Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

AVIATION OCCURRENCE REPORT

UNCONTAINED ENGINE FAILURE

AIR CANADA
MCDONNELL DOUGLAS DC-9-32 C-FTMG
REGINA, SASKATCHEWAN
05 MARCH 1994

REPORT NUMBER A94C0034

Canada

MANDATE OF THE TSB

The Canadian Transportation Accident Investigation and Safety Board Act provides the legal framework governing the TSB's activities. Basically, the TSB has a mandate to advance safety in the marine, pipeline, rail, and aviation modes of transportation by:

- conducting independent investigations and, if necessary, public inquiries into transportation occurrences in order to make findings as to their causes and contributing factors;
- reporting publicly on its investigations and public inquiries and on the related findings;
- identifying safety deficiencies as evidenced by transportation occurrences;
- making recommendations designed to eliminate or reduce any such safety deficiencies; and
- conducting special studies and special investigations on transportation safety matters.

It is not the function of the Board to assign fault or determine civil or criminal liability. However, the Board must not refrain from fully reporting on the causes and contributing factors merely because fault or liability might be inferred from the Board's findings.

INDEPENDENCE

To enable the public to have confidence in the transportation accident investigation process, it is essential that the investigating agency be, and be seen to be, independent and free from any conflicts of interest when it investigates accidents, identifies safety deficiencies, and makes safety recommendations. Independence is a key feature of the TSB. The Board reports to Parliament through the President of the Queen's Privy Council for Canada and is separate from other government agencies and departments. Its independence enables it to be fully objective in arriving at its conclusions and recommendations.

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Synopsis

A McDonnell Douglas DC-9-32 was departing Regina, Saskatchewan, on a scheduled flight to Calgary, Alberta, with 63 passengers and a crew of five on board. During the take-off run, the pilots heard several muffled bangs and felt significant airframe vibration. They rejected the take-off and brought the aircraft to a stop on the runway. The passengers were evacuated with no injuries. The aircraft sustained substantial damage to the left engine, cowlings, and the engine support pylon, and the two right main landing gear tires were blown.

The Board determined that a crack had developed in the left engine combustion chamber outer case (CCOC) through fatigue and intergranular fracture modes. The CCOC ruptured during the take-off run and the engine immediately lost power. The crack was not discovered during maintenance inspections because of a misinterpretation of an airworthiness directive.

Ce rapport est également disponible en français.

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1.0 Factual Information

1.1 History of the Flight

A McDonnell Douglas DC-9-32, operating as Air Canada flight 219, was departing Regina, Saskatchewan, at 1504 central standard time (CST)[1] during daylight hours, on a scheduled flight to Calgary, Alberta, with 63 passengers and a crew of five on board.

The occurrence flight was the second flight since the crew had picked up the aircraft in Winnipeg earlier in the day. The previous flight crew had reported no problems during the aircraft handover in Winnipeg, and the flight to Regina had proceeded without incident. The start-up and taxi out to the runway proceeded normally and, after receiving clearance, the pilot positioned the aircraft at the very beginning of runway 31 in preparation for take-off.

The pilots had set take-off power and the aircraft had accelerated to an airspeed of approximately 115 knots[2] when the pilots heard several muffled bangs and felt significant airframe vibration. The pilots checked the cockpit instrumentation and warning systems, and with no indication of a problem, concluded that one or more tires had failed. They rejected the take-off and brought the aircraft to a stop on the runway. The aircraft decelerated very quickly and although the thrust reversers were deployed, their use was not required. When the aircraft came to a stop the captain made an announcement that the aircraft had blown some tires during the take-off attempt and requested the passengers to please stay seated.

Emergency response services (ERS)[3] were already responding when the airport crash alarm sounded, and they arrived almost immediately; they had reacted based on hearing the bangs during the take-off. After receiving reports of smoke coming from the left side of the aircraft and hearing the urgency expressed by ERS personnel, the captain ordered an evacuation using the forward exits, and the crew carried out the aircraft damage drill checklist. The forward right galley emergency evacuation slide was deployed. High winds caused the inflated slide to trail along the aircraft, and one of the ERS personnel had to hold the slide in place to allow passengers to slide down.

By the time the first three passengers had used the slide, the captain was advised that there was no more smoke and no evidence of fire. The captain then stopped the evacuation via the emergency slide and requested the use of the airstairs. The airstairs were lowered and the remaining passengers evacuated using the main left front door and the stairs.

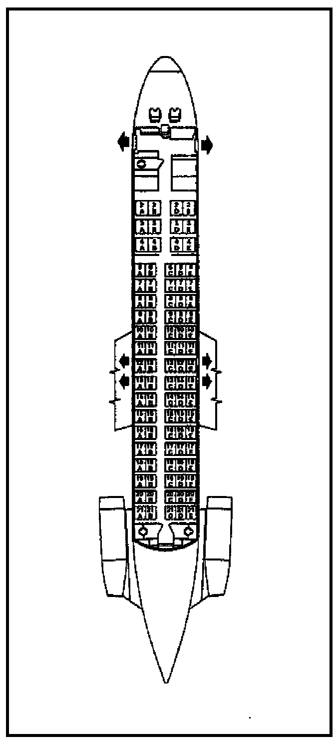

Figure 1
DC-9 Seating and Exits

1 All times are CST (Coordinated Universal Time [UTC] minus six hours) unless otherwise stated.

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

3 See Glossary for all abbreviations and acronyms.

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	-	-	-	-
Serious	-	-	-	-
Minor/None	5	63	-	68
Total	5	63	-	68

All passengers and crew evacuated the aircraft without injury. The evacuees were subjected to chilling weather conditions for up to 30 minutes once out of the aircraft. There were no injuries; however, several people reported significant discomfort because of the cold.

