Transportation Safety Board of Canada

Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A03P0054

IN-FLIGHT ENGINE FAILURE

WESTJET AIRLINES
BOEING 737-200 C-FTWJ
KELOWNA AIRPORT, BRITISH COLUMBIA
11 MARCH 2003

Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Aviation Investigation Report

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Summary

The WestJet Airlines Boeing 737-200 (registration C-FTWJ, serial number 21767) departed Kelowna Airport, British Columbia, at 0840 Pacific standard time for Vancouver International Airport, British Columbia, with 6 crew and 50 passengers on board. Shortly after the aircraft passed through 3300 feet above sea level, the pilots heard a loud bang, similar to that of an engine compressor stall. The rpm of the number 1 engine rotors reduced rapidly, and the number 1 engine exhaust gas temperature reading exceeded the highest value on the indicator. The pilots shut down the number 1 engine (Pratt & Whitney JT8D-17A, serial number 688489) and levelled the aircraft at about 6000 feet. They declared an emergency and notified Kelowna tower of their intention to return to the airport. The aircraft landed on Runway 15 at 0912 with one engine inoperative and taxied back to the terminal without further incident. Airport aircraft rescue and fire-fighting services were called out but not required. There was no injury or fire.

Ce rapport est également disponible en français.

Other Factual Information

General

Cockpit indications were normal at all times from startup until the loud bang was heard. After the aircraft returned to Kelowna, a visual examination of the number 1 engine revealed melted hardware in the turbine section. Visual examination of the fan inlet guide vanes, the 1st stage compressor, and the 2nd stage stator revealed unremarkable damage, but 3rd stage compressor damage was significant. No indications of recent ingestion of birds or other foreign objects were found.

Maintenance records indicated that, during the previous day, the number 1 engine had been surging[1] during start and acceleration from idle. While the aircraft was taxiing to the runway, there were at least three separate surging events and two more while taxiing back to the gate for maintenance examination and rectification. The pilots had described the surges as minor to moderate. The aircraft was removed from service. Maintenance personnel followed the *Pratt & Whitney JT8D-17 Maintenance Manual*, part number 481671, and replaced a pressure ratio bleed control (PRBC) valve. They did not perform a boroscopic inspection for compressor damage, nor was it required by the Pratt & Whitney troubleshooting instructions written in the maintenance manual. A subsequent idle-power engine run indicated that the surging problem had been resolved and the aircraft was returned to service. The engine then operated normally for approximately 3.5 hours until the incident.

WestJet purchased the engine from All Nippon Airways on 02 August 2001. The engine was installed on C-FTWJ and maintained in accordance with existing Transport Canada regulations and directives. Engine performance had been uneventful until the reports of surging prior to the engine failure.

Engine Condition Monitoring

Pratt & Whitney developed an engine condition monitoring (ECM) program to track engine health, with the aim of providing an opportunity for early fault detection. Adherence to the Pratt & Whitney ECM guidelines is not mandatory, but Pratt & Whitney advises each operator to establish its own reporting and analysis procedures and alert levels for parameter shifts. Pratt & Whitney does not specify urgency or how much time should be taken to complete the analysis of the ECM data.

WestJet adopted the Pratt & Whitney ECM program and integrated it into the operation of the 737-200 fleet by recording engine parameters during the cruise portion of the flight. Generally, readings are taken and entered on a form by the flight crews at least once a day. At the end of the day, these completed forms are faxed to the operator's head office where they are manually

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[1] Surging, which is similar in nature to a compressor stall, is a condition in an axial-flow compressor in which one or more stages of rotor airfoils fail to pass air smoothly to the succeeding stages.

entered into a computer. Engine ECM data from all WestJet JT8D engines are then reviewed by the power plant maintenance group for long-term changes in performance characteristics. If required, appropriate maintenance actions can then be implemented. WestJet also provides duplicate data from each flight to Aerothrust Corporation, based in Miami, Florida, which provides redundant performance monitoring and analysis. ECM data from the occurrence aircraft were recorded by the flight crew approximately three hours before the engine failure, but this information had yet to be passed to the WestJet power plant maintenance group for data entry.

The number 1 engine ECM records from 11 March 2003, the day of the incident, were analyzed after the occurrence. These records indicated that the engine exhaust gas temperature had shifted upward by 20°C, accompanied by an increase in engine core speed (N_2) of about 2.5 per cent. Although within the expected range, these upward shifts were sufficiently high to cause them to be categorized as outliers.[2] To be considered statistically significant, further data points would have been required. The data recorded during the previous 30 days were typical of most JT8D engine trend reports. No adverse trends were identified.

