the wing and tail anti-ice system is selected ON while the aircraft is on the ground, the valves will remain closed until the aircraft becomes airborne and the switch indicates that the aircraft is in the air. The crew would then have had to assess the situation and select the system OFF. The valves would then have had to move to the closed

position while there was still electrical power available. It is deemed unlikely that there would have been sufficient time for this sequence to have occurred. It is improbable as well that the valves went full closed as a result of intermittent electrical shorts during the aircraft breakup. During use, the wing and tail anti-ice system bleeds air from the engine compressors, a process that results in a significant engine performance penalty; therefore, the wing and tail anti-ice system is not used during takeoff. This penalty would be felt just as the aircraft becomes airborne. To open the wing and tail anti-ice valves while the aircraft is on the ground, a test switch located behind the co-pilot's seat must be positioned to ANTI. IC. L.G. OVERR. (anti-ice landing-gear override) and held there. When the switch is released, the valves are powered to the closed position.

### **Air-Conditioning System**

The air-conditioning system control panel and the right-side refrigeration unit were destroyed in the post-crash fire. The left-side refrigeration unit, which supplies conditioned air to the cockpit, sustained some impact damage but was untouched by fire and remained relatively intact. Although the unit could not be tested, visual examination revealed it to be in relatively good condition.

### **Instrument Systems**

The left-side (captain's) flight instruments were almost completely destroyed by fire. The engine instruments and the right-side (first officer's) instruments were relatively intact, but many of the instruments had returned to a zero reading with the loss of input signal. The impact damage had not been severe enough to freeze pointers in position, to capture any pointer imprints, or to damage any of the gear trains; thus, reliable indications of the instrument readings at impact could not be obtained from a study of the impact damage.

Examination of the instruments revealed the following:

- 1 The right-side airspeed indicator "bug" was set at 132 knots indicates the calculated  $V_1$  speed.
- 2 The left- and right-engine thrust-meter index displays, which indicate the calculated power settings for setting takeoff power, were both set to a value of 166.
- 3 The left and right fuel-quantity indicators were reading 5400 and 6950 pounds, respectively. The difference may have been as the result of the loss of fuel from the left wing, which was breaking up during the crash; the gauge was reflecting the loss until electrical power was lost to the gauge.

- 4 The left and right fuel-consumed indicators were reading 2078 and 2091 pounds, respectively. It was reasoned that, for the numbers to make sense, the gauges had last been reset to zero at Thunder Bay.
- 5 The left and right fuel load-limit indicators, normally located in the refuelling access area on the underside of the right wing, were set to 7200 and 6800 pounds, respectively. These numbers would normally be the same. On the right instrument, the set knob was somewhat displaced from the needle, which could account for the difference in the settings.

The static ports from the right side of the fuselage were severely fire damaged, with the lines from the ports inboard of the connecting nuts burned away. All portions of the navigation system instrumentation were either consumed or too badly damaged by fire and impact to allow an assessment of serviceability.

### **Indicator Lights**

A study of the annunciator and other indicator lights was conducted by Mr James Foot to determine if any of the lights was illuminated at impact, which in turn would give an indication of the status of the lights associated with that system. Mr Foot is an electrical/mechanical analyst employed by CASB and working at the CASB engineering laboratory in Ottawa. A certified electrician, he has a diploma in chemical technology and a bachelor's degree in mechanical engineering. Mr Foot prepared a report on his study of the lightbulbs and filaments, which was entered as Commission exhibit 441, and he gave testimony on this subject at the Commission hearings.

The examination entails a microscopic inspection of the bulb filaments for stretching, distortion, coloration, and types of failure. Normally, when shocked, an incandescent filament will exhibit deformation of the coils in the form of stretching or uncoiling, and the filament may or may not be fractured. A fractured filament without deformation is normally associated with a cold shock, since the tungsten fails in a brittle manner. Cooldown for a "hot" filament to a "cold" filament, which occurs with the loss of electrical power, takes place in less than 50 milliseconds for a typical lightbulb or lamp.

A total of 117 lamps were examined, 21 of which had fractured filaments. Nine of the lamps with fractured filaments were from the landing-gear-position indicator. Two of the lamps from that indicator – the service door light and the right main landing-gear red light – exhibited a small amount of localized stretching, although not enough to allow a conclusion that either or both lamps were on at impact. The observation that 21 filaments were considered to have fractured when cold indicates that localized g forces (impact forces) were significant. It

was reasoned that had any lamp filament been incandescent (on) during the crash, the g forces were sufficient to have caused filament distortion, thus identifying those filaments that were incandescent. However, this theory assumes that electrical power was still available to the lamps when the impacts occurred.

It was concluded that one lamp from the number 1 constant speed drive (CSD) annunciator was illuminated when its envelope cracked, but it could not be determined whether the envelope was cracked during the accident or prior to it. All the other lamps exhibited signs of being off at impact, which is not to say that they all should have been off. Lamps could have shown signs of being off because the local impact forces were low or because of the loss of electrical power prior to impact.

The CSD on each engine connects the generator to the engine and drives the generator at a constant speed of 8000 rpm, irrespective of changes in engine operating speed and/or electrical load. The CSD warning light will illuminate if there is low oil pressure, if the oil overheats, or if there is a reduction in CSD speed. It is possible that the light illuminated during the crash when the engine speed became too low to operate the CSD at a constant speed.

### **Radio and Navigation Systems**

There is no evidence that communication radios or navigation radios and systems were of significance in this accident. All the radios and other cockpit-located components were burned and could not be tested. The last radio transmission from the aircraft occurred just before the takeoff commenced, indicating that the communications radio was functioning. It is highly unlikely that the failure of any navigation equipment would have contributed to the crash.

## **Flight Controls**

Many of the component parts of the flight control systems were recovered, and examination, testing, and assessment of these components did not indicate any pre-crash fault or unserviceability. All the fractures were identified as impact overload in nature, with no evidence of fatigue or other premature failures. The considerable crash and fire damage to the flight control systems, particularly from the cockpit to the centre wing area, precluded a complete analysis of the pre-crash serviceability of each system.

### **Primary Flight Controls**

The primary flight controls consist of the ailerons located on the outboard trailing edge of each wing, the rudder hinged to the trailing edge of the vertical stabilizer, and the elevator located at the trailing

edge of the horizontal stabilizer. The controls are hydraulic powered, and all have mechanical backup systems. There was nothing found during the investigation that indicated the primary flight controls were not fully serviceable.

**Gust Locks** Mechanical gust locks can be engaged on the ailerons, elevators, and rudder to prevent the wind from damaging these components when the aircraft is parked. All the locks are operated by a single control in the cockpit; to allow engagement, the ailerons and rudder must be centred and the elevator trailing edge must be full down. The elevator gust lock was not engaged when examined after the crash, and it operated freely. The mounting bracket for the rudder gust lock was broken as a result of overload transmitted through the gust-lock operating cable during breakup of the aircraft. There was no evidence to indicate that the rudder lock was engaged at the time of impact.

In addition to the physical evidence, there is other evidence that the gust locks were not engaged during the takeoff: the pilots in all likelihood performed a flight control check prior to takeoff, which could not be accomplished with the locks engaged; there is an interlock system that prevents forward throttle movement when the gust-lock control is in the engaged position; and the aircraft was rotated during takeoff (evidence that the elevator was free to travel).

### **Secondary Flight Controls**

The secondary flight controls consist of the wing flaps, lift-dumpers, and speed brakes. The controls are hydraulic powered, and the flaps have an electrical backup; there is no backup system for the lift-dumpers or speedbrakes. There was nothing found during the investigation that indicated the secondary flight controls were not fully serviceable.

**Wing Flaps** The wing flaps are located at the trailing edge of each wing, between the ailerons and the fuselage. From examination and measurements of the flap actuators and from the position of the cam shaft, which operates the flap control switches, it was determined that the flaps on both sides of the aircraft were between 25° and 27° extended at the time of the crash. The cockpit controls were destroyed in the fire, and the selected flap position could not be determined. According to Captain Berezuk, who was seated in seat 12A, the flaps were set at 18° prior to commencement of the takeoff. This setting would be normal for the conditions of the takeoff. (The fact that the flaps were found positioned at 25° to 27° will be discussed in chapter 12 of this Report, Aircraft Performance and Flight Dynamics.)

**Lift-dumpers** The lift-dumpers are installed on the upper surface of each wing's inboard half, in front of the wing flaps, and are used to reduce the landing roll of the aircraft. The damage to the lift-dumper controls and the hydraulic manifold precluded any determination of the selected lift-dumper position. System analysis was limited to tests of hydraulic actuators (to establish serviceability) and to an examination of damage to the linkage and lift-dumper surfaces (to determine the actual position of the surfaces at the time of the aircraft's breakup). The damage patterns on the lift-dumpers and the surrounding fixed portions of the aircraft clearly show that the lift-dumpers were in the closed (retracted) position at the time of the crash, and there is no evidence that the lift-dumpers were deployed at any time during the takeoff. The cockpit lift-dumper controls were not recovered.

**Speed Brakes** The speed brakes are hinged on either side of the tail cone. The complete speed-brake assembly was torn from the aircraft during the crash. Examination and testing of the recovered components did not reveal any significant discrepancies, and there was no evidence to support a definitive finding as to speed-brake position during the flight or during the time of impact with the trees. The damage to the speed brakes shows they were in the closed position at the time of ground contact. The cockpit control was not recovered. When the throttles are advanced for takeoff, or to the detent, an electrical signal is given to the hydraulic actuator to close the speed brakes, and the control lever is moved by spring force to the in position.

### **Supplementary Flight Controls**

The supplementary flight controls include trim controls for the aileron and rudder, the adjustable horizontal stabilizer, and the automatic pilot system. There was nothing found during the investigation that indicated the supplementary flight controls were not fully serviceable.

**Trims** Trimming of the ailerons and rudder is accomplished mechanically by rotating trim knobs on the pedestal to alter the neutral positions of springs within the control systems. Longitudinal trim is provided by adjusting the entire horizontal stabilizer. The horizontal stabilizer, which is hydraulic powered, is controlled by trim wheels in the cockpit connected with a cable system to the control unit's input mechanism. In case of hydraulic failure, stabilizer deflection can be accomplished with an electric motor controlled by a switch on the pedestal.

During the investigation, it was noted that the screwjack of the rudder trim system was slightly out of the neutral position in the direction of deflecting the rudder to the left. The position of the rudder trim setting as found is not a good indication of the setting prior to aircraft breakup.

When one control cable breaks, the other will usually pull and turn the drum to a new position before overloading fails the second cable. From the index mark painted on the vertical stabilizer, the horizontal stabilizer setting was at  $-1.5^\circ$  after impact. It was determined from the Fokker F-28 Flight Handbook that, for takeoff, the horizontal stabilizer should be set at between  $+2^\circ$  and  $-2^\circ$ , depending on the centre of gravity of the aircraft; therefore,  $-1.5^\circ$  would be a normal setting for the takeoff. The locking feature of the redundant electric drive system in the horizontal stabilizer actuator will retain the stabilizer surface in position when hydraulic pressure is lost, and there is reasonable confidence that  $-1.5^\circ$  was the setting prior to impact. The position of the aileron trim could not be determined.

**Autopilot** The autopilot is an electromechanical system that provides flight stabilization and manoeuvre control in the three aircraft control axes, namely yaw, pitch, and roll. The autopilot can be coupled to the VHF navigation and flight systems.

Although it would not be expected to have the autopilot on during takeoff, the possibility of inadvertent engagement or seizure of the clutch mechanism in a critical component, such as the elevator or the stabilizer, was considered. Unfortunately, the autopilot computers were destroyed in the fire, leaving only the servo units available for examination. Examination and testing revealed no faults other than those that were crash related.

The stabilizer position after impact indicates the probability that no "runaway" of the trim or autopilot system occurred during the takeoff. Failure of the trim to move from the preset position, if such had occurred, should not have been a significant problem for the pilot. The possible result of a failure in the elevator autopilot control is less certain. However, since no fault was found in the autopilot servo clutch, the pilot would have had no problem overriding any spurious output to the elevator controls.

## **Flight Data Recorder/Cockpit Voice Recorder**

The aircraft is equipped with a flight data recorder (FDR) and a cockpit voice recorder (CVR). In normal operation, the FDR in C-FONF would record 19 parameters, with indications of aircraft heading; speed; attitude; altitude; acceleration; engine thrust; positions of the control column, control wheel, and rudder pedal; pitch trim position; and whether the autopilot and pilot's radio key are on or off. The CVR records all conversation and noise within the cockpit and radio conversations with outside agencies.



Both the FDR and the CVR were located and recovered by a member of the investigation team approximately 24 hours after the crash. On March 11 CASB investigator David Adams located the recorders in the expected area – near the right rear cargo entry door in front of the rear pressure bulkhead, but buried in debris. The recorders were delivered by CASB investigators to the CASB engineering laboratory in Ottawa at 8 p.m., March 11, 1989. The FDR was determined to be a Sundstrand UFDR (universal flight data recorder), and the CVR was determined to be a Sundstrand Model V-557.

It is a matter of concern that the crash, fire-fighting, and rescue (CFR) unit at Dryden did not have a chart of the F-28 aircraft depicting the locations of important safety-related items. This type of chart, commonly referred to as an aircraft crash chart, is essential in assisting fire-fighters to locate items such as batteries and oxygen bottles, which pose a danger to themselves or others, or objects such as the recorders, which provide information vital to the safety of future travellers. It is absolutely essential that every airport CFR unit have a crash chart available for each type of aircraft that commonly frequents its airport, and that all unit personnel have a good understanding of the charts.

### **Data Recovery**

The recorders on C-FONF suffered extensive fire damage but generally sustained little impact-related damage. The fire had destroyed the normal fasteners, and both recorders had to be cut open; a pneumatic cutoff wheel was used to minimize further damage to the storage medium. On disassembly, it was discovered that the recording medium (one-quarter-inch mylar tape) of both recorders had essentially been destroyed by severe heat damage. There was no practical way to recover the analog information from the CVR tape remnants. Attempts at partial recovery of the digital information on the FDR tape remnants, using optical and scanning electron microscopes, were not successful. No data were recovered from either recorder.

Because no data from the recorders were available to allow determination of the flight profile or to indicate the conversations that took place in the cockpit, it was necessary to conduct a highly detailed investigation into the events that took place during the final minutes of the flight. Unfortunately, because of the lack of information from the recorders, some details about the flight will never be known.

### **Fire Damage Analysis**

Representatives from the manufacturer, Sundstrand Data Corporation, assisted in the investigation in an attempt to determine the temperatures endured by the crash-protected enclosure of the FDR. Sundstrand conducted a series of elevated temperature tests, for various durations,

on a tape transport of identical construction to that recovered from C-FONF. It was determined from damage comparison that the FDR from C-FONF was subjected to a flame at an assumed temperature of 1100°C for 1.5 hours. Then, based on the review of the C-FONF FDR metallurgical information provided by CASB, the estimate was refined to exposure to an average temperature of 850°C for a period in excess of two hours.

### **Fire Survivability**

Flight recorder regulations in place on March 10, 1989, are contained in the United States Federal Aviation Administration (FAA) Technical Service Order C51a (TSO-C51a), the standard for flight recorders, which has been adopted by Canadian authorities for Canadian-registered aircraft. The regulations require that flight-recording devices withstand a temperature of 1100°C for 30 minutes with 50 per cent of the recorder enclosed in flames. Discussions between CASB investigators and personnel from the FAA and Sundstrand, and a review of the documentation regarding the certification tests, confirmed that both recorders in C-FONF met the specifications contained in TSO-C51a.

An international working group, the European Organization for Civil Aviation Equipment (EUROCAE), is endeavouring to bring about changes to the regulations for flight recorders. The Transportation Safety Board of Canada (TSB) is a member of the organization. A more rigorous fire test for the next generation of flight recorders was developed at a EUROCAE meeting in May 1989. The proposed new specification is still based on 30 minutes at a temperature of 1100°C, but with 100 per cent of the recorder enclosed in flames rather than 50 per cent, and with a thermal flux (heat transfer) of 50,000 BTU per square foot per hour. The increase in the flame coverage and the addition of the thermal flux parameter ensure that the test represent a severe fire; the current test is non-uniform and interpretive. The general feeling in the recorder community is that the addition of the thermal flux requirement makes the test twice as severe. The specifications recommended by EUROCAE are contained in two documents: "ED55 – Minimum Operational Performance Specifications for Flight Data Recorder Systems"; and "ED56 – Minimum Operational Performance Specifications for Cockpit Voice Recorder Systems."

With current technology, an increase in the duration of the fire test in addition to the thermal flux requirements would require increased insulation and thus a larger box in which to house the recorder. Since it is undesirable to increase the size of the box, industry representatives at the May 1989 meeting were generally opposed to an increase in the test duration, although the accident investigation community, and Canada in particular, expressed a strong interest in both an increase in the test duration and the addition of the thermal flux parameter. In the interest

of preserving this most valuable investigative tool, I recommend that the TSB continue to press for the adoption of more rigorous test requirements for data recorders.

### **Location of Recorders**

The recorders in the F-28 aircraft are normally located just in front of the rear pressure bulkhead. This area of C-FONF, which was pressurized, suffered extensive fire damage in the crash, whereas the area behind the bulkhead, which was non-pressurized, was undamaged by fire. It was noted by the investigators that if the recorders had been located in this non-pressurized area, they likely would not have been fire damaged and therefore would have yielded useful information.

Recorders are certified to endure the temperature, humidity, and environmental conditions in non-pressurized areas of aircraft; however, locating recorders in these areas is generally viewed as undesirable because of increased maintenance concerns. Current recorders are essentially tape drives with many mechanical parts, prone to serviceability problems in hostile environments. Although locating recorders in non-pressurized areas may result in less chance of damage in a crash or fire, the recorder may not be serviceable when required because of its exposure to the elements. Further study of recorders and their locations, correlated to maintenance history, would be helpful for assessing the relative desirability of locating recorders in non-pressurized areas. Solid-state recorders may increase the commercial acceptability of locating recorders in non-pressurized areas.

### **Solid-State Recorders**

Solid-state FDRs are now operating on some aircraft in North America, and solid-state CVRs are in the process of being certified; they will be operating on aircraft in late 1991. Data for both recorders are stored in computer chips; there are no moving parts. It is possible to record almost 300 parameters on present magnetic-tape FDRs. Existing solid-state FDRs have about the same capacity, although some solid-state FDRs with double that capacity are now being offered on the Airbus A320 and the new Boeing 777. Solid-state CVRs can record from 30 to 120 minutes by having memory modules added to them. In December 1990 the cost of 120 minutes of memory was predicted to be about U.S.\$50,000.

Modern electronic aircraft have thousands of parameters on their electronic buses, and FDRs on these aircraft are able to save data of a quality and quantity that has not been previously available. Based on recent TSB experience working with the tape recorders from A320 aircraft involved in occurrences, the FDRs and CVRs contain enough information to provide detailed accounts of the occurrences. The use of

solid-state recorders, with their ability to store greater amounts of more reliable data, will improve on the capability of data recorders and undoubtedly be of greater benefit to everyone who has a use for the data, particularly those involved in accident investigation.

The manufacturers of solid-state recorders are building recorders to meet the EUROCAE specifications as detailed in publications ED55 and ED56 with regard to fire and heat, water submersion, and impact and acceleration forces. At the time of publication of this Report, these specifications were not law in any country; however, it is anticipated that the specifications will be universally adopted. It is also believed that, because solid-state recorders have no moving parts, the recorders will be better able to withstand the environment in the non-pressurized areas of aircraft. The solid-state recorders are the same size as the most popular magnetic-tape recorders in service.

## **Flight Path Reconstruction**

In support of the overall investigation, the CASB engineering laboratory constructed three-dimensional flight path models, using computer-generated imagery. Information for such modelling is normally obtained directly from flight data recorders. Since the recorders from this accident were destroyed by fire, the information had to come from other sources. These sources included eyewitnesses, wreckage distribution, photographic evidence, survey evidence, tree-strike evidence, a model of the F-28 aircraft, past flight recorder data from this very aircraft, and some assumptions based on an understanding of the way aircraft fly. It is important to note that the reconstruction depicts an approximation of the aircraft's flight path and behaviour; the results are qualitative and were not, and should not be, used for quantitative analysis. From an analysis of the reconstructed flight path, the aircraft did not exhibit any unusual yaw, pitch, or roll prior to impact. This finding agrees with the conclusions reached related to aircraft damage assessment and aircraft attitude.

## **Aircraft Weight**

The maximum structural gross takeoff weight of the Fokker F-28 Mk1000 aircraft is 65,000 pounds. Before taking off from Dryden on the accident flight, the crew of C-FONF did not leave a completed weight-and-balance form with the company agent, as required. As part of the calculations used to estimate the weight and centre of gravity of the aircraft at takeoff, the investigation team's operations group reviewed passenger and baggage weights used by Air Ontario, Air Canada, and Canadian Airlines International Ltd (CAIL) as well as those included in

the Transport Canada-issued A.I.P. Canada: Aeronautical Information Publication, TP 2300E.

In determining aircraft takeoff weight and centre of gravity, Air Ontario F-28 flight crews normally use a winter weight of 169 pounds per passenger and a baggage weight of 23.5 pounds per bag. Air Canada uses winter weights of 193 pounds for males and 146 pounds for females, arriving at an average winter weight of 178 pounds, and a per bag weight of 26 pounds. CAIL uses 28 pounds per bag. The A.I.P. dated October 20, 1988, contains weight calculation data extracted from an airline/Transport Canada survey, with winter weights of 188 pounds for males and 141 pounds for females and an average weight of 164.5 pounds. These passenger weights include exterior clothing and articles of carry-on baggage. Using the above passenger and baggage weights and other relevant information, the operations group calculated that C-FONF weighed between 62,600 and 64,800 pounds when it commenced its takeoff roll prior to the crash.

## **Airworthiness of C-FONF**

As part of the investigation, the maintenance records of C-FONF were reviewed in detail to determine the manner in which Air Ontario was operating and maintaining the aircraft and to ascertain whether the aircraft was being operated and maintained in accordance with the *Aeronautics Act*, the Air Regulations, the Air Navigation Orders (ANOs), and Transport Canada policies.

### **Applicable Legislation and Regulations Effective March 10, 1989**

Section 4 of the *Aeronautics Act*, as amended, makes the minister of transport, or such other minister as designated by the Governor in Council, responsible for the development and regulation of aeronautics within Canada and applies to all aircraft operations within Canada. Section 4 of the Act authorizes the Governor in Council at the request of the minister to make regulations and orders for such development and regulation of aeronautics. Subsection 4.9 is a broad section giving the Governor in Council general powers to make such regulations as necessary, including licensing of persons involved in aeronautics and the conditions under which aircraft may be utilized and operated within Canada.

Part II of the Air Regulations, Consolidated Regulations of Canada, deals with Canadian aircraft registration, airworthiness certification, and markings of aircraft. The documents that govern airworthiness certifi-

cation and standards for aircraft and aeronautical products in Canada are the United States Federal Aviation Regulations, and the Canadian airworthiness manual and engineering and inspection manual. Sections 210 through 221 of the Air Regulations deal with aircraft certification and airworthiness and provide the minister with the powers to ensure that he or she is satisfied that an aircraft operating in Canada “conforms to the applicable standards of airworthiness or is of a design in respect of which a type approval has been issued” or a “certificate of airworthiness in respect of that aircraft” has been granted (s. 211(2)). The Air Regulations empower the minister to make such orders or directions in the form of Air Navigation Orders (ANOs) relating to, among other things, the aeronautical design, airworthiness, approval, and operation and use of aircraft and aeronautical products in Canada.

## **Certification**

### **Certification Requirements**

Before an aircraft can be operated commercially in Canada, the operator must meet certain conditions. With regard to certification, the operator first must apply for and be granted a certificate of airworthiness (C of A) and then must maintain the aircraft in accordance with applicable regulations.

From the Department of Transport Certificate of Airworthiness/Flight Permit Application Form 26-0024 1-77 Amended by AL 24 (not verbatim):

The operator must submit to the Department of Transport an application for a certificate of airworthiness for an aircraft. The application clearly identifies the aircraft and contains the following affirmations: that the aircraft conforms with the Aircraft Type Approval or Type Certificate Number and is airworthy; that the aircraft has been inspected and on the date of inspection was serviceable; that the aircraft was flown and found to meet the standards; and, that all applicable DOT airworthiness/serviceability requirements have been complied with.

The following is from the Air Regulations:

211.(2)

The Minister shall, on being satisfied that an aircraft conforms to the applicable standards of airworthiness or is of a design in respect of which a type approval has been issued and is still current, issue a certificate of airworthiness in respect of that aircraft.

The following is from ANO Series II, No. 4:

*Conditions of Certificate of Airworthiness*

3. Every certificate of airworthiness issued in respect of an aircraft is issued on condition that
  - (a) the aircraft will be maintained in accordance with a maintenance program that meets the aircraft standards of airworthiness established by the Minister pursuant to section 211 of the *Air Regulations*, and
  - (b) an entry will be made in the Aircraft Journey Log of the aircraft by an authorized person, certifying that the aircraft is
    - (i) airworthy, or
    - (ii) released to service,whichever is applicable, at the times and in accordance with the procedures set out therefor in the *Airworthiness Manual* or in the *Engineering and Inspection Manual*.
5. Notwithstanding anything in this Order [ANO Series II, No. 4], a certificate of airworthiness issued in respect of an aircraft is not in force at any time when either of the conditions set out in paragraph 3(a) or (b) fails to be satisfied in respect of that aircraft.

Transport Canada inspectors Randy Pitcher and Ole Nielsen both testified that the certificate of airworthiness of an aircraft is void (that is, invalid) if there is any essential aircraft equipment unserviceable and the defect has not been deferred with respect to the approved minimum equipment list (MEL) for the aircraft. This subject is dealt with in greater detail later in this chapter.

### **Canadian Certification History of C-FONF**

On May 6, 1988, a "Certificat de Navigabilité pour Exportation" (certificate of airworthiness for exportation), number 14638, was issued for the aircraft by the minister of transport for the Republic of France. Typed on the certificate was, "The airplane identified by this Certificate has been examined and found to conform to Canadian Type Approval No. A-108." Aircraft type approval A-108 was issued by the Department of Transport on February 27, 1973, with respect to the Fokker F-28 Mk1000 (approved August 3, 1972) and Mk2000 (approved August 30, 1972) aircraft.

Transport Canada issued a provisional certificate of registration (C of R) and flight permit for C-FONF on May 11, 1988, which allowed Air Ontario to fly the aircraft from France to London, Ontario. On May 19, 1988, Transport Canada issued a C of R for the purpose of private operation, and on June 10, 1988, it issued a C of R for the purpose of commercial operation. A further C of R was issued June 13, 1988. (It

appears a typographical error was made; the June 10 C of R stated F28 MK100, whereas the June 13 C of R stated F28 MK1000.)

A certificate of noise compliance for the aircraft was issued May 26, 1988.

The application for the issue of the Canadian C of A was made under company approval number ACA 57078 (May 18, 1988). A Canadian C of A in the "standard" category was issued May 30, 1988, by Transport Canada after an inspection of the aircraft in London, Ontario, by a Transport Canada inspector.

The Air Ontario Maintenance Control Manual was amended to include reference to the F-28 aircraft. The amendment (no. 3) was approved by Transport Canada on June 3, 1988.

### **Letter of Approval**

A letter of approval, dated March 22, 1989, 12 days after the crash at Dryden, was sent by Transport Canada (Aviation Regulation), London, Ontario, to Air Ontario; on it the Fokker F-28 had been added to the list of aircraft that Air Ontario was authorized to maintain. In testimony, Ms Elaine Summers, CASB chairwoman of the investigation's records and documents group and formerly a Transport Canada airworthiness inspector, stated that a letter of approval would normally be issued at the time the company maintenance control manual amendment regarding a new aircraft is approved, in this case June 3, 1988. In testimony, Mr Nielsen stated that the operating certificate is not predicated on the issuance of a letter of approval. The letter of approval is without basis in legislation, and the authority for a company to maintain an aircraft type is in the approved maintenance control manual.

Airworthiness Staff Instruction, File No. ARD 5009-003-33, Air Carrier Approvals, Audits and Surveillance, was issued by the acting director, Airworthiness Branch, Transport Canada, on July 20, 1987. The purpose of the instruction was to establish the national standards for air carrier certification, audits, and inspections. The instruction contains some information regarding the letter of approval and a sample of the letter. Part II, paragraph 1.3.4, "Issue of Company Approval," states: "Upon being satisfied that the Air Carrier meets all of the Transport Canada requirements, the RMA [regional manager (airworthiness)] may issue a Letter of Approval" (Exhibit 494, p. 18). It is not stated in the instruction that issuance of the letter is a requirement for operation of the aircraft by the company. In order to obviate the ambiguity of the instructions regarding the requirement for a letter of approval, I urge that the issuance of the letter be made mandatory as an indication that Transport Canada is satisfied that the applying air carrier has met all Transport Canada requirements.



## Minimum Equipment List

Most large aircraft are designed and certified with a significant amount of redundancy in their systems so that the minimum standards of airworthiness are satisfied by a substantial margin. A minimum equipment list (MEL) is an alleviating document that regulates the dispatch of an aircraft with inoperative essential aircraft equipment. Basically, compliance with an MEL allows an operator to defer repair or maintenance and fly an aircraft without all the essential equipment operative in order to complete a flight segment, or until repairs can be made. Compliance with an MEL is accomplished through one or more of the following means: adjusting the operating limitations to provide an equivalent level of safety; transferring functions or referencing other operating components; changing the operating procedures; or changing the maintenance procedures. A fundamental understanding is that the continued operation of an aircraft with inoperative essential equipment should be minimized. In Canada, MELs are prepared by the operator and approved by Transport Canada.

Essential aircraft equipment is defined in ANO, Series II, No. 20, section 2 ("Interpretation") as follows:

"essential aircraft equipment" means an item, component or system installed in an aircraft, that

- (a) has a primary role of providing information or performing a function required by regulation or order; or
- (b) is directly related to the airworthiness of the aircraft;

(Exhibit 311, p. 1)

It is a matter of concern that during the testimony of many witnesses, no one, including commercial pilots and Transport Canada employees, found the definition of "essential aircraft equipment" to be readily usable or useful to pilots and technicians during normal aircraft operations. I will discuss this lack of a useful definition of essential aircraft equipment in detail in chapter 16 of this Report, F-28 Program: APU, MEL, and Dilemma Facing the Crew.

Air Navigation Orders, Series II, No. 20, sections 4, 7, and 8, state as follows:

- 4. An air carrier may submit [to Transport Canada] for approval a minimum equipment list for each type of aircraft that he operates.
- 7. No air carrier shall operate an aircraft if any essential aircraft equipment is inoperative unless he does so in compliance with a minimum equipment list.

8. Notwithstanding section 7, no aircraft shall be operated where, in the opinion of the pilot-in-command, flight safety is or may be compromised.

(Exhibit 311, p. 2)

From June 1988 until December 1988, Air Ontario conducted F-28 operations without having an F-28 MEL approved by Transport Canada. Operation of an aircraft without an approved MEL is permitted; however, the Air Ontario F-28 aircraft could not have been legally operated between June and December 1988 with any essential aircraft equipment inoperative. Evidence before me revealed that Air Ontario operated the F-28 aircraft between June and December 1988 with essential aircraft equipment inoperative.

## Maintenance History

### Airframe

The aircraft C-FONF, serial number 11060, had a date of manufacture of November 3, 1972. The aircraft was initially sold to Turk Hava Yollari (THY) (Turkish Airlines, Istanbul) about January 1973. It was subsequently sold by THY to Transport Aérien Transrégional (TAT) (France) about January 1988, and then leased by TAT to Air Ontario for the period March 15, 1988, to March 14, 1989. The aircraft was accepted by Air Ontario about mid-March 1988. At that time, the aircraft had flown a total of 20,394:38 hours and 23,316 cycles. (A cycle is one takeoff and one landing.) At the time of the crash, the aircraft had flown 21,567:23 hours and 24,635 cycles.

The aircraft's maintenance trail, from the time the aircraft was prepared for delivery to Air Ontario to the time of the crash, was closely examined by Commission investigators and canvassed at length during the hearings of this Inquiry. Prior to delivery to Air Ontario, the aircraft was inspected and brought to normal TAT and Canadian standards. It became known during the testimony of Mr Teoman Ozdener, a former director of maintenance for Air Ontario and previously the engineer responsible for the F-28 at THY, that the aircraft had been parked and stored for about two years at THY, Istanbul, before it was purchased by TAT. Mr Ozdener holds a master of science degree in mechanical engineering from California State University and has been employed as a senior liaison engineer in structures and substructures for McDonnell Douglas. Mr Ozdener testified that during the type of storage to which C-FONF was subjected, parts of the aircraft, especially hydraulic seals, deteriorate and lead to breakdowns that in turn cause delays and flight cancellations.

The records for the maintenance performed since the aircraft entered Canada indicate that the aircraft was maintained in accordance with the

Transport Canada–approved maintenance system contained in the Air Ontario Maintenance Control Manual. The records also indicate that all requirements of the approved maintenance program were completed on time or within the approved tolerance (10 per cent of the time between inspections or other related activity, or 50 hours non-cumulative, whichever is less). As well, none of the components on the aircraft when it crashed was overdue for inspection, replacement, or overhaul on a time basis.

During the review of the maintenance records, it was discovered that the records contained numerous entry and mathematical errors. It was the opinion of Ms Summers that, at the time of the accident, the errors had not resulted in any components going beyond their operating limits or any inspections being missed. (It was discovered during the investigation of the wreckage that the left and right inboard wheel brakes were worn beyond specified limits, but errors in the records were not a factor here.)

The aircraft was last reweighed on May 16, 1988, at TAT, France, and had a basic empty weight of 36,501.89 pounds and a centre of gravity of 483.22 inches aft of the datum. The weight and balance were amended October 19, 1988, to 36,539.00 pounds and 483.06 inches, because of some minor additions, deletions, and substitutions (primarily the change to a different flight data recorder). Although an additional weight of approximately 136 pounds was added when new fire-blocking seat material was installed in December 1988, the weight and balance were not appropriately amended. The engineering and inspection manual referred to in the Air Regulations requires that the operator amend and submit revised weight and balance reports to Transport Canada. Although the total weight change may have been small, it still must be included in the weight and balance calculation. By failing to recalculate and revise the weight and balance on C-FONF and submit it to Transport Canada, Air Ontario failed to comply with the requirements of Transport Canada's engineering and inspection manual and was therefore in breach of the Air Regulations.

## **Engines**

The history of the engines is outlined below:

	<b>Left (No. 1)</b>	<b>Right (No. 2)</b>
Make	Rolls-Royce	Rolls-Royce
Model	Spey RB 183-2 Mk555-15	Spey RB 183-2 Mk555-15
Specification	1037	1037
Serial number	9130	9187
Date of manufacture	December 1971	February 1973
Date installed C-FONF	April 28, 1988	May 4, 1988

At the time these engines were installed in C-FONF, this aircraft had a total time of 20,393:03 hours and 23,315 cycles. The engine times/cycles at the time of installation were as follows:

	<b>Left (No. 1)</b>	<b>Right (No. 2)</b>
Total hours since new	21,729:55	10,026
Hours since overhaul	8,380:10	4,037
Total cycles since new	20,938	6,641
Cycles since overhaul	9,055	2,357
Cycles since hot section inspection (HSI)	zero	zero

Prior to its first flight of March 10, 1989, C-FONF had a total time of 21,565.7 hours and a total of 24,632 cycles. According to the Air Ontario SOC log, the aircraft flew 1:41 hours and three cycles on March 10, 1989. The engine times/cycles at the time of the crash were calculated to be as follows:

	<b>Left (No. 1)</b>	<b>Right (No. 2)</b>
Total hours since new	21,901:57	10,198:02
Total cycles since new	21,258	6,961

As of March 10, 1989, all applicable engine airworthiness directives (ADs) had been complied with. Logbook entries verify that both engines were maintained in accordance with the approved maintenance program.

### **Deferred Unserviceabilities**

An exhaustive review of the journey log for C-FONF, undertaken during the course of the hearings of this Inquiry, revealed that many aircraft unserviceabilities were carried forward or deferred by the Air Ontario maintenance department in the approximately six months that Air Ontario operated its F-28s without an approved MEL. The following is a list of such deferrals dating from June 9, 1988, when Air Ontario first began revenue operations with the aircraft, to December 19, 1988, when the F-28 MEL was approved by Transport Canada and officially put into use by Air Ontario. The evidence was that Transport Canada had given verbal approval to the proposed MEL, but there was disagreement over the actual date that verbal interim approval of the MEL by Transport Canada was received by Air Ontario. This subject is covered fully in chapter 16 of this Report, F-28 Program: APU, MEL, and Dilemma Facing the Crew.