1.3 Damage to Aircraft

The aircraft sustained substantial damage to the left engine and cowlings, and minor damage to the engine support pylon. The two right main landing gear tires were blown and severe skid damage was evident on the left inboard tire.

1.4 Other Damage

No other damage resulted from this occurrence.

1.5 Personnel Information

	Pilot-in-command	Co-pilot
Age	48	40
Pilot Licence	Airline Transport	Airline Transport
Medical Expiry Date	01 May 94	01 June 94
Total Flying Hours	15,287	7,071
Hours on Type	4,550	483
Hours Last 90 Days	222	143
Hours on Type Last 90 Days	222	143
Hours on Duty Prior to Occurrence	9.5	8
Hours off Duty Prior to Work Period	48	50

Records indicated that the flight crew was certified and qualified for the flight in accordance with existing regulations. The duty schedule fell within accepted guidelines and there was no evidence that physiological factors affected the crew's performance.

1.6 Aircraft Information

Manufacturer	McDonnell Douglas
Type and Model	DC-9-32
Year of Manufacture	1968
Serial Number	47340
Certificate of Airworthiness (Flight Permit)	Valid
Total Airframe Time	61,244 hr
Engine Type (number of)	P&W JT8D-7 (2)
Propeller/Rotor Type (number of)	N/A
Maximum Allowable Take-off Weight	48,988 kg
Recommended Fuel Type(s)	Jet A, Jet A-1, Jet B
Fuel Type Used	Jet A-1

The aircraft, a McDonnell Douglas DC-9-32, was manufactured and imported into Canada in 1968. The occurrence aircraft was configured for 12 executive class and 80 standard class passengers. The flight crew for the occurrence flight was comprised of two pilots and three flight attendants, as is normal.

1.6.1 Engine Description

The DC-9 is powered by two Pratt & Whitney JT8D-7 turbofan engines, each producing 14,000 pounds of static thrust. The Pratt & Whitney JT8D-7 engine, constructed largely of steel and titanium, has a diameter of 1.08 metres and weighs approximately 1,400 kilograms. The engine comprises three basic sections: the compressor section (front), the combustion section (middle), and the turbine and exhaust section (rear). (See Figure 2.) Air entering the engine travels through either of two circular ducts. The outer ring of air travels into an annular bypass duct that runs the full length of the engine. The inner core of air travels into the compressor duct, is further compressed, and is then ejected into the combustion section.

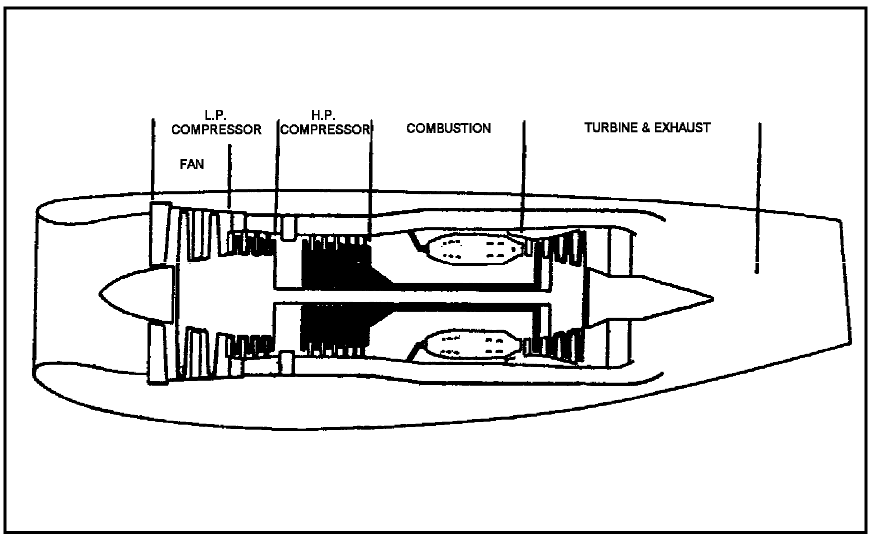

Figure 2
Pratt & Whitney JT8D Engine

The combustion section is housed by a circular casing known as the combustion chamber outer case (CCOC). (See Figure 3.) The front end of the CCOC is attached to the diffuser case which is attached to the aft end of the compressor section by a flange with numerous bolts. The aft end of the CCOC attaches to the front of the turbine section with a similar flange and bolts. Fuel is introduced and ignited in the combustion section and the exhaust travels out through the turbine section and then the tailpipe.

1.6.2 Engine Instrumentation

Engine power is indicated by revolutions per minute (rpm), fuel flow, exhaust gas temperature (EGT), and exhaust pressure ratio (EPR) gauges. The cockpit is also equipped with engine vibration instrumentation, designed to provide a visual indication to the crew when an engine is subjected to abnormal vibrations.