The number 1 engine was removed from the aircraft and shipped to Aerothrust Corporation, an overhaul facility in Miami, Florida, for further examination. At the time of the failure, the engine had accumulated 34 014 hours/40 551 cycles since new, and 4371 hours/3916 cycles since the last shop visit. Representatives from the TSB, Transport Canada, WestJet, Pratt & Whitney, and the National Transportation Safety Board attended the engine tear down in Miami. All of the low-pressure compressor (LPC) and high-pressure compressor (HPC) stages, along with a box of miscellaneous loose compressor airfoils, were shipped to the TSB Engineering Laboratory in Ottawa, Canada, for further metallurgical analyses.

Engine Examination

The JT8D-17A engine comprises six basic sections: the front compressor (stages 1 through 6), also called the LPC; the rear compressor (stages 7 though 13), also called the HPC; the combustor; the high-pressure turbine; the low-pressure turbine; and the exhaust.

All of the LPC and HPC stages, with the exception of the 1st and 2nd stages, suffered some form of mechanical distress or failure. The TSB Engineering Laboratory examined the full rotor airfoil set from the 3rd stage, using a low- to medium-power stereo microscope. Results from this examination indicated that 13 airfoils had broken in fatigue; the fatigue fracture topography varied from 40 per cent to 85 per cent of the total cross-section. In addition, 14 other airfoils exhibited advanced fatigue cracking. The fatigue cracks propagated from multiple origins on both the convex and concave sides of the airfoils, indicating cyclic loading in reverse bending.

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[2] Outliers are trended engine parameter data points that did not pass a statistical comparison to a previous set of data points. However, without further accumulated data for comparison, this could be normal engine variation.

The stator assembly preceding the 3rd stage rotor was inspected for indications of fatigue damage. All vanes sustained heavy damage to the outboard one-third of the trailing edge. The general damage pattern consisted of tears, rips, gouges, and chipping. No indication of fatigue failure mechanism was found in any of the LPC stator stages. Extensive mechanical damage, however, could have compromised the physical evidence and masked the fatigue features.

The rotors of stages 7 through 13 (HPC) were examined visually using the low- to medium-power mobile optical microscope. The stage 7 rotor exhibited one airfoil broken off near the platform. The fracture showed small fatigue cracks from multiple origins on the concave side of the airfoil. The 8th stage rotor had two airfoils missing and 18 airfoils broken off close to the platform. All 18 broken airfoils exhibited fatigue crack progression in reverse bending, similar in nature to that exhibited by the 3rd stage rotor.

The two missing airfoils from the 8th stage were recovered from the box of miscellaneous compressor airfoils. One airfoil was discoloured, had a rough surface consistent with tumbling, and had a surface that was splattered with particles. Energy dispersive X-ray analysis of the particles adhering to the surface indicated that the particles were predominantly aluminum. By contrast, the other loose stage 8 airfoil had a much smoother surface of uniform color. TSB Engineering Laboratory report LP 114/04 concluded that the discoloured airfoil had dislodged from the disk and was trapped somewhere downstream of the HPC stages. Close examination of the 8th stage disk slots identified one position with very light witness marks from the airfoil tongues and from the retainer; that position was likely occupied by the discoloured airfoil.

One of the conclusions in TSB Engineering Laboratory report LP 114/04 was as follows: “It is likely that the failure of the low-pressure compressor was preceded by the failure of the high-pressure compressor. Manufacturer’s historical data seem to suggest that.”

Pratt & Whitney, the engine manufacturer, and Boeing conducted their own analysis of the evidence and produced a report on 18 February 2005. The report concluded that “An unidentified piece of broken hardware in the stator stage just preceding or just following rotor 3 provided an excitation source that resulted in liberation of rotor 3 airfoils and the subsequent engine failure. Other noted distress to the compressor, particularly the 7th, 8th, and 9th stage rotor blades, can be explained in this scenario.”