- [1] June 9, 1988 – Fuel reported venting from wing vents by YZ ATC [Toronto Air Traffic Control]. Rectification – deferred MX Control #0158 YAM 9-6-8.
- [2] June 19, 1988 – #2 system auxiliary AC hydraulic pump intermittent. Rectification – carried fwd.
- [3] June 22, 1988 – F/O clock u/s. Rectification – carried fwd.
- [4] June 23, 1988 – left flight control light (hyd pump) illuminated constantly. Rectification – carried fwd.
- [5] June 24, 1988 – Flight crew reported #1 hyd quantity system gauge u/s. Rectification – operate as per Flight Manual operating deficiencies list Vol 1. Deferred.
- [6] June 28, 1988 – Anti-skid u/s. Left side does not test in flight. Rectification – carried forward. Operate as per Flight Manual.
- [7] July 15, 1988 – Captain's clock u/s. Rectification – Swapped for F/O clock. F/O clock u/s and carried fwd.
- [8] July 27, 1988 – Cockpit pack temperature control only in manual position. Rectification – carried forward.
- [9] August 15, 1988 – Flt crew reports APU fire ext test to be intermittent. Rectification – carried forward. Operate as per Flight Manual CDL [Configuration Deviation List].
- [10] August 31, 1988 – Yaw damper slightly unsteady. Rectification – C/F.
- [11] September 1, 1988 – Aileron control pilot wheel slight left right motion in cruise; autopilot on causing yaw damper to move all the time. Rectification – previously carried forward ... Servicing tool on order.
- [12] September 12, 1988 – Yaw damper is starting to slew tail around again resulting in aileron's moving with slight rocking motion. Rectification – carried forward. Operate as per F-28 Flight Handbook.
- [13] September 22, 1988 – F/O's alt [altimeter] not lit. Rectification – C/F. Parts on order.
- [14] September 22, 1988 – Cpts panel does not have lit time piece. Rectification – C/F
- [15] September 25, 1988 – Barber pole showing at least once during take-off and landing roll. Indications problem only, liftdumpers do not come out. Rectification – carried forward. Test equipment ordered.
- [16] September 25, 1988 – #2 fuel flow meter is intermittent. Works about 75% of the time. Did same in #1 position yesterday. Rectification – carried forward. Parts ordered.
- [17] October 9, 1988 – Please adjust F/O's rudder pedals for correct left right alignment. Rectification – carried fwd.
- [18] October 14, 1988 – Cockpit a/c pack magnetic indicator shows "off line" most of the time. Temperature can only be controlled manually. Rectification – carried forward – continue operation in manual mode.

- [19] October 19, 1988 – APU hangs up at 20% RPM, TGT then rises to red line (705°) without further increase in RPM. APU was turned off. Rectification – APU u/s – Deferred.
- [20] October 29, 1988 – Wing and tail anti-ice panel goes dark (lights go out) when selected on, comes back on when selected off. Rectification – carried forward.
- [21] November 15, 1988 – If cockpit air conditioning not selected cold after t/o the pack drives full hot producing a hot smell. Rectification – previously carried fwd.
- [22] November 23, 1988 – Knob on L/H thrust index gauge slips. Rectification – C/F. Part on order.
- [23] November 28, 1988 – Gen. #1 drive coupling disengaged. - Rectification – C/F.
- [24] November 30, 1988 – Cockpit pack temp control u/s in auto selection. Rectification – C/F.
- [25] December 2, 1988 – Upper half of airfoil anti-ice panel is without lights (intermittent, when pressure is applied lights come on). Rectification – Deferred.
- [26] December 2, 1988 – Automatic control for cockpit air cond pack is intermittent. Magnetic indicator is “off line” most of the time, occasionally it goes to “in line.” Rectification – previously deferred.
- [27] December 14, 1988 – Autopilot rolls wings inducing yaw in put above 15,000’ and mach .60 same as page 18866 #1. Rectification – C/F.
- [28] December 18, 1988 – #3 Alt under frequency when APU loaded up. Rectification – C/F as per ANO Series 2, #20. Alt not ESS [essential?] for flight.

As will be seen in chapter 16 of this Report, which deals in detail with the MEL, the definition of “essential equipment” in ANO Series VII, No. 2, is ambiguous. In the absence of a clear definition as to what constitutes essential equipment, it may be that some of the above-noted defects do not relate to essential aircraft equipment; it is, however, obvious that some of them do relate to it. Some of the more obvious defects related to essential equipment are those listed above as numbers 2, 4, 9, 15, 19, 23, and 25, but the list is not necessarily complete. *Any deferral of a defect related to a piece of essential equipment must be made with reference to an approved MEL.* This procedure must be carried out to ensure that the deferral is made with a full appreciation of the ramifications of the unserviceability on both operations and maintenance; it is also required by legislation. Based on the evidence before me, it is my opinion, and I conclude that, *any deferral of a defect related to an item of essential aircraft equipment, without reference to an approved MEL, effectively voids the certificate of airworthiness.* That being the case, it follows, and I find, that Air Ontario operated its F-28 aircraft, C-FONF, on a number of occasions without a valid certificate of airworthiness.

## Reportable Incidents

The Canadian Aviation Safety Board Regulations, as part of the *CASB Act*, define, in section 2, what are “reportable incidents” and require, pursuant to section 5(1), that these incidents be reported to CASB. Contravention of the Act or the regulations is referred to in section 32 of the *CASB Act*, which states, “Every person who contravenes any provision of this Act or the regulations for which no other punishment is provided is guilty of an offence punishable on summary conviction.”

One type of reportable incident is smoke occurring in an aircraft. The review of Air Ontario records revealed three apparently reportable incidents related to smoke in the cabin of C-FONF in flight. There is no indication that the incidents were reported to CASB. The three incidents were recorded in Air Ontario logbooks as follows:

- [1] January 21, 1989 – cockpit a/c pack causing smoke in cabin. Pack switched “off” for remainder of flight. Rectification – Carried fwd.
- [2] February 27, 1989 – On 1st & 2nd flight of day, cabin filled with oil smoke – very thick. Rectification – found cooling turbine drain releasing oil on duct. Drain repositioned.
- [3] March 6, 1989 – On first t.o. cabin became smoky. Pass. complained. Smoke detector went off. Cabin temp. on overhead showed 30°. Smoke went away after 5 – 10 mins. Rectification – oil found in APU outlet ducts, oil removed.

On March 8, 1989, aircraft C-FONF, piloted by Captain Robert Nyman, at the time an Air Ontario F-28 check pilot with no management duties, and First Officer Keith Mills took off from Winnipeg. Just after takeoff, the cabin once again filled with an oily haze, which, according to Captain Nyman, emanated from the APU. Captain Nyman stated in evidence that this occurrence was another instance of a recurring problem on the aircraft. It had not been logged in the aircraft journey logbook, but Captain Nyman agreed that it should have been entered. No record of deferral appears in the logbook, nor is there a description of rectification by maintenance. Neither this occurrence nor the three previously listed ones were reported to CASB, nor was the aircraft grounded until such time as the problem could be rectified.

The absence of any report to CASB with respect to the above occurrences indicates either a lack of awareness of the reporting requirements by those involved, who are presumed to know the law, or a reluctance to report the incidents owing to the possible consequences and the follow-up actions required. In the worst-case scenario, these incidents could have entailed the grounding of the aircraft until a thorough CASB investigation had been completed, which could have

resulted in loss of the aircraft from revenue service for a considerable period. The temptation not to report to CASB was obviously there. In my view, it is unlikely that flight crew and maintenance personnel would be ignorant of the requirement to report cabin smoke to CASB. The evidence is overwhelming that Air Ontario management and many of the F-28 flight crews were bent on keeping the F-28s flying.

### **State of Serviceability of C-FONF on March 10, 1989**

The following unserviceabilities were outstanding according to the C-FONF journey logbook on the morning of March 10, 1989, prior to departure from Winnipeg:

- [1] September 22, 1988 – Capt's panel does not have lit time piece. Deferred IAW ANO Series 2-20. Licence ACA 87077. (Note – This deferral had been carried for almost six months).
- [2] February 8, 1989 – Roll and yaw not working properly in autopilot. Licence ACA 87118. Deferred
- [3] February 8, 1989 – F/O windshield wiper creeps up in flight. Licence ACA 87118.
- [4] February 23, 1989 – Pilot reports LH fuel gauge still intermittent (reads full). Licence ACA 87015. Carried Forward – Deferred.
- [5] February 24, 1989 – Number 1 Constant Speed Drive warning light tests but won't come on after shut-down. Licence ACA 87042. Deferred MEL 02-24.
- [6] March 9, 1989 – APU will not fire test. Licence ACA 87101. Deferred MEL 49-04.

During her testimony before me, flight attendant Sonia Hartwick stated that there were other discrepancies brought to the attention of the flight crew, either by Mrs Hartwick herself or by flight attendant Katherine Say, prior to the first flight on March 10, 1989. As far as could be determined during the investigation, these discrepancies were not entered in the journey logbook or any other log. It is not known what determination the flight crew may have made about these reported discrepancies, but there was no evidence that the discrepancies were rectified at any time. They were as follows:

- 1 The exit light over the main entry door was not working.
- 2 The exit light over the cabin door, on the cabin side, was not working.
- 3 The cabin emergency floor lighting was dimmer than normal and had a bluish rather than a bright white colour.
- 4 There were three altitude-compensating oxygen masks missing from the back of the aircraft.



5 There had been some difficulty closing the main entry door in Winnipeg. A plastic surclip that normally held the door handle in the stowed position when the door was closed had broken, and the handle was being held in place by double-sided tape. The difficulty in closing the door could have been attributable to the fact that the door operating handle was being held in the stowed position by the tape while an attempt was made to close the door. Neither the tape itself nor the fact that the surclip was broken apparently posed any danger of the door opening inadvertently.

I have no reason to believe the flight crew was not made aware of the above discrepancies. Since the approved MEL did not provide alleviation for some of these deficiencies and since the crew took off without having these discrepancies rectified, the crew would have done so in violation of existing regulations regarding essential equipment unserviceabilities.

## **Validity of Certificate of Airworthiness of C-FONF while Operated by Air Ontario**

### **Letter of Approval**

My review of the evidence suggests that a letter of approval is an administrative tool, with no basis in law, used to assist the regulator in ensuring that operators have knowledge of their requirements with regard to the certificate of airworthiness and to assist the regulator in auditing and inspecting the company to which the letter applies. Upon reviewing the evidence regarding Air Ontario's letter of approval, it is my opinion that the absence of any reference to the F-28 aircraft in the letter did not affect the validity of C-FONF's certificate of airworthiness.

### **Maintenance Control Manual**

Amendment number 3, which added the F-28 aircraft to the Air Ontario Maintenance Control Manual, was approved June 3, 1988. This amendment effectively gave Air Ontario the right to operate C-FONF as long as the carrier followed the maintenance practices described in the approved manual, other regulations not considered. Upon review of the evidence and information before me, it appears that Air Ontario deviated from its Maintenance Control Manual only with regard to the minimum equipment list (MEL), as described earlier.

### **Minimum Equipment List**

In accordance with the applicable legislation, and according to the testimony of Transport Canada inspectors Randy Pitcher and Ole Nielsen, the certificate of airworthiness of an aircraft is invalid if the aircraft is operated with any essential equipment unserviceable and there

is not an approved MEL pursuant to which the unserviceability can be deferred. The MEL for the F-28 aircraft operated by Air Ontario was not approved until December 19, 1988. Between the time C-FONF went into operation with Air Ontario in June 1988 and December 19, 1988, the aircraft was frequently dispatched and operated with essential aircraft equipment inoperative. Rectification of this inoperative equipment was deferred without reference to an approved MEL. Rectification was deferred with reference to the flight manual's operating deficiencies list, deferred with reference to the configuration deviation list, or deferred by stating "operate as per the F-28 flight handbook"; or the deficiency was simply carried forward. As well, there is ample testimony that notes describing unserviceabilities were written on pieces of paper and passed from pilot to pilot without the pilots entering the information in the journey logbook until the end of the flying day; effectively, this practice allowed the aircraft to be flown when unserviceable. None of these procedures is Transport Canada approved. Based on the evidence before me, and as previously stated, Air Ontario, prior to December 19, 1988, when the F-28 MEL was finally approved, operated C-FONF without a valid certificate of airworthiness each time it operated the aircraft with essential equipment inoperative.

## Findings

### Aircraft Wreckage Investigation

- There were no pre-crash faults found with the aircraft or engines that could have contributed to the accident.
- The engines were operating at takeoff power or greater during the takeoff.
- The engine anti-icing system was selected ON during the takeoff.
- All aircraft and engine damage was the consequence of impact with trees and the ground and the ingestion of foreign material.
- The fact that one of the engines reportedly smoked during a start at Winnipeg was not related to the accident.
- The auxiliary power unit (APU) was unserviceable because it would not fire test, and it was not used during the stop at Dryden.
- During post-crash testing of the APU, it was discovered that its fuel

control unit was unserviceable.

- The landing gear was moving to the up position at the time of the crash.
- The wing flaps were positioned at 18° at takeoff but were found at 25° to 27° extended at the time of the crash.
- The wing and tail anti-icing system was off during the takeoff.
- There was no evidence of fire prior to the aircraft striking the trees.
- The flight recorders revealed no useful information because they were destroyed in the post-crash fire.
- The brakes of both inboard main wheels were worn beyond limits.

### **Airworthiness of C-FONF**

- Both aircraft main engines were maintained in accordance with the approved maintenance program.
- Air Ontario personnel often deferred aircraft unserviceabilities in an unauthorized manner and then flew the aircraft without the unserviceability being rectified.
- Because of the unauthorized manner in which some aircraft unserviceabilities were deferred, Air Ontario on a number of occasions operated its F-28 aircraft, C-FONF, without a valid certificate of airworthiness.
- Air Ontario failed to report certain reportable aircraft incidents to CASB in accordance with requirements of the *CASB Act*, as evidenced by the fact that on at least four occasions there was smoke in the cabin of an Air Ontario F-28, yet CASB has no record of such reports to that effect.

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## **RECOMMENDATIONS**

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### **Aircraft Crash Charts**

Based on the evidence that there were no F-28 aircraft crash charts

available at the crash, fire-fighting, and rescue (CFR) unit at Dryden on the day of the accident, and that the flight data and cockpit voice recorders were destroyed by fire, I had intended to make recommendations as to the availability of crash charts and their use in the training of CFR unit personnel. It appears, however, that, since the hearings of this Commission, Transport Canada has been instrumental in ensuring that all Transport Canada-owned and operated airports have aircraft crash charts readily available. These initiatives more than satisfy my concerns in relation to Transport Canada-owned and operated airports, and recommendations for such airports are, accordingly, not required. In relation to all airports in Canada that are not Transport Canada-owned or operated, I make the following recommendation:

- MCR 33** That Transport Canada, in cooperation with airport operators, ensure that all Canadian airports not owned or operated by Transport Canada, which service a scheduled air carrier operation, have appropriate crash charts made available to the same degree and extent as at airports owned and operated by Transport Canada.

### **Survivability of Flight Data Recorders and Cockpit Voice Recorders in Aircraft Crashes**

The recorders in C-FONF were destroyed by fire and were of no use to the investigators of this crash. Because recorders capture essential parameters of aircraft information and performance, and are normally the source of the best investigative information, it is vitally important that their crash survivability be enhanced. I therefore make the following recommendations:

- MCR 34** That Transport Canada and the Transportation Safety Board of Canada, through national and international initiatives and committees, continue to press for the adoption of more rigorous survivability test requirements for aircraft flight data-recording systems.
- MCR 35** That Transport Canada and the Transportation Safety Board of Canada undertake a research program leading to the development of the most suitable deployable or non-deployable aircraft flight data-recording systems that can reasonably be expected to survive any crash and yield usable data.

- MCR 36 That Transport Canada and the Transportation Safety Board of Canada study, or cause to be studied, the location of aircraft flight data–recording systems in aircraft, with a view to assuring the survival of the recording systems in any crash.

### **Letter of Approval Requirement**

It is not clear in the Transport Canada instructions whether the issuance of a letter approval is a requirement. In the approval process of the maintenance control manual or any amendment thereto, in my view, the letter serves a purpose, and thus I make the following recommendation:

- MCR 37 That Transport Canada make mandatory the issuance of a letter of approval to an air carrier as an integral part of the approval process of the “maintenance control manual” or any amendment thereto.

### **Definition of “Essential Equipment”**

Testimony given at this Commission’s hearings revealed that there is not a definition of the term “essential equipment” that is readily usable or useful to pilots and technicians during normal aircraft operations. It is therefore recommended:

- MCR 38 That Transport Canada redefine in Air Navigation Order Series II, No. 20, the term “essential equipment,” in order that it be unambiguous and easily understood by pilots and technicians who have to use or refer to the term.

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# 11 AIRCRAFT CRASH SURVIVABILITY

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On March 10, 1989, Air Ontario flight 1363 carried 65 passengers and an aircraft crew of four when it crashed. Forty-four passengers and one crew member survived the crash of C-FONF.

The first section of this chapter briefly outlines the survivors' accounts of this crash and their escape from the aircraft wreckage. Most survivors were interviewed and were asked, for purposes of the investigation, to provide their recollections of the crash. Having heard the evidence of many of the survivors and rescuers, I was struck by the fact that so many passengers survived this severe crash and managed to escape from the aircraft wreckage and fire. Their stories are a lasting reminder of the effect that such a tragedy can produce.

Subsequent sections provide more clinical descriptions as to what happened to the aircraft as it crashed.

## Passengers' Recollections

The aircraft was hitting trees, hitting trees, and at that point the aircraft. I guess was decelerating and we were inside the blender effect ... you take a blender, threw in some metal, some trees, people and turn it on.

(Transcript, vol. 14, pp. 91-92)

These are the words used by Mr David Berezuk, a surviving passenger and an Air Ontario Dash-8 captain, to describe his memory of that short flight. They vividly depict the reality of the aircraft accident. I heard many other descriptions of the crash, and, for most of the surviving passengers, those few seconds of flight can be described as a slow motion replay in their minds. It seems that, as the realization grew that an accident was inevitable, events crystallized in the memory of each person.

Many of the passengers described how the aircraft taxied out and lined up for its takeoff roll. Many described two liftoffs during the takeoff roll, and some were very specific about the height and angle of the aircraft during each of those liftoffs. As the aircraft finally lifted off near the west end of the runway, many on board knew that something was wrong. Passenger Murray Haines, an Air Canada DC-9 captain, described the takeoff in the following words:

As the aircraft got to speed, it rotated I would say at least 10 degrees, and it lifted a bit and then sat back down. And then more power was added, and it rotated further. And then the mushing I'm talking about ... it just maintained this attitude and was mushing through the air. It didn't drop a wing until we started hitting the trees.

(Transcript, vol. 19, p. 45)

As the aircraft began hitting the trees, flight attendant Sonia Hartwick shouted to the passengers to brace themselves, telling them to grab their ankles and keep their heads down. In the rear of the aircraft cabin, Captain Berezuk shouted similar commands, as did Mr Clyde Ditmars at the front.

After the first tree strike, the aircraft levelled briefly and a few passengers thought the aircraft would fly away. Then the aircraft hit more trees, and the drumming noise on the bottom of the fuselage intensified. Special Constable Dennis Swift of the Royal Canadian Mounted Police recalled his feelings as the aircraft plunged into the trees:

I was bent over and hanging on and it was – the trees kept coming and coming and coming. I could – was visually thinking of what was going on.

As the aircraft was going through the trees, I could hear the trees grinding away or tearing away at the underside of the aircraft. It seemed to take forever. It was – it seemed to take an awfully long time.

And I was just, I don't know, subconsciously thinking of how long it was going to be before the trees finally came through the floorboards of the aircraft and what would happen at that point.

It just seemed to take a long time. The rumbling through the trees and the tearing away of metal.

(Transcript, vol. 18, pp. 84–85)

One can imagine the horror experienced by the passengers as the aircraft tore through the trees. Bent in the brace position, some passengers saw a bright flash of light outside the left side of the aircraft, and others saw the light flash through the cabin. Originating from somewhere at the left rear of the aircraft, this flash, described by some as a fireball, shot from the rear to the front of the cabin. The flash was followed by a spray of jet fuel through the cabin that soaked the clothing of many passengers. Then the aircraft came to a sudden stop. Mr Brian Perozak related the abruptness to a previous experience:

Yes, I remember impacting the trees and it felt like we were almost stopped, and then – and then the impact was worse, like, we stopped dead.

...

I had an accident a few years ago in a vehicle hitting a tree and the truck stopped dead at 40 miles an hour and, like that, even harder, without moving.

(Transcript, vol. 16, p. 241)

From the testimony, it was apparent that the abrupt stop rendered many surviving passengers momentarily stunned or unconscious. Those who remained conscious testified that, as the fuselage came to a stop, the overhead bins became dislodged, causing cabin baggage stored therein to move about and to fall on the passengers below. Snow, mud, and parts of trees had entered the cabin, covering some of the passengers. More fuel sprayed on the still seat-belted passengers through holes in the cabin. As they fumbled for their seat belts, they smelled smoke, saw fire, and searched in a darkened cabin for a way out.

The aircraft had broken into three parts and lay in the woods in the shape of a large U. The front portion of the aircraft, compressed to the left, formed one arm of the U; the main fuselage, the passenger cabin portion of the aircraft, formed the base; and the tail section lay parallel to the nose of the aircraft.

There were 13 rows of seats in the aircraft, each row with three seats to the left of the centre aisle and two to the right (figure 5-2 in chapter 5, *Events and Circumstances Preceding Takeoff*). When the tail section swung away from the fuselage, the last row of seats, row 13, remained with it. Captain Murray Haines and one of his daughters found themselves almost in the open on the right side of this section. Two RCMP special constables and a prisoner were more enclosed on the left. With the exception of Special Constable Dennis Swift, all these persons easily exited the aircraft. He suffered a severely fractured leg, and, after removing his seat belt, he fell into the gap between the fuselage and the tail section. He was then stepped on while he lay there, until fellow passengers Mr Alfred Bertram and Mr John Biro dragged him to a safer position.

Passengers from row 8 back to the rear of the aircraft found that escape out the front of the aircraft was blocked by what seemed to be an impenetrable wall of debris. The left wing of the aircraft had disintegrated during the aircraft's descent through the trees, and a curtain of fire blocked escape to the left. Mr Thomas Harris, seated beside the left-side emergency exit at row 8, was the only survivor to escape through that exit, suffering severe burns to his hands in doing so. Passengers seated in the rear of the cabin went through either the opening in the fuselage at the rear of the aircraft or through the right-hand window



exit. This exit may have been partly blocked, either inside or outside the fuselage, and those who exited this way could not determine if their point of egress was in fact the emergency exit.

Seated at the rear of the aircraft were a number of families who were travelling on spring school-break vacations. The Godin family of four from Thunder Bay was seated in row 9. Mr Daniel Godin was travelling with his wife and two children. After assisting his wife and one child exit the burning wreckage (his other child followed another passenger out of the aircraft), he returned to the interior of the rear portion of the aircraft, where he helped two survivors extricate themselves from debris and moved them towards the opening in the rear of the fuselage. He left the wreckage only after assuring himself that there were no other passengers amid the debris in the tail section visible through the thick, black, acrid smoke. After ensuring the safety of his family outside the aircraft, Mr Godin proceeded to the burning front section of the aircraft, which he entered. He then assisted four injured survivors to a safe distance from the burning aircraft. Next he opened suitcases that had been strewn about and distributed clothing to some survivors as protection against the snow and the cold. Despite having been doused with fuel during the crash sequence, he returned to the aircraft and attempted to rescue two passengers from an intense fire in the left-hand portion of the interior aircraft, only to be forced back by the flames and heat. It has been estimated that, in addition to his family, Mr Godin assisted 12 passengers to escape the aircraft.

Captain Haines, having first taken one of his daughters away from the aircraft, returned to extricate his wife. His other daughter exited through what may have been the right emergency exit location.

At the front of the wrecked aircraft, surviving passengers faced even greater dangers. Here the fire moved the fastest, and here the cabin area was compressed by the crash forces. It was from row 7 forward, and principally on the left side of the aircraft, that the majority of the fatalities occurred.

Two friends, Mr Brian Adams and Mr Brian Perozak, on their way to a curling tournament, were seated in the two seats on the right side of the aircraft in row 4. After the crash, they found themselves buried under trees, snow, luggage, and part of the aircraft. They could feel other passengers exiting over the part of the aircraft wreckage that was covering them. After a few minutes of struggle to free himself from the debris, Mr Perozak was able to unlatch his seat belt. He then crawled through a small opening in the rubble and got clear of the aircraft. Turning around, he observed his friend Mr Adams, whose legs were trapped under the wreckage. Mr Perozak immediately began to remove debris from his friend's legs. During this time, others exiting the aircraft fell over both of them as they hurried to leave the aircraft wreckage. Mrs

Nancy Ayer, her body in flames, fell on the trapped Mr Adams; she was then assisted by Mr Godin to an area away from the burning aircraft. Despite having suffered what would prove to be fatal burns, she encouraged rescuers to look after others. Mrs Shelley Podiluk, holding her baby, exited the wreckage with the assistance of Mr Ricardo Campbell. During this time, the fire in the aircraft was quickly approaching Mr Perozak and the trapped Mr Adams. The fire was close enough for Mr Perozak to feel the synthetic fibres in his sports coat become tacky from the heat. Mr Adams, trapped and lying on his back, saw a nearby tree catch fire and realized that there was little time left to escape. He described the scene as follows:

And the heat was – the heat was getting hot and Brian [Perozak] was saying the heat is getting unbearable, I can't stand the heat or something like that.

...

And I can remember thinking that we have time to give it one more try to pull my leg free. If we can't, I have got to tell him to get out and I'm on my own.

And Brian at this time wedged his hands so he was grabbing on my calf and I somehow got some leverage on my – with my right foot on something and we just tug and all of a sudden it just popped out for some reason.

(Transcript, vol. 16, pp. 203–204)

Many of the passengers who exited the right side of the aircraft gathered in the woods; flight attendant Sonia Hartwick and others called for everyone to stay together away from the aircraft. On the left side of the aircraft, two passengers were later found pinned in the wreckage and were extricated by rescuers; Mr Michael Kliever, suffering burns and massive trauma, lay pinned on top of Mr Uwe Teubert, his body sheltering Mr Teubert from the heat of the fire. Mr Teubert shouted for help, but, although some may have heard his calls, it appears that no one discerned where they were coming from. It was not until nearly an hour after the crash that these two men were freed from the burning wreckage. When Mr Kliever was removed, Mr Teubert, badly injured, managed with assistance to extricate himself from the wreckage. Mr Kliever died later in hospital.

Most of the survivors made their way out of the woods along the path made by the first rescuers on the scene. The first group of survivors reached Middle Marker Road less than 20 minutes after the crash. At 12:32 p.m., 21 minutes after the crash, Fire Chief Ernest Parry radioed that there were about 20 to 25 survivors walking to the corner of McArthur and Middle Marker roads. Many of these people, suffering from burns and other injuries, departed the crash site in their shirt-

sleeves and stocking feet. They were put into vehicles or sent to a nearby house to keep warm. All were subsequently transported to the Dryden hospital, by ambulance and in vehicles volunteered by local people who had come to help.

Another example of unselfish assistance provided to surviving passengers by a crash survivor is to be seen in the actions of Mr Alfred Bertram. A flight services specialist working at Rankin Inlet, Northwest Territories, Mr Bertram was wearing a green Transport Canada security pass. His pass was still clipped to his shirt when he helped carry the stretcher bearing Mrs Ayer from the crash site to McArthur Road. By the time he reached the road, he was wet from falling in the snow, and his hand was frozen in position on the stretcher. When the stretcher was finally placed in an ambulance, almost an hour after the crash, the ambulance attendant, seeing Mr Bertram's badge and assuming he was an airport official, told him to return to the crash site. Mr Bertram headed back down the road, stopped, and helped load equipment to be taken into the site. Then, as he walked towards the crash site, he met two more survivors who were being brought out and was asked by those assisting the survivors to find an ambulance. After doing so and helping at the corner for a few minutes more, he started back down the road again. This time he did not get as far. With "rubbery legs," he decided that he might be a hindrance if he went back to the crash site. One and a half hours after the crash, Mr Bertram was taken to a police car for a much-needed rest.

Dennis Swift, the RCMP special constable, after being assisted from the aircraft and having a crude splint placed on his broken leg by fellow passengers Bertram and Biro, sat in the snow and recorded in a notebook his observations regarding the crash. He and one other survivor, Mr Michael Ferguson, were finally taken out of the woods by stretcher more than one hour after the crash. They were the last survivors to leave the crash site. Their ambulance did not depart until after 1:45 p.m., approximately the same time as the ambulance carrying Mr Kliewer and Mr Teubert left. Mr Godin, who travelled to the hospital with Special Constable Swift and Mr Ferguson, helped administer oxygen during the trip and assisted them into the hospital on arrival. Mr Godin's day as a survivor/rescuer finally ended two hours after the crash, when, cold and exhausted, he was reunited with his family at the hospital.

A number of other passenger survivors performed acts of heroism on that day. The evidence of many of the surviving passengers forms part of the record of this Commission. That record, gathered on behalf of all the passengers on flight 1363, has been invaluable.

## **Survival Factors**

The following section consists of observations regarding relevant aircraft passenger survival factors. It is based on the investigation conducted by the human factors investigators, as reported by them in writing and in testimony before this Inquiry.

### **Cabin Safety**

Prior to the final takeoff of C-FONF on March 10, 1989, a pre-flight safety demonstration was conducted by the flight attendants. All passengers had access to emergency information cards for the F-28 aircraft, which were stowed in the seat pouches. The majority of the survivors report having paid some degree of attention to the flight attendants' pre-flight safety demonstration and/or having read the emergency card. Various survivors reported that the overhead luggage racks contained such carry-on items as passengers' overcoats and at least one garment bag, all seat backs were upright, the seat trays were stowed, and all passenger seat belts were properly fastened.

During the week of March 6–10, 1989, flight attendants Katherine Say and Sonia Hartwick detected a number of problems with the aircraft. Each of the problems was recorded in the aircraft journey log and compared against previous entries to determine if these faults had been previously entered and if they had been previously repaired. Sonia Hartwick indicated that Katherine Say had a list of problems which she intended to take up with the manager of in-flight services when the flight attendant returned to the London offices on March 13.

Specifically, smoke, the cause of which was never conclusively determined, had entered the cabin and flight deck on several occasions during that week; there were discrepancies in the number and types of emergency oxygen masks in the passenger cabin; there was some difficulty experienced in locking the main aircraft entry door, and it was necessary to tape the door-locking handle in place; the emergency floor track-lighting was dim and bluish; and the emergency exit lights over both the aircraft's main entry door and the passenger side of the cabin entry door were not working; and there was difficulty with the aircraft pressurization system. It was reported that each of the problems listed above was brought to the attention of the captain, logged in the journey logbook each time it was discovered, and reported to maintenance. However, during that week none of the problems was corrected.

On May 18, 1988, Transport Canada inspector J. Rutherford had conducted a passenger safety inspection of C-FONF. During this inspection, a number of minor safety deficiencies were observed, among them a lack of directional indicators on the floor proximity lighting. On

June 2, 1988, Transport Canada inspector J. Brederlow conducted another cabin safety inspection of C-FONF and commented on the lack of a restraining web for a rear coat closet and the lack of shoulder harnesses for the flight attendants' seats. In fact, there was no legal requirement that the aircraft have flight attendant seat shoulder harnesses installed.

Because the aircraft was so badly damaged by the impact and the post-crash fire, it was difficult to assess many cabin safety issues. For example, some passengers reported that the collapsed overhead luggage racks and ceiling panels restricted their egress from the aircraft. However, with the cabin being all but destroyed by fire, it was not possible to determine if the collapse was attributable to design, construction, or maintenance. Given the nature of the impact and the breakup of the fuselage, it would seem unreasonable to expect luggage racks and ceiling liners not to collapse. The speed with which the fire took hold of the cabin interior was also considered. There is a requirement that passenger seats be constructed with fire-blocking material, but rapid fire propagation continues to be a recognized problem with most aircraft. (The issue of cabin material is addressed further in a later section of this chapter.)

Another cabin safety issue involves the clothing worn by the flight attendants. Flight attendant Hartwick's outer clothing comprised slip-on shoes, a light dress, and a sleeveless vest. She lost one shoe in the aircraft and the other outside the aircraft, in the snow. She eventually borrowed a pair of shoes from a passenger, enabling her to better help the survivors. I see a need for there to be more attention paid to clothing all flight attendants in a manner that will allow them to better provide the leadership required of them in an emergency.

## **Passenger Behaviour and Evacuation**

Shortly after the aircraft became airborne, many passengers and at least one flight attendant, Soria Hartwick, realized that the aircraft was not flying properly. Even before the initial contact with the trees, a few passengers were assuming a brace position, and flight attendant Hartwick, seated in the midsection of the aircraft in seat 8D, commanded passengers to brace themselves. Twenty survivors reported heeding her instructions. Some survivors, particularly those seated beside family members, attempted to protect their seat mates by covering them with their arms or bodies. All survivors, including those who had not heard the flight attendants' commands, had assumed some semblance of the brace position prior to the aircraft striking the ground.

The survivors reported hearing the aircraft initially begin hitting the trees. As the aircraft descended lower into the trees, battering sounds were increasingly more severe and the aircraft was shuddering increas-

ingly more violently. The sound of the aircraft striking trees and the sound of tearing metal, up to and including the final ground impact, was accompanied by passengers' screams and yells. A passenger seated in the midsection of the aircraft reported looking up prior to the aircraft striking the ground and observing passengers being rocked about, items falling from the overhead luggage racks, fuel entering the cabin area and dousing the passengers, and a flash of fire. After ground impact and prior to the aircraft shuddering to a complete stop, passengers, still with their heads down in the brace position, observed a large quantity of dirty wet snow entering the cabin. This snow was mixed with mud and sections of trees. A strong smell of fuel also accompanied the influx of this debris. Because of the confusion inside the cabin, these survivors were unable to determine from which direction this debris entered the cabin. In addition, four passengers reported seeing and hearing electrical sparks and seeing and feeling the heat from a flash fire.

The scene inside the three sections was reported by survivors as chaotic, owing in large measure to the deformation of the fuselage. A large number of seats had failed at their floor-attachment points. These seats, along with their occupants, were strewn about, adding to the confusion. The accumulation of bodies, seats, and debris was primarily concentrated in the left front side of the fuselage. Survivors seated in the centre section described an accumulation of debris varying in depth from two to three feet that, in some cases, totally covered and immobilized them. Portions of the overhead racks had also failed during the last stages of the impact sequence, spilling their contents onto passengers and into the aisle. These broken sections of overhead racks, some already in flames and dripping molten, burning plastic, fell on a number of survivors.

Once the aircraft came to rest, the interior of the cabin sections was dimly lit by overcast daylight entering through the windows and through the two large gashes in the aircraft's right side. The interior lighting system was off, and the aircraft's emergency strip lighting either malfunctioned or, because of the debris, was not visible. Passengers' evidence revealed that the only guidance for survivors to exit the aircraft was from the daylight entering the cabin through the windows and various openings.

At the time the aircraft came to a stop there were already a few spot fires in the interior and on the exterior of the cabin. These fires increased in intensity, and the most severe one, just forward of the left wing, propagated rapidly. The fires soon filled the cabin sections with extremely thick black acrid smoke, severely restricting visibility inside the broken cabin enclosure and rendering normal breathing extremely difficult.

Survivors reported being severely jostled during the crash, and all were stunned or in varying degrees of consciousness by the time the aircraft stopped. Evacuation efforts began within seconds and became progressively more frantic as the intensity of the flames and smoke increased and as more and more survivors regained control of their senses. A few survivors recalled hearing the flight attendant ordering passengers to evacuate.

Forty-seven passengers evacuated, or were evacuated from, the aircraft, of whom two later died in hospital. Although the passenger reaction during the evacuation could not be described as panic, the evacuation was certainly disorganized and chaotic. Many passengers reported seeing other survivors scrambling over them or having their seat backs pushed onto them by passengers during the frantic effort to escape. There were many reports that, despite the frantic situation, survivors were helping one another exit the aircraft, and there were no reports of any competitive behaviour. Because of the increasingly intense fire, the smoke, the spilled fuel, and numerous minor detonations, all passengers perceived an immediate threat to life.

As previously stated, the person occupying seat 8E, the seat immediately adjacent to the right emergency exit, stated that when the aircraft eventually came to rest and he was ready to exit, he egressed through this overwing emergency exit and was followed by the flight attendant, who was seated to his left, and then by a young passenger seated immediately behind him in seat 9E. The survivor from seat 8E believed the emergency exit door had already been opened; he is certain he did not open it. Apparently, these two passengers were the only ones to egress via the right-hand overwing emergency exit.