Figure 3
CCOC Location and Detail

For the conditions prevailing at the time of the occurrence, performance charts indicate that the appropriate take-off engine power setting was 2.04 EPR. The crew set the engines to take-off power and observed a reading of 2.04 EPR on the cockpit gauges and normal engine indications during the initial stages of the take-off roll.

Immediately on hearing the bangs, the crew checked the engine instruments and noted that the instruments continued to indicate normal readings and were matched between the two engines. The crew also noted that there was no engine vibration indication.

The crew members then turned their attention to the outside of the aircraft during the aborted take-off procedure. They noted, however, that the cockpit instrument gauges were virtually unreadable due to the significant aircraft vibrations. In their opinion, these vibrations were likely resulting from the blown tires on the right side of the aircraft.

When the captain ordered the evacuation, he noted that the left engine EPR gauge continued to indicate 2.04, and the EGT gauge was indicating in the yellow cautionary range.

1.6.3 Warning Light Indications

There are two master caution lights mounted on the glare shield, one in front of each pilot. The pilots were certain that the master caution lights did not illuminate at any time during the occurrence. The pilots indicated that their cockpit duties during the rejected take-off procedure precluded their observing the caution lights in the overhead annunciator panel.

Prior to the cockpit area being examined by accident investigators, the positions of cockpit controls and switches were manipulated by maintenance personnel. Electrical power had also been applied to the aircraft, and the starboard engine had been started in an effort to taxi the aircraft. As a consequence, cockpit gauge readings, positions of electrical relays, positions of circuit breakers, and the status of the left generator maintenance annunciator panel could not be verified. In addition, the status of cockpit caution and warning lights could not be recorded.

Several electrical tests were conducted on the occurrence aircraft in an effort to determine why the pilots had not observed any warning lights in the cockpit following the uncontained engine failure. In addition, the direct current (DC) and alternating current (AC) electrical systems were reviewed in detail for possible scenarios that could explain the failure of the master caution lights to illuminate. The reason for the reported absence of cockpit master warning indications could not, however, be determined. (Refer to Engineering Report LP 53/94.)

1.6.4 Landing Gear and Brakes

The DC-9 landing gear is a tricycle-type arrangement with retractable main landing gear units on the underside of the left and right wings and a retractable nose landing gear unit. Each of the two main landing gear consists of an inward retracting leg structure with two wheels and tires, one wheel on each side of the landing gear leg.

There are two redundant hydraulic supplies to the brakes. Either the left or right hydraulic system is capable of powering all four mainwheel brakes. Normally they are powered by both the left and right systems simultaneously. Braking pressure applied by the pilot depressing the rudder pedals in the cockpit is modulated by an anti-skid system which senses wheel rotation and controls the hydraulic pressure to prevent wheel lock-up during aggressive braking or low traction situations. The anti-skid system also features a caution light that will illuminate in the cockpit to warn the pilots that the system is not functioning.

The anti-skid system responded normally to all the pre-flight checks and the crew did not observe an anti-skid caution light during the occurrence. In executing the rejected take-off procedures, the captain initially used maximum braking, and then reduced braking pressure in response to the suspected blown tires.

1.7 Meteorological Information

The observed weather at the Regina Airport at 1500 CST, four minutes prior to the occurrence, was as follows: estimated ceiling 2,000 feet broken, visibility 15 miles, temperature one degree Celsius, dew point minus one degree Celsius, winds 320 degrees at 22 gusting to 27 knots, altimeter setting 29.82. The windchill effect was equivalent to minus 16 degrees Celsius.

1.8 Aerodrome Information

The Regina aerodrome is publicly certified and is operated by Transport Canada. Runway 31 is 7,900 feet long and 150 feet wide and is surfaced with asphalt. The runway surfaces are inspected by the Regina airport maintenance staff at each shift change as a standard operating procedure. The condition of runway 31 was checked at the shift change approximately one hour prior to the occurrence, and was found to be bare and dry, with no debris or surface contamination.

1.9 Flight Recorders

The flight data recorder (FDR) and the cockpit voice recorder (CVR) were sent to the TSB Engineering Branch Laboratory for analysis. The initial results from the FDR analysis indicated that both the FDR and the CVR lost electrical power simultaneously during the take-off roll. The FDR data indicated that the aircraft accelerated normally to about 115 knots indicated airspeed at which time the electrical power was lost. Up to the point that electrical power was lost, all aircraft systems appeared to be operating normally. Specifically, the engine parameters were normal and matched between the left and right engines during the take-off roll. Neither the FDR or CVR revealed any indication of an aircraft or operating problem.

A fault internal to the FDR recording mechanism reduced the useful recording time of the recorder from 25 hours to 3.5 hours. The information recorded by the FDR was transferred to its magnetic tape as sequential strips of information on one track, rather than on the normal seven parallel continuous tracks. This problem was determined to have been caused by a track switching difficulty in the recording mechanism.

1.10 Wreckage and Impact Information

Numerous pieces of the left engine casing and various portions of the left engine cowling were found along runway 31, from a point about 950 feet from the beginning of the runway (about 850 feet from the commencement of the aircraft's take-off roll), to a point about 2,200 feet down the runway. The distribution of the engine and cowling debris was predominantly on the left side of the runway between 1,600 and 1,800 feet down the runway. Both of the aircraft's right main wheels locked and began to skid at a point 2,113 feet from the start of the take-off roll. The left inboard tire locked between approximately 2,970 feet and 3,270 feet into the take-off roll; it then locked and released intermittently during the remaining 78 feet.