Compressor Surge Troubleshooting

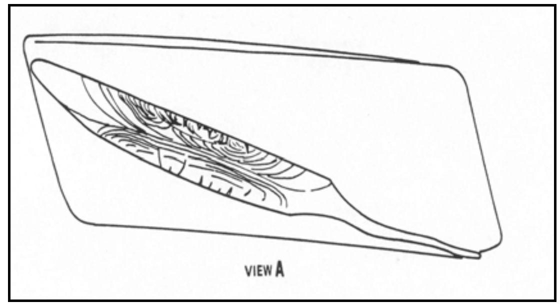

Figure 1. Fracture surface profile

Photo 1. Fractured 3rd stage compressor airfoil

The off-idle surge troubleshooting flow chart contained in *Pratt & Whitney JT8D Maintenance Manual*, part number 481671, task 72-00-00-810-006, states that a boroscopic inspection is required only if damage is observed in the first stage of the compressor or the rear stage of the turbine. In addition, the manual does not indicate that potential compressor airfoil fatigue cracking may develop as a result of a compressor stall or surge. Consequently, maintenance personnel are likely unaware that compressor airfoil fatigue cracking can occur. Another *Pratt & Whitney JT8D Engine Manual* (part number 481672) contains sketches (reproduced in Figure 1) of fracture surface profiles for 8th stage HPC airfoils, which resemble the fracture surface noted by the TSB Engineering Laboratory analysis (Photo 1). This manual is intended to be used to identify these fracture surfaces only when the engine has been removed from the aircraft and disassembled. The Pratt & Whitney manual states that these fracture surfaces indicate excessive airfoil stress and that it specifically applies to engines that have been removed following engine stalls. If the engine remains on the aircraft, a boroscopic inspection will likely reveal broken airfoils, but cracks that have not resulted in airfoil failure would be difficult to detect. As well, not all stages of the compressor are accessible. However, a boroscopic inspection of the 3rd and 8th stage compressors is possible.

The PRBC valve (part number 658385, serial number 6154807), had accumulated 4368 hours since installation. Before the engine failure, the PRBC valve had been removed from the engine during surge troubleshooting, disassembled, and repaired. During the repair, damage was found on an adapter plug, and on the diaphragm assembly and spring. The screen on the housing was deformed. The damage noted to the PRBC components is typical of a valve that has been in service for over 4000 hours and that has been subject to an unusual and rapid change in air pressures, as occurs during a compressor surge or stall. Aged PRBC valves, especially the diaphragm assembly, are not as resilient to rapid changes in air pressure. Once the damaged PRBC valve was replaced, the ground engine runs convinced the maintenance personnel that the surging problem had been resolved. However, PRBC valves, especially when new or overhauled, have slightly different operating characteristics that can mask underlying compressor problems. The *Pratt & Whitney JT8D Maintenance Manual* contains a flowchart to aid in troubleshooting compressor stalls and surges. The flowchart indicates that, after replacing the PRBC valve, an engine surge test should be performed. However, this particular test is not contained in the *Pratt & Whitney JT8D Maintenance Manual*. Absent from the flowchart is an instruction to perform "Test E - Test to Repaired Engines." Test E should be performed after replacing the PRBC valve to determine the points at which the PRBC valve will open and, therefore, the correct operation of the PRBC valve.[3]

Analysis

Damage observed in the turbine section was consistent with a disruption in airflow from the compressor resulting in increased exhaust temperatures beyond the limits of the turbine components. Due to the extensive mechanical damage to the engine and compressors, the origin of the engine failure and an accurate assessment of the engine condition prior to the occurrence could not be established with certainty. The conclusions of independent analyses (by Pratt & Whitney and by the TSB Engineering Laboratory) differ regarding the origin of the damage, resulting in two scenarios that could explain the engine anomalies and subsequent engine failure.

Scenario One

In the first scenario, as indicated by TSB Engineering Laboratory report LP 114/04, it is likely that the engine failure was initiated when an 8th stage rotor airfoil dislodged from its respective disk slot and contacted an adjacent stator. Supporting this scenario is physical evidence suggesting that the discoloured airfoil from the 8th stage rotor had dislodged prior to the engine failure. As the exact amount of time that the airfoil had been dislodged before the engine failure could not be determined, no categorical conclusion could be drawn. However, it is unlikely that the airfoil was dislodged for the entire 3.5 hours of engine operation following the original compressor surging.

Also, the reason for the airfoil liberation from the disk could not be determined. In this scenario, the most likely reason is that the airfoil retaining pin failed. A search of the loose debris submitted with the high-pressure compressor module did not locate any of the retainer. The retainer, because of its small size, could follow the gas stream and exit the engine. Material the size of the retainer could damage airfoils in the downstream path and cause compressor surging. This surging could result in cyclic loading of the 8th and 9th stage rotor airfoils, and failure of the aged PRBC valve. The general damage pattern to the LPC compressor stages, including the 3rd stage, indicates that some of the LPC stages also experienced conditions leading to a widespread fatigue cracking of the airfoils. In this scenario, this fatigue cracking would be secondary to, and a result of, the failure of the 8th stage rotor.

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3 Test E, Ground Check for Bleed System Operation, is now in the *Pratt & Whitney JT8D Maintenance Manual* (part number 481671), Section 6, Tests for Repaired Engines.