The passenger in seat 7D stated that while he was pinned in his seat, he reached behind to his right side and twisted and pulled a latch. He could not positively identify the latch, but he may in fact have pulled in the emergency exit door. During the investigation, a burned corner remnant of the emergency exit door was found inside the aircraft abeam the emergency exit. It could not be positively determined how the right emergency exit was opened.

The person occupying seat 8A egressed through the overwing emergency exit to his immediate left. He was certain the exit was opened or torn out during the crash. He suffered serious burns while exiting the aircraft and was later flown to Winnipeg. Immediately after his exit an intense fire developed in the vicinity of the left emergency exit, thereby eliminating its use by any other passengers.

All other survivors exited the aircraft through tears in the aircraft fuselage. Fourteen survivors, including a baby held in her mother's arms, evacuated through a gash in the fuselage just forward of the right wing. Twenty-six evacuated through the opening aft of the right wing;

and one severely injured survivor egressed through an opening forward of the left wing.

There were seven surviving children under age 16, all of whom required some assistance to egress. The assistance was provided either by their parents or by the passengers seated next to the children. None suffered serious physical injury. As noted, one child was a baby held in her mother's arms on board the aircraft.

The aircraft had crashed in a heavily treed area which was strewn with deadfall and underbrush. The wet, heavy snow that had been falling prior to takeoff persisted for some time after the crash, adding to the already hip-deep snow at the crash scene. The temperature was at the freezing point.

All the survivors were poorly dressed for exposure to these conditions. The majority had removed their winter coats and jackets on the aircraft in preparation for the flight to Winnipeg. Eleven of the 47 survivors, including the flight attendant, lost their footwear during the crash or while extricating themselves from the aircraft.

As the survivors, most of them injured and many of them suffering from shock, exited the aircraft, they gradually gathered into small groups among the trees some 200 feet from the burning aircraft. Three survivors were too seriously injured to move any more than approximately 75 feet from the aircraft. They were assisted and tended to by less seriously injured survivors.

Once away from the immediate threat posed by the fire, the survivors were more motivated to work collaboratively, and in many cases they performed selfless acts in attempts to reduce the suffering of those less fortunate than themselves. Some passengers removed their jackets to allow others with no shoes to stand on them, and others gave up their shirts or sweaters to those who were cold. Some passengers performed rudimentary first-aid treatment on the injured. Other passengers provided encouragement to those who were more emotionally upset, and still others provided physical assistance to those who had difficulty walking.

The surviving flight attendant, Sonia Hartwick, despite her emotional shock, provided some of the leadership required to keep the groups close together. Once out of the aircraft she commanded those survivors still exiting to continue moving well away from the fire; then, while waiting for evacuation from the site, she ensured that survivors, many of whom were suffering from shock, did not wander off into the woods. She provided encouragement to survivors as well as assisting with the care and comfort of a severely burned passenger.



## **Seat Belts**

Survivor statements indicate that all seat belts held; however, several survivors stated that they had some difficulty releasing their seat belt buckles. It is probable that the agitated state of some of the survivors resulted in frantic and inept efforts at releasing their seat belts. Others had difficulty finding their seat belt buckles because, since their bodies had shifted in their seats during the crash, the buckles were not positioned where expected. Some survivors indicated that they had difficulty because their access to the seat belt buckles was restricted by debris.

One survivor who reported having difficulty with his seat belt was Mr Gary Jackson, a prisoner in handcuffs being escorted to a detention centre. Mr Jackson believed his difficulty was due to a combination of factors: he was somewhat in panic or shock, his hands were burned and very painful, and he had handcuffs on. He was unable to release his seat belt until one of the escorting special RCMP constables, Mr Donald Crawshaw, who had initially left Mr Jackson in his seat, returned to the wreckage to assist the prisoner in response to his calls for help.

The fabric portion of most of the seat belts was destroyed by fire. A full physical assessment of the effectiveness of the seat belts was therefore impossible. However, each passenger seat originally had two seat belt anchor points, two anchors, and two parts of a single buckle; thus, there were 130 seat belt anchor points, 130 seat belt anchors, and 65 buckles.

All 130 seat belt anchor points were in place, but only 121 of the seat belt anchors were in place and intact; two further seat belt anchors were recovered intact, but were not in place. Only five seat belt buckles were eventually recovered, four of them still operative. None of the seat belts for the flight attendants' seats or the cockpit seats was recovered.

Assuming all passenger seat belts in the aircraft were the same as those recovered, it can be said that they met Canadian regulatory specifications. Because none of the flight crew seat belt components was recovered, no statement of compliance or non-compliance with Canadian regulatory specifications can be made.

## **Seats**

It was found that many of the passenger seats were detached from the floor and were bunched in the forward portion of the aircraft. Most of the passenger seat frames were damaged and distorted as the result of impact and deceleration forces. The seats in rows 6, 7, and 9 on the right side of the fuselage were still in place after the crash. The seats in rows 13 right and 8 left showed very little frame damage, but they were dislodged and the front attachment knobs were missing.

In general, the seats towards the front and the left side of the aircraft were more severely damaged than were the other seats. The strongest part of the seats is the twin tubular beam that forms the base for each individual row, and many of these beams were bowed from excessive force. The most severe seat beam deformation was observed in rows 1 to 3 on the right side and rows 1 to 7 on the left side. The majority of these seats were subjected to deceleration forces with significant components in the sideward and downward directions during the final phase of the crash (analysed in the Flight Dynamics study, technical appendix 4).

Because of the fire destruction, apart from the very base structure of the captain's seat, nothing remained of the flight attendants' seats or the cockpit seats.

The forward flight attendant's seat was a pedestal seat without armrests, side restraints, or a rigid back. The seat was forward facing, located in the galley area, to the right of the centre line of the aircraft, and had a lap belt but no shoulder harness. Its location was intended to allow the flight attendant immediate access to an exit and the aircraft's only exit chute. Directly in front of this position and facing the seat were the aircraft galley cupboards and equipment. The flight attendant's seat and seat belt met the specifications of Canadian air regulations. For a detailed account of the shoulder harness issue, see chapter 22 of this Report, F-28 Program: Flight Attendant Shoulder Harness.

All the passenger seats had been upholstered with fire-blocking neoprene foam material and complied with Transport Canada regulations in regard to fire.

In order to comply with United States FAR 25.813, the seats immediately in front of and next to the overwing exits are required to have seat backs that will not recline. This requirement is achieved by the removal of the cables operating the reclining mechanism. In the other Air Ontario F-28 aircraft (C-FONG), the cables had been removed and the subject seats would not recline; in the accident aircraft, however, the recline cables were still in place.

In all other respects, all seats on C-FONF met Canadian requirements.

## **Interior Lighting**

There were 16 emergency lights and 16 evacuation lights installed throughout the passenger compartment of C-FONF. There were seven lights of each type in the ceiling, and others in strategic places in the cabin. In general, the emergency and evacuation lights were co-located. The emergency lights receive electrical power from normal aircraft power systems, and the evacuation lights receive power from seven self-contained power supply units located throughout the cabin and

containing rechargeable batteries. There is a three-position emergency light switch on the overhead panel on the flight deck, labelled OFF, TEST, and ARM. Under normal flight conditions, this switch is in the ARM position. With this switch in the ARM position, the evacuation lights, being powered by the self-contained battery units, will illuminate in the event of a total electrical power loss to the aircraft electrical system. In addition, there were four exit-location signs in the cabin containing bulbs from both the emergency and the evacuation light systems.

This accident occurred in daylight, and, therefore, lack of light was itself not a problem during the evacuation phase. There was evidence, however, that dark smoke permeated the cabin shortly after the crash, causing difficulty with visibility for the passengers in the central and forward areas of the cabin. If the crash had occurred in darkness, the conditions in the wreckage would have been much more chaotic and may have resulted in a greater loss of life. Surviving passengers were questioned as to whether they saw lights in the aircraft during the time the aircraft was breaking up and when it came to rest. Most passengers did not notice whether lights were on or off. A few stated that they had seen lights of some kind but could not say whether they were aircraft lights; some thought the light may have been from the fire. Two passengers identified lights that they saw as interior cabin lights.

When one considers the bedlam in the aircraft and the smoke and debris in the cabin that would have obstructed the passengers' vision, it is not surprising that the evacuation lights, if they functioned at all after the crash, were not noted by many. With the fuselage breaking into three distinct pieces, the electrical wiring to the lights would surely have been severed in a number of places. It is probable that some individual evacuation lights flashed or came on when the aircraft's normal power supply systems were interrupted during the final phase of the crash. In conclusion, it could not be established with any degree of certainty whether the evacuation lights worked as designed.

## **Survivor Survey**

The Dryden accident provided an opportunity, albeit a tragic one, to obtain valuable information on the emergency evacuation of a medium-size jet aircraft and on other survivability issues. A study of these subjects could lead to the discovery of safety deficiencies and recommendations for their rectification. With this objective in mind, the human factors and survivability group of the CASB accident investigation team formulated a list of specific questions that interviewers would pose to each survivor.

Interviews began March 11, 1989, the day after the accident. Forty-two

survivors were interviewed, many of whom were questioned while in their hospital beds. They represented various ages, backgrounds, and degrees of flying experience, either as a passenger or a pilot.

The following is a synopsis of the questions posed to the survivors and the responses received.

- 1 *Prior to takeoff from Dryden, did you pay attention to the flight attendants' safety demonstration?*

Nine survivors (21 per cent) responded that they had not paid specific attention to the flight attendants' demonstration. Two of these nine were pilots, and another three of this group stated that they had paid attention to the demonstrations given prior to takeoff in Thunder Bay.

It is interesting to note that one of the passengers, a 12-year-old girl, indicated that she had neither paid attention to the demonstration nor read the aircraft's evacuation card because "[i]t's always the same stuff and I know it all anyway." This passenger had difficulty releasing her seat belt after the crash and required assistance from the passenger seated next to her. The seat belt release, according to the passenger who provided assistance, functioned normally.

- 2 *Prior to takeoff from Dryden, did you read the evacuation card?*

Eighteen survivors (43 per cent) replied that they had not read the evacuation card.

Seven survivors (17 per cent) had neither read this card nor paid attention to the flight attendant safety demonstration.

- 3 *Did you assume the brace position prior to impact?*

Five survivors (12 per cent) stated that they had not. On further questioning, however, it was determined that although these survivors had not assumed the textbook brace position, these passengers had all braced themselves in some fashion. It is particularly significant to learn that 20 (48 per cent) of the survivors replied that they had assumed their brace position as a result of the flight attendants' orders prior to impact.

- 4 *Did your seat collapse as a result of the accident?*

Thirty-two (76 per cent) replied that their seat did not collapse, and five (12 per cent) stated that their seat collapsed.

- 5 *Did you have a problem releasing your seat belt?*

Seven respondents (17 per cent) replied that they had difficulty releasing their seat belt. Among these passengers was the prisoner travelling with his wrists handcuffed in front of him. One respondent mentioned undoing his trouser belt instead, as a result of nervousness.

Two survivors (5 per cent) related difficulties as a result of the seat belt buckle, once fastened, being displaced to one side of the abdomen.

- 6 *Did you strike any object in the aircraft space around you or were you struck by any object?*

Nineteen survivors (45 per cent) indicated either having been struck by an object or hitting something during the crash sequence. Only two respondents positively stated that their head struck the seats in front of them. Seventeen (40 per cent) could not remember what they had hit or what had hit them. Of this group, most stated that their lack of recollection was due to having their head lowered in the brace position and/or having their eyes closed. Many mentioned that there was too much debris moving around the cabin in a blur to identify what was hit.

Nineteen passengers (45 per cent) recall having overhead racks falling on top of them.

- 7 *Did you have any problems exiting the aircraft?*

Eight respondents (19 per cent) mentioned having some difficulty exiting the aircraft.

Most of the problems resulted from debris in the aircraft. Three survivors (7 per cent) had difficulty because their feet became lodged under the seat in front of them during the crash sequence.

- 8 *Did you assist anyone to exit the aircraft?*

Fifteen survivors (35 per cent) reported having given some form of assistance to other passengers.

- 9 *Did you receive assistance to exit the aircraft?*

Eleven passengers (26 per cent) reported having received assistance.

## Crash Survival and Impact Survival

“Crash survival” is related to the ability of the aircraft’s occupants to survive the impact or impacts, to evacuate the aircraft before conditions become intolerable as a result of fire, submersion, and other hazards, and to survive post-crash conditions until rescued.

“Impact survival” is related to the aircraft’s ability to protect the occupant during a crash, with the following criteria applied:

- 1 The occupants’ immediate environment must remain relatively intact; that is, there should be no intrusion into the livable space.
- 2 The deceleration forces acting on the occupants should not exceed human tolerance.
- 3 The seat/restraint system should prevent injuries from a second collision.
- 4 The immediate environment should protect the restrained occupants against serious contact injuries.

This section of the Report deals with the ability of the aircraft and all its parts to protect the occupants from the effects of rapid deceleration and the breaking up of the aircraft and considers the security of the seats and seat belts. The crashworthiness analysis provides a general understanding of the average magnitude of the impact forces experienced during the crash. The susceptibility of the aircraft to fire and the effects of the fire on the occupants are discussed in the following section of this chapter.

Mr James Hutchinson, a mechanical engineer and chief of the Engineering Analysis Division of the Canadian Aviation Safety Board (CASB), who served as chairman of the investigation team's aircraft structures group, outlined in testimony the reason for conducting an investigation into the structural breakup of an aircraft in an accident. Basically, the structures investigation provides an overall assessment of the crash dynamics of the accident sequence to determine the nature of the breakup patterns. These patterns are then compared with what could be normally expected, based on historical data, for the type of crash being investigated. If a particular breakup pattern was not consistent with the assessment of the impact dynamics, then a detailed examination would be required. In this accident, the breakup patterns of the F-28 aircraft, C-FONF, were all consistent with the overall assessment of the impact dynamics, and the investigators did not observe any breakup pattern that, in an engineering-design sense, was considered to be of an unexpected nature or could not be explained to their satisfaction.

Using the topographic maps produced by the survey team, the structures group estimated the terrain angle in the crash area to form a downslope of approximately  $4^\circ$  in the upper section of the wreckage trail, varying to approximately  $8^\circ$  on the lower section. The crash calculations were divided into two parts: the first from the point where the aircraft started striking trees on the top of the knoll, approximately 726 m from the end of the runway until the aircraft struck the ground 144 m farther on; and the second from the point the aircraft struck the ground until it came to a stop. The aircraft slid about 80 m after striking the ground.

Calculations using an estimated aircraft speed of 205 to 220 feet per second (121 to 130 knots) and an estimated coefficient of friction for flight through the trees resulted in longitudinal deceleration levels of approximately 1.33 g for the first part of the crash sequence. The shallow angle of the aircraft path through the trees on a slightly negative slope had the effect of keeping the deceleration levels (g) relatively low. Deceleration levels for the second part were calculated using the impact velocity derived from the previous calculations. It was estimated that the longitudinal deceleration levels on the second part were 2.33 to 3.05 g. The higher levels were attributed to the significant increase in sliding

resistance on the ground over the resistance when travelling through the trees. The estimated deceleration levels are average levels for the aircraft as a whole, based on the total distance travelled. In reality, there were local deceleration levels that varied significantly from the average. The peak vertical level in the forward left side of the cabin, where primary ground contact was made, was calculated to be in the order of 15 to 20 gs. These calculations were based on a structural analysis of the deformation of the seat beam structures of one of the rows of three seats located in the forward left cabin area.

It should be noted that these calculated vertical g forces present only one vector of the peak crash force resultant that governed the damage and injury mechanism during the principal impact. Since the peak horizontal deceleration during main impact is a function of peak vertical deceleration and sliding resistance, the peak horizontal deceleration can be approximated by estimating the coefficient of sliding friction. During his testimony, Mr Hutchinson used a value of 1.4 for this purpose. Applying that value to the calculated vertical gs, the peak horizontal gs at main impact would have been in the order of 21–28 gs.

These estimated peak crash forces affected the front and left side of the fuselage during principal ground impact. They exceeded the human tolerance to deceleration when restrained by a seat belt only, the existing occupant-protection criterion, and the standards for structural integrity of jet transports. The severity of the process explains why the persons closest to the point of impact of the aircraft were killed, disabled or trapped. The survival of a few individuals in this area can be attributed only to random and fortuitous circumstances. The peak horizontal and vertical vectors, which occurred simultaneously, can now be combined to arrive at a crash force resultant in the order of 26–34 gs.

All the seats from the aircraft were recovered. Those from the forward left side in rows 1 to 7 were the most severely deformed, and seats that appeared to be from the right side in rows 1 to 3 were also deformed. Except for seats from rows 6, 7, and 9 on the right side, all seats were detached from their floor anchors. The original positions of some of the seats were determined by matching fracture surfaces and according to relative seat position and damage assessment. All passenger seats, except those from the right side of rows 6, 7, 9, and 13, and all those from row 8, were found to have deformed partially or completely because of impact and deceleration forces.

The regulations adopted by Canada that specify the required strength of passenger and crew seats of transport category aircraft are found in United States Federal Aviation Regulations (FARs) 25.561 and 25.562. The present regulations were in effect as of March 10, 1989. However, FAR 25.561 was amended and FAR 25.562 was added since the F-28 aircraft received its Canadian type certification, and these changes to the

regulations were not made retroactive. In summary, FAR 25.561, regarding inertia forces and applicable to the F-28 seats, required that the structure be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing in which the g forces experienced by the occupant do not exceed: upward 2.0 g, forward 9.0 g, sideward 1.5 g, and downward 4.5 g. As well, seat deformation must not occur at or below the noted g loads. Present regulations, namely those covered by the amendment to FAR 25.561, increase the above g minima to upward 3.0 g, forward 9.0 g, sideward 3.0 g on the airframe and 4.0 g on the seats and their attachments, downward 6.0 g, and rearward 1.5 g. FAR 25.562 gives details regarding dynamic testing and inertia forces relating to aircraft seats and their attachments. One of the seat/aircraft design criteria is that the seats must remain attached at all points of attachment, although the structure may have yielded, at a peak floor deceleration of a minimum of 14 g.

As explained above, the forward and left side of the aircraft were subjected to peak crash forces in the order of 26–34 gs; therefore, it is not surprising that many seats were deformed and became detached and that the fuselage broke open in two places.

After the crash, only three seat belts were still anchored to their seats and one additional belt buckle was recovered; all four buckles were found to be functional. Most of the seat belt anchors were still attached to their seat frames. Nine anchors had separated, and only two of these were recovered. Because nearly all of the seat belts were destroyed during the post-crash fire, they could not be properly evaluated for effectiveness.

Upon review of the evidence regarding the structural investigation I can find no fault with or attach any adverse significance to the design and integrity of the F-28 aircraft or to current seat design criteria. It was indeed a stroke of luck for the surviving passengers that the aircraft was broken apart during the final stages of the crash sequence, thus creating an escape route from the wreckage and fire.

## **Aircraft Fire**

### **Introduction**

Most of the information in this section of the Report was gathered and analysed by Mr Brian Boucher, a pilot with Air Canada, a specialist in fire-fighting, and, at present, the director of training for the Niagara-on-the-Lake, Ontario, fire department. He has been an assistant to the Ontario Fire Marshall's Office since 1983 and is involved with the Lester B. Pearson Disaster Contingency Planning Committee. Among the



organizations of which Mr Boucher has been an active member are the Canadian Air Line Pilots Association (CALPA), the International Federation of Air Line Pilots Association (IFALPA), and the International Civil Aviation Organization (ICAO). Among the various fire-related groups on which he has served are the Aircraft Rescue and Firefighting Committee for the National Fire Protection Association, IFALPA's Airport Ground Environment Committee, and ICAO's Aircraft Rescue and Firefighting Study Group. Although his credentials and experience in fighting structural fires are impressive, Mr Boucher noted in evidence that he has never had occasion to participate as a fire-fighter at a major aviation fire.

Mr Boucher is a graduate of the Ontario Fire Academy and, as of April 1990, was in the process of completing a bachelor of science degree from the University of Cincinnati, concentrating on fire and safety engineering. Because of his extensive training and experience, Mr Boucher was asked to participate in the investigation and analysis of the fire aspects of the crash of C-FONF. Since he was not involved in the early stages of the investigation, he gathered the information for his analysis from inspection of the recovered wreckage and from photographs, videotapes, interview transcripts, personal interviews, relevant documents, and evidence adduced at the Commission hearings. He prepared his Fire Analysis Report, which was entered as Exhibit 514 and which, together with his sworn evidence, provided most of the information for the following section.

## **Fire Propagation**

### **Dynamic Phase**

The dynamic phase of the fire represents the time when the aircraft was in motion and on fire. The evidence shows that when the aircraft began to strike the heavy timber, about 726 m from the end of the runway, the left fuel tank ruptured. Fuel from the tank began vaporizing and trailing behind the aircraft in the form of a mist. Mr Boucher was of the opinion that all the fuel from the left tank was released during the time the aircraft was airborne. It is possible the right wing also ruptured and was releasing fuel during the dynamic phase, but there is no confirming evidence. The fuel on the left side of the aircraft ignited, and there is evidence of fire along the aircraft's path through the trees from a point about 50 m after entering the trees to the final resting spot of the aircraft. Trees were scorched but did not continue to burn after the sprayed fuel was burned. There is no evidence that the right side of the aircraft was on fire during the dynamic phase.

The fuel vapour plume created during the dynamic phase of the fire, in its flammable range, was probably ignited from the heat of the left

engine and/or the severed energized electrical components and wiring exposed during the breakup of the left wing. The fuel vapour plume and fire followed the aircraft to its resting position. A number of passengers reported seeing flashes of fire on the left side of the aircraft as it was travelling through the trees.

Investigators who walked the path of the aircraft through the trees reported a strong odour of jet fuel present throughout. The odour was from the raw fuel that was released and not burned and from carbon by-products produced by the fire.

### **Static Phase**

The static phase represents the time commencing after the aircraft was fully stopped and on fire. As the aircraft came to a halt, a large section of the forward left side of the fuselage separated, exposing the passengers seated in this area. The fire plume caught up to the aircraft and became static, initially burning debris and fuel on the left forward side of the aircraft. The fire plume, according to some witnesses, reached as high as 30 feet.

Many passengers stated that there was a strong smell of fuel inside the cabin. The smell was either from the misting fuel that was following the aircraft or from the fuel and fuel vapour that came from the right fuel tank, which was ruptured but not burning at this time. There was evidence of fuel spillage into the cabin, some passengers reporting that they were soaked with fuel. Fuel from the right wing tank poured onto the ground through a blanket of snow. The snow effectively trapped the fuel vapours and prevented a fire from starting on the right side of the aircraft. The vapour plume from the left wing tank probably mixed with a cloud of snow generated during the final impact. Some of the fuel in the vapour plume entered the aircraft, but, because of the snow, it remained out of its flammable range, which was fortunate in that there was an initial fire-free path out the right side of the aircraft for the ambulatory passengers. It is evident that the fuel that splashed on the surviving passengers was not in its flammable range since these passengers did not catch on fire.

The fire plume entered the aircraft through the large opening in the left forward area of the fuselage and contacted the fuselage sideliners, the overhead bins, and the combustible carry-on articles (collectively, the "interior combustibles"). The evidence indicates that burning plastics and other burning articles began dropping almost immediately onto both survivors and non-survivors. Because of the probable heavy concentration of fuel vapour that entered the aircraft and saturated the interior combustibles, the rate of flame-spread was very fast. The left forward area, where the fire entered the aircraft, was where most of the deceased were found. From there the fire then spread forward into the cockpit

and rearward along the cabin ceiling, igniting all interior combustibles. Toxic and flammable gases travelled through convection heating to the ceiling and out through openings in the fuselage. The fire burned from the top down, as evidenced by the fact that the top of the aircraft was burned away while the lower portions of the fuselage remained intact.

The fire was fuel regulated: because of the breaks in the aircraft, there was adequate oxygen to support combustion, and the fire would burn as long as there was material to burn or until the fire was extinguished. It is not likely that fuselage flashover occurred. (Flashover is the spontaneous combustion of heated gases.) In order for flashover to occur, the temperature of the gases in the confined area of a fuselage must exceed 550°C. Although the temperature in this case may have exceeded 550°, the large openings in the fuselage allowed the heated gases to escape, and, accordingly, the fire propagated normally. The vapours from the fuel in the right wing most likely ignited because of the radiant heat and flames from the aircraft cabin as the fire spread. The fire in the area of the right wing was not intense; most of the fuel seeped into the snow, which effectively trapped the fuel vapours. The fire was most intense in the forward left area of the fuselage, as evidenced by the complete destruction of this area; in contrast, a good portion of the right side of the fuselage was not burned to the same extent.

It is the evidence that two Dryden airport crash fire rescue (CFR) fire trucks arrived at the McArthur Road and Middle Marker Road location at approximately 12:18 (Red 3) and 12:19 p.m. (Red 1). The Unorganized Territories of Ontario (UT of O) rapid attack vehicle arrived at the scene at approximately 12:34 p.m., and the UT of O tanker truck arrived at approximately 12:40 p.m. Red 2 (CFR) arrived at approximately 12:43 p.m. At 12:44 p.m., two Town of Dryden fire trucks arrived. Captain Roger Nordlund, the UT of O fire chief, arrived at approximately 12:45 p.m.

It is quite disturbing that, despite the presence of sophisticated fire-fighting equipment and many fire-fighters, no attempt was made to extinguish the fire until approximately 2:00 p.m., one hour and 50 minutes after the crash. Some time after 1:30 p.m., the UT of O pumper truck was driven from the intersection of McArthur Road and the Middle Marker access road, where it had been parked since about 12:35 p.m., down the Middle Marker access road to a point opposite to and approximately 360 feet from the crash site. A handline from the truck was then dragged by eight to ten volunteers through the bush to the site, and fire retardant was applied to the fire at approximately 2:00 p.m. Fire-fighters continued to suppress small flare-ups for about another hour. At 6:00 p.m. the pumper truck and portable pond (port-a-pond) were moved closer to the crash site via a newly bulldozed road. Fire-

fighters remained at the site until about 11:30 p.m., and UT of O fire-fighters returned to the site during the next two days to ensure that further fire did not break out. Crash fire rescue is the topic of chapter 9 of this Report, Dryden Municipal Airport Crash, Fire-fighting, and Rescue Services.

The Fokker F-28 Mk1000 aircraft was approved in the transport category by Transport Canada on August 3, 1972, and, accordingly, was issued Canadian Type Approval No. A-108. Among other standards, the following standards applied: CAR 4b, dated September 1962, amendments 4b-1 through 4b-16, inclusive; and FAR 25, amendments 25-1 through 25-12, inclusive, 25-14 through 25-22, inclusive, and 25-24.

Accordingly, cabin materials on the F-28 aircraft, including seats and interior panels, were required, by type approval, to comply with the flammability standards of FAR 25 amendments no. 25-15 and no. 25-17, which, respectively, introduced the vertical Bunsen burner test and clarified the application of the standard with respect to specific materials and components.

Since the F-28 is a large aircraft used in commercial service, ANO Series VII, No. 2, applied. It required, in accordance with the Flammability Requirements for Aeroplane Seat Cushion Order (ANO Series II, No. 28, promulgated on June 6, 1986), that seat cushions comply with the flammability requirements introduced in FAR 25 by amendment no. 25-59, issued on October 26, 1984.

On July 21, 1986, the FAA issued two regulatory amendments: amendment no. 25-61, establishing upgraded flammability standards, and amendment no. 121-189, regarding implementation of the new standards. Because of industry feedback regarding the repeatability of the tests and the compliance times, and after further research and testing, the FAA issued, on August 25, 1988, amendments no. 25-66 and no. 121-198. These amendments established refined test procedures and apparatus to improve test repeatability, added a smoke emission test requirement and criteria to minimize the possibility that emergency egress would be hampered by smoke obscuration, and incorporated provisions for additional compliance time for unique components for which timely compliance could not be achieved.

Transport Canada has attempted to adopt the new FAA standards for cabin interiors in the proposed Improved Flammability Standards for Compartment Interior Materials Order (ANO Series II, No. 32). As of October 1, 1991, ANO Series II, No. 32, had not been promulgated; therefore, it was not applicable to the F-28 aircraft C-FONF.

## **Combustibility of Materials**

The seat materials in C-FONF met the specifications requirements set out

in Air Navigation Order (ANO) Series II, No. 28, which require that the materials in aircraft such as the F-28 meet the fire-protection standards as indicated in Federal Aviation Regulation (FAR) 25.853(c). The material standards deal with such matters as ease of ignition, rate of flame-spread, ability to self-extinguish, flame drippings, and toxicity of fumes given off during burning. Transport Canada inspectors approved the aircraft's seats for compliance on December 30, 1988.

Because of the difficulty in tracing the history of C-FONF, the exact description of the interior furnishings of the aircraft could not be determined with certainty. During the time Air Ontario operated C-FONF, the aircraft was fitted with new seat material and new carpets. There is no evidence that the aircraft interior was ever refurbished with other new cabin materials, and it is assumed that, except for the seats and carpets, the materials in the aircraft at the time of the accident were as described by Fokker Aircraft B.V. as being in the aircraft at the time of initial delivery. As in most modern aircraft, the interior furnishings of C-FONF consisted primarily of plastic materials. The following is a description of the predominant materials found in the cabin at the time of the crash, and their use:

- acrylonitrile butadiene styrene (ABS): sidewall panel trim and the blinds and retainers
- polyvinylchloride (PVC): decorative sheet-covering of sidewall panels and partition walls
- nylon (polyamides): window supports
- acrylics (PMMA): outer and inner window panes
- glass fabric epoxy laminate and nomex: sidewall panels, partition walls, and cargo-hold liners
- chloroprene rubber: window seals
- tedlar-covered glass fabric epoxy sandwich, nomex core: ceiling panels and hat-rack liner
- polycarbonate: ceiling light covers
- modified polyphenylene oxide (PPO, called Noryl): passenger service unit panels, speaker panels, airduct panels, blind panels
- neoprene: seat cushions
- aluminum: hat-rack frames, floor panels.

Thermoplastics (ABS, PVC, PPO, PMMA, and polycarbonate) made up the major part of the interior furnishings. These plastics normally have higher ignition temperatures than wood products but can be easily ignited with a small flame and will burn vigorously. The rate of flame-spread of burning plastics is as high as two feet per second, about 10 times greater than the flame-spread for burning wood. The smoke generated by burning plastics is dense, black, and sooty. Chemicals

added to plastics to inhibit flammability often result in more toxic contaminants in the smoke. By-products of burning plastics are often toxic chemicals such as carbon monoxide (CO), hydrogen cyanide (HCN), hydrogen chloride (HCl), phosgene (benzine, toluene, styrene), and acrolein. Plastics subjected to heat and flame will melt, flow, and drip, causing burns to people and starting secondary fires. During his testimony, Mr Ricardo Campbell, who was a passenger in seat 7D on the right side of the aircraft, stated that molten burning material from the overhead bins dripped on him and the baby Podiluk after the aircraft came to rest. The chloroprene rubber (window seals) and the neoprene material of the seat cushions have fire characteristics similar to natural rubber. Overall there was not much rubber in the window seals, and the seat cushions burned very slowly because of their fire-inhibiting qualities. The contribution of the rubber products, the epoxy, and the aluminum to the lethality of the fire and its by-products was considered minimal compared with the contribution of the plastics.

Having reviewed all the evidence concerning the crash survivability of this accident, I conclude that the high survival rate in this severe crash was due to unpredictable and uncontrollable factors such as:

- daylight conditions,
- the heavy snow cover on the downsloping terrain, and
- the breaking apart of the aircraft during the final crash sequences, thus allowing many occupants to escape the wreckage and the fire.

Combined with the investigation problems associated with the near-total destruction of the aircraft by impact and fire, these factors preclude me from making technically specific safety recommendations with regard to crash survivability.

## **Findings**

- During the crash, g forces in the aircraft reached 15 to 20 g, with local forces reaching perhaps 34 g.
- The breakup patterns of the F-28 aircraft, C-FONF, were all consistent with the overall assessment of the impact dynamics, and there was no observed pattern that, in an engineering design sense, was considered to be of an unexpected nature or that could not be explained. Therefore, I find that there is no evidence of fault in the design and integrity of the F-28 aircraft.

- Aircraft interior furnishings burned and gave off heavy sooty smoke and toxic gases; and burning, molten-plastic-like material fell on passengers.
- The clothing and slip-on shoes worn by flight attendant Sonia Hartwick did not afford her adequate protection after the crash. The weather was cold, and Mrs Hartwick lost her shoes in the crash.
- Passenger seats were deformed and many were detached from the aircraft floor and bunched in the front of the cabin after the crash.
- Overhead racks fell on at least 19 passengers.
- Many survivors of the crash were hindered in their escape by debris in the aircraft; some of the debris was certainly carry-on baggage from the overhead racks and from under the aircraft seats. (The subject of carry-on baggage is dealt with in chapter 24 of this Report, Flight Safety.)

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## RECOMMENDATION

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It is recommended:

- MCR 39 That Transport Canada press for the adoption of standards for aircraft interiors that would prevent the rapid spread of fire and the emission of toxic fumes.

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# 12 FOKKER F-28, Mk1000, AIRCRAFT PERFORMANCE AND FLIGHT DYNAMICS

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Mr Ralph E. Brumby, principal engineer, aerodynamics, Douglas Aircraft Company, in an article written in 1979, discussed wing surface roughness and aircraft performance:

Most flight crew members and investigators are aware of the highly adverse aerodynamic effects of large amounts of wing surface roughness, such as the irregular shapes that can form on the leading edge during an icing encounter. However, what is not so popularly known is that seemingly insignificant amounts of wing surface roughness can also degrade flight characteristics ... roughness caused by frost, snow or freezing fog adhering to the wing surface, large accumulations of insect debris, badly chipped paint, or a distribution of "burred" rivets over the wing surface.

(Exhibit 532, tab 11, "Wing Surface Roughness, Its Causes and Effects," *DC Flight Approach* (January 1979), 32)

A number of witnesses on board C-FONF on its final flight provided testimony as to their observations of snow and ice on the aircraft wings prior to takeoff at Dryden. These witnesses, and others, described in general terms the aircraft flight performance on takeoff and its flight path. Their descriptions greatly assisted the investigators and this Commission in determining what might have caused the F-28 aircraft to perform the way it did and, more importantly, why it failed to perform in a normal manner during its takeoff roll and its brief flight.

The most important and useful sources of information available for the investigation of aircraft flight dynamics and performance are the aircraft flight data recorder (FDR) and cockpit voice recorder (CVR). Because the recorders in C-FONF did not survive the fire, it was necessary for this Commission of Inquiry to pursue other avenues to determine what caused the flight profile of C-FONF.

It was the expressed view of the surviving crew member; of numerous passengers on the ill-fated aircraft, among them two professional airline pilots; and of a large number of observers on the ground, many of them pilots, that snow and ice adhering to the upper wing surfaces of C-FONF was the physical cause of the crash. The evidence of these witnesses, coupled with a thorough investigation by CASB investigators seconded to my Commission, left virtually no doubt that there was substantial



contamination adhering to the upper wing surfaces during takeoff. The aircraft accident investigative process required and the mandate of this Commission of Inquiry demanded that a detailed and thorough analysis be conducted to determine the degree to which surface contamination affected the flight dynamics of C-FONF and whether performance of the aircraft degraded to the point that the aircraft was unable to maintain flight.

I stated in Part 2 of my first *Interim Report*, in the section dealing with wing contamination, that:

The adverse effects on aircraft performance and handling qualities caused by contamination of an aircraft's lifting surfaces, as described by the professional pilot witnesses in their evidence, whether due to snow, ice, frost, or other contamination, are well documented and universally known in the aviation community (p. 25).

In the following section, on safety awareness, I stated:

It is a matter of particular concern that, despite the existence in many countries of applicable laws which prohibit takeoffs with contaminated aircraft-lifting surfaces, and despite the existence of similar prohibitions in the flight operations manuals of many Canadian aviation companies, icing-related accidents on takeoff continue to occur. A possible explanation is that air and ground crews are not sufficiently aware of the insidious hazards of ice, snow, and frost contamination to aircraft surfaces and the accompanying performance degradations (p. 28).

The fact that the experienced crew of C-FONF departed from the Dryden airport terminal and elected to take off in weather conditions that not only suggested but also should have red-flagged, even to a pilot far less experienced than Captain Morwood, the possibility of snow- and ice-contaminated wings, clearly indicated to me either an incomprehensible and deliberate disregard by the flight crew of these obviously dangerous conditions or, more probably, a failure to appreciate fully the adverse effects of the cold-soaking phenomenon and the problems of performance degradation caused on takeoff by contaminated lifting surfaces. These problems are discussed elsewhere in this chapter.