The aircraft came to a stop 3,448 feet from the beginning of runway 31. The aircraft remained on the runway until the right main landing gear wheels could be replaced the following day.

1.10.1 Engine and Pylon Damage

The top of the left engine had a large gaping hole approximately 0.5 metre by one metre in size, making the inside of the combustion chamber and the combustor cans clearly visible. The CCOC had ruptured at approximately the three o'clock position (as viewed from the aft end of the engine looking forward) and the case had torn open through approximately 150 degrees, to the ten o'clock position. The rupture tore through the outer engine case and the engine cowling. Several pieces of engine cowling skin were blown off the cowling structural formers. The rivet hole damage indicated that the forces acted perpendicular to the formers and the pieces were blown directly outwards.

Along the aft edge of the hole there was an area of the outer engine case about 15 centimetres across that was burned and deformed. Molten metal globules, likely consisting of engine casing material, were found in the immediate area and in the tailcone of the engine. The CCOC and the outer engine case, from the three o'clock position down to the five o'clock position, ejected inward towards the fuselage and damaged the engine pylon fairing structure.

1.11 Fire

There was a small fire in the left engine following the engine failure, as evidenced by the burned engine case; however, the fire extinguished itself by the time that ERS had arrived and deployed their equipment.

1.12 Aircraft Evacuation

When the aircraft came to a stop, the captain made an announcement over the aircraft public address system advising passengers to remain seated, and informing them that the problem was believed to be blown tires. The in-charge flight attendant and the other two flight attendants checked for smoke, but could not see any.

Arriving almost immediately, the ERS crew chief indicated a higher level of urgency to the captain. The captain, concerned with the possibility of a more serious problem, then ordered the in-charge flight attendant, who had returned to the cockpit area, to evacuate the passengers using the forward exits.

The in-charge flight attendant, upon hearing the captain's order to evacuate, opened the forward right door and deployed the inflatable emergency evacuation slide located at that door. As the slide deployed, it self-inflated and extended outward from the side of the aircraft. The winds were blowing from the front of the aircraft at 20 to 27 knots, and the slide was blown back along the side of the aircraft. The captain asked for and received help from one of the ERS staff to position the slide correctly.

The flight attendants instructed the passengers to leave their belongings behind (in accordance with the airline's standard procedure) and leave the aircraft via the front exit. Once the slide was held in place by one of the ERS personnel, two passengers and an off-duty flight attendant evacuated the aircraft.

The ERS crew chief then advised the captain that the smoke from the engine had stopped and there was no evidence of fire. The captain, fearing that the continued use of the slide could result in injuries to the passengers, then instructed the cabin crew to evacuate the remaining passengers via the left front cabin door, using the integral slide-out airstairs. The overwing exits were not used during the evacuation. Some passengers, despite orders to the contrary from the flight attendants, paused to take their carry-on baggage with them. Passenger estimates of the time required to evacuate the aircraft varied from 2 to 10 minutes. There were no reported injuries.

1.12.1 Emergency Escape Slide Airworthiness Standards

The emergency escape slides fitted on the newer Transport Category aircraft are required to conform to Section 25.810 of Part 25 of the Federal Aviation Regulations (FAR). With respect to the ability of the slide to be usable in various wind conditions, Section 25.810(a)(1)(iv) of FAR 25 states:

> It must have the capability, in 25-knot winds directed from the most critical angle, to deploy and, with the assistance of only one person, to remain usable after full deployment to evacuate occupants safely to the ground.

The DC-9 aircraft involved in this occurrence was certified for manufacture prior to the introduction of this FAR requirement and is, therefore, exempt from this standard.

1.12.2 Emergency Escape Slide Occurrence History

A review of the Transportation Safety Board (TSB) and International Civil Aviation Organization (ICAO) databases was conducted, and the accident investigation agencies of Australia, Britain, France, Sweden and the United States were contacted to determine if there was a history of aircraft evacuation difficulties using escape slides in strong wind conditions. ICAO and the other investigation agencies were unable to find any recorded problems indicating that winds had affected the use of emergency evacuation slides.

There were 16 occurrences in the TSB database which involved evacuations of aircraft where the emergency escape slides were deployed. There were seven reported difficulties with the slides. Two of these included some comment about the wind having an effect on the slides. In one case, the slide had to be stabilized by an individual on the ground because of strong winds (22 to 30 knots with gusts to 36 knots) (TC ASI Occurrence No. A82H20001). In the other case, during an evacuation of another DC-9 in Regina, Saskatchewan, strong winds (23 knots gusting to 33) and the tilted attitude of the aircraft made evacuation by a forward emergency slide impractical; however, all passengers managed to evacuate the aircraft in about 90 seconds using alternate exits (TC ASI Occurrence No. A83H30005).

1.12.3 Passenger Handling After Evacuation

The captain advised air traffic control (ATC) that the passengers were being evacuated, and he requested transport to take them to the terminal building. Most of the passengers left their outer clothing on board the aircraft. The flight attendants and emergency response personnel assisted passengers by providing blankets from the aircraft and from the ERS vehicles. Many passengers reported being inadequately dressed for the cold temperature and experienced considerable discomfort as they waited for transportation from the runway.