Scenario Two

The second scenario focuses on the 3rd stage rotor. The number of 3rd stage rotor airfoils that exhibited fatigue is consistent with significant vibratory excitement of that stage. Prior to the engine failure, a liberated piece of material, either just preceding or just following the 3rd stage, could travel aft, inducing damage to subsequent compressor stages and resulting in reduced compressor stability. The vibratory excitement caused by the material transiting the compressor sections could result in the failure of a 3rd stage rotor airfoil and the subsequent engine failure.

Summary

The ECM data recorded on the day of the occurrence indicated that there was an inefficiency within the compressor. However, it is unlikely that the impending failure could have been predicted, given the intended purpose of the ECM program. Furthermore, no discernable changes in previous trended parameter levels suggested an emerging problem. One or two more days of ECM data would have had to be entered before it would have been possible to know if the outliers were the beginning of some parameter shift or simply normal data variation.

In either scenario, damage from loose compressor hardware resulted in a marginally compromised compressor. The physical evidence in both the 3rd and 8th stage rotors indicates that compressor surging and vibratory excitement may have contributed to the ultimate failure of the engine. At a minimum, the compressor stalls were symptoms of an existing gas path inefficiency. The replacement PRBC valve, due to its slightly different operating characteristics and the inaccuracies in the JT8D troubleshooting flowchart, masked the compromised compressor. During troubleshooting to determine the cause of the compressor surges, a boroscopic inspection was not performed, nor was one required. Had a boroscopic inspection been performed, it is possible that missing or damaged compressor hardware would have been detected.

The following TSB Engineering Laboratory reports were completed:

LP 45/03 – LP Compressor Stage Failure, and
LP 114/04 – HP Compressor Stage Failure.

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

Findings as to Causes and Contributing Factors

1. The compressor gas path was compromised either by the failure of an 8th stage airfoil retaining pin or by a liberated stator in close proximity to the 3rd stage rotor.

2. Airflow instabilities resulted in vibratory excitement of the 3rd and 8th stage rotors leading to widespread fatigue cracking in the rotor airfoils.

3. As a result of the compressor airfoil fatigue cracking, either a 3rd or 8th stage rotor airfoil was liberated during the initial climb, resulting in severe engine damage and loss of engine power.

Findings as to Risk

1. The *Pratt & Whitney JT8D Maintenance Manual* does not have a warning about potential compressor airfoil fatigue cracking that may develop as a result of compressor stall or surge. Consequently, maintenance personnel may be unaware that compressor airfoil fatigue cracking can occur as a result of a compressor surge.

2. The troubleshooting flowchart in the *Pratt & Whitney JT8D Maintenance Manual* omits any reference to a test procedure that should be performed after replacing a pressure ratio bleed control (PRBC) valve. This omission, combined with a PRBC valve with slightly different operating characteristics, may result in the compressor appearing to be stable when it is not.

3. WestJet maintenance personnel replaced the PRBC valve and the start bleed control valve in accordance with the *Pratt & Whitney JT8D Maintenance Manual*. A boroscopic inspection was not carried out nor was it required by regulation or procedure and, as a result, compressor gas path anomalies that might have been detected were not.

Other Finding

1. The damage noted to the PRBC components is typical of a valve that has been in service for some time and has been subject to an unusual and rapid change in air pressures, as seen during a compressor surge or stall.

Action Taken

On 02 December 2003, as a result of this incident, the TSB issued Safety Advisory A030023-1 to Transport Canada, with copies to Pratt & Whitney USA, Boeing Commercial Aircraft, and WestJet Airlines. The letter suggested a review of current aviation maintenance practices and procedures, specifically regarding engine performance troubleshooting and compressor stall incidents, to ensure that information identifying possible compressor airfoil fatigue damage is not overlooked or dismissed.

Transport Canada responded by issuing Service Difficulty Advisory 2004-05. This advisory strongly advises maintainers, operators, and other responsible persons that compressor surging should be given the same attention as compressor stalls. Surges should be considered minor stalls and should not be underestimated in the damage that can occur. The Advisory also stated that compressor surges and stalls can induce latent fatigue fractures culminating in engine failures.

As a result of this investigation, the *Pratt & Whitney JT8D Maintenance Manual* (part number 481671), Engine General – Troubleshooting – 04 Task 72-00-00-810-06 Figure 102, Sheet 2, Flowchart Block 9, was reworded and clarified to run “Test E” under Engine General – Adjustments/Test – 01 Task 72-00-00-760-006, “Tests for Repaired Engines.” This test involves determining the points at which the PRBC valve opens and closes and is more than the “idle surge check” that WestJet performed after it replaced the PRBC valve.

This report concludes the Transportation Safety Board’s investigation into this occurrence. Consequently, the Board authorized the release of this report on 16 March 2005.

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