In order to investigate properly the flight dynamics of the Fokker F-28 Mk1000 aircraft and to determine how wing surface contamination affected its takeoff performance, a performance subgroup of the investigation team's operations group, consisting of experts in aerodynamics and aeronautical engineering, was formed. The subgroup was chaired by Mr Donald J. Langdon, a systems engineer with the Canadian

Aviation Safety Board (CASB), now the Transportation Safety Board of Canada (TSB), located at Uplands Airport, Ottawa, Ontario.

When the investigation of this aircraft accident, commenced by CASB, was assumed by this Commission of Inquiry, I sought and obtained the assistance of highly qualified experts not normally involved in aircraft accident investigation. Collaborating on investigating and researching the flight dynamics of the Fokker F-28 Mk1000, and in preparing a report on that subject, were Mr J. Murray Morgan, a physicist, an engineering test pilot of National Aeronautical Establishment (NAE) at National Research Council Canada (NRC), and an expert both in human performance in the cockpit and in computer-generated simulations; Mr Richard H. Wickens of NAE at NRC, an aerodynamicist specializing in low-speed aerodynamics; and Mr Gary A. Wagner, a pilot with Air Canada, a member of the Canadian Air Line Pilots Association (CALPA), an aeronautical engineer, and an adjunct assistant university professor lecturing in aerodynamics. I am indebted to these highly specialized individuals, recruited by Mr Langdon, for providing this Commission with a thorough and in-depth analysis of aircraft flight dynamics and performance issues.

Assisting in aircraft performance matters for my Commission were Mr David G. Rohrer, a CASB accident investigator seconded to my staff as a technical adviser, and Captain Allan Murray, a senior airline captain with Canadian Airlines International, who has extensive experience flying the F-28 Mk1000. Mr Rohrer was the chairman of the operations group; Captain Murray, a member of that group, participated on behalf of CALPA, which prepared an operations group working paper and thereafter the operations group's report.

Because witnesses had observed snow and ice on the wings of the aircraft and because of the concerns that my investigators had at an early stage of the investigation regarding ice contamination, Mr Langdon, again on behalf of my Commission of Inquiry, also requested the assistance of the low-temperature laboratory of NRC. Dr Myron M. Oleskiw, a research meteorologist with expertise and experience in studying ice accretion on air foils, fulfilled the request to determine the process of accumulation and adherence of precipitation on the aircraft surfaces.

I note that CASB sought on a number of occasions the assistance of both NRC and NAE and has cooperated on an informal basis with them on matters such as ultralight and amateur-built aircraft flight testing, helicopter crashes, FDR interpretation and transcription, development of computer software for the readout of FDR tapes, and fuel and lubricant analysis. I commend this type of cooperation, and I strongly urge and recommend that the TSB continue in the future to elicit and use the valuable expert resources of NRC and NAE.

## Background

During the first week of May 1989, the members of the operations group travelled to Charlotte, North Carolina, and to Tampa, Florida, to visit Piedmont Aviation Inc. and USAir ground- and flight-training centres. Piedmont Aviation Inc. was purchased by USAir in early 1987, and over the next two years USAir and Piedmont Aviation Inc. merged their operations, completing the system merger by the summer of 1989. Unless specifically referring to USAir, I will refer to the collective operation of Piedmont Aviation Inc. and USAir as Piedmont Airlines or simply Piedmont.

The purpose of the group's visit was to review in detail the Fokker F-28 flight crew ground-training course given by Piedmont, under contract, to members of a number of Air Ontario Fokker F-28 flight crews, including Captain George Morwood and First Officer Keith Mills. Mr David Adams, this Commission's human factors expert, who worked with the operations group, was among those examining Piedmont's flight attendant crew training. While there, the operations group also reviewed Piedmont's progress and training records for Captain Morwood and First Officer Mills and met with the ground school instructor who had taught the two pilots.

In addition, some of the team members flew Piedmont's Fokker F-28 Mk1000/4000 aircraft flight simulator in Tampa to attempt to duplicate the performance and the flight profile of aircraft C-FONF as described by witnesses and estimated from initial accident investigation information.

Investigators' examination of the aircraft wreckage indicated that there were no mechanical malfunctions, nor was there evidence of engine power loss. Review and examination of the available weather data indicated that a low-level wind shear phenomenon was unlikely.<sup>1</sup> Witnesses did, however, describe both snow and ice on the wings. Witness statements and flight path reconstruction data indicated a flat flight profile before the aircraft crashed, and witnesses described how the aircraft lifted off, settled back on the runway, and lifted off again at or near the west end of the runway.

The flight investigation team consisted of Mr Rohrer; Mr Ronald Coleman, a CASB accident investigator; Captain Allan Murray; and Captain Robert Nyman, a senior F-28 qualified pilot with Air Ontario

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<sup>1</sup> A wind shear is an atmospheric condition in which the wind velocity vector (the wind speed and direction) changes significantly with small changes in the horizontal or vertical position. On takeoff, a wind shear could result in a significant performance loss if the aircraft climbed into a rapidly decreasing head wind, a rapidly increasing tail wind, or a strong vertical down draft.

and a member of the operations group. Together with the assistance of Piedmont Airlines, the team programmed various performance parameters into Piedmont's Fokker F-28 flight simulator and flew 30 takeoff profiles to identify factors that may have caused the aircraft to perform in the manner observed by witnesses.

The simulator is capable of simulating flight with a fidelity that meets Canadian and United States regulatory standards. The team was specifically interested in the modes of flight necessary to duplicate such flight anomalies as power loss, slush on the runway, wind shear, and mechanical malfunctions. Runway contamination could be simulated, but wing contamination could not.

During the tests by the operations group, the simulator was flown by Captain Nyman of Air Ontario and Captain Allan Murray of Canadian Airlines International, both qualified F-28 pilots.

The investigation team performed all takeoff profiles from a standing start on the runway using rated power and a flap setting of 18°. Airport elevation, runway length, and ambient temperatures and pressures similar to those at Dryden at the time of the accident were programmed into the simulator. Aircraft performance was measured at varying runway-contaminant depths of up to one-half inch of slush.

In addition to conducting the takeoffs from a slush-covered runway, the team flew a number of takeoffs, each time adding or changing factors that would progressively decrease the performance capability of the aircraft. In separate flights, one engine was failed at critical engine failure speed ( $V_1$ ), wind shear was created by simulating a 30-knot tail wind at  $V_1$ , the aircraft was rotated at excessive rates and over-rotated to greater pitch attitudes than recommended, and the simulator was programmed to prevent the aircraft from rotating further than 6° pitch angle.<sup>2</sup> In each case where one of the factors was simulated, there was no significant degradation in performance and the aircraft completed its takeoff without difficulty.

The operations group concluded that the aircraft type performed well and had more than adequate thrust to operate from a 6000-foot runway at the estimated gross weight of C-FONF, and at the temperatures,

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<sup>2</sup>  $V_1$ , the takeoff decision speed, is computed for each takeoff and is, in general terms, the speed below which the takeoff should be rejected should an engine failure occur and above which the takeoff should be continued.  $V_1$  is computed so that should an engine failure occur at or before that speed on a limiting runway, there would be adequate runway to stop the aircraft. Furthermore, should the engine failure occur at or after  $V_1$  and the pilot continue the takeoff, the aircraft would be safely flyable and have a performance level that would allow the aircraft to reach a height of at least 35 feet over the end of the runway. A number of other complex criteria are involved in the  $V_1$  concept and certification rules, but the above provides the general concept and purpose behind the  $V_1$  takeoff decision speed.

pressures, and wind conditions present at Dryden on March 10, 1989. However, the Piedmont flight simulator was not highly calibrated, and, after analysing the results of the flights, the operations group realized that more in-depth study was necessary.

In order to inquire further into the performance of the Fokker F-28 aircraft, members of the operations group travelled to the aircraft design and manufacturing facility of Fokker Aircraft B.V. at Schiphol Airport, Amsterdam, The Netherlands. There they met with a number of Fokker's technical authorities, including Mr Rinse Jellema, Mr Frans Hollestelle, and Mr Jack van Hengst.

Mr Jellema, an aeronautical engineer, is the manager of the fleet airworthiness department, which is responsible for Fokker's fleet airworthiness, quality assurance, and safety investigations. He represented Fokker Aircraft during the early stages of the investigative process and assisted CASB's Engineering Branch in its examination of the aircraft wreckage and in dealing with the crashworthiness aspects of the aircraft crash.

Mr Hollestelle, who is Fokker's operations engineer, flight crew training and operations support, reviewed with the operations group the F-28 performance data and the operational capabilities of the aircraft and assisted in determining the performance capability of the aircraft by using the information available to the flight crew of C-FONF at Dryden prior to its takeoff and crash.

Mr van Hengst is the chief aerodynamicist and the manager of the aerodynamics and aeroelasticity department of Fokker Aircraft. He worked on the design and the development of the original Fokker F-28 Mk1000 and subsequent series F-28 aircraft, worked on the development of the Fokker-100 aircraft, and has participated in several research projects conducted by Fokker Aircraft unrelated to the F-28 and the Fokker-100 aircraft programs. Mr van Hengst provided to members of the operations group and the performance subgroup historical data on the design and development of the F-28 Mk1000 aircraft, together with aerodynamics studies relating to airfoil surface roughness and wing contamination. Fokker Aircraft also shared with my Commission investigators its collective knowledge of contamination-related accidents experienced by the Fokker F-28 over the years.

## **Manufacturer's Performance Research and Testing**

The Fokker F-28 Flight Handbook was prepared by Fokker Aircraft B.V. (Fokker Aircraft or Fokker) to provide flight crew members as well as operations staff with a manual containing all information regarding

operations and performance. This handbook consists of three volumes. Volume 1 includes operating information; volume 2, certified performance information; and volume 3, additional performance information. The general performance information set out in the handbook is presented to comply with the appropriate performance criteria and certification requirements of United States Special Civil Air Regulation No. SR-442B.

The procedures, techniques, and other conditions detailed in these manuals were developed and recommended by Fokker Aircraft and approved by the Rijks Luchtvaart Dienst (RLD), the Dutch airworthiness regulatory authority, for use in the operation of F-28 aircraft. Fokker emphasizes that the procedures are only for guidance in identifying acceptable operating procedures; they are not considered mandatory so as to prohibit operators from developing their equivalent procedures.

Accordingly, manuals such as Piedmont Aviation Inc.'s F-28 Operations Manual, USAir's F-28 Operations Manual (also referred to as USAir's Fokker F-28 Pilot's Handbook), and the draft F-28 Operations Manual prepared by Air Ontario are examples of equivalent procedures developed by operators to fit their operations. In no event, however, may the F-28 operations manuals prepared and developed by operators be less restrictive than the procedures, techniques, and other conditions contained in Fokker's F-28 Flight Handbook.

In certifying the F-28, Fokker Aircraft elected to meet the requirements of the United States Civil Aviation Regulation 4(b) (CAR 4(b)), now called Federal Aviation Regulation 25 (FAR 25). The Dutch RLD adapted and conformed to the United States CAR 4(b) and FAR 25 as its certification requirements and standards. Fokker Aircraft also met the equivalent British Civil Aviation Regulations (BCARs) in its certification process.

An examination of the applicable legislation and a review of the evidence by this Commission confirmed that the aircraft met all the requirements of CAR 4(b) (and now FAR 25) and of the BCARs; accordingly, the aircraft met the applicable equivalent Canadian legislation for the purposes of operation in Canada. I am also satisfied that, since the aircraft met the requirements of Dutch CARs, United States CARs and FARs, and British CARs, Transport Canada was in a position to issue the appropriate certificate of registration and certificate of airworthiness for the Fokker F-28 Mk1000, Canadian registration C-FONF.

## **Water/Slush Ingestion by Engines on Takeoff**

The flight crew of a NorOntair Twin Otter took off from the Dryden airport at approximately 12:50 p.m. on March 10, 1989, approximately 39

minutes after the crash of C-FONF. In testimony before this Commission, members of the crew described the amount and type of contamination at the terminal ramp and on the east half of runway 29 to be one-quarter to one-half inch of slush at that time. Two witnesses on the ground heard engine noises coming from C-FONF during its takeoff run that they variously described during testimony as "burping," "sharp," "explosive," and "quick" then "gone." In view of this evidence, it was deemed necessary to determine if the noises described by these two witnesses might have been caused by slush ingested into the engines during the aircraft's takeoff run.

In order to comply with the United States FAR 25.1091-type certification requirements, Fokker Aircraft was required to design and locate the engine air inlet ducts on the F-28 aircraft in such manner as to minimize the ingestion of foreign matter during takeoff, landing, and taxiing, and it had to demonstrate that the design of the aircraft precludes a hazardous quantity of water and/or slush on the runway from being directed into the engine inlets. The evidence shows that flight and ground-run tests were conducted in natural slush conditions at Schiphol Airport in Amsterdam on February 5, 1968, with Dutch RLD observers present.

Fokker, in its certification report no. V-28-7, dated March 11, 1968, and entitled "Investigation on F-28 Slush Ingestion Characteristics," described the tests, the test results, and the conclusions. The tests consisted of one takeoff with 25° of flap selected and two ground-run accelerate-stops with, respectively, 42° and 25° of flap. During the tests, the spray patterns were observed from inside the aircraft and observed and photographed from two observation posts alongside the runway. There were large variations in the density and depth of the slush layer. The first part of the runway, where the aircraft was accelerating, was covered with patches up to two inches thick of relatively dry snow and low-density slush. On the portion of the runway where the aircraft passed at high speed or was stopping, the predominant condition was high-density slush, one-quarter to one-half inch thick. The temperature was slightly above zero. There were water deflectors on the nose tires.

Spray from the nose wheels emerged in the shape of a flat, narrow disc and passed beneath the wing and the fuselage between the main undercarriage struts. A small amount of slush deposit was found on the nose-gear doors and the underside of the fuselage aft of the nose-wheel well. This secondary spray from the nose tires was effectively blocked from the engine intakes by the fuselage. No spray from the nose tires was seen to pass over the wing or into the intakes. The spray from the main wheels had a similar shape and, apart from a small jet of slush emerging at a steeper angle from between the two wheels of each main undercarriage strut, passed well below the plane through the underside

of the aft fuselage. The jet of slush was effectively prevented from entering the intakes by the inboard sections of wing and flap.

It was concluded that, under conditions representative of slush conditions that can be expected in airline service, the design of the aircraft precludes a hazardous quantity of water and/or slush from being directed into the engine intakes. Since there was no observed ingestion, Fokker concluded that the tests also showed that the location of the engines is also favourable in minimizing the ingestion of other forms of runway contamination.

Fokker provided to this Commission certification report no. V-28-7, together with photographs taken by Fokker, which describes and demonstrates the testing and conclusions. Shown below as figure 12-1 is one of the photographs provided by Fokker Aircraft showing the F-28 during slush tests moving at high speed in slush. Mr van Hengst, who was present during the tests, described in detail during his evidence before the Commission the findings of Fokker Aircraft. He also advised that he is not aware of any operators who have reported contamination entering the engines on slush-covered runways.

Mr van Hengst testified that, at a flap setting of 25°, slush lodged between the flap and the flap vane, a condition Fokker considered might cause damage on flap closure. Accordingly, Fokker, to avoid damage to the flap vane system due to the slush compaction between the flap and vane, recommended that takeoffs in slush be conducted at an 18° flap setting. Fokker in evidence showed that flaps set at 18° provide a shielding effect similar to a 25° setting but without exposing the flap and vane to slush compression damage.

There is some possibility that snow, slush, or ice that left the wing upper surface during the takeoff run was ingested into the engines. The Piedmont operations manual, in the section on adverse weather, contains information regarding ice that may form on the upper surface of the wings while the aircraft is on the ground. The ice forms either because of warm fuel, which can cause snow to melt, with the water subsequently refreezing; or because of extremely cold fuel, as may be the case after long flights at very low ambient temperatures, which causes water condensation or rain to freeze. It is stated in the manual that "[d]uring take-off this ice may break away and at the moment of rotation enter the engine causing compressor stall and/or engine damage" (p. 3A-24-1). During testimony, however, no one described seeing anything that could be taken to be unusually large amounts of ice or snow separating from the wing of C-FONF during the takeoff roll. Moreover, there was no damage found during examination of the engines that showed they had ingested slush or ice. (For details, see the section on engine investigation in chapter 10 of this Report, Technical Investigation.) During manufacturer's certification tests of the F-28 Rolls-



Figure 12-1 F-28 during Slush Test, February 5, 1968



Source: Fokker Aircraft B.V.

Royce engines, as described in chapter 10, it was demonstrated that the engines were able to ingest great quantities of water with no apparent difficulty. Bearing this point in mind along with the fact that most witnesses testified that the engines were operating normally throughout the takeoff run, it is probable that if the engines ingested snow, slush, or ice from the wings during takeoff, the ingestion could have caused only a fleeting abnormality and perhaps an uncommon noise.

From the evidence that I have heard and the documents reviewed, I am satisfied that, during the takeoff run of C-FONF from the Dryden airport on March 10, 1989, slush from the runway was not ingested into the aircraft's engines. If contamination from the aircraft wings had been ingested, it would not have caused a reduction in thrust or a failure of the engine such as to affect tangibly the takeoff performance of the aircraft.

## **Wing Leading-Edge Damage**

### **Denting**

Commission investigators were advised that the wing leading edges of one or both of Air Ontario's F-28 aircraft may have been dented. Since a smooth leading-edge surface is critical to the production of lift, my investigators felt it was important to make inquiries to determine if there was denting on the wing leading edges of C-FONF. They also approached Fokker Aircraft to determine the effects that denting on the wing's leading edge has on aircraft performance. Information on this subject was also solicited during the appearance of Air Ontario pilots on the witness stand. Some of the pilots recalled having some knowledge of denting on the wings of the F-28 aircraft, but only one stated that there were dents on aircraft C-FONF. Captain Monty Allan, a first officer on the F-28 at the time of the accident, stated that he was aware of dents on the wings, particularly of a fist-sized dent on the leading edge of C-FONF. Since the dents were written up in appropriate logbooks and apparently were not repaired, he believed the dents were within allowable limits. None of the other pilots was sure of the size or position of the dents. Ms Elaine Summers, the chairwoman of the investigation team's records group, stated in testimony that, while examining aircraft C-FONG after March 10, 1989, in relation to another incident, she noted some dents on the leading edge of the left wing.

Fokker Aircraft advised that on August 15, 1971, an F-28 aircraft operated by Martin's Air Charter encountered hail in flight at 230 knots at an altitude of 10,000 feet. The leading edges of the wings, the empennage (tail section), and the engine inlets were dented, and the fuselage nose was worn. The maximum depth of the dents was about 4 mm, and there were about 25 dents per m span of the wing. The

structural integrity of the leading edges was not impaired, and continued flying was permitted by the Dutch RLD, provided Fokker could show that the aerodynamic capabilities were not downgraded. (The wing was required still to be able to generate the maximum lift coefficient ( $C_{LMAX}$ ) as certified for the aircraft.)

On August 16, 1971, a test flight was flown on the aircraft, during which flight stall tests were performed to assess the maximum lift coefficient and the stalling characteristics. The flight was flown by a Fokker test pilot, and an F-28 captain with Martin's Air Charter acted as co-pilot. Observers on board included individuals from the Dutch RLD and Fokker's aerodynamics department. The testing revealed no measurable effect on the maximum lift coefficient and the stalling characteristics due to the dents in the leading edges of the wings.

In the report of the testing, Fokker described the hail encountered and the test results. The aircraft's stalling characteristics were found very satisfactory and not impaired whatsoever by dents in the leading edges of the wings. Fokker concluded in the report that, based on the indicated angle of attack during the tests, the g-break lift coefficients in the aircraft were at least equal to the g-break lift coefficients when the aircraft was certified and, most likely, were better.<sup>3</sup>

It is the evidence of Mr van Hengst that this report, generated as a result of the test flights, was used by Fokker Aircraft as a basis for the configuration deviation list (CDL) for the F-28, which specifies the amount of denting allowed on the leading edge of the wing. To summarize Mr van Hengst's evidence, basically the CDL stated that the amount of allowable denting on the leading edge of an aircraft wing can be no more than an amount equal to 25 per cent of the dents found on the test aircraft and that the maximum depth of any one dent was 4 mm. In determining the CDL requirements, structural integrity of the wing as well as aircraft performance was taken into consideration.

Mr van Hengst in his evidence discussed other types of denting on leading edges. He concluded that sharp dents in the leading edge of the wing would have the greatest effect on lift, with smooth dents on the trailing edge having no effect. Apart from those tests described in the aerodynamics report provided to this Commission, Fokker conducted no other tests relating to the effects of dents on aircraft wings. Since Mr van Hengst's views on the effects of denting on the leading edge are important, I include the following quotation:

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<sup>3</sup> In ground terms, g-break is the point where an aircraft can no longer maintain one-g level flight. That condition is used during certification test flight to define the aircraft stall speed and corresponding maximum lift coefficient ( $C_{LMAX}$ ).

- A. ... When we did this flight test with the dents, deep in my heart, I thought it had an effect. And I learned a lot of it. I learned that maybe it has something to do with the sharpness and the steepness of the disturbance, and looking in all the data and wind tunnel testing done in the early days, that convinced me that that is a rule.

As long as the edge of the disturbance is not sharp but smooth, then the effect on the aerodynamics is mild. I won't say there is no effect. It depends on the place where it is. If it is on the leading edge, there will be effect. If it is on the trailing edge, there will be no effect.

- Q. And if they are sharp, if the dents are sharper?

- A. If it is sharpened, it's worse. That's the worst thing ... you can have.

(Transcript, vol. 71, p. 147)

Mr van Hengst also responded to a question about the effect of the dents on adhesion of contamination to the leading edge of a wing:

- A. I – well, I'm not a [physicist], but if you look at the mechanism, if the precipitation is simply rain, it doesn't matter whether the surface is smooth, say a metal surface. As long as the temperature of the surface is cold, it will adhere. It will stick to the surface. And no matter whether it is [a] little bit roughened, it simply sticks.

(Transcript, vol. 71, p. 148)

### **Condition of the Paint**

In order to complete the picture regarding the condition of the leading edges of the wings on the F-28 aircraft flown by Air Ontario, the Air Ontario pilots were questioned about the condition of the paint on the leading edges. During testimony, Captain Robert Perkins stated that he learned on the F-28 course that the F-28 aircraft was susceptible to leading-edge damage. He had noted some chipped paint on, he believes, C-FONF, and he stated that the paint on C-FONF was older than that on C-FONG. Captain Allan stated that the paint on C-FONF was peeling and flaking, and on C-FONG it was bubbling and blistering; the bubbles were "tiny, tiny, very small" (Transcript, vol. 91, p. 68), about the size of the tip of a pen. Captain Allan was never genuinely concerned about the leading-edge paint on the F-28 aircraft.

Mr van Hengst did not provide a detailed opinion on the aerodynamic effects of chipped paint on the wing leading edges. He stated that the wings should be kept as smooth as possible to minimize skin friction during flight. He also stated that the roughness on the wing from paint chipping and peeling is not especially significant and does not significantly affect lift characteristics.

While there may have been some denting and degradation of the paint on Air Ontario's two F-28 aircraft, I have no evidence before me to indicate that the condition of the wings' leading edges could have contributed appreciably to the degradation of the takeoff performance of C-FONF. I make this finding based on the fact that there was never any reported takeoff or performance degradation of either of Air Ontario's two F-28 aircraft during their operational lives. Accordingly, I do not believe that denting or chipped paint on the leading edges of the wings of C-FONF contributed to the performance degradation during its ill-fated takeoff run from Dryden on March 10, 1989.

### **Unexpected Stalling Due to Wing Anti-Ice Air Leakage**

The matter of unplanned aircraft stalling while on approach for landing was brought to the attention of my investigators by members of the International Federation of Air Line Pilots Associations (IFALPA), who had observed unplanned stalling caused by leakage of hot anti-icing bleed air through joints in the wing's leading edge. The leaks cause the airflow characteristics to be modified. The partial flow separation that then occurs over the parts of the wings where the leaks appear adversely affects the aircraft stall characteristics. Accordingly, the matter was reviewed to determine whether this phenomenon may have occurred during the takeoff of C-FONF.

Both the Fokker F-28 Flight Handbook and the Piedmont and USAir operations manuals stress that wing anti-ice should not be put on during any phase of the takeoff or while the aircraft is airborne below 1500 feet above ground level. Wing anti-ice requires engine bleed air and results in a loss of some engine thrust. To ensure maximum available engine thrust during takeoff, pilots are advised not to use wing anti-ice during takeoff. Although the observations made by the IFALPA members related to flight at low speeds during the approach and landing with wing anti-ice on, my investigators took steps to determine if the wing anti-ice system was off during the takeoff at Dryden. This exercise was carried out to confirm that C-FONF had maximum thrust available during takeoff and also to eliminate any concern about possible wing stall due to wing anti-ice bleed-air leakage. The investigation confirmed that the wing anti-ice valves were in the off position after the crash and, owing to the absence of debris in the air passages of the anti-ice system, were in the off position during the time the aircraft was travelling through the trees.

It is unlikely that, owing to performance penalties which would have been suffered, the pilots would have used wing anti-ice in any event: C-FONF was being operated from a 6000-foot runway and the aircraft

weight at takeoff was close to maximum structural takeoff weight. Although there was observed wing drop shortly after takeoff, the aircraft was also observed to have regained a wing-level attitude.

There is persuasive evidence that the anti-ice system was off during the takeoff of C-FONF, and there is no evidence of previous wing anti-ice air leakage problems on either of Air Ontario's F-28 aircraft. The fact that the anti-ice valves were closed would eliminate any concern that air leakage had affected the flight characteristics of the aircraft. I am therefore satisfied that wing anti-ice air leakage was not a factor during the takeoff from Dryden.

## **Relevant F-28 Wing Surface Contamination Occurrences**

To determine whether the F-28 aircraft had a history of contamination-related accidents, my investigators reviewed the aircraft type's accident history. The F-28 accident and incident record, as revealed in International Civil Aviation Organization (ICAO) and CASB occurrence data bases, is not unusual in any sense. The records do not indicate any particular trend, nor is there evidence of the aircraft having abnormal flight characteristics. On the contrary, the Fokker F-28 Mk1000 appears to have relatively good performance and is reportedly easy to fly.

Two occurrences involving wing contamination and the Fokker F-28 are significant to this investigation and warrant a detailed description of the circumstances and the findings. The first occurred in Germany, at the Hanover airport, on February 25, 1969, and the second occurred in Turkey, at the Cumaovasi airport in Izmir, on January 26, 1974.

### **Hanover, Germany, February 25, 1969**

The crew of an F-28 aircraft attempted to take off from runway 09 left on a demonstration flight from the Hanover airport at about 1626 GMT (1726 local), February 25, 1969. Runway 09 left is 2387 m (7832 feet) long and 45 m (150 feet) wide, and it has no slope. The elevation of the airport is 170 feet above mean sea level (asl).

At rotation speed, the captain rotated the aircraft to about 12°, and the aircraft lifted off. It immediately rolled to the right to an angle of bank of about 25°, which could not be corrected by aileron control. The aircraft did not accelerate and descended until the right wing tip struck the runway. The aircraft rolled to the left and then to the right, and the captain rejected the takeoff. The aircraft came to rest approximately 50 m (164 feet) to the right of the runway and 1975 m (6480 feet) from where the takeoff roll commenced. The stick-shaker had activated three times while the aircraft was airborne. The only damage to the aircraft

was to the right wing, the flap, and the aileron. None of the two crew or nine passengers was injured.

Given the conditions at the time of takeoff, the aircraft should have reached rotation speed of 103 knots after a ground roll of 475 m (1558 feet) and become airborne at 113 knots. The Fokker F-28 Flight Handbook recommends that the aircraft be rotated to 5 to 10° on takeoff. From the flight data recorder it was determined that the aircraft was rotated at 105 knots after a ground roll of 535 m (1755 feet) and became airborne at 110 knots. The aircraft reached a maximum height of 50 to 60 feet and a maximum speed of 127 knots. The first stall developed three to five seconds after liftoff.

The captain held a valid airline transport pilot licence (ATPL) and had a total of 11,500 flying hours with recent flying experience on the Caravelle, the Hansa Jet, and the Nord 262 aircraft. He had a type rating on the F-28 with 12 to 14 hours on the aircraft. The co-pilot held a valid ATPL and had a total of 8000 flying hours. He had 10 to 15 hours on the F-28.

The aircraft was serial number 11004, registered as PH-ZAA, and was the fourth prototype and the first commercially operated aircraft of the F-28 series. It was owned by a German charter company (LTU). The aircraft was modified up to the latest standards of the production series and met Netherlands (RLD) requirements for airworthiness. There was no evidence that there had been any defects or malfunctions that had a bearing on the incident. The aircraft's weight and balance were within limits. The stabilizer setting for the flight had been set to 1° ANU (aircraft nose up); in the flight manual the recommended setting is 1° AND (aircraft nose down). The incorrect stabilizer setting would reduce the amount of control column force required to effect aircraft rotation.

The aircraft had been parked for about five hours preceding the attempted flight. During this time, the temperature was between -1 and -2°C, the relative humidity was near 100 per cent, there was overcast cloud based at 700 to 900 feet, and there was precipitation in the form of light snow and undercooled drizzle. At takeoff time, the temperature was -2°C and the visibility was 3 km in snow. The wind was 060° at 7 knots. The runway was covered with rime or ice but had been chemically de-iced and sanded during the day; the measured braking action was medium to good. The preceding takeoff had been made by a Viscount aircraft 15 minutes before the incident. On the basis of the weather, the investigators concluded that no wind shear, either in force or direction, existed, and that any turbulence from departing aircraft had dissipated.

During the pre-flight inspection, the captain and a factory mechanic noted that the precipitation had formed a thin layer of ice patches on the wing. The captain judged this accretion not significant enough to have it removed. It was later established that the ice was mostly at the nose

of the wing, back to approximately 30 per cent of the chord and extending over the full span of the wing. The accretion was described by the captain and mechanic as a thin, irregular layer of ice patches, the ice crystals being of a granular form. A passenger, while leaving the aircraft via an emergency exit over the right wing, had trouble keeping his balance because of ice on the wing.

Fokker Aircraft, which participated in the investigation, was able to assess the degree and amount of contamination on the wing. In terms of area covered by the contamination, Mr van Hengst stated in testimony as follows:

- A. It was distributed over the whole wing, and what also happened is that it stands there, and in the memory of one of the witnesses, at that early day in the morning, there was also between all this freezing drizzling the sun coming up. It was in the morning.

And one of the parts of the wing was in fact already melting, and the other not. Because the aircraft was standing like this and the sun is coming like this so this part was starting to melt and the other one not.

So ... what then happened is they took off and in fact, one of the wings was clean due to the sun and the other not, and that is the reason why it rolls off.

(Transcript, vol. 70, p. 78)

During the takeoff, the aircraft was over-rotated. It was found that the stabilizer was incorrectly set, resulting in lower control forces at rotation. However, the maximum rotation angle that was reached, about 12°, would not have caused an F-28 with a clean wing to stall.

It was therefore concluded that the contamination on the wing, in the form of a thin, irregular sheet of granular ice crystals, must have been the factor that caused the wing to stall.

Fokker Aircraft determined that the roughness on the nose and upper surface of the wing was equivalent to ice particles of 1 or 2 mm in diameter, distributed approximately one particle for each square cm of wing surface.

#### **Izmir, Turkey, January 26, 1974**

The crew of a Turkish Airlines F-28 aircraft, serial number 11057 and registration TC-JAO, attempted to take off from Cumaovasi airport, Izmir, Turkey, at about 0710 local time, January 26, 1974. The aircraft became airborne after a ground roll of approximately 975 m (3200 feet); however, when it was 8 to 10 m (26 to 33 feet) above the ground, it yawed to the left and pitched nose down. The aircraft contacted the ground in a near-level attitude, first by the outboard fairing doors of the



left flap, then by the left side of the fuselage belly. The aircraft disintegrated and caught fire within 100 m (328 feet) of travel. Four crew members and 62 passengers died as a result of the accident; one crew member and 6 passengers survived.

With the conditions at the time of takeoff, the aircraft should have reached rotation speed after a ground roll of 850 m (2800 feet). From the flight data recorder it was determined that the aircraft became airborne at 124 knots after a 975 m (3200-foot) roll. The speed increased to 133 knots and then dropped to 124 knots, and the aircraft veered left.

The captain was an ex-airforce jet fighter pilot, held a valid airline transport pilot licence, had 577 hours in F-28 aircraft, and had 2600 hours' total flying time. He had been an F-28 captain since 1972 and an F-28 check pilot since 1973. The co-pilot was also ex-airforce, and his experience was in transport-type aircraft and helicopters. He had 395 hours in the F-28, had 2794 hours' total flying time, and held a valid airline transport pilot licence.

The aircraft broke into three main sections: the tail section, the fuselage, and the cockpit. The fuselage came to rest upside down. There was no evidence of any aircraft failure or malfunction prior to the accident.

The aircraft had been parked overnight in an open area of the airport. On the morning of January 26, the temperature was 0°C and the relative humidity 95 per cent. At the time of takeoff, the temperature was 3°C and the relative humidity 97 per cent. Frost formation was not noticed during the aircraft walkaround prior to the takeoff. The next day, however, with meteorological conditions almost the same, frost accumulation was seen on the wings of another F-28 parked outside overnight. There was more frost on the left than on the right wing, which was towards the buildings.

It was concluded that the cause, or probable cause, of the accident was that the aircraft stalled because of over-rotation and frost accretion on the wings.

## **Wing Contamination – Research**

Following the February 25, 1969, F-28 takeoff occurrence at Hanover, Fokker reviewed early research on the subject of surface roughness on airfoils and conducted a series of wind tunnel and simulator tests. Fokker wished to confirm the findings of existing literature and determine the effects of apparently unobtrusive amounts of contamination on the ability of the F-28 wing to produce lift.

Literature published in the 1930s on the effects of protuberances and surface roughness on the characteristics of airfoils concluded that protuberances on the upper surface of an airfoil, so small they would

ordinarily be considered surface roughness, have a significant detrimental effect on the maximum-lift and drag characteristics. As the portion of such roughness approaches the leading edge along the upper surface, the effect becomes particularly critical.

Mr Richard Wickens, an expert in low-speed aerodynamics and one of the members of the performance subgroup, stated during his testimony that the data in the reports and memoranda of the 1930s indicate that, on smooth airfoils, smaller grain roughness has a greater detrimental effect on the lift than does larger grain. When asked if the literature is saying that more smoothly finished airfoils are more susceptible to lift reduction when subjected to some sort of roughness, Mr Wickens stated:

- A. That's what it appears to be saying. The ... more smoothly finished airfoil is capable of achieving higher maximum lift coefficients, and this curve is still going up. So that when you roughen them, you have a greater relative loss.

(Transcript, vol. 69, p. 88)

Mr Wickens further stated that although there is not a great deal of lift capability lost when the rear portion is roughened, there is still some loss, although nothing like that seen when the complete airfoil, including the nose, is roughened. Mr Wickens stated as follows:

- A. There was one other point, and that is there are data points which indicated only the rear half of the airfoil in this case was roughened, and according to this, that appears to restore the performance back to its original clean state, with this exception.
- Q. So when only the rear half of the airfoil was roughened, the lifting capability was almost the same as it was with a totally clean surface?
- A. There was a slight loss, but it was nowhere near as much as with the complete airfoil roughened, including the nose.
- Q. So can I assume from this that the roughness on the front portion of the wing is more critical than the roughness on the back portion of the wing?
- A. Yes.

(Transcript, vol. 69, pp. 89-90)

Mr van Hengst aptly summarized the conclusion of the early research reports as follows:

- A. Well, the basic conclusion which you can draw from this report is that contamination on a wing will give rise to loss in lift, and especially loss in maximum lift.

(Transcript, vol. 70, p. 82)

Based upon this early research literature and the description by the flight crew and by the engineer who inspected the F-28 prior to its takeoff at Hanover, Fokker conducted wind tunnel tests using a scaled 20-to-1 F-28 model aircraft with both wings roughened and contaminated evenly on a scale of one 1 mm diameter particle for each square cm of wing surface.

Following the wind tunnel tests and studies conducted by Fokker Aircraft, the company produced a report, entitled "Note on the Aircraft Characteristics as Affected by Frost, Ice or Freezing Rain Deposits on Wings, December 16, 1969." Referred to as the "Wind Tunnel" report (no. L-28-222), it was forwarded at that time to all F-28 operators. The report deals with the effects of sandpaper roughness on the wings of both jet and propeller aircraft and specifically describes the degradation in takeoff lift and the acceleration characteristics of the F-28 caused by roughness on the wings. It is included in its entirety as technical appendix 5 to this my Final Report. An illustration of the F-28 model in a wind tunnel is reproduced as figure 12-2.