The passengers remained on the airport runway until a bus was dispatched to the runway to transport them back to the terminal building. The bus was configured for use as a mobile command post with a table fixed to the floor and limited seating which reduced its passenger capacity. The passengers were moved to the terminal building in three loads. Those passengers transported on the third load waited on the runway for approximately 30 minutes before being moved to the terminal building. During this time the passengers were exposed to windchill values of minus 16 degrees Celsius.

1.13 Tests and Research

The left engine and the anti-skid system control box were shipped to the airline's maintenance facility for detailed examination. The FDR and CVR were sent to the TSB Engineering Branch Laboratory for analysis (see Section 1.15). The initial results from the FDR analysis indicated that the FDR and CVR both lost electrical power during the take-off roll; therefore, the aircraft electrical system was examined.

1.13.1 Engine Teardown and Examination

1.13.1.1 General

Under TSB supervision, the engine was dismantled at the airline's major maintenance complex with participation by the engine manufacturer. Several components were removed from the engine and sent to specialty component shops for further testing. The fuel control unit (FCU), the fuel pressure and dump (P&D) valve, and the fuel nozzles were removed for specialty testing. After disassembly the CCOC was sent to the TSB Engineering Branch Laboratory for further analysis.

1.13.1.2 Fuel Control Unit Tests

It was determined that the FCU functioned normally in all respects with the exception that the motor bellows in the FCU had failed and exhibited a high cycle vibratory fatigue crack. In-flight monitoring did not reveal any significant fuel flow discrepancies because the design of the sensing bellows assembly provides redundancy, by means of an evacuated bellows, which allows the FCU to continue normal operation. This malfunction had no relevance to the occurrence.

1.13.1.3 P&D Valve and Fuel Nozzle Tests

The P&D valve and fuel nozzles showed some anomalies; however, there was no evidence of any irregularity that could have affected or caused the engine rupture.

1.13.1.4 CCOC Metallurgical Analysis

The failure of the CCOC was traced to a crack originating in the area of the rear flange. Visual and microscopic examinations revealed several different fracture topographies reflecting different modes of crack growth. There was a minute fatigue crack precursor on both sides of a rear flange bolt hole. The initial extension of the crack proceeded in an intergranular fashion for a distance of 40 millimetres (mm). The next stage of the crack propagation was by a low cycle fatigue mechanism, which extended the crack another 90 mm. The final extension of the crack was by rapid ductile tearing which resulted in the rupture of the CCOC.

With the exception of the ductile portion of the crack, the fracture surface was covered by a high temperature oxide. The oxide formation hindered the study of the fine features of the fatigue portions of the crack, particularly the striation spacing. The intergranular portion of the crack, however, retained its typical blocky appearance in spite of the oxide barrier.

1.13.2 Anti-Skid System

The anti-skid control box was tested and found to function normally in all respects. It was determined that the left DC bus lost power when the left engine failed, thus removing power from the anti-skid control modules. The AC cross-tie lockout (see 1.13.3 for explanation) prevented the automatic restoration of power to the left DC bus. As a result, the aircraft's braking system reverted to the manual mode with no wheel-locking protection (refer to TSB LP 58/94).

1.13.3 Aircraft Electrical System

The aircraft's primary AC system is powered by two generators, one fitted on each engine. During normal operations, these generators also supply, through transformer rectifier units (TRUs), all of the aircraft's DC operated services and units. Each of the AC generators powers a split bus system with the left and right sides designed for isolated operation. Two nickel cadmium batteries supply a limited portion of the distribution systems under certain abnormal conditions.

The two systems normally operate independently, but under specific conditions can be automatically inter-connected. Typically, if a generator fails and is automatically disconnected, an AC cross-tie relay (ACTR) will close, connecting the left and right generator buses together, allowing both buses to be fed by a single generator.

Under specific conditions, however, the inter-connection of the two systems may not be desirable and an AC cross-tie lockout relay (ACTLR) prevents closure of the ACTR.

When the CCOC ruptured, shredded pieces of the outer engine case contacted and damaged the left main generator control wiring harness. It was determined that an AC cross-tie did not occur, resulting in the loss of specific electrical services normally powered by the left generator. The actual cause of the AC cross-tie lockout was not determined. It is suspected, however, that it may be related to the dropout voltage of the power ready relay (PRR) in the ground control unit (GCU) (refer to LP 53/94).

1.13.4 JT8D Engine

1.13.4.1 CCOC Occurrence History

The JT8D engine is one of the most widely used turbofan engines in commercial service. It is installed on Boeing 727 and 737 aircraft as well as McDonnell Douglas DC-9 aircraft. A search of the ICAO occurrence database and the databases of the investigative agencies listed in Section 1.12.2 revealed that, although the total number of occurrences is not high, the continuing recurrence of CCOC failures is significant.

As a result of uncontained failures of JT8D engines in 1985 at Manchester, England, and at Tampa, Florida, and other instances of CCOC cracking, the United States Federal Aviation Administration (FAA) issued several Airworthiness Directives (AD) including 86-04-01 and 87-11-07. These ADs specified minimum inspection intervals based on cycles since new and since the last inspection of the combustion chamber outer casing.