The tests revealed that there was a 25 per cent loss of maximum lift coefficient and that the maximum angle of attack was reduced by approximately 5°. Early experiments at cleaning contamination from the forward 50 per cent of the airfoil chord restored most of the lift characteristics. In an effort to determine more closely where the F-28 wing was most sensitive to surface roughness, Fokker removed roughness from the forward 15 per cent of the wing chord, starting at the leading-edge nose. Fokker found that the lifting capability of the wing was almost completely restored.

The wind tunnel tests also demonstrated that, with severe roughness, the wing can be stalled before it reaches the angle of attack that would normally activate the aircraft's stall-warning system.<sup>4</sup>

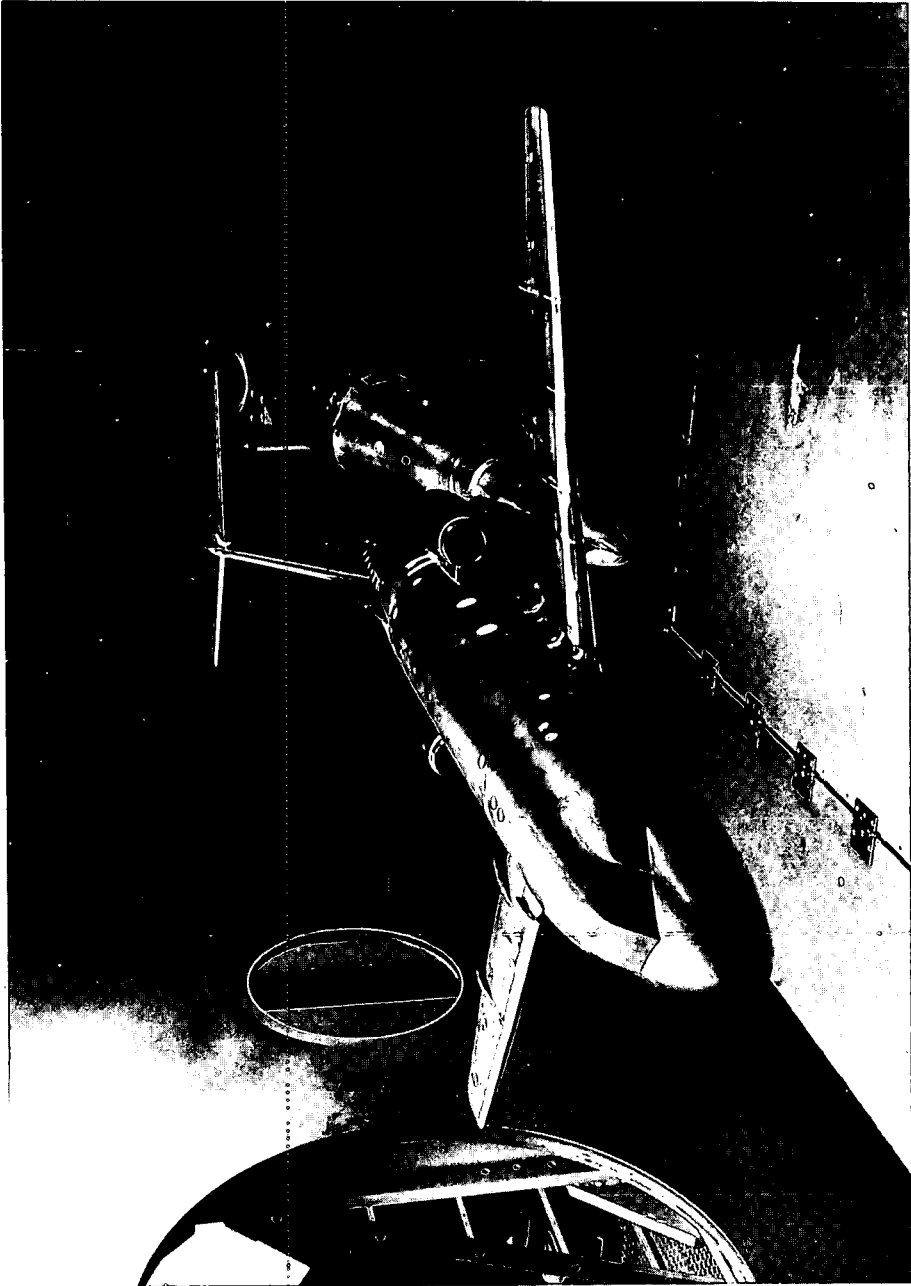
The horizontal stabilizer on the F-28 during normal operations, including takeoff, is designed not to exceed an angle of attack of approximately 7°. Fokker designed the horizontal stabilizer to guarantee continued controllability even when the wing is stalled.

Similar wind tunnel tests showed that contamination roughness on the horizontal stabilizer had little or no effect on its performance, even when the wing is stalled as a result of contamination. The tests confirmed that

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<sup>4</sup> A stall-warning system (SWS) is a system designed to alert a pilot to an impending aircraft stall. It consists of an angle of attack sensor(s), an aircraft configuration input data system, and a mechanical alerting mechanism, commonly a stick-shaker. The SWS is set to activate at a predetermined angle of attack a few degrees below the wing's normal stalling angle of attack. When activated, the stick-shaker vibrates the pilot's control column. Under normal conditions, activation is generally used to indicate the prudent limit of usable lift.

Figure 12-2 Wind Tunnel Model Used in the Design of the F-28 Mk1000 Aircraft



Source: Fokker Aircraft B.V.

contamination on the horizontal stabilizer would not have a significant effect on controllability and would not affect the total lift generated by the lifting surfaces. Generally, the horizontal stabilizer provides negative lift (the lower, uncontaminated surface is the critical surface), and the angle of attack of the stabilizer is well below its stalling angle of attack.

According to Mr van Hengst, the stall-warning device on the F-28 is activated at  $11^\circ$  wing angle of attack. Complete airflow separation where the aircraft loses aileron control occurs on a clean wing at a point between a  $19^\circ$  and  $20^\circ$  angle of attack. On a contaminated wing, however, complete airflow separation occurs with loss of aileron control at a  $9^\circ$  to  $10^\circ$  angle of attack. In other words, with roughnesses of 1 to 2 mm on every square cm of the entire wing, the aircraft will stall prior to the stall-warning device activating; in some cases, complete loss of aileron control could happen prior to such warning.

The results of the wind tunnel tests were fed into Fokker's engineering flight simulator to determine how the aircraft would behave with various degrees of roughness on the wings. The results were interpreted in various ways, but in every case the indication was a loss in the wing's ability to produce lift when contaminated. The two graphs that Fokker prepared from its engineering flight simulator data are included to demonstrate the loss of lift caused by varying degrees of wing contamination.

Up to a point, as figure 12-3 indicates, the more the wings were contaminated the greater the loss of lift. For example, during takeoff at a weight of 60,000 pounds, with  $18^\circ$  of flap and with a clean wing, the stalling speed of the aircraft was about 104 knots. With the wing lightly frosted, the stalling speed was about 117 knots, and with the wing heavily frosted, about 128 knots. The  $V_R$  speed (takeoff rotation speed)<sup>5</sup> for the aircraft was 121 knots and the  $V_2$  (takeoff safety speed)<sup>6</sup> was 127 knots. With a clean wing, the speed margin at rotation speed before stall was approximately 17 knots. With a lightly frosted wing, the margin was 5 knots. With a heavily frosted wing, the wing was in a stalled condition as it was rotated.

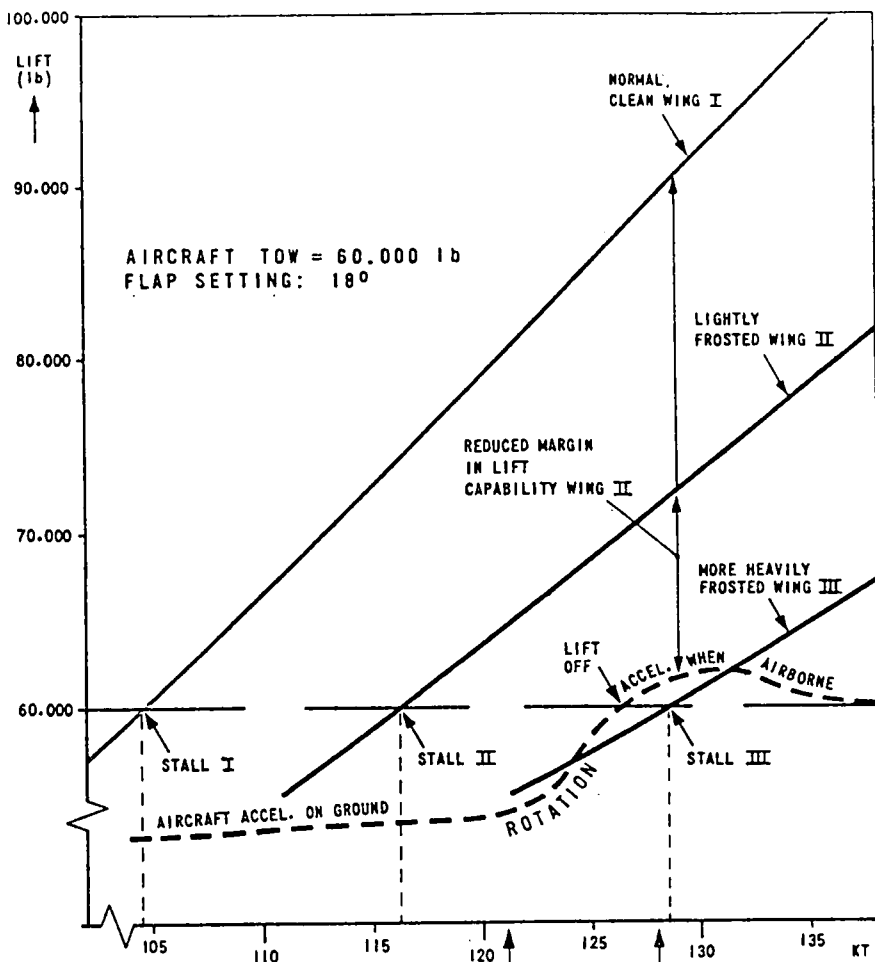
Figure 12-4 describes the decrease in stall margin between a normally clean wing and a lightly frosted wing and demonstrates that an aircraft

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<sup>5</sup>  $V_R$ , the takeoff rotation speed, in general terms is defined as the speed at which rotation is initiated during the takeoff to attain  $V_2$  climb speed at the 35-foot screen height.  $V_R$  must not be less than 1.05 times the minimum control speed in the air ( $V_{MCA}$ ) or less than  $V_1$ .

<sup>6</sup>  $V_2$ , the takeoff safety speed, in general terms is equal to the actual speed at the 35-foot screen height as demonstrated in flight and must be equal to or greater than both 1.20 times the stall speed in the takeoff configuration and 1.10 times the minimum control speed in the air ( $V_{MCA}$ ).

Figure 12-3 Comparative Margins for Two Arbitrarily Chosen Frost-Contaminated Wings and the Normal Clean Wing

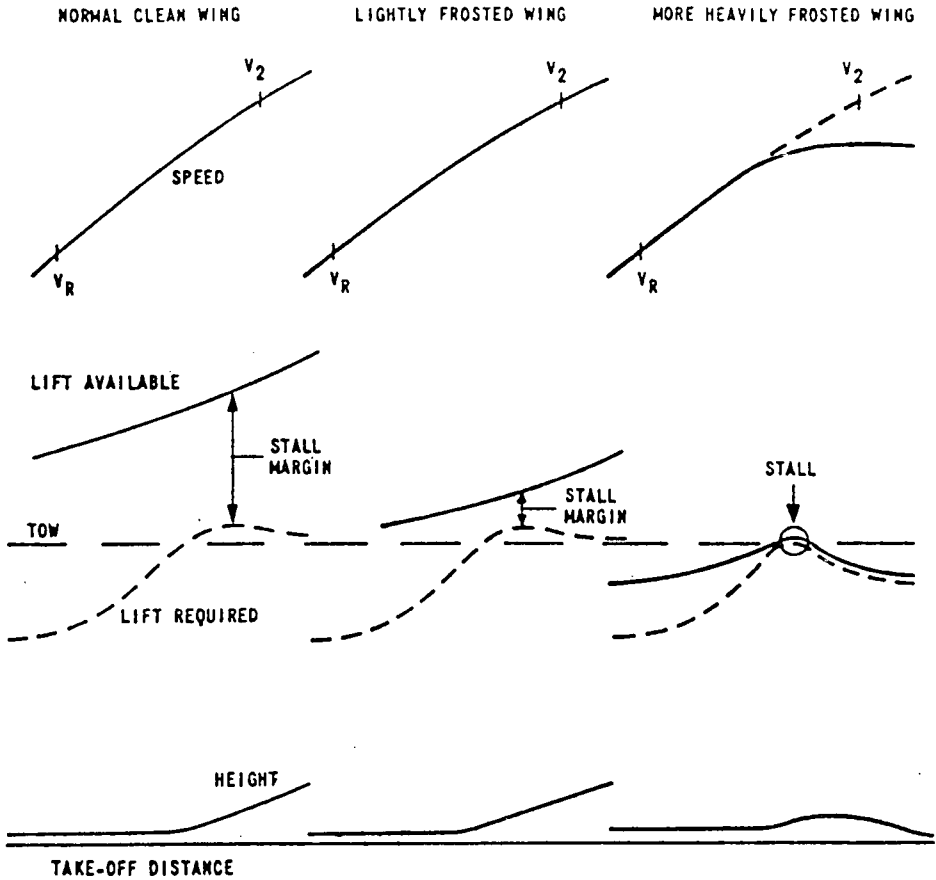


SPEED MARGIN TO STALL AT	$V_R$	$V_2$
WING I	16.5 KT	24 KT
WING II	5 KT	12 KT
WING III	-	-

Figure 1

Source: Shipwise (Fokker Aircraft), February 15, 1974

Figure 12-4 Comparative Stall Margins<sup>1</sup>



<sup>1</sup> Illustrates differently the comparative stall margins for the same (figure 12-3) two arbitrarily chosen frost-contaminated wings and the normal clean wing.

with more heavily frosted wings is unable to sustain flight because the wing is in a stall condition at rotation.

As a result of the research and testing, Fokker Aircraft concluded with an ominous warning printed in large capitals on a separate page: "*Since there is no way of measuring the amount of frost contamination in relation to its effect on the wing lift capability, get the aircraft de-iced before departure*" (Exhibit 532, tab 4).

## **Flight Dynamics of the Fokker F-28 Mk1000**

Following the initial test flights conducted by the operations group in Piedmont's F-28 flight simulator, the group confirmed that a more detailed examination of F-28 performance was necessary to identify factors that could produce a takeoff profile similar to the accident profile at Dryden. As noted, some members of the operations group travelled to Amsterdam to visit Fokker Aircraft to compare the manufacturer's contract flight crew training program with that of Piedmont. At the time, the performance subgroup also attended at the Fokker Aircraft facility in Amsterdam to commence its study of the F-28 aircraft flight profile. This section of my Report is based upon two reports prepared as a result of these investigations.

The first report, "Flight Simulator Investigation into the Take-off Performance Effects of Slush on the Runway and Ice on the Wings of a Fokker 100," was issued in August 1989 by Fokker Aircraft B.V. Referred to as the "Flight Simulation" report, it summarizes Fokker's data and findings on the takeoff performance of a Fokker 100 engineering flight simulator adjusted to approximate the flight characteristics of an F-28 Mk1000 aircraft. (The "Flight Simulation" report was entered as Exhibit 544 during the testimony of Mr Jack van Hengst.)

The second report, entitled "A Report on the Flight Dynamics of the Fokker F-28 Mk-1000 as They Pertain to the Accident at Dryden, Ontario, March, 1989" (the "Flight Dynamics" report), was researched and prepared by Mr Murray Morgan, Mr Gary Wagner, and Mr Richard Wickens.

Mr Morgan, manager of the in-flight simulator in the flight research laboratory of NAE at NRC in Ottawa, is a physics graduate and engineering test pilot with extensive experience in real-time software and mathematical techniques. Mr Wagner, an Air Canada pilot and a member of CALPA, as well is a qualified aeronautical engineer and an adjunct assistant university professor. Mr Wickens, a senior research officer in the low speed aerodynamics laboratory of NAE at NRC, is a qualified mechanical engineer with a specialty in low-speed aerodynamics.



The team's objective was to re-create the flight profile of C-FONF on takeoff at Dryden on March 10, 1989, and to determine the conditions that could have caused such a profile. Their report, entered as Exhibit 526, was addressed by each author during his testimony.

I believe that the data contained in the "Simulation" and the "Flight Dynamics" reports provide, in detail and with clarity, a thorough review of wing contamination and aircraft performance research and findings, and I have included both reports in the technical appendices to this my Final Report. (The Fokker "Flight Simulation" report appears as technical appendix 3 and the "Flight Dynamics" report as technical appendix 4.) It is my belief that the aviation community, and in particular flight crews, will find the background and detailed information, the test procedures, and the graphics contained in these two reports to be of value in appreciating more fully the insidious nature of wing contamination.

Because some of the data contained in these reports are complex in nature, I have provided the following summary and analysis to assist aviation safety organizations and other interested groups in disseminating information that has general application to all types of aircraft.

## **Fokker Flight Simulation Report**

To assist my investigators, Fokker agreed to make available its Fokker 100 fixed-base engineering flight simulator to conduct flight tests on the F-28 Mk1000. The Fokker 100 aircraft is a new and larger derivative of the F-28 series aircraft, and, although somewhat similar in appearance to the F-28, it has appreciable aerodynamic differences. The Fokker 100 engineering flight simulator was capable of being adjusted to approximate the flight characteristics of the F-28 Mk1000 aircraft, and it was possible to simulate slush on the runway to provide rolling resistance contamination. The simulator was also capable of simulating performance degradation caused by wing leading-edge ice. Fokker, by calculation, was able to equate flight performance degradation from wing leading-edge ice with roughness caused by wing surface contamination. Aerodynamic testing demonstrated that 1 inch of leading-edge "horned" ice created approximately the same 30 per cent loss of lift as did the roughness of 1-2 mm diameter particles distributed one per square cm of wing surface.

To investigate the effect of runway slush and wing contamination, Fokker adjusted the Fokker 100 engineering simulator to enable it to perform as C-FONF should have performed during its takeoff at Dryden if the runway had been bare and dry and the aircraft wings clean. A 6000-foot airport runway was selected with an elevation of 1500 feet asl and 0° slope to approximate Dryden airport conditions. Takeoffs were

conducted on a dry runway and on a runway covered with equivalent water depth (EWD) of up to 0.5 inches.<sup>7</sup> Most takeoffs were conducted with runway slush of 0.15 inches EWD to approximate the average EWD that was estimated, based on judgements, reports, and simulator studies, to have been on runway 29 at Dryden airport. Takeoffs were conducted with wing-ice equivalent on the wing from 0, representing a clean wing, to 1.00, representing contamination in an amount equal to one 1–2 mm diameter particles per square cm of the wing surface. A total of 30 takeoffs using 18° of flap were flown by the performance subgroup on June 7 and 8, 1989, and Fokker Aircraft flew a further 12 takeoffs on August 1, 1989, using 25° of flap. Normal takeoff profiles were varied by lifting the nose wheel out of the slush during the takeoff roll, rotating the aircraft more slowly at  $V_R$ , and failing the critical engine at  $V_1$ .

The details of the simulation testing, findings, and observations are summarized on pages 3 through 9 and in figures 35, 36, and 37 (reproduced below) of the "Flight Simulation" report. Fokker's observations were as follows:

- 1 The takeoff distance of an F-28 Mk1000 without runway slush or wing contamination was closely approximated by the F-100 simulator through weight and thrust selections.
- 2 The increase in takeoff distance of an F-28 Mk1000 with runway slush but without wing contamination was closely approximated by the F-100 simulator.
- 3 The effect of ice on the wing is considerable. Above a certain wing-contamination level, aircraft performance loss is so large that the aircraft cannot climb out of ground effect using normal handling techniques.
- 4 Engine failure at  $V_1$  is catastrophic when combined with slush on the runway and some contamination on the aircraft wing.
- 5 There is greater sensitivity to wing contamination at higher altitudes owing to decreased aircraft performance.

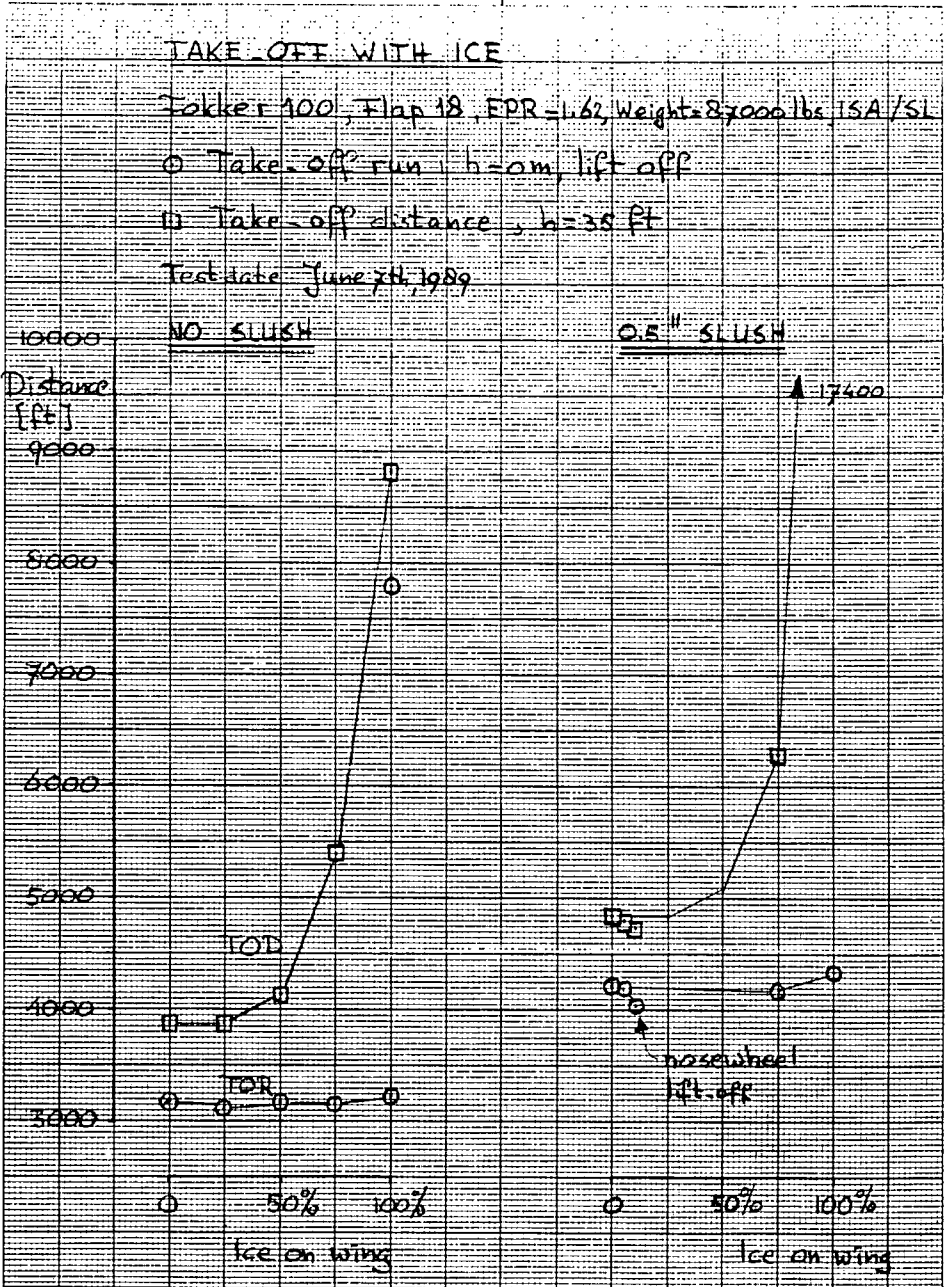
The above-noted figures of the "Flight Simulation" report graphically describe the increase in both takeoff distance (TOD) and takeoff run (TOR) required as a result of contamination on the wing and slush on the runway.<sup>8</sup> They are reproduced below as figures 12-5, 12-6, and 12-7.

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<sup>7</sup> Equivalent water depth (EWD), in general terms, is the depth of free-standing water that is equivalent to the depth of given precipitation. (Precipitation covers the whole range of densities, from that of dry snow, to slush, to free-standing water.)

<sup>8</sup> Takeoff distance (TOD) is the horizontal distance from the start of the takeoff until the aircraft reaches a screen height of 35 feet. Takeoff run (TOR) is the horizontal distance from the start of the takeoff to the point at which the main landing gear of the aircraft lifts off the runway.

Figure 12-5 Fokker 100 Simulation of Takeoff with Ice, Flaps 18°



Source: Exhibit 544, figure 35

Figure 12-5 describes the Fokker 100 simulator with 18° of flap at sea level taking off with power and weight equal to full power on an F-28 at 63,500 pounds. By loading up the wing with contamination from 0, representing a clean wing, to 1.00, representing contamination in an amount equal to 1–2 mm diameter particles per square cm of wing surface, but with no runway slush, the takeoff run of the F-28 ranged between 3100 and 3250 feet. However, as contamination on the wing increased from 0.5 to 1.00, the takeoff distance increased from approximately 4150 to 8800 feet.

During takeoffs with 0.5 inches of runway slush, the takeoff run ranged between 4200 and 4350 feet, representing an increased takeoff run of approximately 1000 feet owing to slush. Raising the nose wheel out of the slush decreased the takeoff run marginally.

With 0.5 inches of runway slush and a wing-contamination range of 0.5 to 1.00, the takeoff distance increased dramatically. With 0.5 inches of runway slush and 0.5 wing contamination, the takeoff distance was 5100 feet. Fokker estimated that by increasing the wing-contamination level to 1.00, representing a wing completely contaminated with 1–2 mm particles on each square cm of the wing, the takeoff distance of the F-28 would be 17,400 feet. In other words, the aircraft was unable to climb out of ground effect.

Figure 12-6 provides information that reflects the runway slush condition assumed to exist at Dryden at the time C-FONF crashed. All takeoffs were conducted with runway slush of 0.15 inches equivalent water depth (EWD) and flaps set at 18°. Takeoff runs increased from 4400 to 6000 feet and takeoff distances increased from 5100 to 7900 feet as wing contamination increased from 0 to 0.8.

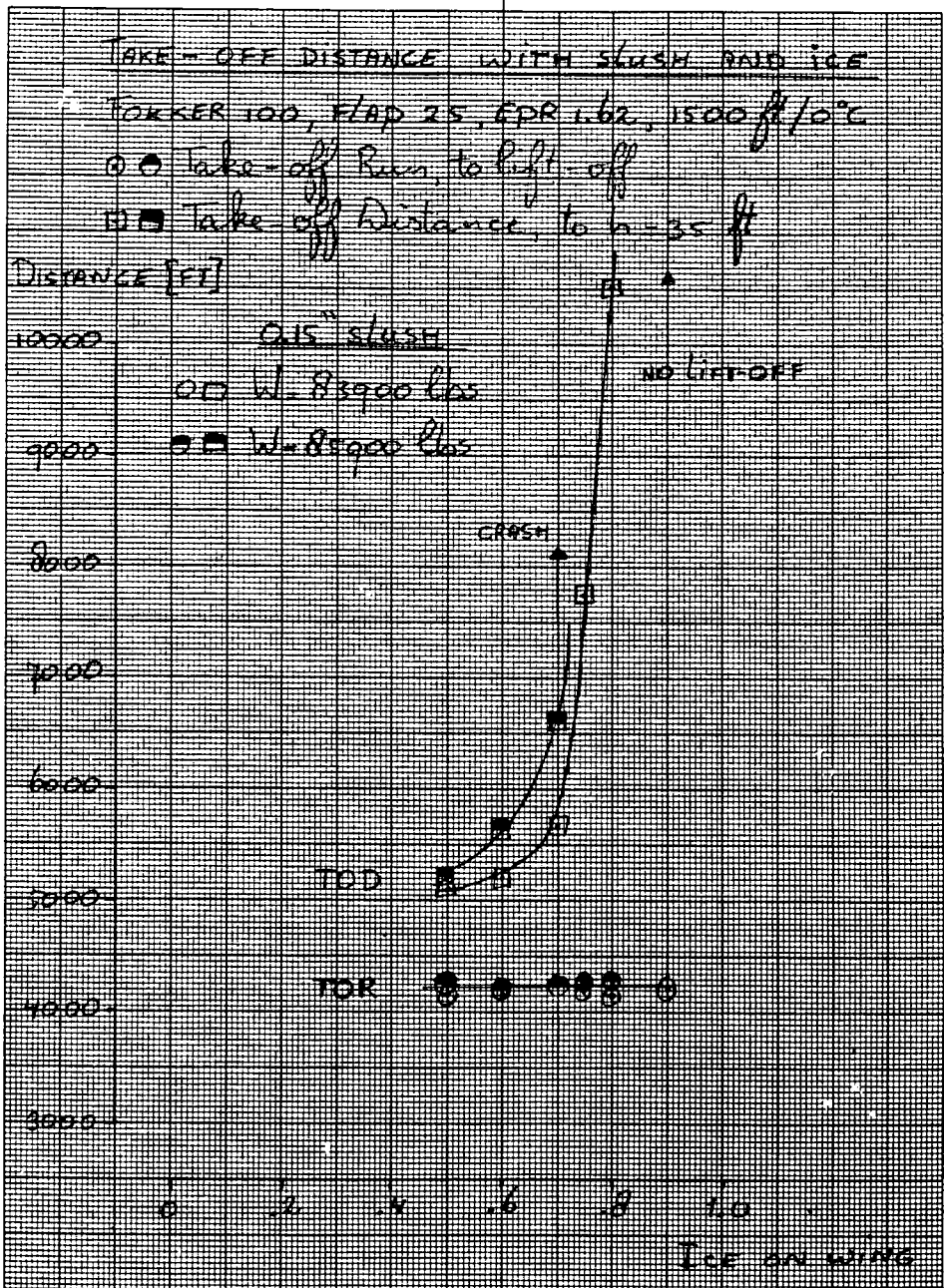
It is assumed that C-FONF had an equivalent wing-contamination level of at least 0.8 during its takeoff. With wing contamination in excess of 0.8, and slush depth of 0.15 inches EWD, both the takeoff run (TOR) and the takeoff distance (TOD) are greater than the runway length available at Dryden.

Figure 12-7 demonstrates the estimated takeoff performance of C-FONF utilizing 25° of flap in 0.15 inches of EWD of slush. Although the takeoff run performance is better at a 25° flap setting than it is at 18°, with higher amounts of wing contamination the takeoff distance required continues to be high or even increases, and at 0.8 wing-contamination level the aircraft failed to lift off.

In all cases where an engine failure occurred at  $V_1$ , with moderate wing contamination, the aircraft was unable to fly away, and in each instance it crashed.

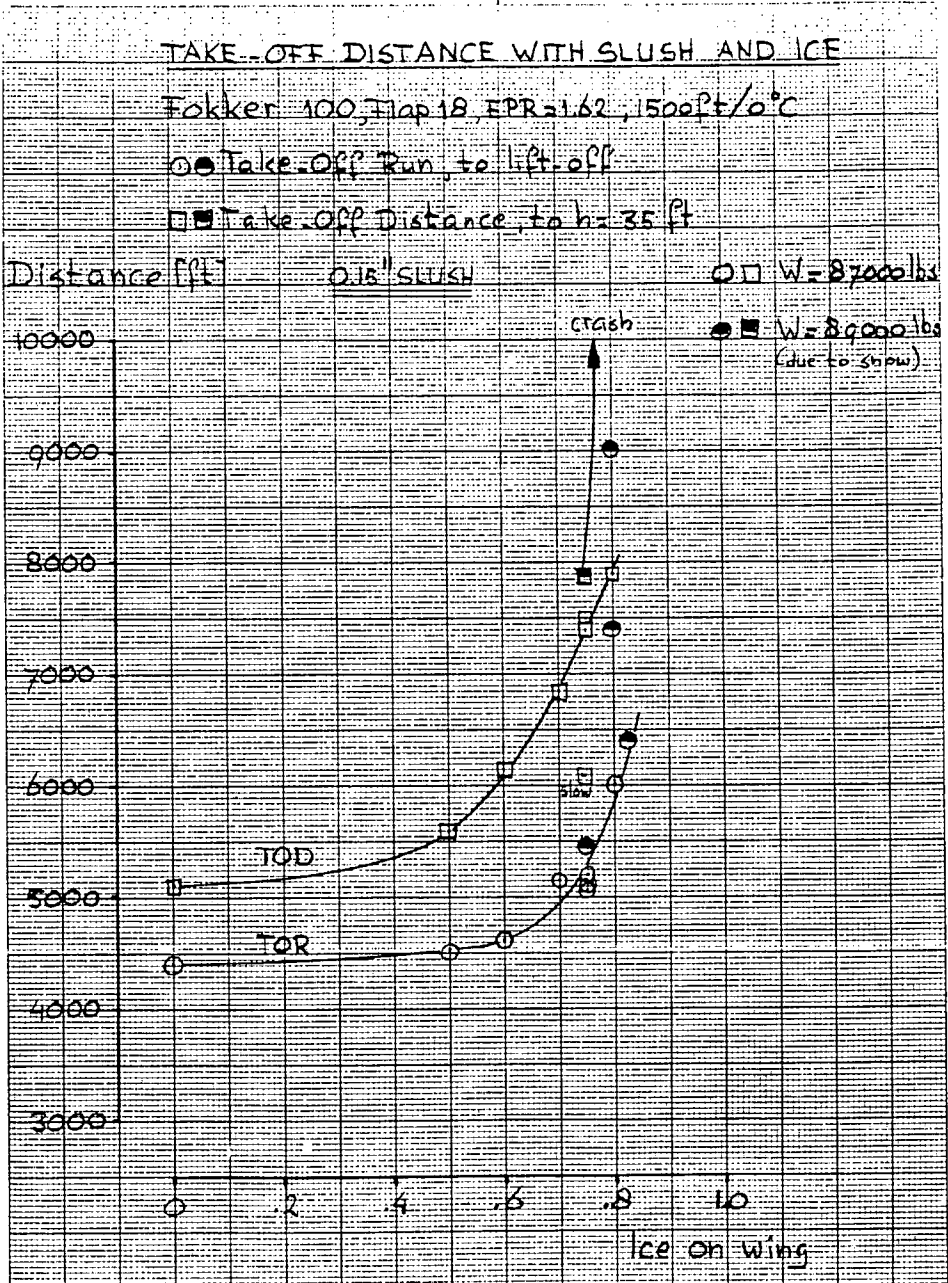
It was clearly revealed from the tests that by rotating the aircraft at a slower rate at  $V_R$ , the takeoff run increases slightly but the takeoff distance actually decreases. It was noted that, under similar conditions

Figure 12-6 Fokker 100 Simulation of Takeoff with Slush and Ice, Flaps 18°



Source: Exhibit 544, figure 36

Figure 12-7 Fokker 100 Simulation of Takeoff with Slush and Ice, Flaps 25°



Source: Exhibit 544, figure 37

of slush and wing contamination, with a slow rotation the takeoff run increased by 10 m (32.8 feet) from 1545 m (5070 feet) to 1555 m (5100 feet) while the takeoff distance actually decreased 435 m (1427 feet) from 2285 m (7495 feet) to 1850 m (6070 feet).

Mr van Hengst had the following to say regarding the use of a slow rotation technique when the aircraft wings are contaminated:

- Q. So if there is contamination and the pilot suspects contamination on the wing, there is a real advantage to him to rotate slower?
- A. Yeah. In fact, this is the same what is already said in our information we released to customers, and what is shown in the Boeing Airliner, what we just discussed yesterday.
- Q. So you have advised, in the flight manuals, and advised customers of that fact, that slower rotation may in fact save a situation that otherwise might result in a crash?
- A. Well, we advise that you increase your margin, but our advice is first to clean the wing.

(Transcript, vol. 71, p. 35)

When asked what general conclusions were reached by Fokker Aircraft as a result of the simulator test flights, Mr van Hengst responded as follows:

- A. Well, that it was impossible to try to take off an aircraft with contamination on the wing. And you should always remember that this simulation test shows distributed contamination of 1 to 2 millimetre. That is the equivalent, so if the distributed roughness was worse than the picks, what you have seen on that grey plate, it should be worse and it can be worse. That's one.

The second is for the engineering and technical pilots, it's very educative to do such studies. We did it with our test pilot in 1969, but you never must draw the conclusion that there is a chance to take off, because in actual practice, nature is never a thing what you can interpolate it linearly from zero to 100 per cent.

(Transcript, vol. 71, pp. 36-37)

## **Flight Dynamics Report**

The following pages provide a summary of the performance subgroup's "Flight Dynamics" report and of the evidence given before this Inquiry by the authors.

The function of the subgroup was to investigate both the takeoff performance of the F-28 and the effects of environmental conditions at the time of the accident on the aircraft's performance. The subgroup utilized F-28 performance data supplied by Fokker and developed

computer programs to model mathematically the aerodynamic characteristics of the F-28 with and without contamination. Thereafter, the subgroup validated and correlated the results and offered conclusions as to the engineering reasons for the flight path observed at Dryden. The objective of the computer-simulation work was to develop a range of possible flight path scenarios similar to the one flown by C-FONF and then determine a range of conditions that could have caused C-FONF's flight path.

The purpose of the simulation and modelling was to determine, in the absence of recorder data, possible causes of the reported flight path of C-FONF. The modelling also allowed independent confirmation of the Fokker 100 engineering flight simulator study results, necessary because the study was carried out on a somewhat different aircraft. The modelling further allowed the exploration of other relevant areas such as engine-out performance and non-standard handling techniques. The aerodynamic analysis described in the "Flight Dynamics" report was carried out to support the simulation efforts and to provide enhanced background for this Commission's investigation.

The authors utilized available information with respect to C-FONF on March 10, 1989, including witness statements regarding aircraft performance as well as contamination on the aircraft wings and on the runway. The authors' analysis of available information suggested a sequence of events approximating the following, which was used by them for modelling purposes and was termed the "Dryden scenario":

The aircraft, in an 18 degree flap configuration, commenced its take-off run from a normal position on the runway, achieved rotation speed somewhat further down than was normal and commenced a rotation. During the initial rotation the machine either became briefly airborne, or simply extended the oleos, and then settled back onto the runway, reducing its body angle somewhat. A second rotation very close to the end of the runway resulted in the aircraft becoming airborne but maintaining a very low altitude until striking the trees. Subsequent technical investigation has shown that at some time during the take-off attempt the wing flaps were extended from 18 to 25 degrees and that at the time of impact the undercarriage was in transit (neither fully down nor fully up).

(Exhibit 526, p. 67)

The modelling task was simplified because, since the aircraft did not gain significant altitude, consideration of the vertical dimension could be eliminated. The subgroup accounted for the change in flap setting after the first rotation. The small change in overall drag coefficient resulting from the landing gear was not significant to the relevant portion of the takeoff performance.



Commission investigators were advised, and some Air Ontario pilots testified, that the paint on the leading edges and surfaces of the wings of one or both of Air Ontario's F-28s was cracked and deteriorated. The original paint on the leading edges and wings of an F-28 is 0.016 inches thick and consists of three or four layers. Although there was some evidence before me to indicate that the paint on the leading edges of the wings of C-FONF was in a deteriorated condition, the authors of the "Flight Dynamics" report and Fokker aerodynamicists, in particular Mr van Hengst, were of the view that the effect of the cracked paint on the maximum lift coefficient and stalling angle of attack is not significant. It was not determined to what degree, if any, cracked or deteriorated paint contributes to the adhesion of contamination to a wing.

In conducting their analysis, the authors of the "Flight Dynamics" report made the following assumptions:

- 1 The powerplants generated normal thrust throughout the takeoff attempt (although single powerplant failure was considered for completeness).
- 2 There were no structural failures prior to impact.
- 3 There was no failure of the brakes or tires such as to cause the ground roll to be extended.
- 4 There were no flight control system failures.
- 5 There was no interference in the flight control system from any source.
- 6 The flight crew handled the aircraft with normal handling techniques.
- 7 There were no system or instrument failures such that the flight crew was unable to fly the aircraft with the precision required for instrument flight.
- 8 There were no adverse wind conditions that would have affected the aircraft's performance.

All evidence before me, as detailed in this my Final Report, confirms either that the authors' assumptions were correct or indicates that there was no evidence found during the investigation or revealed in testimony to suggest that the assumptions were incorrect.

Witness evidence indicates that 18° of flap was selected on C-FONF before the takeoff run commenced. Investigation determined, however, that the flaps were positioned at approximately 25° when the aircraft crashed, suggesting that a selection from 18° to 25° was made by the flight crew some time after the takeoff roll commenced. It is probable that the selection of 25° of flap was made after the first liftoff, when it may have become apparent to the flight crew that a successful takeoff was in doubt. Performance analysis by Fokker and by the subgroup authors indicates that, with contamination on the wings, the use of 25°

of flap will not improve aircraft performance after liftoff. It is the view of both Mr Wagner and Mr van Hengst that extending the flaps beyond the position selected and used for the takeoff should not be considered in conditions of wing contamination; the greater flap angle would have a detrimental effect on the aircraft performance should the aircraft actually become airborne.

### **Aerodynamics**

The aerodynamics section of the "Flight Dynamics" report, authored by Mr Richard Wickens, surveys the aerodynamics principles relevant to the Fokker F-28 during the ground-roll and initial climb phase. Mr Wickens also discusses the degree to which surface roughness, such as ice contamination, affects this low-speed portion of the aircraft's flight envelope. Fokker supplied aerodynamic data to the performance subgroup. Materials provided included the results of a wind tunnel test at the Nationaal Lucht-en Ruimtevaartlaboratorium (NLR), the Dutch national aerospace laboratory; a description of the aerodynamics of wing stall; flight test experience with the aircraft; airfoil pressure distribution at a variety of angles of attack; boundary layer data for an F-28 airfoil section; and Fokker's data base from which the F-28 simulator model was created.

The following is a summary of the findings and conclusions of Mr Wickens, as noted in the aerodynamics section of the "Flight Dynamics" report.

The F-28 wing section is designed for a cruise Mach number of 0.75 and a high maximum lift coefficient at low speeds. (Mach 1.0 is the speed of sound.) A generous wing nose radius minimizes the likelihood of separation under high lift conditions and promotes stall from the trailing edge. There is a stall fence on the forward midsection of the wing. Stalling of the basic smooth wing is from the trailing edge. The stall then spreads outwards from the leading-edge fence location in a fan-shaped manner towards the wing-tip and wing-root regions. These regions stall last, and, since the ailerons are near the wing tip, lateral control is possible after other sections of the wing are in a stalled condition. As well, because of the position of the fences, air flow into the engines remains smooth to high angles of attack. In ground effect, with the main wheels on the ground, stalling occurs at an angle of attack some 4° lower than flight in free air, but only the inner portion of the wing stalls. Maximum coefficient of lift ( $C_{LMAX}$ ) is unchanged.

During wind tunnel tests conducted by Fokker Aircraft, artificial roughness on the upper surface of the wing of an F-28 aircraft model caused a premature stall during which time boundary layer separation could have occurred all along the leading edge. The roughness corresponded to an element size of about 1–2 mm on the full-scale F-28 wing,

while the distribution corresponded to approximately one element per square cm on the same wing. With the flaps set to 30° on the model, the wing stalled at an angle of attack 7° lower than for the clean wing. Compared with the clean wing, the model showed 33 per cent loss of maximum lift coefficient.

Research on model wing sections at Reynolds Numbers<sup>9</sup> ranging from 100,000 to 10,000,000 showed that roughness not only increases drag below the stall but also increases the likelihood of a premature stall, particularly if the wing nose is roughened. Since the Reynolds Number increases towards the values experienced by the F-28 wing during takeoff (greater than 10,000,000), the loss of maximum lift can be as high as 50 per cent compared with a clean surface.

In some cases, the airfoil is sensitive to the size of the roughness elements, the loss of maximum lift being less for very small roughness heights. Most airfoil sections, however, respond to roughness of any scale by stalling prematurely and incurring the maximum loss of lift. Removal of roughness on the nose and over the first 15 per cent of the chord restores the airfoil to a surface close to its original "clean" characteristics.

## Dynamic Simulations

The dynamic simulations section of the "Flight Dynamics" report, authored by Mr Gary Wagner, presents a description of and commentary on the results of the simulation flights carried out by the performance subgroup. Mr Wagner discusses the Fokker "Flight Simulation" report and provides background to it. He discusses the various modelling and flying techniques, both conventional and non-standard, utilized during the subgroup's sessions and summarizes the simulation experience. The following is a summary of the material dealing with the simulation sessions.

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<sup>9</sup> Reynolds Numbers, a measure of the scale effect, enable one to correct for the difference between doing a test under model conditions at small scale and extrapolate the data to full-scale values. It also determines when a laminar flow makes a transition to turbulent flow. Physically, it is the ratio of the inertia forces to the viscous forces in any flow. Inertia forces are the stream lines and flow outside the boundary layer. Viscous forces are the stream lines and flow inside the boundary layer. Reynolds Numbers are dimensionless. In the case of the F-28, and based on its wing mean aerodynamic chord, they range between approximately 15,000,000 at takeoff speed and 30,000,000 at cruising speed. Turbulence over a flat plate surface normally commences when Reynolds Numbers reach approximately 1,000,000. Reynolds Numbers are used in classical research of boundary layer and Reynolds Numbers behaviour on wings.

(Based on evidence of Mr Richard Wickens.  
Transcript, vol. 69, pp. 66-68)

Dynamic simulations were those tests and experiments conducted in the Fokker 100 fixed-base engineering simulator. Three series of dynamic simulation sessions were flown using various wing- and runway-contaminant levels. Two series of simulations were flown on June 7 and June 8, 1989, by Mr Wagner and monitored by Mr Murray Morgan, and the third series was flown by Mr Jan Hofstra, a Fokker Aircraft test pilot, on August 1, 1989. The data from the simulations were plotted in the Fokker report to present pictorially and numerically the flight profiles and changes that would be experienced in aircraft performance.

Mr Wagner stated in his overview:

A fundamental assumption made during the simulation exercise was that the pilots of the accident aircraft would have believed that their aircraft was flyable and would, therefore, have employed normal handling techniques. Therefore, for "Dryden" simulations no special procedures or techniques were allowed which would have provided a better flight profile due to the simulator pilots' a priori knowledge of the external conditions being applied. Ad hoc experiments with off nominal techniques left no doubt that handling technique greatly affects the resulting flight profile in the presence of contamination. This observation was later confirmed by the off-line numerical modelling.

(Exhibit 526, p. 62)

### **Dynamic Simulations: Modelling and Flying Techniques**

**Runway Contamination** The slush model depth was varied from 0 to 0.45 inches to determine the level of slush contaminant required to extend the takeoff run to the distance reported by the witnesses at Dryden (that is, approximately 500 feet in excess of the normal takeoff run). It was determined that a slush depth of 0.15 inches resulted in this increase. Mr Wagner noted that, because of reduction in the maximum coefficient in lift resulting from wing contamination, the aircraft must be rotated to a higher than normal pitch attitude in order to effect liftoff; this process takes additional time and results in a longer takeoff roll. The additional component was considered in the simulation.

For contaminated runway takeoffs, normal control wheel inputs were used in all but a few runs, where the nose was raised 2–3° at about 80 knots to get the nose wheel out of the slush (the specified procedure in the Fokker F-28 Flight Handbook). It was found that raising the nose wheel decreased the aircraft ground roll by approximately 100 feet.

**Wing Contamination** The wing contaminant was modelled by using the Fokker roughness simulation for the entire wing. The contaminant factor could be varied between 0 and 1.00. This factor is not equivalent to contaminant depth, although it is labelled as such on the plots provided

in the Fokker report. Wing contaminants with different characteristics, even of identical depth, will result in very different performances. For example, a thin layer of a rough contaminant can result in a far greater performance loss than a thick layer of a smooth contaminant that follows the wing contour. In any consideration of wing performance, form and position of a wing contaminant are much more important factors than is thickness.

During the dynamic tests, it was determined by the authors that, at wing-contaminant levels greater than approximately 0.8, the aircraft would not fly off the runway at the aircraft speeds and conditions that generally matched those of C-FONF. Selection of contaminant levels ranging from 0.5 to 0.8 did, however, result in flight profiles that generally matched the profile of C-FONF. The runs that most closely matched the flight profile described by witnesses at Dryden were achieved with a slush depth of 0.15 inches and a wing-contaminant level of approximately 0.8.

For contaminated wing takeoffs, although normal control wheel rotation forces were used, the resultant rotation rate was slightly slower than with the clean wing model. The reason for the slower rotation rate was that the wing contamination had the effect of increasing the nose-down pitching moment of the wing; therefore, with normal forces being applied to the control wheel, the nose-up moment caused by the elevator had less rotational effect on the aircraft.

As the contaminant levels were increased, numerous takeoff runs were flown where the stick-shaker actuated immediately on or just after liftoff. This effect occurred because of the significantly greater angles of attack achieved in these cases. It was judged by the investigators that normal pilot technique would be to attempt to reduce the angle of attack to stop the stick-shaker. Nose-down control-wheel inputs were made accordingly, attempting to maintain an aircraft attitude right at the edge of stick-shaker activation. The reasoning here was that most pilots, in view of current training with respect to wind shear escape manoeuvres and ground school training, would expect to achieve close to maximum available lift at the point of stick-shaker activation.

In pointing out that the wing was stalling prior to stick-shaker activation, Mr Wagner in the "Flight Dynamics" report stated as follows:

It should be noted that in cases of significant wing contamination, the wing can be well beyond the stalling angle of attack by the time the stick shaker activates. In essence, the stick shaker is responding to the normally expected maximum angle of attack of the clean wing. The stall warning system is not actually measuring stall and flow separation from the wing. Rather, it infers the onset of stall from the

known performance of the wing and is programmed to activate at a fixed geometric angle of attack based on that knowledge.

(Exhibit 526, p. 64)

Of significance is the fact that, with any amount of wing contamination, the aircraft wing may stall before the angle of attack required to activate the stick-shaker is reached.

**Engine Failure on Takeoff** A few takeoffs were attempted by Mr Wagner during which an engine was failed at  $V_R$ . All engine failures were complete (that is, no attempt was made to fly the simulator with partial engine failure). Regardless of the contaminant level on the aircraft, directional control was not a problem after the engine failed. Normal and appropriate control inputs were used to attempt to maintain proper speeds and direction. The climb-out characteristics of the aircraft were conventional with the engine failure, except that only a limited wing-contaminant load could be carried.

The wing-contaminant level at which the aircraft was able to lift off and climb was significantly reduced. Successful takeoffs were accomplished with wing contamination of less than 0.5, although that level provided minimal performance. Because the relationship between wing-contaminant levels and contaminant thickness is highly non-linear, the authors in this section of the "Flight Dynamics" report caution that the result cannot be interpreted to mean an aircraft is able to carry half the contaminant load with an engine failure. The report states that "it was clear that the reduced thrust at rotation severely reduced the available performance margin and thus limited the aircraft's capability to carry any contaminant through a successful takeoff" (Exhibit 526, p. 61).

**Summary of Simulation Experience** The following is a summary of the authors' observations and findings as a result of their flight-simulation experience and analysis:

- The effect of increasing the slush depth was limited, in general terms, to increasing the takeoff run. Additional effects became evident regarding the ability of the aircraft to accelerate after rotation with the wing significantly contaminated.
- The effect of wing contamination was to degrade the performance of the wing, the degree of degradation being a non-linear function of the contaminant level. As the wing-contaminant level increased from 0, the aircraft's climb performance was immediately reduced.
- At moderate levels of wing contaminant, the stick-shaker actuated shortly after liftoff, and the flight profile after that point reflected the pilot's attempt to keep the aircraft at the edge of the stick-shaker, being  $13^\circ$  angle of attack for the simulator. For

a contaminated wing, that angle of attack was already post-stall in most cases. Climbing out of ground effect became impossible in many instances.

- At critical levels of wing contaminant, between 0.75 and 0.825, the aircraft was able to lift off and sometimes fly. However, as the aircraft climbed out of ground effect, the performance loss resulted in the aircraft descending and touching down or crashing off the end of the runway.
- As the contaminant level increased, the liftoff pitch attitude and airspeed had to be increased to provide adequate lift to lift off. Since increasing levels of wing contaminant decreased the stalling angle of attack, liftoff occurred closer to and then beyond the true stalling angle of attack. Eventually, either liftoff occurred post-stall or the aircraft stalled shortly after liftoff as it climbed out of ground effect. Successful flight with the wing contaminated at levels between 0.7 and 0.825 was effectively impossible using normal techniques. The profiles resulting from flight at these wing-contaminant levels were, in general terms, representative of the flight profile of C-FONF resulting in the Dryden accident.
- In cases where an engine was failed, the aircraft was not flyable with even moderate levels of wing contaminant. The high angles of attack required to generate adequate lift with the contaminated wing produced drag levels so great that the thrust of one powerplant was inadequate to allow the aircraft to accelerate. Post-stall drag was also extremely high. The only way to get the aircraft to fly with the wing contaminant is to have sufficient thrust to accelerate to a sufficiently high airspeed. Thrust with one engine operating is inadequate to provide that acceleration.

(Based on Exhibit 526, pp. 64–65)

***Non-Standard Handling Techniques*** Non-standard handling techniques were explored by the authors in an effort to determine whether the aircraft could overcome performance degradation resulting from contaminated wings. Successful flight was achieved in certain cases that might otherwise have resulted in either no takeoff or takeoff and a subsequent crash. The authors could not, however, predict precisely when these flights would succeed; when non-standard procedures were used, successful takeoffs with wing contaminant at levels between 0.7 and 0.825 were irregular and not guaranteed. Nevertheless, it was determined that the following non-standard handling techniques did allow for more successful takeoffs:

- Selection of rotation speed. A pilot who applied a speed increment above  $V_1$  prior to rotation would have a higher probability of a successful takeoff. The converse is also true.

- Use of a lower rotation rate. A pilot who used a slower rotation rate would have a higher probability of a successful takeoff.
- Use of a partial rotation (as opposed to continued rotation until liftoff). A pilot who rotated the aircraft to usual liftoff attitude and held it there rather than rotating further would have a higher probability of a successful takeoff.

The above recommended techniques are also contained in the Fokker F-28 Flight Handbook. Fokker recommends these techniques where it is not completely certain that the wings and tail are clear of ice or snow.

The authors emphasize in their report that use of non-standard handling techniques is not intended to assist or condone operation of aircraft carrying wing contaminant. There are many other tradeoff factors that are balanced out in any takeoff. The authors state that the foregoing non-standard handling techniques may degrade such tradeoffs.

These non-standard handling techniques may, however, assist a flight crew finding themselves, for some reason, in a takeoff situation where there is no possibility for a safe rejected takeoff and the aircraft is not performing as expected. This situation could be the result of a number of factors, such as wing contamination, aircraft overloading, incorrect flap selection, or incorrect speed selection. The situation could also occur on a rejected landing and go-around if, on approach, the aircraft is contaminated with ice.

Once an aircraft has reached rotation speed ( $V_R$ ) there is normally little or no opportunity to reject the takeoff. When asked whether a crew experiencing the effects of contamination at rotation or immediately after liftoff should continue or reject the takeoff, Mr Wagner stated the following:

- A. I would say that my best judgement would be that, once you've rotated and barely got a little bit airborne, it would be highly unlikely for a man to put his efforts into aborting the takeoff rather than putting his efforts into finding a way to try and make that takeoff successful. That would be my best judgement, sir.

(Transcript, vol. 73, pp. 146-47)

On the basis of the evidence I have heard, I am firmly convinced that pilots should be made more aware of the inherent dangers of wing contamination. It is vitally important for a pilot to understand how wing contamination changes the aerodynamic characteristics of an aircraft, and to understand how the application of certain techniques, as described above by Mr Wagner, may allow a pilot to deal with an abnormal takeoff situation. It is incumbent on all pilots and on their respective



organizations to ensure that this training is accomplished. Without prescribing how the necessary training be accomplished, I would state that it is possible flight simulators may be useful in this endeavour. It must be stressed, in the strongest terms possible, that neither the performance subgroup nor this Commission advocates the use of non-standard handling techniques to operate aircraft in adverse weather conditions as an alternative to the proper preparation of the aircraft for flight.

### **Mathematical Modelling and Modelling Validation**

Mr Murray Morgan is the author of the mathematical modelling and modelling validation sections of the "Flight Dynamics" report. The following is a summary of the methods used for and the results of the mathematical analysis and validation of the flight dynamics of the attempted takeoff of C-FONF.

A computer model was developed to allow investigation of the effects of aircraft and runway contaminants on the takeoff performance of the aircraft. There is no "man in the loop" (pilot) in a computer model, thus removing one of the variables from the equations. The model was therefore able to reflect more accurately the effects of aircraft and runway contamination. Initially, two independent off-line computer models of the F-28 were developed simultaneously by Mr Morgan and Mr Wagner. The outputs from each model were periodically compared, and, where differences were found, the source was isolated and corrected. Once the programs were both operating and producing comparable results, the more powerful computer used by Mr Morgan at NAE was employed for most of the investigation and production of results.

There was no attempt made to model contamination of the horizontal stabilizer. The reasoning was twofold: first, as there was sufficient power (lift) on the tail to rotate the aircraft during the takeoff, the contamination on the horizontal stabilizer was not a factor during rotation; secondly, the angle of attack of the tail reduces as the aircraft accelerates after becoming airborne, thereby further decreasing the effect of any contamination.

The aerodynamic and performance models were based on two sources of data: the F-28 simulation data base provided by Fokker; and the Fokker wind tunnel study of the contamination model of the F-28 lift and drag characteristics when the flying surfaces were contaminated with artificial roughness. To develop a functioning simulation that included "man in the loop" control of the aircraft, the engineering and pilot judgement of Mr Morgan and Mr Wagner also played an important role. With the performance and contamination model of Fokker and control response algorithms developed by the authors, a functioning off-

line simulation for the F-28 was developed. To verify the accuracy of the computer simulation, use was made of flight data recorder (FDR) data from 21 previous takeoffs by C-FONF. A month prior to the Dryden accident, C-FONF was involved in a minor accident, when a wheel failed on a landing. Investigation of this event necessitated FDR tape removal; hence, data from this tape were available to the authors.

**Model-Run Matrix** Once the modelling had been completed and validated, a matrix of cases was empirically determined and run. For all cases, the baseline configuration was an aircraft weight of 63,500 pounds, full-rated thrust,  $18^\circ$  of flap, and a  $V_R$  of 122.5 knots. The nominal rotation was an initial pitch rate of  $3^\circ$  per second towards a target attitude of  $10^\circ$  followed by a further rotation at  $1^\circ$  per second to  $13^\circ$  of pitch attitude after liftoff. This is the procedure preferred by Fokker Aircraft. Thereafter, three parameters of prime interest were varied: the depth of slush, the proportion of wing contamination, and the selection of  $V_R$ . These runs were completed using the nominal rotation technique, described above, together with the profile referred to above as the "Dryden scenario." Nominal ( $3^\circ$  per second) and reduced ( $2^\circ$  per second) rotation rates were used for the initial rotation. The sets of conditions tested were:

- a. Slush Depth. 0, 0.1, 0.2, 0.3, and 0.4 inches.
- b. Contaminant Ratio. 0 and .50 to 1.00 in steps of 0.01. (Zero to 1.00 represents 0 per cent to 100 per cent contaminant. When this resolution produced ambiguous results, boundaries were defined by making special runs at finer resolution.)
- c. Rotate Speeds. 117.5 knots, 122.5 knots (nominal), and 127.5 knots.
- d. Rotation Rates.  $3^\circ$  and  $2^\circ$  per second.

(Based on Exhibit 526, p. 73)

**Presentation of Results** Plots of the test runs are included in the "Flight Dynamics" report of (technical appendix 4, pages 76–85). These plots show that the presence of slush on the runway significantly increased the distance required to reach  $V_R$ , while wing contamination had little effect on this distance. However, as the level of wing contamination increased, the distance to liftoff increased quite rapidly, owing to the marked increase in drag produced by the contaminated wing at high angles of attack following rotation. This characteristic represents a situation in which the full extent of performance loss may not be apparent to the flight crew until the aircraft is rotated. Prior to this point, the reduction in acceleration is little more than what could be attributed to a slush layer. Figure 5 on page 76 of the "Flight Dynamics" report shows the reasons for this effect. As the level of wing contamina-

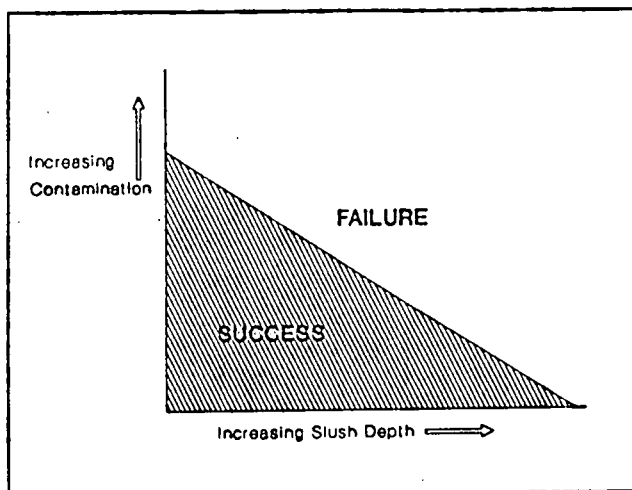
tion increased, even in the absence of slush, the distance between  $V_R$  and the liftoff point increased only slowly, until a dramatic "knee" was reached numerically at just over 0.6 contamination ratio. This is coincident with the aircraft being at or beyond the coefficient of maximum lift ( $C_{LMAX}$ ) for the contaminated wing at its rotation angle of  $10^\circ$  and having to generate the necessary lift by increasing speed rather than increasing the coefficient of lift ( $C_L$ ).

The drag rise, caused by the contamination once the aircraft was rotated, resulted in low acceleration rates. This in turn meant that excessive distance had to be used by the aircraft to attain enough speed to generate sufficient lift. Another effect was the increase in Theta required at liftoff as the level of contaminant increased. (Theta, or body angle, is the angle between the aircraft and the horizontal.) Moderate increases in Theta compensated for the reduction in the coefficient of lift due to the contaminant up to a contamination ratio of approximately 0.58. At that point the rate of increase in Theta, with respect to the level of contaminant, steepened markedly because of the reduced lifting capability of the wing.

The two "various boundary" plots in the "Flight Dynamics" report (p. 77) represent the crux of the performance investigation. They show that it is possible to define two boundary conditions, in terms of combinations of slush depth and wing-contamination factor, that can lead to catastrophic results during attempted takeoffs. A boundary condition here means "a continuous relationship between level of contamination and runway slush depth which represents the dividing line" between a successful or unsuccessful takeoff (pp. 73-74). This boundary relationship, which is illustrated in the "Flight Dynamics" report, is reproduced below as figure 12-8. The "various boundary" plots (figures 6 and 7 in the "Flight Dynamics" report) can be interpreted according to figure 12-8, below.

Figures 8a-10b of the "Flight Dynamics" report illustrate in detail the various test runs. A review of the figures reveals that there are well-defined boundaries of slush depth and contamination level that either allow or prevent the aircraft from flying successfully. For example, with a rotation speed ( $V_R$ ) of 122.5 knots, a slush depth of 0.25 inches, and a wing-contamination level of 0.65, the aircraft flies away. At 0.68 wing contamination, the aircraft gets airborne, but, 500 feet beyond the end of the runway, it is only at 10 feet. At 0.69 contamination, the aircraft returns to the runway and runs off the end. In another example, with a rotation speed of 127.5 knots, a slush depth of 0.10 inches, and a wing-contamination level of 0.823, the aircraft flies away despite two bursts of stick-shaker. At 0.824 wing contamination, the aircraft height never exceeds 5 feet, and it eventually returns to the surface 1100 feet beyond

Figure 12-8 A Boundary Condition Plot for Successful Takeoff



Source: Exhibit 526, figure 3

the end of the runway. The figures also demonstrate that pilot technique can have a marked effect on the success or failure of a takeoff.

The implication of the results presented in this section of the "Flight Dynamics" report, especially the two sets of boundary conditions, is that there "exists a combination of values of slush depth and wing contamination which can cause aircraft trajectories of the type described by witnesses to the Dryden accident" (Exhibit 526, p. 75).

**Validation** Mr Morgan performed a thorough validation process to ensure that the computer model would fairly and accurately represent the basic behaviour of the F-28 aircraft, and the information and plots in the "Flight Dynamics" report indicated that very close agreement between the recorded performance of C-FONF and the mathematical model had been achieved. Accordingly, the authors of the report were confident that the information and results produced by the computer model were accurate.

### Discussions and Conclusions

The authors of the "Flight Dynamics" report state that dynamic simulation demonstrated that the increased takeoff roll and short airborne segment could have been the result of the conditions of runway slush and wing contamination tested in the simulations. The numerical

simulations strongly support the observations made in the Fokker 100 engineering simulator. A general observation made by the authors of this report is that the higher the rotation speed and the slower the rotation rate, the greater the probability that the takeoff will be successful. This observation conforms to the advice given in the Fokker Aircraft F-28 Flight Handbook. The "Flight Dynamics" report in its conclusions emphasizes, however, that the performance subgroup treated only the aerodynamic and aircraft-handling aspects of the accident and assumed there were no other factors that could have been related to the accident. The authors emphasize that major failures of aircraft systems or other factors not mentioned in their report and not considered in the simulation could also have resulted in the accident flight profile, alone or in conjunction with the known wing contaminant.

With the above caveats in mind, the authors of the "Flight Dynamics" report concluded as follows:

1. The witness reported flight paths and "Dryden scenario" which was based on [the witness reports are] physically possible from an engineering viewpoint.
2. The aerodynamic performance of the F28 ... was definitely degraded by the wing contamination ... the contaminants on the wings degraded the lifting capability and increased the drag on the accident aircraft.
3. The increased ground distance to the reported liftoff point could have been due to the following factors, individually or in combination:
  - a) Small slush accumulations on the runway
  - b) Selection of higher than normal rotation speed.
4. An additional contributing factor to the increased ground distance to liftoff was the higher speed and/or pitch attitude required for liftoff as a result of wing contaminant ... This was due to the additional time required to reach the required speed [for liftoff] and/or to rotate the aircraft to the higher liftoff attitude. At the liftoff speed for the F28 in the Dryden case on the order of 130 knots, each additional second during rotation increased the ground run by approximately 200 feet.
5. The deteriorated condition of the paint on the wing leading edge probably did not affect the aerodynamic characteristics of the aircraft directly. However, the effect of the deteriorated paint on the adherence characteristics of contaminants at the leading edge is unknown, but could potentially have been a minor factor in the amount of contaminant that remained on the wing.
6. Simulation and analytical work by [the authors of the "Flight Dynamics" report] has defined a range of conditions in terms of wing and runway contaminant levels which, alone, could have resulted in the accident profile.

7. Without [cockpit voice and flight recorder] data, the pilots themselves, and a mathematical description of the wing and runway contaminant levels, it can **NOT** be conclusively stated that wing or runway contamination alone caused the aircraft to crash.

(Exhibit 526, pp. 109–10)

Mr Morgan during testimony explained each of the above conclusions. When asked his opinion as to the cause of the accident, assuming there were no major failures of the aircraft systems and no degradation of engine performance, he stated:

- A. If there really are absolutely no other factors, my opinion would be that ... the accident was a result of the contamination beyond reasonable doubt.

(Transcript, vol. 72, p. 155)

In summing up his conclusions during testimony, Mr Wagner stated:

- A. ... assuming everything else worked the way it's supposed to work and there were no failures of any sort, as we described, I would say that there is a high probability that the engineering cause of the flight profile was the contamination on the airplane.

(Transcript, vol. 73, p. 78)

During his testimony, Mr van Hengst, chief aerodynamics analyst at Fokker Aircraft, was given information provided by another witness, a meteorologist. The information was that there was a minimum of 1.4 mm of rough precipitation along the wings of the F-28 in Dryden. When it was suggested by counsel: "So the conclusion, then, is that, in Dryden, with 1.4 millimetres, there is no takeoff possible" (Transcript, vol. 71, p. 124), Mr van Hengst agreed.

## Particular Effects of Aircraft Contamination

### Propeller-Driven Aircraft

Although the Final Report of this Commission of Inquiry primarily addresses the performance of the F-28 aircraft, information was gathered during the Inquiry regarding the performance of propeller-driven aircraft and the effect on them of wing contamination.

Although the performance study was specifically conducted for the F-28 aircraft, the results obtained are applicable to any other aircraft in

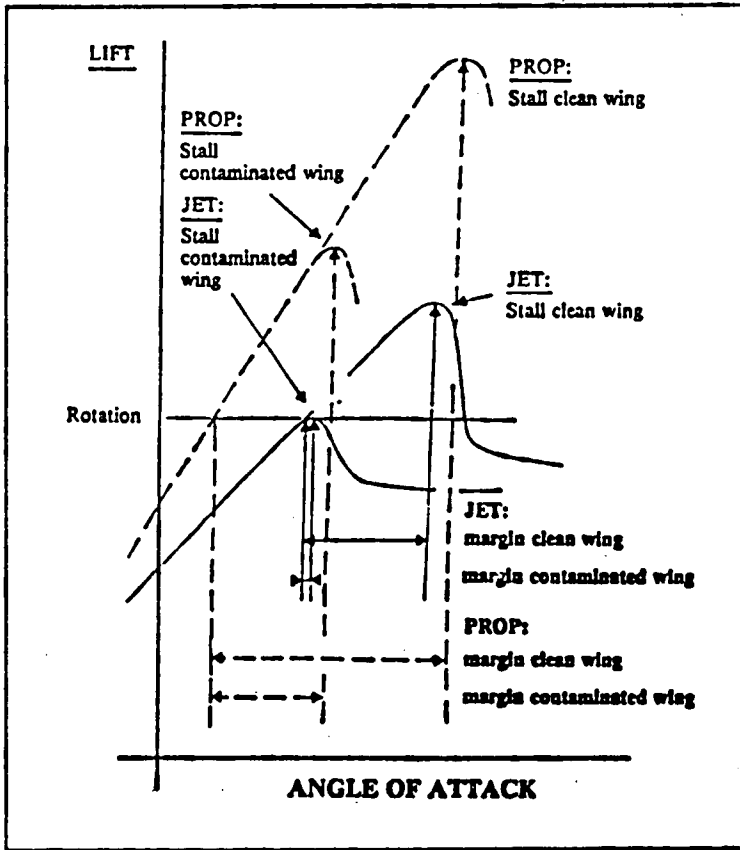
this class, that is, to any jet-propelled, swept-wing aircraft. There is, however, a more severe performance penalty paid for contamination of a jet-propelled aircraft than for contamination of a propeller-driven aircraft. The shallower lift curve slope and the reduced maximum coefficient of lift of the swept wing make its performance more readily degradable. As well, the jet aircraft does not have the advantage of a relatively large area of its wing being immersed in high-velocity air from the propeller slipstream. The jet aircraft's only lift-producing capability is the result of the aircraft motion relative to the air. Diagrams in Fokker's Report no. L-28-222 (technical appendix 2 to the Final Report) and the "Flight Dynamics" report (technical appendix 4) show performance comparisons between jet- and propeller-driven aircraft when their wings are contaminated. Figure 12-9, from the "Flight Dynamics" report, depicts the comparison.

Mr van Hengst, Fokker's chief aerodynamics analyst, was questioned about the effects of contamination on a propeller-driven aircraft as compared with a jet-driven aircraft. He concluded that it was dangerous to fly with contamination on either type and explained the peculiar danger regarding contamination on a propeller-driven aircraft. He explained that if an engine fails and the wings are contaminated, then, in effect, one wing loses the benefit of the high-energy slipstream, which results in a rolling moment in the aircraft.

Mr Richard Wickens, in researching and writing the aerodynamics portion of the "Flight Dynamics" report, also reviewed the 1930s literature on the effects of surface roughness on airfoils, the material reviewed by Fokker Aircraft during its wing-contamination studies subsequent to the F-28 crash at Hanover, Germany. Mr Wickens and NRC wanted to obtain their own data as well as more recent information to confirm both the earlier literature and the Fokker Aircraft studies conducted in 1969 on the F-28 Mk1000 aircraft. Mr Wickens also wished to determine if there were any differences among various airfoils. Since he could not simulate high Reynolds Numbers in NRC's wind tunnel to determine differences among the wing sections of various jet airfoils, he utilized a ½ model NACA 4415 airfoil with an engine nacelle and a powered propeller. The airfoil had an aspect ratio of slightly over 6. The wing had a general shape corresponding to that of a de Havilland Twin Otter and a 15 per cent thickness, somewhat similar to that of both the Twin Otter and the F-28. The wing was tested in both a clean and a roughened condition and was tested both powered and unpowered.