In 1988 the Canadian Aviation Safety Board (CASB) investigated a CCOC failure on a Boeing 737 aircraft at Vancouver International Airport (TSB Occurrence No. A88H0001). The failure occurred during the take-off roll at approximately 100 to 110 knots; the crew heard a similar bang and rejected the take-off. After reports of smoke from the left engine, the crew ordered an emergency evacuation. A somewhat more extensive engine fire ensued, likely as a result of the proximity of the 737 engine installation to hydraulic and fuel systems. The continued concern of the United States National Transportation Safety Board (NTSB), and the data from the Vancouver occurrence and other occurrence investigations, culminated in the FAA's issuing a revised airworthiness directive.

1.13.5 CCOC - Additional Information

1.13.5.1 Airworthiness Directive - CCOC

On 03 October 1989, the FAA issued a revised airworthiness directive AD 87-11-07 R1 (see Appendix A) requiring repetitive inspections for cracks in the rear flange, PS4 boss, and drain bosses[4] of the CCOC in JT8D engines[5]. The revision was prompted by the continued reports of uncontained rupture of the CCOC. The FAA indicated that the CCOC flange cracks, if undetected, could result in uncontained engine failure, in-flight engine shutdown, engine cowl release, and airframe damage.

4 Bosses are attachment pads that are welded to the exterior of the CCOC by the manufacturer to enable the connection of PS4 and drain lines.

5 The CCOC inspection intervals are defined in terms of engine cycles. An engine start, an application of take-off power, and an engine shutdown constitute an engine cycle.

6 "Shop visit" is defined in the AD as the input of an engine to a repair facility where subsequent maintenance entails the separation of a major flange, removal of a compressor disk hub or spool, or turbine disk.

A range of techniques could be used to accomplish these inspections required by the AD, including eddy current, ultrasonic, fluorescent penetrant, fluorescent magnetic penetrant, and visual inspections. The AD details various inspection intervals (1,000 to 12,000 cycles) depending on CCOC component and the extensiveness and method by which the inspections were accomplished. The AD also requires the inspection of the CCOC at each engine shop visit[6] in addition to the specified cyclic intervals. The AD directs that CCOCs found to be cracked are to be removed from service prior to further flight.

1.13.5.2 CCOC Inspection History

Computer records indicated that the last time the occurrence CCOC rear flange had been inspected was 24 July 1989. At that time, a 12,000-cycle reinspection time-frame was assigned. The CCOC failed 7,503 cycles later. The left engine (Air Canada No. 621), with the occurrence CCOC installed (Air Canada No. T-16), had returned to the powerplant shop for maintenance on two occasions, on 27 January 1991 and 10 December 1992, since the last rear flange inspection. The shop visit inspection requirements for the CCOC rear flange were not accomplished on either occasion.

On 27 January 1991, the engine was removed from service because of vibrations and because of metal in the tail-pipe. Records indicate that the CCOC boss and flange inspections were annotated as "NRTV" (not required this visit) with the bosses having 3,733 cycles and the rear flange having 9,733 cycles remaining before inspection. The engine was returned to service without the CCOC inspections, and the number of cycles before next inspection remained unchanged.

The next visit to the maintenance facility was on 10 December 1992 to replace a time-expired, stage-three, low-pressure turbine disk. The maintenance data sheet shows that the CCOC arrived with 6,594 cycles remaining for the rear flange and 594 cycles remaining for the bosses. A notation was made on the sheet to "carry out boss inspection." The inspection record shows that the appropriate inspection was done and the bosses were assigned a new time-to-reinspection of 6,000 cycles. It is unlikely that the rear flange was inspected because the cycles-to-next-inspection remained at 6,594. The CCOC and engine were returned to service; the CCOC ruptured 2,097 cycles later.

1.13.5.3 Maintenance Implementation of AD

The inspectors and mechanics working in the airline's maintenance facility conduct their activities in accordance with engineering orders (EO) as published by the airline engineering staff. The EO and their execution are monitored by Transport Canada for compliance with applicable regulatory requirements. A review of the EO indicated that inspection techniques and repetitive intervals, with the exception of the shop visit criteria, accurately reflected the AD. The EO did not incorporate the inspection requirements dictated by a shop visit.

1.13.5.4 AD Compliance Record Keeping

Inspectors and mechanics stamped or initialled the maintenance data sheet to identify the need for the inspection; however, there was no provision to detail the degree of inspection or the method of inspection used. Computerized records contained codes indicating that an inspection had been accomplished and indicated the number of hours or cycles until the next inspection. Detailed component inspection records were not maintained beyond the most recent inspection. There were no records available that indicated the extent and method used in carrying out the previous inspections on the CCOC.

1.13.5.5 Work Accomplished and Inspection Requirements

When an engine entered the airline's maintenance facility, the nature of the reported problem was reviewed and a work card was written up. The work card outlined the repair work required as well as any periodic inspections and certifications that were due. Inspections and certifications were carried out in accordance with the initial work requirements and limitations. Engines that were initially perceived as needing only minor work could subsequently have their repair requirements upgraded. There was no evidence that a mechanism existed for re-evaluating the inspection and certification requirements for an engine in light of upgraded repair requirements.