It was determined that a clean wing with the benefit of high-energy propeller-driven airflow would achieve about 25 per cent additional maximum coefficient of lift ( $C_{LMAX}$ ) at takeoff speeds compared with the same wing without the benefit of propeller airflow. For a contaminated wing with propeller airflow, the  $C_{LMAX}$  would be similar to that of the

Figure 12-9 Jet- and Propeller-Driven Aircraft Comparison



Source: Exhibit 526, figure 1

same clean wing without propeller airflow. For a contaminated wing of a propeller-driven aircraft where the propeller airflow is lost (engine stoppage), the  $C_{LMAX}$  would be approximately the same as that of a contaminated wing of an aircraft that does not have the benefit of propeller airflow (jet aircraft).

As can be seen, if one engine of a propeller-driven twin-engine aircraft fails, the wing that loses the propeller airflow loses the increased  $C_{LMAX}$  created by the airflow. Where there are clean wings and the aircraft is flying at high airspeeds, there should be little difficulty controlling the aircraft. However, if the wings are contaminated and the aircraft is at low speed with the engines producing high power, the reduction in the  $C_{LMAX}$  caused by the engine stoppage could cause the wing that loses the propeller airflow to stall. The aircraft would then experience a rolling moment towards the failed engine. This scenario would be particularly



dangerous when the aircraft is at low altitude during takeoff; there would not be enough altitude in which to recover the aircraft.

Mr Wickens and Mr V.D. Nguyen, in a report based in part on research conducted for this Commission of Inquiry, summarized the effects of performance degradation on propeller-driven aircraft due to wing contamination:

A wind tunnel investigation has assessed the effects of distributed upper surface roughness, and leading edge ice formation on a powered wing propeller model.

In the unpowered state, it was found that roughness reduces the lift slope, and maximum lift by 30 to 50 percent, depending upon particle size and Reynolds number. The leading edge region is especially sensitive to these disturbances, however removal of the roughness over a small portion of the nose restored the wing to close to its original performance.

The application of power to the wing, with an increase of slipstream dynamic pressure increases the lift slope and maximum lift; however this benefit is lost if the wing is roughened. Subtraction of the propeller reactions indicated that the slipstream interaction accounted for half the lift increase, and also resulted in reduced drag for the clean surface. This drag reduction was removed when the wing was roughened, indicating that the degradation of wing performance due to roughening is relatively greater when a slipstream is present, compared to the unpowered wing.

Leading edge ice accretion causes similar large losses in lift and increases of form drag although a comparison of the two types of contamination showed that leading edge ice produces a smaller reduction of lift slope prior to flow separation. In both types of contamination, Reynolds number is important, and emphasizes the necessity of testing under near full-scale conditions.

(“Wind Tunnel Investigation of a Wing-Propeller Model Performance Degradation Due to Distributed Upper-Surface Roughness and Leading Edge Shape Modification,” p. 1)

The authors reach seven conclusions, of which numbers (1), (5), and (6) are particularly significant:

- 1) The main effect of distributed upper surface roughness on an unpowered wing is to reduce lift slope and maximum lift by as much as 30 to 50 per cent, depending upon roughness size, Reynolds number, and to a lesser extent, coverage.
- 2) The magnitude of the loss of maximum lift increases with roughness size, and also with Reynolds number and testing of roughened wings should be done at as high a Reynolds number as possible.

- 3) Roughness increases the parasite drag at zero lift and also results in a premature stall with resulting large increases of form drag.
- 4) The leading edge region is especially sensitive to distributed roughness regardless of particle size; there is a significant increase in drag and corresponding decrease of leading edge suction at angles of attack below stall. Conversely, removal of the roughness over a small portion of the nose restores the wing to almost clean performance.
- 5) If the wing is powered and clean, the slipstream interaction increases lift slope and maximum lift by 25 per cent, for thrust coefficients appropriate to the takeoff condition. If roughness is applied, maximum lift decreases by more than 25%, thus producing a lifting performance somewhat below the unpowered wing in the clean state. This may have significance in the event of an engine failure; the contaminated wing will suffer a further loss in maximum lift in the unpowered state.
- 6) An attempt was made to isolate the slipstream interaction on the wing by subtracting estimated propeller forces. When comparing the performance of the powered and unpowered wings, it was noted that roughness produced slightly higher losses on the wing immersed in the slipstream.
- 7) Loss of lift due to an accretion of rime or glaze ice on the leading edge of the wing may reach as high as 50 percent even when the wing is powered, and is sensitive to Reynolds number. Loss of maximum lift is greater for heavy rime ice than for heavy distributed roughness.

(Ibid., pp. 11, 12)

Because many air carriers operate propeller-driven aircraft, I believe that flight crews flying, and other operations personnel involved in operating, these aircraft types should have the benefit of all the information contained in this report by Mr Wickens and Mr Nguyen. I have therefore included as technical appendix 5 the entire report on propeller performance degradation, which was presented by Mr Wickens at an Advisory Group for Aerospace Research and Development (AGARD) conference on "The Effects of Adverse Weather on Aerodynamics" at Toulouse, France, on April 30, 1991.

## **Wing with Leading-Edge Devices versus Hard Wing**

There is, in the aviation industry, some controversy over whether the effects of wing contamination during takeoff are less on aircraft that have wing leading-edge devices (e.g., leading-edge slats or leading-edge flaps) than on those that do not. A wing without leading-edge devices is often referred to as a "hard wing."

Literature suggests that deflection of trailing-edge flaps tends to increase the adverse effects of surface roughness on the maximum

coefficient of lift ( $C_{LMAX}$ ). Leading-edge devices tend to suppress the adverse effects of small amounts of surface roughness; however, it is acknowledged that leading-edge devices do not suppress the adverse effects of larger levels of roughness. Aircraft such as the Boeing 737, equipped with leading-edge slats and flaps, have been reported to experience pitchup and rolloff immediately after takeoff in weather conditions that were conducive to the formation of ice and snow on the wing leading edges. In most cases, the flight crew were able to recover by using extreme control-column movements and maximum power. In the case of the Air Florida, Inc., Boeing 737 crash at Washington, DC, on January 13, 1982, where no recovery was achieved, it was found, inter alia, by the United States National Transportation Safety Board that snow and/or ice contamination on the wing leading edges produced a nose-up pitching moment as the aircraft was rotated for liftoff.

Two expert witnesses, Mr Jack van Hengst and Mr Gary Wagner, suggest that the effect of wing contamination is equally dangerous on a wing with leading-edge devices and a hard wing.

Mr Wagner, in his article "Takeoff & Landing in Icing Conditions, Aerodynamic & Performance Issues" (CALPA's *Pilot*, December 1989), states as follows:

There has been a focus on icing accidents in Canada in recent years, especially those involving aircraft with so-called hard wings (i.e. no leading edge devices). However, analysis of the performance of aircraft with wings with leading-edge devices shows, in general terms, the same kinds of performance problems when these aircraft are operated with contamination present. Since any benefit from the leading edge devices in these conditions is small, it is suggested that pilots of aircraft so equipped take no comfort from the fact that the aircraft are slatted/slotted, etc. and that any airfoil contamination be dealt with in the appropriate way. Should the contaminant not be removed, the same magnitude of performance decrement should be expected whether the wings have leading edge devices or not.

(Exhibit 550, p. 12)

In addressing his article and providing his views on the relative performance of hard wings compared with wings with leading-edge devices, Mr Wagner stated in testimony as follows:

- A. I would think the fact remains, if the airplane's not going to fly, most likely, it's not going to fly, and if you get to the point where you've got so much contaminant on and you rotate the airplane and become slightly airborne, the point I'm trying to make in the article - and I thought my words were strong enough, sir - was that, if that airplane's contaminated, you should have it cleaned and take no comfort from having a

leading edge slat.

I don't think to suggest one is better or worse than the other is appropriate, because, sir, there are so many different designs of leading edge slats, leading edge flaps, it may depend on the trailing edge flap setting – it's a very complex problem.

But the simple fact is, whether the airplane is slatted, slotted, flapped or whatever, if it's contaminated, you're going to have on the order of magnitude similar performance effects of contaminant.

(Transcript, vol. 73, p. 144)

Mr van Hengst explained that, in aerodynamic terms, pilot recognition of a performance problem occurs at a different time during the takeoff, depending on the type of aircraft. If the wing is contaminated, then, for a pilot of a hard-wing aircraft or an aircraft with the wing leading-edge devices retracted, the problem is evident when the aircraft is rotated for takeoff and before it leaves the runway. The aircraft may eventually get airborne but cannot fly out of ground effect. On aircraft with leading-edge devices extended, the problem may become evident to the pilot only after the aircraft becomes airborne. Thus, for aircraft types such as the Boeing 737, flight crews have described pitchup or rolloff as occurring immediately after takeoff. The results can be the same for either phenomenon: the aircraft may not be able to accelerate to a high enough airspeed to fly out of ground effect.

Whether the pilot encounters performance problems such as stall, which might be caused by contamination, at rotation of the aircraft, or whether the problem, identified by a pitchup or rolloff, is evident once the aircraft is airborne, the important issue is immediate rectification of this dangerous situation. And although the two types of wings, when contaminated, may exhibit different takeoff flight characteristics, from the evidence of the expert witnesses it is clear that the effect of the contamination on either type of wing is equally dangerous.

To highlight much of the evidence that was before me, I include the following statement made at a September 1988 de-icing conference in Denver, Colorado, by Mr Ralph E. Brumby of the Douglas Aircraft Company:

[S]imply a listing of some icing-related accidents ... while it is by no means inclusive ... does illustrate that ice contamination is quite democratic. Straight wing propeller aircraft like the Nord 262, small turbojet aircraft with conventional airfoils like the Learjet, and larger aircraft with conventional airfoils such as the F-28, DC-9, and DC-8 as well as aircraft with leading edge high lift devices, such as the 737, are all adversely affected.

(Exhibit 532, tab 10, p. 7)

## Freezing Precipitation on Aircraft Surfaces

### Witness Descriptions of Wing Contamination

There was much eyewitness testimony that snow accumulated on the aircraft wings during the station stop in Dryden. Various descriptions were provided as to how the appearance and amount of the snow on the wings changed during the takeoff roll and rotation.

Mr Brian Perozak, who was seated in row 4 near the front of the aircraft, and Air Ontario Captain David Berezuk, who was seated in row 12, next to the left wing, respectively described the snow on the wings as “fluffy snow” and “wet snow accumulation” in the approximate amount of one-half inch prior to the takeoff roll (Transcript, vol. 16, p. 229; vol. 14, p. 79).

Mrs Sonia Hartwick, the surviving flight attendant, who was seated in row 8, stated: “It crystallized and turned to ice” (Transcript, vol. 10, p. 239). In a tape-recorded telephone conversation with Air Ontario executives approximately one hour after the crash, Mrs Hartwick stated: “the wings were icing up ... before take off there was quite a bit of wet snow on them, as we were taking off it was freezing” (Exhibit 126, p. 2).

Mr Murray Haines, an Air Canada captain who was seated in row 13, stated: “About a third of the way down the runway, when – as the speed got up, the snow crystallized into the ice, and it wasn’t moving off the wings” (Transcript, vol. 19, p. 37).

Captain Berezuk stated: “I saw it [snow] dissipate ... it was a sculptured carpet texture, the parts that were white in colour got more of a greyish opaque colour and the parts that were greyish got more grey in intensity” (Transcript, vol. 14, p. 84).

Mr Perozak, who had a clear view of the front portion of the right wing, observed at the time of initial liftoff a “donut glaze” of ice over the leading edge of the wing (Transcript, vol. 16, p. 234). The glaze was not there at the start of the takeoff. He stated: “It looked like the snow had become ice” (p. 236).

Mr John Biro, a retired Canadian airforce warrant officer who was seated in row 11 next to the right wing, testified as follows:

- A. We started to roll down the runway and at this stage I was looking at the wing rather closely, hoping that as we gained speed this wet snow would slide off.

We reached flying speed at seemingly about the same time as previously. And as the nose of the aircraft lifted, the snow on the back part of the wing, about halfway up across the wing, came off with a buff, almost an explosive-type buff.

And the snow on the forward part of the wing seemed to freeze to an opaque, dull opaque ice, almost a flash freezing type thing. And it had a rough surface, not – not coarsely rough but definitely a rough surface.

(Transcript, vol. 21, p. 12)

Mr Biro also stated that right after liftoff, the painted portion of the wing became visible as the snow blew off and the forward portion of the wing became ice. The ice had a rough surface such as the surface of a “knitted coverlet on the bed ... almost a waffled surface” (p. 32), and Mr Biro agreed that there was “a noticeable difference in colour between the front and the rear of the wing” (p. 37).

Because of concerns at an early stage of the investigation regarding wing contamination, it was decided to investigate phenomena that might explain the passengers’ observations and why the precipitation adhered to the wings. The assistance of the National Research Council was obtained in this regard.

### **National Research Council Report: “Freezing Precipitation on Lifting Surfaces”**

This section of the chapter is based upon a report prepared in support of the investigation and entitled “Freezing Precipitation on Lifting Surfaces.” Researched and submitted by Myron M. Oleskiw, PhD, the “Precipitation” report was entered as Exhibit 521 during his testimony. Dr Oleskiw is an associate research officer at the low temperature laboratory, Division of Mechanical Engineering, NRC. As a research meteorologist he has expertise in computer simulations relating to rime ice formation on airfoils. For brevity and simplification, much of the background information and many of the test procedures, charts, and calculations from the report are not included in this section. However, so that the technical data and the results of Dr Oleskiw’s research will be available to the reader, the study appears in its entirety as technical appendix 6 to this my Final Report.

The low temperature laboratory was requested to perform the following analyses, given the known meteorological conditions at Dryden, Ontario, on March 10, 1989:

- an estimation of the weight of snow per unit area that could have collected on the aircraft prior to takeoff;
- a determination of whether wet snow crystals could have stuck to the leading-edge of the wing during takeoff; and,
- a determination of whether snow on the surface of the wing could have turned to ice (as reported by witnesses) through the mechanisms of adiabatic and evaporative cooling of the airflow over the wing.

Dr Oleskiw was also requested to research the possibility of wing surface cooling being caused after landing by cold fuel in the wing tanks, the fuel having been cooled during flight, and to determine the effect the cooling might have had on precipitation falling on the wings while the aircraft was on the ground. The phenomenon of both the aircraft skin and the fuel cooling while the aircraft is flying in very cold temperatures at higher altitudes, resulting in the aircraft skin, on landing, being colder than the outside temperature, was referred to in much of the testimony at this Commission as "cold soaking." I will deal with the phenomenon of cold soaking further in a later section of this chapter.

The following provides a summary of the "Precipitation" report.

### **Quantity of Precipitation Accumulated**

The thickness of wet snow that would have accumulated on the wings of C-FONF during its station stop at Dryden was estimated to be 1.38 mm. This value was determined from analyses of the visibility data as recorded by an Atmospheric Environment Service observer at the Dryden terminal as well as by a transmissometer located near the threshold of runway 11. The relationship used to estimate precipitation rate from visibility is an empirical one, and the data from which the estimate was derived show considerable scatter. The main uncertainty in the relationship is due to the variation in terminal velocity of the snowflakes because of the variations in their size and wetness and, thus, density. It is expected that, despite the efforts to calibrate the visibility-to-precipitation-rate relationship, unusually wet snowflakes may have contributed to a depth of precipitation greater than 1.38 mm.

During his testimony, Dr Oleskiw stated that he did not include in his calculations any information gathered from witnesses. Being aware of witness testimony that revealed the snow had been falling in a fashion not in agreement with the "hard" meteorological data, Dr Oleskiw estimated that the depth of snow could have been up to three times his estimate of 1.38 mm. According to witness testimony, the snow was heavy and the flakes were very large. Also, the visibilities used in Dr Oleskiw's calculations were from the centre and the west end of the airport. When during his testimony it was suggested that there could have been a "curtain" of snow between the terminal and the east end of the runway, with the transmissometer isolated at the west end of the runway, Dr Oleskiw stated: "a comparatively heavy and unrecorded amount of snowfall could have been occurring at the east end of the runway" (Transcript, vol. 68, p. 281). He considered it probable that, had this information been used in snow depth calculations, the estimated snow depth would have been greater.

Dr Oleskiw estimated the accumulated water-equivalent snowfall during the time the aircraft was on the ground to be 0.50 mm. This accumulation is equivalent to 0.5 kg per square m. Because of the shape and slope of the aircraft surfaces and the consistency and wetness of the snow, it is difficult to estimate the weight of snow and slush that stayed on the aircraft.

### **Freezing of Accumulated Precipitation**

*Adiabatic and Evaporative Cooling* Some of the passengers on board C-FONF saw snow blow off the wings and observed slush on the wings turn to ice during the takeoff roll, especially at or near the point of aircraft rotation. Extensive calculations were made with regard to the effects of adiabatic and evaporative cooling during the takeoff run to determine if these processes could have generated enough heat loss to account for the fact that the slush froze.

The adiabatic cooling of the air just outside the boundary layer plus the evaporative cooling caused by less than saturated air passing over the wing produced a heat loss. The heat loss was, however, more or less offset by the heat gain caused by frictional heating of the boundary layer in combination with the heat release required to freeze the partially melted snowflakes impacting on the wing. With such a small net heat flux, and given the very short time that it would have been acted upon during the takeoff roll, it would have been impossible for essentially any change to occur in the precipitation layer. Any snowflakes impinging on the wing during the takeoff roll would thus have likely met a partially wetted precipitation layer surface.

Dr Oleskiw estimated that between 25 and 32 per cent of the snowflakes that are in the path of the wing during the takeoff roll would stick to the leading edge in the area extending from 3 per cent to about 19 per cent of the wing chord. Further back on the wing the snowflakes would graze the surface and would not stick to it. The fact that the snow on the wing was partially wet, in combination with the likelihood that the impinging snowflakes would have been somewhat wet, leads to the conclusion that many of these snowflakes would have stuck to the forward portions of the precipitation layer during the takeoff roll.

Dr Oleskiw concluded that there was an insufficient amount of adiabatic and evaporative cooling during the takeoff roll to account for the freezing of the precipitation layer on the wing.

*Conduction of Heat into the Fuel Tanks* The wing of the F-28 contains integral fuel tanks that, when full, wet the wing skin for most of the length of the wing between two wing spars located at about 12 per cent and 56 per cent of the wing chord. For the purpose of calculating heat transfer, it was first necessary to determine the temperature of the fuel



in the aircraft before and after the aircraft was refuelled at Dryden. Calculations regarding fuel temperatures were made from the time the aircraft left Winnipeg to the time refuelling was completed at Dryden. Data considered were the initial temperature and weight of the fuel in the aircraft, the temperatures and weights of delivered and offloaded fuel, the outside air temperature both on the ground and at flight altitudes (the cold temperatures at altitude causing the fuel to cool), and the flight leg duration. During a flight of the sister Air Ontario F-28 aircraft, C-FONG, wing surface temperatures and fuel temperatures were measured to establish norms. The flight leg durations were similar to those flown by C-FONF on March 10, 1989, and the outside temperatures were approximately the same. These norms were used by Dr Oleskiw in his calculations. The temperature of the fuel in C-FONF at Dryden just prior to the accident flight was calculated at  $-6.4^{\circ}\text{C}$  before fuelling and at  $-4.7^{\circ}\text{C}$  after fuelling. The ambient air temperature at the Dryden airport at the time was between  $+0.4^{\circ}\text{C}$  and  $+1.0^{\circ}\text{C}$ .

Under certain circumstances and in combination with the other heat flux terms, the contribution of the conductive heat flux from the precipitation layer on the wing to the fuel tanks might have resulted in a complete freezing of the water fraction of the precipitation layer during the 10-minute interval of the heavier snowfall rate while the aircraft was on the ground. The assumed value of the water fraction of the falling snowflakes has been shown to alter significantly the time required to freeze the precipitation layer. The thickness of the precipitation layer also exhibited a strong influence on the freezing time.

Given that the depth of the wet snow on the wings was likely greater than the best estimate of 1.38 mm calculated from the available data, it seems probable that the heat conduction into the fuel tanks would have permitted a lower portion of the water in the wet-snow layer to have frozen, while leaving some upper portion in a partially liquid state. Because the density of the wet snow was between that of dry snow and ice, this layer was composed of a lattice of deformed and coagulated ice crystals interspersed with air pockets and water. As the water froze in the lower portion of this layer, it would likely have left a very rough interface between the lower and upper portions of the precipitation layer.

As the aircraft rolled down the runway, pressure variations outside the boundary layer and aerodynamic forces of air flowing over the wing at speeds, in places, of greater than 300 knots might have forced the remaining water in the upper portion of the precipitation layer to drain away, possibly carrying with it some of the slush, wet snow, and ice from that portion. The resulting very rough ice surface on the wings would have had a significant impact on the aerodynamic performance of the aircraft.

It should be noted that the thermal conductivity of the aluminum skin of the aircraft is in the order of 100 times greater than that of wet snow, air, or the fuel in the tanks. As a result, the aluminum skin might have conducted heat away from the precipitation layer even further forward on the wing than the location of the wing spar forming the forward wall of the fuel tanks. Thus, the rough precipitation layer surface may have extended forward to the leading edge, the more aerodynamically critical portion of the wing.

### **Discussion and Summary**

The description given by Dr Oleskiw during his testimony provides a clear explanation of the phenomenon viewed by the passengers:

- A. ... there are pressure variations as a result of the lift that is being produced on the wing, that these pressure variations and this force of the air going over the wing could have been sufficient to suck or push the remaining water out of the upper portion of the wing – out of the precipitation layer, rather.

It also could have allowed the force of the air to have taken away some portion of this wet snow on the upper portion of the precipitation, leaving behind the frozen precipitation which was entirely frozen.

Now, since the crystal structure and such of this precipitation layer was very coarse, it appears to me that this motion of the air during the takeoff roll could have suddenly exposed a very rough layer, much rougher than was there prior to the takeoff roll, and that as a result, the witnesses on the aircraft that seemed to indicate that they had noticed a sudden change during the takeoff roll might have actually been seeing this sort of a phenomenon occurring.

And that if that indeed did occur, it seems to me, and some of your aerodynamics experts can comment further on that perhaps, that this very rough surface would have been suddenly presented to the outer surface of the wing of the aircraft to the air flow and that that perhaps could have had a very adverse effect on the aerodynamics of the aircraft.

(Transcript, vol. 68, pp. 219–20)

### **Findings**

Dr Oleskiw's findings, with which I agree and which I adopt, are summarized as follows:

- The weight of snow and slush accumulation on the aircraft could not be determined, mainly because of the difficulty in calculating the

amount of snow and slush that would stick to the sloping surfaces of the aircraft.

- The phenomenon of the slush turning to ice during rotation and liftoff could not be adequately explained by the processes of adiabatic and evaporative cooling.
- The heat transfer from the slush to the cold fuel probably caused at least the lower levels of slush on the wing to freeze. As the water drained away from the wing surfaces during the takeoff roll, leaving mainly rough ice on the wings, the change in appearance of the slush and ice layer may have left the impression on the witnesses that the slush had turned to ice.
- The aerodynamically critical portion of the wings, the forward 15 per cent of the chord, was most likely contaminated with rough snow and ice. First, because of the conductivity of the aluminum wing skin, the cooling effect of the tank fuel would extend beyond the limits of the fuel tanks towards the leading edges, causing ice to form on the leading edges; the forward portion of fuel tank limit itself being within the first 12 per cent of the wing chord. Second, it was concluded that the wet falling snow would stick to the leading edge of the wing during the takeoff roll.

## Takeoff from Wet or Contaminated Runways

A runway, whether or not in an isolated area, is considered to be contaminated when more than 25 per cent of its surface, within the required length and width being used, is covered by surface water greater than 3 mm (0.125 inch) deep, or by slush or loose snow equivalent to more than 3 mm of water. The analysis of all the information regarding the runway condition at Dryden at the time of the takeoff of C-FONF on its accident flight indicates that one-quarter to one-half inch of slush covered the runway from its east end to, at least, the intersection of taxiway Alpha, a distance of approximately 3500 feet. It is therefore concluded that the runway was, at that time, contaminated.

All the published Fokker F-28 Mk1000 takeoff information contained in the Fokker F-28 Flight Handbook is based on acceleration and stopping taking place on hard, dry, and smooth runway surfaces and all means of braking being serviceable. The effects of variable factors such as temperature, moisture, density altitude, and wind on aircraft performance are also taken into account.

The takeoff performance criteria, applicable to commercial jet aircraft, including the Fokker F-28 Mk1000, are normally described as accelerate-stop and accelerate-go criteria.

In general terms, for the purpose of aircraft certification, accelerate-stop distance is defined as the distance required for an aircraft to accelerate to decision speed  $V_1$  with all engines operating normally at takeoff thrust; to experience a power failure of the critical engine<sup>10</sup> at  $V_1$ ; to allow an appropriate time delay for the pilots to recognize the failure and, upon recognition, allow an appropriate time to retard all engine throttles or thrust-levers to idle; to apply maximum wheel-braking and deploy speed brakes; and to continue with maximum braking until the aircraft comes to a full stop. Although reverse-thrust is not taken into account in the accelerate-stop calculation, pilots, to assist in stopping the aircraft, would also deploy and use thrust-reversers, if available, on the operating engine(s). (The F-28 does not have thrust-reversers.) The accelerate-stop distance is dependent upon such variables as wind, ambient temperature, aerodrome elevation, runway slope, aircraft weight, and aircraft configuration.

The takeoff path distance, often referred to as the accelerate-go distance, is in general terms the distance required for an aircraft to accelerate to decision speed  $V_1$  with all engines operating normally at takeoff thrust; to experience a power failure of the critical engine at  $V_1$ ; to allow an appropriate time delay for the pilots to recognize the failure and, upon recognition, elect to proceed with the takeoff and rotate the aircraft at a speed of not less than  $V_R$  to the target pitch attitude; and to achieve  $V_2$  prior to or at a height of 35 feet above the end of the runway (often referred to as the screen height).

A runway length that allows for either accelerate-stop or accelerate-go once an aircraft experiences an engine failure at  $V_1$  is called balanced field length or a balanced field.

Taking off from a contamination-covered runway will adversely affect the takeoff performance of an aircraft in different ways, depending on the type and the amount of precipitation on the runway. Slippery runways with little contaminant depth will adversely affect an aircraft's accelerate-stop performance but will not appreciably affect its accelerate-go performance. Although a slippery runway will reduce an aircraft's wheel-braking performance, it creates no significant drag to reduce the acceleration of the aircraft.

Accelerate-stop and accelerate-go performance are both adversely affected in conditions where the runway is contaminated with standing water, slush, or snow. Acceleration is adversely affected by wheel drag in the contamination and by the effects of spray thrown upwards against

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<sup>10</sup> Critical engine is the engine whose failure causes the most adverse effect on the aircraft characteristics relative to the case under consideration. For the purpose of discussion of F-28 performance, neither engine, if it failed, would have had a more adverse effect than the other on aircraft performance.

the aircraft underbody by the aircraft wheels. This drag results in an increase in the distance that an aircraft requires to accelerate to  $V_1$ , to  $V_R$ , and, finally, to  $V_{LOF}$  (the liftoff speed).<sup>11</sup> Where an engine failure occurs at  $V_1$  and the decision is made to go, the drag caused by the contaminant may decrease acceleration to the extent that it would be impossible to accelerate to liftoff speed after the engine failure. Where the decision is made to reject the takeoff and bring the aircraft to a stop, the reduction in the runway coefficient of friction caused by the contaminant will result in an increased stopping distance.

Because of the difficulty in predicting accurately the effect of runway contamination on acceleration and braking performance, aircraft flight manuals generally recommend that takeoffs from runways covered with standing water, slush, or snow be avoided where possible. In spite of general improvements in techniques at clearing contaminants from runways, Fokker recognized that operators might find it necessary to take off from contaminated runways. The Fokker F-28 Flight Handbook contains information to allow calculation of aircraft takeoff performance when operating from hard-surface runways contaminated with standing water, with slush, or with loose, uncompacted snow.

The Piedmont and the USAir F-28 operations manuals, which were the manuals used by Air Ontario in its F-28 operation, also contain information regarding contaminated runways, along with a caution regarding performance degradation. The following passage appears in both manuals:

Apart from the substantial increase in stopping distance when takeoff is rejected on a contaminated runway, the degradation in acceleration caused by snow, slush or standing water can under adverse conditions result in the aircraft needing up to twice the normal takeoff distance.

(Exhibit 307, p. 3A-24-4; Exhibit 329, p. 3-125-7)

Recognizing the negative effects that standing water, slush, or snow have on takeoff performance, both Piedmont and USAir provided identical correction charts recommending maximum allowable takeoff weights for various runway lengths. Inasmuch as Air Ontario pilots used the Piedmont and USAir F-28 operations manuals as guides in their day-to-day operation of the F-28, and because witness evidence indicates that there was one-quarter to one-half inch of slush on at least the east half of runway 29 at the time C-FONF commenced its final takeoff roll at

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<sup>11</sup>  $V_{LOF}$ , the liftoff speed, is, in terms of calibrated airspeed, the speed at which the aircraft first becomes airborne. The aircraft is deemed to be airborne when the aircraft wheels are no longer in contact with the runway.

Dryden on March 10, 1989, I think it important to include, as figure 12-10, the Piedmont and USAir takeoff limitation and correction chart.

The normal operations sections of the Piedmont and the USAir F-28 operations manuals set out identical correction charts. The above-noted excerpt from the two manuals was included by Air Ontario in the first draft of its F-28 operations manual but was removed from the draft of the manual submitted to Transport Canada for approval. The chart was removed after discussion with the drafters, Captain Robert Perkins and Captain Steven Burton; the project manager of the F-28 program, Captain Joseph Deluce; and the director of flight standards for Air Ontario, Captain Larry Raymond. The discussions centred on the fact that the Piedmont charts were much more restrictive than the Fokker F-28 charts.

The contaminated runway performance charts produced for the F-28 aircraft by Piedmont, USAir, and Fokker were all based on the assumption of both engines operating normally throughout the takeoff flight path.

Using Fokker charts and the takeoff distance available of 6200 feet on runway 29 at Dryden, with a temperature of +1°C, a barometric pressure of 1020 millibars, and a tail-wind component of 1 knot (the conditions that existed at Dryden on March 10, 1989), with one-half inch of slush (EWD 0.425 inches), the operations group calculated that the maximum allowable takeoff weight of an F-28 would be 64,400 pounds. Under the same conditions, the Piedmont and USAir charts provided that the maximum allowable takeoff weight of an F-28 would be somewhere between 53,000 and 54,300 pounds.

Two matters that arise from the performance information available to Air Ontario F-28 pilots relating to operation from contaminated runways are of concern to me. My first concern is over the large difference between the correction factors provided by Fokker Aircraft and those supplied in the Piedmont and USAir operations manuals used by Air Ontario. My second concern is that the contamination-correction charts do not consider engine failure during takeoff; the charts are based on both engines operating throughout the takeoff flight path. Although information is provided to pilots for the determination of allowable aircraft weight and balanced field lengths when operating from a dry runway, no equivalent information is provided for takeoffs from a contaminated runway.

The chart provided in the Piedmont and USAir operations manuals imposes severe weight penalties for takeoff on slush-covered runways. If we assume the takeoff portion of the runway at Dryden was covered with one-half inch of slush, then, had the crew of C-FONF, prior to takeoff, referred to and complied with the information set out in the Piedmont and USAir manuals, they would not have been able to take off

Figure 12-10 Piedmont/USAir Takeoff Weight Correction Chart for a Contaminated Runway

5. Takeoff in Standing Water, Slush or Snow

Operation on precipitation covered runways is acceptable, however an assessment for the deteriorating effect on takeoff performance must be made. The following information is presented for guidance and has not been FAA approved.

This part contains information and recommendations to enable an assessment to be made at which the airplane should be able to take off from a snow, slush or water-covered runway. The precipitation is assumed to be of uniform depth over the complete length of the runway.

Takeoff in standing water depths greater than 0.25 inch, slush depths greater than 0.50 inch or dry snow greater than 2.0 inches is not recommended. The maximum takeoff weight shown in the following table is based on both engines operating throughout the takeoff flight path. The weights shown are always lower than dry runway take-off allowable weights. Therefore, no comparison is required. These are the maximum allowable takeoff weights on contaminated runways.

**F28 MK 1000 CONTAMINATED RUNWAY  
MAXIMUM ALLOWABLE TAKEOFF WEIGHT  
FLAPS 18°**

RUNWAY LENGTH - FT	STANDING WATER 0.25 INCHES	SNOW = 1.0 INCHES SLUSH = 0.25 INCHES	SNOW = 2.0 INCHES SLUSH = 0.50 INCHES
5000	48800 lbs	52700 lbs	49500 lbs
5500	49800 lbs	54000 lbs	51500 lbs
6000	50800 lbs	55400 lbs	53000 lbs
6500	51900 lbs	56800 lbs	54300 lbs
7000	52900 lbs	58000 lbs	55600 lbs
7500	53800 lbs	59100 lbs	56600 lbs
8000	54700 lbs	60100 lbs	57500 lbs
8500	55600 lbs	61000 lbs	58200 lbs
9000	56300 lbs	61700 lbs	58900 lbs
9500	56900 lbs	62200 lbs	59500 lbs
10000	57300 lbs	62600 lbs	60100 lbs

Note: This information is good for all temperatures and for airport elevations up to and including 3,000 feet.

unless the runway had first been cleared of slush or the aircraft weight had been no greater than 54,300 pounds. Calculations using the Fokker charts for the same conditions at Dryden indicate that there was sufficient runway for an F-28 to take off at a weight of 64,400 pounds, even though there was one-half inch of slush on the runway. The large variation in permissible takeoff weights between Fokker Aircraft and Piedmont/USAir clearly indicates a difference between the manufacturer's certification requirements and the operational philosophy of Piedmont and USAir. A carrier that is conservative in its view of the requirements concerning contaminated runways might impose severe restrictions, as was the case with both Piedmont and USAir. The draft of the Air Ontario F-28 operations manual that was sent to Transport Canada did not contain a slush-correction chart. A less conservative carrier could simply adopt the less restrictive chart provided by Fokker Aircraft. Even so, approval of all the slush-correction charts mentioned is not required by Canadian, Dutch, or United States regulatory authorities.

Captain Robert Perkins, an Air Ontario F-28 check pilot, stated in his testimony that, because the Piedmont and USAir F-28 slush-correction charts were "fairly restrictive" (Transcript, vol. 43, p. 31), he felt he could use the Fokker F-28 Flight Handbook chart, which was less restrictive. However, while under close questioning during his testimony, he agreed with the subsequent evidence of Transport Canada and Air Ontario pilot witnesses that, to determine takeoff parameters, a pilot in the cockpit would find it difficult and time-consuming to use the detailed charts in the Fokker handbook. Captain Robert Nyman, the director of flight operations for Air Ontario, considered that the tables in the Piedmont and USAir F-28 operations manuals applied because these were the manuals used by Air Ontario F-28 pilots. With respect to Fokker's charts, Captain Nyman stated: "I tried post-accident to go through those charts. I have been trained in performance and use of charts. I found them very difficult to use, and, as has been pointed out by other people, you don't come up with consistent answers. I find them difficult to use" (Transcript, vol. 109, p. 210). During this Commission's hearings, testimony revealed that, within the pilot group of Air Ontario, there was no consensus on whether to use Fokker's or Piedmont's information with respect to operations from slush-covered runways. Clearly this lack of consensus constituted an alarming state of affairs within Air Ontario.

In light of testimony about the nature of the charts contained in the Fokker F-28 Flight Handbook, it is not only probable but virtually certain that the crew of C-FONF had insufficient time to use them to determine slush corrections. Moreover, the fact that C-FONF, at an estimated weight of 63,500 pounds, took off at Dryden from a slush-covered



runway strongly suggests that the crew either did not consider or considered and elected not to apply the slush-correction information contained in both the Piedmont and USAir F-28 operations manuals. The uncertainty regarding which manual to use in calculating slush correction at Dryden would have posed a serious dilemma for the pilots of Air Ontario flight 1363. That dilemma should have been solved by Air Ontario long before March 10, 1989:

The final takeoff of C-FONF was from a runway contaminated with slush on at least the first half of its length and wet on the remainder. The slush was described by a number of witnesses, none of whom had actually measured its depth, as being up to one-half inch deep. The performance subgroup determined through precise analytical and engineering studies that, for the aircraft to reach its rotation point as described by many witnesses, the slush must have been in the order of 0.15 inches EWD. Although an engine failure did not occur, there was potential for the necessity to react to an engine failure during the takeoff and either continue the takeoff or stop on the runway. Calculations show that, according to aircraft weight and existing ambient conditions, the Dryden runway was close to balanced length for dry runway operations. Had an engine failure occurred at or near  $V_1$  during the takeoff, it is probable that, because the last half of the runway was at least wet and thus slippery, the aircraft could not have been stopped on the runway. However, had there in fact been no slush on the last half of the runway, the aircraft, under normal circumstances, should have been able to complete the takeoff had an engine failed at  $V_1$ . Simulator tests conducted by the performance subgroup and Fokker Aircraft at Fokker's facility in Amsterdam indicated that, with one-half inch of slush on the entire runway length and with the aircraft wing clean, the aircraft would reach  $V_1$  in about 3100 feet with a takeoff run of approximately 4250 feet. Engine-failure tests were not conducted under these conditions. If, however, an engine had failed at  $V_1$ , it is possible that, because of the slush, the aircraft would not have been able to get airborne in 6000 feet, the length of the runway at Dryden.