2.0 Analysis

2.1 Introduction

There were several areas worthy of examination in this occurrence, including the crew's reaction to the situation, the evacuation of the passengers, the lack of cockpit indications, the performance of the anti-skid and flight recorder systems, the nature of the CCOC failure, and the maintenance organization's response to the airworthiness directive.

2.2 Crew Performance and Evacuation

There was no evidence that fatigue or other physiological factors adversely affected the crew's performance at the time of the occurrence.

During the take-off roll, the pilots heard several bangs, but they saw no cockpit indications from which they could determine the nature of the malfunction. They interpreted these indications as ruptured tires. The captain decided to abort the take-off and executed the procedures in accordance with the airline's operations manual.

When advised by ATC and ERS of smoke coming from the left engine, the captain carried out aircraft damage and evacuation procedures. It took several minutes to complete the evacuation.

Two factors may have contributed to delaying the evacuation of all passengers. After the captain ordered the evacuation and the evacuation had commenced using the escape slide, he was advised that the threat of a fire was no longer present. He ordered that the remainder of the evacuation be completed by the airstairs. This change in the evacuation process, which required the deployment of the airstairs, undoubtedly resulted in a delay of a few minutes. The process may also have been prolonged by some passengers' attempts to take their carry-on baggage with them.

2.3 Emergency Escape Slide Standards and Performance

The databases examined contain no consistent evidence that the existing standards for escape slides are inadequate to ensure the stability of slides in strong wind conditions.

The emergency evacuation slide in this occurrence was forced up and against the side of the aircraft by the strong winds. One of the ERS personnel was able to stabilize the slide from his position on the ground, and the slide was effective in evacuating at least three of the aircraft's occupants. There is no evidence to indicate that the remaining occupants could not similarly have used the slide. Therefore, it is concluded that the slide met the FAR 25 airworthiness standards and that, in this instance, these standards were adequate.

2.4 Passenger Handling After Evacuation

Following the evacuation, passengers waited up to 30 minutes for transportation from the runway to shelter. A number of passengers did not have adequate outerwear to protect them from the cold. Passengers were exposed to windchill effects equivalent to minus 16 degrees Celsius, and many reported discomfort despite the efforts of the flight attendants and the ERS personnel.

Exposure to such conditions after an evacuation, for even 30 minutes, can have serious effects on both injured and uninjured persons.

2.5 Lack of Cockpit Indications

Although the left engine EPR and rpm likely decayed rapidly after the CCOC rupture, the pilots observed no immediate cockpit indication of the engine failure.

During the aircraft's deceleration, it is likely that some engine instruments would have displayed evidence of the engine malfunction. This evidence may not have been noticed by the pilots, whose attention was focused on their primary task of stopping the aircraft on the runway.

The loss of AC power from the left generator, coupled with the AC cross-tie lockout, effectively froze the EPR reading for the left engine, which is dependent on AC power, at its last reading of 2.04. This indication, in addition to the reported absence of the illumination of the master warning lights, would have given the pilots erroneous information on the condition of the left engine.

2.6 Tire Failures

The associated failure of the aircraft's electrical system subsequent to the engine rupture disabled the anti-skid portion of the braking system. When the captain made the initial application of maximum braking to reject the take-off, the tires stopped turning and began to skid. The skidding of only the right-side tires was likely the result of unconscious compensation by the captain to correct for the tendency of the aircraft to veer to the left because of asymmetric engine thrust. The captain's subsequent moderation of brake pressure was insufficient to release the wheel lock-up. To completely release pressure on the brakes would have been contrary to rejected take-off procedures.

Once the tires were locked and skidding, the tires would have continued to slide on a layer of molten rubber until they ruptured. Despite the lack of the anti-skid system, the asymmetric thrust, and the eventual tire failures, the crew maintained control of the aircraft and brought it to a stop near the centre line of the runway.

2.7 Flight Recorder Performance

Analysis of the recorders revealed that both the FDR and the CVR stopped operating simultaneously during the take-off roll. Up to that point all aircraft systems appeared to be operating normally. The malfunction in the information recording mechanism of the FDR reduced the useful recording time of the recorder from 25 hours to 3.5 hours;

however, neither the FDR or CVR revealed any indication of an aircraft or operating problem prior to the moment that they ceased operation. The cessation of the recorders was a result of the failure of the electrical system subsequent to the CCOC rupture (refer to LP 53/94).

2.8 CCOC Failure

A crack developed in the left engine CCOC after originating at a rear flange bolt hole. Through fatigue and intergranular fracture modes, the crack progressed to a length of approximately 130 mm. The crack weakened the CCOC to the extent that the stresses of normal take-off power exceeded the remaining strength of the CCOC. When the CCOC ruptured during the take-off run, the engine immediately lost power.

The crack was not discovered during maintenance inspections because of a misinterpretation of the airworthiness directive. The engineering orders issued to technical personnel did not incorporate the requirement for CCOC inspections at every shop visit. The left engine had been subjected to two shop visits since the last recorded CCOC rear flange inspection; however, inspections of the flange were not carried out and the developing crack was not discovered. The rupture of the CCOC occurred despite an airworthiness directive and special inspection program to prevent such an event.