Neither United States Federal Aviation Regulations, which are the benchmark regulations for certification requirements for most transport aircraft, nor Canadian Air Regulations and Air Navigation Orders address the issue of engine failure during takeoff on a wet or contaminated runway; indeed, there are no standards available to enable manufacturers or operators to determine what weight corrections to apply. It is therefore not difficult to conclude, as in fact I do, that passengers and aircraft crew members are exposed to different degrees of risk on takeoff, depending on whether the takeoff is made on a contaminated or wet runway or it is made from the same dry runway.

Clearly this is an aviation safety issue that has existed for some time and must be addressed. As shown in a subsequent chapter of this Report, available information indicates that regulators are finally taking steps to address the problem.

The fact that Transport Canada and CASB have been aware of the problem for a considerable time is illustrated by the following abbreviated versions of two occurrence reports prepared by CASB, by the recommendations contained in those reports, and by Transport Canada's reaction to the recommendations.

The following information is from CASB report no. 86-A60024. On July 20, 1986, a Boeing 737 was taking off from Wabush, Newfoundland, when, as the aircraft speed approached  $V_1$ , a bird was ingested by the left engine and the engine lost power. The crew rejected the takeoff, and the aircraft came to a stop in a bog 200 feet beyond the end of the runway. No one was injured in the occurrence. CASB determined that, because the runway was wet, the distance required to stop the aircraft exceeded that which was available. Pre-flight performance calculations did not take into account the effects of the wet runway. Such calculations were not and are not required by regulations. CASB also found that existing aircraft flight manuals do not provide data that take into account the effects of wet runways on accelerate-stop distances.

The "safety action" portion of the CASB-produced report of this occurrence states the following:

In view of the absence of certificated performance data and the apparent lack of knowledge on the part of flight crews regarding wet runway takeoff performance, the CASB recommends that:

The Department of Transport revise air carrier procedures involving wet runway take-off operations, in order to provide a margin of safety comparable to that for dry runway operations.  
CASB 87-45

The Department of Transport require air carriers to improve flight crew knowledge of the effects of wet runways on take-off performance and the means available to flight crews to provide a margin of safety comparable to that for dry runways.  
CASB 87-46

Transport Canada's response to the above recommendations was as follows:

Notwithstanding the amount of information available at present, Transport Canada will request the Transport Development Centre to initiate a research project to investigate the effect of wet runways on aircraft performance.

In a return letter to Transport Canada, CASB expressed regret that Transport Canada's response was limited to a long-term study. CASB further expressed concern that overruns can continue to happen whenever a rejected takeoff occurs at or near  $V_1$  on a performance-limited wet runway and requested that Transport Canada reconsider its position on this important issue.

The following information is from CASB report no. 86-P64053. On July 14, 1986, a Boeing 737 landed at Kelowna, British Columbia, shortly after a torrential rain storm. During the landing roll, the aircraft hydroplaned, the thrust-reversers and ground-spoilers did not deploy, and the aircraft overran the runway. CASB determined that the pilot's landing procedures on the wet runway, combined with limitations imposed by the aircraft's air-ground logic system, prevented deployment of the ground-spoilers and reversers. As a consequence, the crew was unable to stop the aircraft on the runway.

With regard to wet runway performance, the "safety action" portion of this report contains the following rather startling information:

The CASB has knowledge of 16 occurrences involving aircraft weighing more than 12,500 pounds overrunning the runway on landing in Canada between 1980 and 1987. Most of these involved runways where the braking action was reduced by water or other surface contaminants. Canadian operators routinely conduct flight operations on wet or otherwise contaminated runways that are at or near the certified performance limits of aircraft within their fleets. The latitude for error is small. The anticipated stopping distances contained in aircraft flight manuals will not be achieved if braking action is poor.

CASB pointed out in the report that existing certification standards used for determining the landing distance applicable to transport-category aircraft certified under Federal Aviation Regulation 25 require that the tests be conducted on bare, dry, smooth, hard-surfaced runways. Without detailing the issues brought to light in this occurrence, other than the wet runway performance, I will recite the CASB recommendation made as a result of this investigation. CASB recommended that:

The Department of Transport ensure that the recurrent training of flight crews of transport-category aircraft emphasizes the cumulative performance penalties and the uncertainties of expected stopping distances associated with operations on wet or contaminated runways. Particular emphasis should be placed on the need for a timely decision to effect a successful go-around.

CASB 88-05

Although not making a recommendation regarding the lack of certification requirements for aircraft-stopping performance on wet or contaminated runways, CASB did state a concern on this issue as follows:

The Board is equally concerned that the aircraft certification criteria currently in existence for ascertaining contaminated runway landing performance data do not provide aircrew with sufficiently accurate data upon which to base landing decisions. Current procedures provide for safety margins that are derived from factoring the dry landing distances by arbitrary amounts. Consequently, flight crews often land on performance limited runways using performance data for which there is no empirical evidence to assure a stop on the available runway.

The response to CASB by Transport Canada regarding the above recommendation CASB 88-05 was as follows:

Transport Canada air carrier inspectors have been instructed to monitor training for landing on contaminated runways and to be alert to any degradation of standards.

This is apparently the last correspondence between CASB (now the TSB) and Transport Canada relating to the above-noted occurrences and the issue of wet or contaminated runways.

On February 5, 1991, based on occurrence investigations, in particular that of the Boeing 737 overrun at Wabush, and on other information collected, and after evidence on this subject was heard before my Commission of Inquiry, Transport Canada issued Airworthiness Manual Notice of Proposed Amendment, NPA 91-2, File No: 5009-006-525, entitled, "Take-off from Wet and Contaminated Runways." The proposed amendment requires a change to the airworthiness requirements of chapter 525, paragraph 525.1581, by the addition of a new subparagraph (g) as follows:

The Aeroplane Flight Manual shall contain information in the form of approved guidance material for supplementary operating procedures and performance information for operating on wet and contaminated runways.

The proposal is intended to ensure that suitable approved guidance information is provided in the aircraft flight manual by the aircraft manufacturer as part of the aircraft type design.

In the explanatory information that accompanied the proposed amendment, Transport Canada outlined the approach of the United States Federal Aviation Administration (FAA) and the European Joint

Aviation Authorities (JAA) with regard to wet or contaminated runways, and I quote from the document as follows:

The FAA published Advisory Circular AC 91-6A on May 24, 1978 which provides information, guidelines and recommendations concerning the operation of turbojet aircraft when water, slush, and snow are on the runway. This AC discusses the performance problems, provides sample performance adjustments and states that appropriate information should be included in the operations manual of the air carrier. A proposed revision, AC 91-6B, was announced in the Federal Register on August 1, 1986, but has not yet been promulgated. This draft revision updates the AC and clarifies that the operational requirements in Part 121 (for Commercial Operators of Large Aircraft) and Part 135 (for Air Taxi Operators and Commercial Operators) require adjustments to take-off and landing data when operating on wet or contaminated runways. The revised AC also states that the information should be included in the AFM [aircraft manufacturer's aircraft flight manual] or in the [aircraft] operations manual but that if the information is provided in the AFM then it need not be FAA approved.

In November 1987, the FAA published NPRM [Notice of Proposed Rulemaking] 87-13, Standards for Approval of a Reduced  $V_1$  Methodology for Take-off on Wet and Contaminated Runways. The proposal introduces the concept of using a 15-ft screen height (in lieu of 35 ft) for wet and contaminated runways with a corresponding reduction in  $V_1$ . Although actual accelerate-stop performance is not required, it is implicit in the proposal that rejected take-off safety would be improved on wet or contaminated runways at the expense of a reduced screen height. To date there has been no new regulations arising from this NPRM.

The European JAA have published JAR 25X1591 which requires supplementary performance information to be furnished by the manufacturer in an approved document in the form of guidance material to assist operators in developing suitable guidance recommendations or instructions for use by their flight crews when operating on wet or contaminated runway surface conditions. It further states that if the information is in the [aircraft manufacturer's] AFM, then it must be segregated, identified as guidance material, and clearly distinguished from the operating limitations specified in JAR 25.1533 and 1587.

It is apparent that at this time no regulatory body is prepared to go so far as to make it mandatory for aircraft to comply with balanced field criteria when operating on a wet or contaminated runway. There is,

however, consensus that guidance material is required. It is stated in the Transport Canada amendment document that, since the information will be provided as guidance only, non-compliance will not affect airworthiness approval; it will remain an operational decision covered by the appropriate operating regulations and/or procedures for each operator. Because of the difficulty in defining the exact state of a contaminated runway surface, in practice an aircraft may or may not perform as predicted in the guidance material. However, the mandatory inclusion in a manual, AFM or other, of approved guidance material relating to operations on a wet or contaminated runway will, in my view, go a long way towards improving the safety of such an operation. Operational decisions should be based on expected performance and not on guesswork, as is the case at present.

It appears that various regulatory bodies are working actively towards a solution to the problem of operating aircraft safely from wet or contaminated runways, and that their proposed amendments to the regulations, if they are in fact all promulgated, will improve passenger and crew safety.

However, it is doubtful that mere guidelines will produce the desired safety results. Although operators may endorse the approved guidance material, in the absence of any compulsion to follow it they have the option of ignoring it. As well, because of the previously mentioned difficulty regarding the definition of the state of the runway surface, adherence to guidelines will not necessarily ensure that a particular aircraft can be operated safely on a particular wet or contaminated runway. I believe that the regulators, in cooperation with manufacturers and operators, should continue to search for a technically accurate means of defining runway surface conditions and their effects on aircraft performance, and for an equitable means of requiring operators to adhere to balanced field criteria when operating on wet or contaminated runways. I recognize that economic penalties on air carriers would be imposed, but only through the regulatory process can a uniform and high level of safety be assured for all operating conditions.

Notwithstanding the efforts being made by the regulators with regard to aircraft performance on wet or contaminated runways, airport operators should make a concerted effort to ensure that runways are not contaminated when aircraft are landing and taking off.

# Information and Procedures Available for Safe Operation in Cold Weather Conditions

This section outlines the information and procedures regarding operation in cold weather conditions that were accessible to Air Ontario F-28 pilots, including the crew of C-FONF. Chapter 1.7.5.1, Section 1, Volume 1, of Fokker's F-28 Flight Handbook provides the following information and procedures for a safe operation of the F-28 in cold weather conditions:

## 1.7.5 ADVERSE WEATHER

### 1. COLD WEATHER OPERATION

This chapter contains information and procedures for a safe operation of the F-28 in cold weather conditions. For performance criteria see subsection 2.

#### 1.1 General

Small and apparently insignificant ice and snow deposits on the aerodynamic surfaces, accumulated during stand-over, can seriously affect the maximum lift of the wing, the controllability and the performance of the aircraft.

During a normal take-off the angle of attack reaches approx. 9 deg at rotation.

Thin layers of ice resulting from, for instance, frost or freezing fog, may cause a certain sandpaper roughness of the wing and tail upper surfaces.

This roughness may cause airflow separation at angles of attack below 9 deg resulting in control problems, wing drop or even a complete stall shortly after rotation.

Relatively "warm" fuel uplifted during a ground stop may cause dry snow falling on the wing to melt. After a subsequent cooling period this water may refreeze, forming an invisible ice coating underneath the dry snow.

When the tanks contain sufficient fuel of sub zero temperatures as, for instance, may be the case after long flights at very low ambient temperature, water condensation or rain will freeze on

the wing upper surfaces during the ground stop forming a smooth, hardly visible ice coating.

During take-off this ice may break away and at the moment of rotation enter the engine causing compressor stall and/or engine damage.

Snow falling on "warm" leading edges will melt and may form, under certain wind conditions, "run back ice" on wings and stabilizer, causing possible lift loss and/or controllability problems.

IN VIEW OF THE ABOVE IT IS OF VITAL IMPORTANCE THAT FUSELAGE, WINGS, ENGINE INTAKE AREAS, TAIL SURFACES, CONTROL SURFACES, HINGES AND IN PARTICULAR WING AND STABILIZER LEADING EDGES ARE COMPLETELY CLEAR OF ICE OR SNOW BEFORE TAKE-OFF.

It is recommended that, when operating in slush conditions, de-icing grease or fluid is applied to the lower and upper surfaces of the flap vanes and the wing shroud and flap areas which come in contact with the vane surface.

The effectivity of pre-flight application of de-icing fluid is influenced by several factors such as the amount of snow or ice deposits, outside air temperature, relative humidity, aircraft skin temperature and the water/glycol mixture used.

Arrange the departure so that a minimum of time elapses between the moment of de-icing and take-off.

When spraying with passengers and/or crew on board, switch off the airconditioning units to prevent glycol fumes from entering the cabin and/or cockpit.

(Exhibit 314, Fokker F-28 Flight Handbook, p. 1.7.5.1)

Both the Piedmont and the USAir F-28 operations manuals repeat much of Fokker's information and provide the following under the title "Cold Weather Operations":

This section contains information and procedures for a safe operation of the F-28 in cold weather conditions. Most recommendations mentioned are a result of experience gained during winter operation in Northern Europe, Canada and the Northern States of the USA.

Small and apparently insignificant ice and snow deposits on the aerodynamic surfaces, accumulated during stand-over, can seriously



affect the maximum lift of the wing, the controllability and the performance of the aircraft.

During a normal take-off, the angle of attack reaches approximately 9° at rotation. Thin layers of ice resulting from frost or freezing fog cause a certain sandpaper roughness of the wing and tail upper surfaces. This roughness may cause air-flow separation at angles of attack below 9° resulting in control problems, wing drop or even a complete stall shortly after rotation.

Relatively warm fuel uplifted during a ground stop may cause dry snow falling on the wing to melt. After a subsequent cooling period this water may re-freeze, forming an invisible ice coating underneath the dry snow.

When the tanks contain sufficient fuel of sub zero temperatures as may be the case after long flights at very low ambient temperature, water condensation or rain will freeze on the wing upper surfaces during the ground stop forming a smooth, hardly visible ice coating.

During take-off this ice may break away and at the moment of rotation enter the engine causing compressor stall and/or engine damage.

Snow falling on warm leading edges will melt and may form run back ice on wings and stabilizer, causing possible lift loss and/or controllability problems.

IN VIEW OF THE ABOVE IT IS OF VITAL IMPORTANCE THAT FUSELAGE, WINGS, ENGINE INTAKE AREA'S, TAIL SURFACES, CONTROL SURFACES, HINGES AND IN PARTICULAR WING AND STABILIZER LEADING EDGES ARE COMPLETELY CLEAR OF ICE OR SNOW BEFORE TAKE-OFF.

(Exhibit 307, Piedmont F-28 Operations Manual, p. 3A-24-1; Exhibit 329, USAir F-28 Operations Manual, p. 3-125-1)

Both the Piedmont and USAir operations manuals discuss de-icing procedures under identical headings: "Fluids for De-Icing and Anti-Icing." I quote the Piedmont provisions in their entirety as follows:

It is recommended that, when operating in slush conditions, de-icing fluid is applied to the lower and upper surfaces of the flap vanes and the wing shroud and flap areas which come in contact with vane surface.

For different de-icing fluids the times of protection (the holdover times) vary considerably. Furthermore, these times depend to a large extent on the meteorological conditions and methods of application.

The time of protection will be shortened, for instance, by snow, increasing content of moisture, wet airplane surface, relative high temperature of airplane surface and of the fluid being used, or high wind velocity and unfavorable wind direction. All these conditions cause an unwanted dilution of the protective film. If these conditions accumulate, the time of protection can be shortened considerably.

**CAUTION: PRIOR TO EXTERIOR DE-ICING, THE APU AND PACK SHOULD BE SHUT DOWN.**

If possible, ground power should be used to satisfy electrical needs during de-icing. Prior to de-icing, an announcement should be made to the passengers advising them that de-icing will be accomplished and slight fumes or smoke may be present following the de-icing operation. After de-icing is accomplished, start the APU and permit it to operate approximately two (2) minutes prior to turning on a pack.

Engine Anti-ice must be ON during all ground and flight operations when in icing conditions and/or the ice detect light is illuminated.

When penetrating or operating in icing conditions in-flight maintain a minimum of 83% HP RPM to ensure full and simultaneous Engine and Airfoil Anti-icing operation.

Icing conditions exist when OAT is 50°F/10°C or less and visible moisture in any form is present (such as clouds, fog with visibility of one mile or less, rain, snow, sleet, ice crystal); or standing water, slush, ice, or snow is present on the ramps, taxiways or runways.

(Exhibit 307, Piedmont F-28  
Operations Manual, p. 3A-24-2)

None of the above information contained in Fokker's F-28 Flight Handbook or set out in the Piedmont and USAir F-28 operations manuals is contained in the Air Ontario Draft F-28 Operations Manual dated June 1, 1989. The only provisions contained in the Air Ontario Flight Operations Manual (September 15, 1987) dealing with wing contamination while on the ground and its effects is contained in section 7, "Operational Directives." One short sentence under 7.1.1, "Icing Conditions," states: "Take-off shall not be attempted when frost or freezing precipitation is adhering to the surfaces of the aircraft" (Exhibit 146, p. 73). This prohibition is included in the broader operational directive dealing generally with in-flight operating procedures in icing

conditions. As a flight operations directive, this prohibition applies to all aircraft, including the F-28. However, no information and procedures by way of advice and cautions, as appear in the Piedmont, the USAir, and the Fokker manuals, are provided.

The obvious lack of information, advice, and direction relating to ground-accumulated wing contamination in the Air Ontario Draft F-28 Operations Manual and the Air Ontario Flight Operations Manual suggests a lack of thoroughness, rigour, and understanding on the part of the drafters of these manuals. There was unambiguous information in the Piedmont and USAir operations manuals as well as in the Fokker F-28 Flight Handbook available to both Captain Morwood and First Officer Mills. (It is normal for pilots to carry their own operations manuals and for the flight handbook to be on the aircraft at all times.) It is the evidence of a number of Air Ontario pilots that the ground school course provided by Piedmont was excellent: the effects of contamination on the aerodynamic performance of the F-28 were discussed in detail, and the pilots were appropriately cautioned.

## **The Phenomenon of “Cold Soaking”**

The portion of the Fokker F-28 Flight Handbook chapter that I have quoted warns about small and apparently insignificant ice and snow deposits seriously affecting the lift capability and controllability of the aircraft, possibly causing, in turn, a complete stall shortly after takeoff. Fokker also warns about the possibility of dry snow falling on a wing containing warm uplifted fuel, potentially resulting in a thin-ice coating on the upper wing surface. Fokker speaks of wing-tank fuel at subzero temperatures causing water condensation or rain to freeze to the upper surfaces of the wing while the aircraft is on the ground. Finally, Fokker Aircraft insists that it is of vital importance that the aircraft be completely clear of ice or snow before takeoff. The Piedmont and USAir F-28 operations manuals reiterate Fokker’s information, cautions, and instructions.

As noted above, the F-28 manuals are referring in part to a phenomenon that may be understood by most pilots but is by no means fully understood by all pilots; that is, cold wing-tank fuel causing precipitation to freeze to the aircraft surfaces. “Cold soaking” is a term used to indicate that an object has been in a cold temperature long enough for its temperature to drop to, or near to, the ambient temperature. Temperature at altitude is almost always colder than at ground level, and, although the outer skin of an aircraft in flight will cool quickly, the fuel in the wing tanks, because of its latent heat properties, will cool more slowly. The longer the aircraft remains at altitude, the closer the temperature of the fuel will be to the ambient temperature. On landing,

the reverse occurs. The skin of the aircraft will warm quickly to ambient temperature, while the fuel will warm more slowly. However, the aircraft skin that is touched by the cold-soaked fuel will remain close to the temperature of the fuel touching it.

A well-known phenomenon frequently occurs on an aircraft that has landed with cold-soaked fuel in the wing tanks: moisture from the air deposits in the form of frost on the surfaces that are touched by the cold fuel. These frost deposits form under the wing tanks. On landing, the fuel in the wing tanks is normally depleted; since there is no tank fuel to touch the skin on the top of the wings, there usually will not be a frost deposit on the upper wing surface.

On occasion, however, there will still be enough cold fuel in the tanks on landing to touch the skin on the top of the wings. Addition of fuel at a warmer temperature will raise the level of fuel to touch the upper surface of the wing but may not bring the resultant temperature of the fuel above the freezing level. Frost can then form on the upper surface of the wing that is touched by the cold fuel. Rain can freeze to the upper wing surface in the form of a smooth, transparent sheet of ice, often virtually invisible; falling wet snow can also freeze to the upper wing surface, and the resulting ice surface may not be smooth.

As shown in the study by Dr Oleskiw and as evidenced during his testimony at the Inquiry, the cold-soaking phenomenon was at work at Dryden during the time C-FONF was on the ground prior to the crash. There can be little doubt that wet falling snow froze to the upper surfaces of the wings and ultimately prevented the aircraft from flying.

During the Inquiry, Air Ontario pilots were asked of their knowledge of cold soaking. Most were aware of the phenomenon, but some pilots had no knowledge of it prior to the crash of C-FONF. As shown above, all the F-28 manuals to which the Air Ontario pilots had access contain some information regarding the cold-soaking phenomenon, although the term "cold soaking" is not used.

The Piedmont and USAir F-28 operations manuals also present information to pilots on the use of de-icing fluids and include a caution that the time of protection against freezing provided by such de-icing fluids can be shortened considerably, depending on type of snow, moisture content, temperature of aircraft surfaces, and type of fluid being used. The Piedmont and USAir F-28 operations manuals in particular warn that icing conditions exist when the outside air temperature is +50°F/+10°C or less and visible moisture in any form is present, or standing water, slush, ice, or snow is present on the ramps, taxiways, or runways.

In view of all the cautions, warnings, and instructions provided by the Fokker F-28 Flight Handbook and the Piedmont and USAir F-28 operations manuals, one wonders what more information should have

been provided to the pilots of C-FONF to convince them that takeoff in weather conditions which are conducive to the formation of ice or frost on the wing can be completed only when such conditions have been assessed and dealt with appropriately. Although de-icing and anti-icing are available, I am of the view that, for safe aircraft operations, a thorough understanding of all aspects of wing contamination is necessary, including its formation, removal, and prevention, and its effects on the aerodynamics of aircraft. This understanding can be accomplished only through education and training.

## Assessing the Condition of the Outside of the Aircraft

The requirement to take off with a “clean aircraft” necessitates that the aircraft be inspected before takeoff if weather conditions are such that there is any suspicion of the wings and tail being contaminated.

In my *Second Interim Report*, dealing with aircraft ground de-icing and related flight safety issues, I noted, however, that several senior airline pilots gave evidence that it is difficult, indeed impossible in some aircraft, for a pilot-in-command to determine from inside the aircraft whether the wing and the tail surfaces are clean at the time takeoff clearance is received. Darkness, precipitation, dirty or crazed windows, physical distance limitations, and aircraft design can all influence the ability of a flight crew member to observe accurately from the flight deck or the cabin the condition of the aircraft’s lifting and control surfaces.

Similarly, the upper surfaces of the wings and tail of large aircraft are impossible to see from the outside without the use of elevated structures such as ladders, ground vehicles, and cherry-pickers. Although the upper surfaces of the wings can be seen to a degree from inside the aircraft, one still cannot see the upper surfaces of the horizontal stabilizer, particularly in “T-tailed” configured aircraft such as the DC-9, B727, F-28, and F-100. The distance from the windows to the ends of the wings also makes it difficult to discern detail. As well, to look out of the windows a pilot would have to leave the flight deck – obviously an undesirable activity, especially while waiting for takeoff.

Similarly, without elevated devices one cannot see from the outside the upper surfaces of the wings and the horizontal stabilizer on high-wing aircraft such as the Dash-8, ATR42, or BAe 146, and, because the windows are below the level of the wings, it is impossible to see such surfaces from inside these aircraft.

A number of expert witnesses were asked to give their views on means to allow flight crews to assess the condition of the outside of the

aircraft, in particular the upper surfaces of the wings and tail, without the use of outside personnel or of equipment external to the aircraft. The need for flight crews to observe the upper surfaces of wings and fuselages is not a recent idea. Mr Murray Morgan, a research pilot with NAE at NRC, drew on his experience as a pilot in the Royal Air Force. A former pilot of the large British delta-winged Vulcan "V" bomber, he stated that it had a retractable periscope installed in the roof of the aircraft. Mr Morgan explained that the crew was able to use this articulating periscope to observe the various upper surfaces of the aircraft.

Mr Gary Wagner, an Air Canada pilot and an aeronautical engineer, in testimony suggested that research be conducted into sensory equipment for detecting contamination. Mr Wagner also suggested that a video camera could be used for looking for ice (contamination) and for assessing the outside state of the aircraft, including the flaps.

Mr Eugene Hill, the manager of certification development of Boeing Aircraft's Renton division, in testimony suggested that, as an alternative to a person on a cherry-picker at the end of the runway giving an assessment to the pilot, a video camera mounted in the aircraft could be used to assess the outside of the aircraft. Mr Hill suggested that a closed-circuit television system including a camera with a telescopic lens and a spotlight would be appropriate for inspecting both the wings and the tail of the aircraft.

Mr Jack Lampe, the manager of cargo services and the de-icing commissioner for United Airlines out of O'Hare Airport in Chicago, provided this Commission with informational material from the Vibro-Meter Corporation with respect to a wing ice-detection system for aircraft. The system consists of a sensing device, about the size of a quarter, located on the wing. It has a conduit that goes from the sensing device through the fuel cell and into the fuselage to a black box that is hard-wired to a meter in the cockpit. The sensor detects when ice is adhering to it and activates a display in the cockpit.

Mr Lampe testified that McDonnell Douglas had dedicated an aircraft for the testing of this system. The company spent 22 days in Alaska, testing under various conditions, and agreed that this ice-detection system is the acceptable candidate to address the clear-ice problem on the MD-80 airplane. Mr Lampe, who stated that McDonnell Douglas intended to outfit all new MD-80 productions after mid-1991 with the unit, said that a retrofit kit would be available for installation on all existing MD-80s. The kit was being marketed at that time, principally by McDonnell Douglas, to address the clear-ice problem on the MD-80 aircraft.

Speaking as a United Airlines manager, Mr Lampe stated:

- A. It's something we're going to specify on any new airplanes that we buy, and we expect to retrofit existing airplanes with it after Boeing approves its installation.

... I think it's the only sane way, perhaps, to address inspection prior to takeoff, with the exception, perhaps, of a camera that might be mounted, which would give you some visibility of your leading edges.

We've done some experimentation with that using existing cameras that we have on buses, for example, that operate quite well in low light to see if that might offer some surveillance to the cockpit so they could make a better call on whether they have contamination on the wing or whether they don't.

(Transcript, vol. 82, pp. 85-86)

There is merit to all these approaches. Without well-developed procedures and adequate facilities, it is impractical and potentially dangerous to inspect externally an aircraft near the end of the runway prior to takeoff. I comment on this subject to bring to the attention of those in the aviation industry the fact that there are alternatives to the problems of external aircraft inspection.

## Findings

- While the aircraft C-FONF was on the ground at Dryden on March 10, 1989, heat conduction into the wing fuel tanks (the cold-soaking phenomenon) permitted the lower portion of the water in the wet snow layer that accumulated on the wings to freeze, while leaving the upper portion in a partially liquid state. It is probable that the freezing of the water in the lower portion of this snow layer would have left a rough interface between the lower and upper portions of the precipitation layer on the wings.
- As the aircraft rolled down the runway during takeoff, pressure variations outside the wing boundary layer and the aerodynamic forces of air flowing over the wings probably forced the remaining water in the upper portion of the precipitation layer to drain away, carrying with it some of the slush, wet snow, and ice, and leaving behind a rough ice surface on the wings. This condition would have significantly degraded the aerodynamic performance of the aircraft.
- In addition, it is probable that snowflakes that were in the path of the aircraft wings during the takeoff roll stuck to the leading edge of the wings, in a band extending from approximately 3 per cent to about 19 per cent of the wing chord, thereby contributing to the degradation of the aerodynamic performance of the aircraft.

- During the takeoff of aircraft C-FONF from the Dryden airport, the wings of the aircraft were contaminated to a critical level, resulting in the degradation of the aircraft's aerodynamic performance by reducing its lifting capability and increasing the drag on the aircraft to the extent that, as the aircraft climbed out of ground effect, the performance loss caused the aircraft to descend and crash.
- During the takeoff run of aircraft C-FONF at the Dryden airport, slush thrown up from the runway probably did not enter the engines.
- If, during the takeoff run of C-FONF at the Dryden airport, contamination from the wings of the aircraft entered the engines, the contamination did not cause either a failure of the engine(s) or a reduction in thrust sufficient to tangibly affect the takeoff performance of the aircraft.
- Although there was some evidence of denting and chipped paint on the leading edges of the wings of aircraft C-FONF, neither of these factors contributed appreciably to the performance degradation of the aircraft during its takeoff from the Dryden airport, excepting that they may have been a minor factor in the amount of contaminant that remained on the wing.
- Wing anti-ice air leakage, such that it would cause control difficulties, was not a factor during the takeoff of C-FONF from the Dryden airport.
- Wing contamination is equally dangerous on jet-powered aircraft and propeller-powered aircraft.
- Wing contamination is equally dangerous on hard-wing aircraft and aircraft with wing leading-edge lift devices.
- The draft F-28 Operations Manual submitted by Air Ontario to Transport Canada did not contain a takeoff limitation and correction chart for contaminated runways (otherwise referred to as slush correction charts).
- Some Air Ontario F-28 pilots used the USAir F-28 Operations Manual while others used the Piedmont F-28 Operations Manual, both of which contained a takeoff limitation and correction chart (labelled for guidance only) that was considerably more restrictive than the chart and graph contained in the Fokker F-28 Flight Handbook (Aircraft Flight Manual), which was also available to F-28 pilots.



- Air Ontario had no policy in place to guide its F-28 pilots as to which slush correction charts were to be used by them for takeoff on a contaminated runway, and there was no consensus among the F-28 pilots as to which charts should be used, a highly unsatisfactory situation.
- The takeoff limitation and correction chart and graph contained in the Fokker F-28 Aircraft Flight Manual available to Air Ontario F-28 pilots was time consuming, and difficult and impractical to use in the cockpit of the aircraft.
- Had the pilots of flight 1363 followed the guidelines contained in the Piedmont/USAir takeoff limitation and correction charts at Dryden, they would have been restricted from taking off unless the runway had first been cleaned of contamination or the aircraft weight had been reduced to 54,300 lbs for takeoff. (The aircraft's actual weight at takeoff was estimated to be 64,440 lbs, just under the limit allowed by the Fokker chart.)
- Had the pilots of flight 1363 used the chart and graph contained in the Fokker F-28 Aircraft Flight Manual, the takeoff at Dryden on March 10, 1989, would have been permitted.
- Approval of slush correction charts is not presently a requirement of Canadian, Dutch, or United States regulatory bodies.
- A lack of certified data regarding aircraft takeoff performance requirements on contaminated runways makes it impossible to calculate whether the aircraft could have been stopped on the runway had an engine failure occurred at or prior to  $V_1$ .
- Neither United States FAA regulations nor Canadian Air Regulations and Air Navigation Orders address the issue of aircraft performance on takeoff from contaminated runways.
- Transport Canada and the Transportation Safety Board of Canada, and its predecessor CASB, have been aware of the lack of certified data regarding aircraft performance requirements on contaminated runways for a considerable period of time.
- Because of the absence of regulations with regard to the determination of aircraft performance requirements when operating aircraft from slippery or contaminated runways, the degree of risk that an aircraft's passengers and crew members are exposed to when the aircraft takes

off from a slippery or contaminated runway is different from that when the aircraft takes off from the same dry runway.

- Initiatives already taken by regulatory bodies, including Transport Canada, with regard to the determination and provision of guidelines to aircraft operators for operations from contaminated runways, will, if promulgated, improve passenger and crew safety.
- Air Ontario F-28 pilots had access to numerous cautions, warnings, and instructions not to take off unless all of the aircraft lifting surfaces were completely clear of ice or snow.
- In general, personnel involved in the aviation industry are not sufficiently aware of the nature and effects of wing contamination.
- In general, pilots are not sufficiently aware of the effects of cold soaking of fuel in relation to precipitation and frost adhering to the wing surfaces, and the conditions that lead to this phenomenon.

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## RECOMMENDATIONS

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It is recommended:

- MCR 40 That Transport Canada ensure that all operations personnel involved in air carrier operations, including managers, operations officers, maintenance personnel, and pilots, be made fully aware of the nature and the danger of wing contamination on both jet- and propeller-driven aircraft.
- MCR 41 That Transport Canada ensure that all personnel involved in air carrier operations, including managers, operations officers, maintenance personnel, and pilots, have, and be able to demonstrate, a thorough understanding of all aspects of wing contamination, including its formation, removal, and prevention, and its effects on the aerodynamics of aircraft, with particular emphasis on the insidious nature of the "cold-soaking" phenomenon.
- MCR 42 That pilots be informed in writing by Transport Canada how the application of non-standard handling techniques, as described in the "Flight Dynamics" report prepared for this

Commission and included in the Final Report as technical appendix 4; as described in the Fokker F-28 Flight Handbook; and as described in testimony by expert witnesses, may assist a pilot to deal with an abnormal or emergency situation discovered during takeoff. It is stressed that this Commission does not advocate the use of non-standard handling techniques to operate aircraft in adverse weather conditions as an alternative to the proper preparation of the aircraft for flight.

- MCR 43 That Transport Canada require that aircraft flight manuals and related aircraft operating manuals contain approved guidance material for supplementary operating procedures, including performance information for operating on wet and contaminated runways.
- MCR 44 That Transport Canada, in cooperation with aircraft manufacturers and operators, expedite the search for a technically accurate means of defining runway surface conditions and their effects on aircraft performance.
- MCR 45 That Transport Canada require air carriers to provide adequate training to flight crews with respect to the effects of contaminated runways on the performance of aircraft in the context of landings, takeoffs, and rejected takeoffs.
- MCR 46 That Transport Canada, in cooperation with aircraft manufacturers and operators, expedite the search for an equitable and practical means of requiring operators to adhere to balanced field criteria when operating on wet or contaminated runways.
- MCR 47 That Transport Canada, in cooperation with airport operators, expedite the search for more efficient methods of ensuring that runways are maintained free of contaminants that affect the takeoff performance of aircraft.
- MCR 48 That Transport Canada participate in and encourage research concerning devices that can allow pilots to assess the external state of the aircraft from within the flight deck. In addition to assisting pilots in assessing possible contamination of the aircraft, such devices would assist pilots in assessing any mechanical or technical problems on the exterior of the aircraft.

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# FINAL REPORT

## TECHNICAL APPENDICES

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- 1 Occurrence No. 825-89-C0048: Structures/Site Survey Group Report LP 38/89: Accident: Fokker F28, Mk 1000, Registration C-FONF, 10 March 1989  
*Canadian Aviation Safety Board Investigation Team*
- 2 Fokker Aircraft B.V. Amsterdam, Fokker Aerodynamics, Report No. L-28-222: Note on the Aircraft Characteristics as Affected by Frost, Ice or Freezing Rain Deposits on Snow
- 3 Fokker Aircraft B.V. Amsterdam, Report No. VS-28-25: Flight Simulator Investigation into the Take-off Performance Effects of Slush on the Runway and Ice on the Wings of a Fokker 100
- 4 A Report on the Flight Dynamics of the Fokker Mk 1000 as They Pertain to the Accident at Dryden, Ontario, March 1989  
*J.M. Morgan, G.A. Wagner, R.H. Wickens*
- 5 Wind Tunnel Investigation of a Wing-Propeller Model Performance Degradation due to Distributed Upper-Surface Roughness and Leading Edge Shape Modification  
*R.H. Wickens and V.D. Nguyen*
- 6 Freezing Precipitation on Lifting Surfaces  
*Myron M. Oleskiw*
- 7 Human Factors Aspects of the Air Ontario Crash at Dryden, Ontario: Analysis and Recommendations to the Commission of Inquiry  
*Robert L. Helmreich*