3.0 Conclusions

3.1 Findings

1. The flight crew was certified and qualified in accordance with existing regulations and there was no evidence that fatigue or other physiological factors adversely affected their performance at the time of the occurrence.

2. The flight crew responded to the limited information available to them, interpreted the situation as tire failure, and rejected the take-off.

3. The decision to evacuate the aircraft via the front exits was made in view of the indications of smoke from the rear of the aircraft.

4. The deployment and use of the emergency evacuation slide in the existing wind conditions were effective and in conformity with the established airworthiness standards.

5. Following the evacuation, passengers were exposed to windchill effects equivalent to minus 16 degrees Celsius for up to 30 minutes while waiting for transportation to shelter.

6. The absence of an AC cross-tie subsequent to the engine rupture disabled the anti-skid portion of the braking system, and halted operation of the flight recorders.

7. The pilots had no warning of either the CCOC rupture or the electrical system failure.

8. With the anti-skid portion of the braking system disabled, braking resulted in wheel lock-up and tire failure.

9. Flight recorder analysis revealed that all aircraft systems appeared to be operating normally until both the FDR and the CVR stopped operating simultaneously.

10. A fault internal to the FDR recording mechanism reduced the useful recording time of the recorder from 25 hours to 3.5 hours.

11. The crack, which developed in the left engine CCOC through fatigue and intergranular fracture modes, originated at a rear flange bolt hole and progressed to rupture and loss of power.

12. The crack in the CCOC was not discovered during maintenance inspections because of a misinterpretation of the airworthiness directive.

13. Prior to the cockpit area being examined by accident investigators, the positions of cockpit controls and switches were manipulated by maintenance personnel.

3.2 Causes

A crack had developed in the left engine CCOC through fatigue and intergranular fracture modes. The CCOC ruptured during the take-off run and the engine immediately lost power. The crack was not discovered during maintenance inspections because of a misinterpretation of an airworthiness directive.

4.0 Safety Action

4.1 Action Taken

4.1.1 Airworthiness Directive (AD) 87-11-07 R1

Preliminary information from the investigation indicated the possibility of a misinterpretation of the AD. Consequently, the Board recommended that:

> The Department of Transport require that the maintenance records for all in-service JT8D engines used by Canadian operators be reviewed with respect to compliance with the intent of AD 87-11-07 R1; and that, where applicable, the combustion chamber outer cases be reinspected;
> (A94-05, issued March 1994)

and

> The Department of Transport use appropriate channels to advise other operators of the JT8D engine internationally of the potential for misinterpretation of AD 87-11-07 R1.
> (A94-06, issued March 1994)

In response, Transport Canada issued Service Difficulty Advisory (SDA) AV-94-01 dated May 1994, which advised Canadian operators of JT8D engines to review their records with respect to compliance with the mandatory requirements and interpretation of the FAA AD 87-11-07 R1. A copy of the advisory was passed to the FAA for their information and their discretion in informing international operators.

4.1.2 CCOC Inspections

The records for all engines that had been repaired and overhauled by Air Canada were reviewed for compliance with the inspection requirements, particularly in relation to "shop visits." Any engines that were found not to comply were immediately inspected.

A complete review of the engineering order/airworthiness directive compliance process within the airline's maintenance system was conducted. Document review and control is being accomplished to ensure that current requirements are reflected on inspection forms.

In addition, all compliance items were reviewed and the process of issuing engineering orders was re-designed to ensure accuracy of compliance in the future.

4.1.3 Preservation of Evidence

The attempt to move the aircraft without the prior approval of accident investigators resulted in the loss of valuable evidence. Following the incident, Air Canada advised key members of their management and staff of the need to protect evidence to the extent possible as required by TSB Regulations.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board, consisting of Chairperson John W. Stants, and members Zita Brunet and Hugh MacNeil, authorized the release of this report on 16 May 1995.

Appendix A - Airworthiness Directive 87-11-07 R1

Appendix B - List of Supporting Reports

The following TSB Engineering Branch laboratory reports were completed:

LP 37/94 - CVR Analysis;
LP 38/94 - FDR Analysis;
LP 52/94 - JT8D Combustion Case Failure;
LP 53/94 - FDR/CVR Power Failure;
LP 55/94 - Fuel & Oil Samples;
LP 58/94 - Anti-Skid System; and
LP 60/94 - FCU Bellows Examination.

These reports are available upon request from the Transportation Safety Board of Canada.

Appendix C - Glossary

AC	alternating current
ACTLR	AC cross-tie lockout relay
ACTR	AC cross-tie relay
AD	Airworthiness Directive
ATC	air traffic control
CASB	Canadian Aviation Safety Board
CCOC	combustion chamber outer case
CST	central standard time
CVR	cockpit voice recorder
DC	direct current
ERS	Emergency response services
EGT	exhaust gas temperature
EO	engineering orders
EPR	exhaust pressure ratio
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCU	fuel control unit
FDR	flight data recorder
GCU	ground control unit
hr	hour(s)
ICAO	International Civil Aviation Organization
kg	kilogram(s)
mm	millimetre(s)
NRTV	not required this visit
NTSB	National Transportation Safety Board
P&D	fuel pressure and dump
PRR	power ready relay
rpm	revolutions per minute
SDA	Service Difficulty Advisory
TC	Transport Canada
TRU	transformer rectifier unit
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time

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