Australian Government
Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT
Aviation Occurrence Investigation – 200700356
Final

In-flight engine failure
Sydney
03 February 2007
Boeing Company 747-438, VH-OJM

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Abstract

At 1200 Eastern Standard Time, on 3 February 2007, after departing Sydney Airport and while in a climb at approximately 4,000 ft above ground level, the flight crew of a Boeing 747-438 aircraft, registered VH-OJM, heard several loud bangs and felt vibration through the aircraft structure. Observing an increase in the exhaust gas temperature indication for the number-3 engine, the crew following the non-normal checklist, shut down the engine, dumped excess fuel and returned the aircraft to Sydney Airport.

A subsequent examination of the engine found that it had sustained a high pressure compressor (HPC), stage 1, blade failure. The mode of failure was known to the engine manufacturer, who had attributed it to blade tip rubbing, due to distortion of the engines high pressure case (module 41). To address the problem, the engine manufacturer had introduced service bulletin (SB), SB72-F002. The number-3 engine did not have the service bulletin embodied at the time of the failure.

Although the exact time of the blade tip rubbing and subsequent cracking could not be determined, the engine manufacturer believed that crack initiation to blade failure took approximately 50 cycles.

During the investigation, the aircraft operator experienced a subsequent failure, bringing the total number of failures of this type for the operator to five. Similar failures were reported by another aircraft operator, with 16 similar failures reported in total.

As a result of the incident, the operator accelerated its modification embodiment program and expects to have all installed engines modified by early 2010.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external bodies.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the Transport Safety Investigation Act 2003 and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

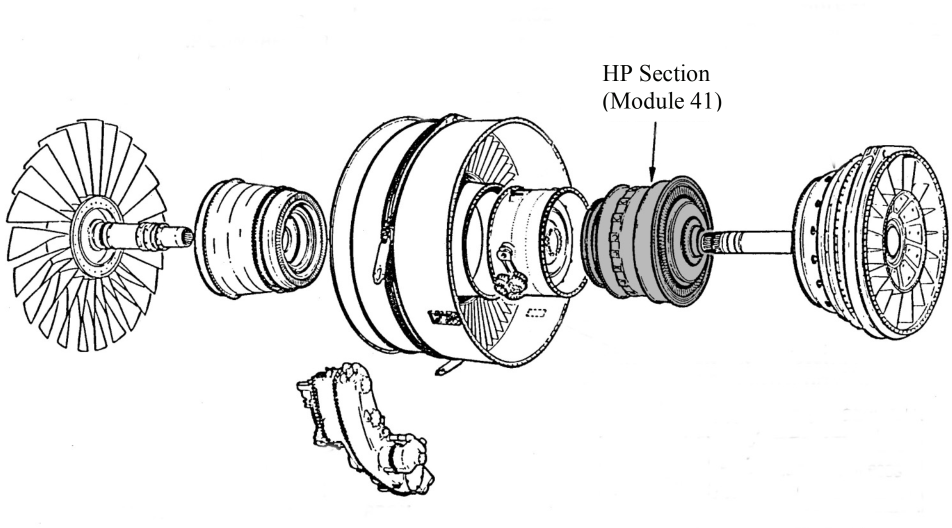
History of the flight

At 1200 Eastern Standard Time[1], on 3 February 2007, after departing Sydney Airport and while in a climb at approximately 4,000 ft above ground level, the flight crew of a Boeing 747-438 aircraft, registered VH-OJM, heard several loud bangs and felt vibration through the aircraft structure. An increase in the exhaust gas temperature indication for the number-3 engine was then observed. Following a review of the engine non-normal checklist, the crew shut down the number-3 engine, dumped excess fuel and returned the aircraft to Sydney Airport.

A subsequent examination of the number-3 engine found that it had sustained a high pressure compressor (HPC), stage 1, blade failure. The blade had failed at its root, and following liberation, had caused considerable damage to the engine high pressure section module 41 (Figure 1). The engine was removed from the aircraft and Module 41 returned to the manufacturer.

The engine, a Rolls Royce RB211-524G2-T, serial number 13184, had completed a total of 21,032 hours and 2,359 cycles since its previous refurbishment.

Figure 1RB211 Engine modules, high pressure (HP) section (module 41)



High Pressure Compressor (HPC) blade failures

Failures of HPC blades were uncommon events, particularly failures at the blade root. However, the operator advised that over the previous 5 years they had experienced three other engine HPC stage 1, blade root failures, with one further

1 The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time, as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) +11 hours

failure occurring during the period of this investigation. Three of the five failures occurred on the same aircraft at different installation times and at different wing locations.

Since 2001, of the world fleet of RB211 (-T) engines, there had been a total of 16 HPC stage 1 blade root failures, which included blades being released (resulting in an in-flight shut down being carried out) and two blades being found cracked during maintenance inspection. Those failures were limited to the five failures to this operator and eleven to another operator. Those two operators represented 49 percent of the world fleet of RB211 engines in service.

Second operator blade failures

A review of the failures for the second operator showed that seven of the eleven failures occurred on their Boeing 747 freighter aircraft fleet.

In addition to their RB211 (-T) engine failures, that operator also experienced one failure of the HPC stage 1 blade, on another of the engine manufacturer’s engine models which utilised the same HPC stage 1 blades as the RB211 (-T) engines. That failure was the only recorded failure of this type on that engine model to date.

Engine manufacturer

The engine manufacturer was aware of these failures, and had attributed them to complex vibration, induced by asymmetric blade tip rubbing around the HPC stage 1 rotor path. The tip rubbing was believed to be the result of distortion of the HP module 41 case, and was associated with high casing loads. The rubbing and vibration experienced on the blade tips induced stresses that led to cracking at the blade root. The cracking then propagated until blade release occurred. Although the exact time of the blade tip rubbing and subsequent cracking could not be determined, the engine manufacturer believed that crack initiation to blade failure took approximately 50 cycles.

To address the issue, the manufacturer introduced service bulletin SB72-F002 released 2006. That service bulletin provided design changes to reduce case distortion and high structural loads on the HP case.

The manufacturer expected that all parts required for the accomplishment of service bulletin SB72-F002 would be available to operators from February 2006.

The engine manufacturer was also conducting comparative analysis of the two affected operators’ fleets with other (non-affected) operators, in an attempt to identify key factors that may be attributed to these failures. That analysis included examination of the engine’s operating parameters, actual flight hours, turnaround time, routes flown and operator specific procedures (i.e. reduced reverse thrust usage). At the time of release of this report, no clear factors had been identified to explain the reason for the failures being limited to the two operators, and further analysis is being conducted.

Aircraft operator

At the time of service bulletin SB72-F002 issue, the aircraft operator had only experienced three failures within its fleet. The operator had initiated the inclusion of SB72-F002 into its maintenance program, modifying engines as they came due for workshop overhaul. At the time of the incident, the operator had modified approximately 15 percent of its fleet. None of the five incident engines had the service bulletin embodied.

The operator had increased its maintenance program to facilitate accelerated completion of embodiment of SB72-F002 on its RB211-524G-T fleet (comprising 84 installed engines). By February 2008 the operator had modified 46 percent of its fleet, with projected total fleet modification completed by 2010.

From data gathered, the manufacturer determined that statistically there was a high probability of one further failure within their fleet before modification of all engines was completed. The data also showed that these failures occurred on predominantly mid-life engines, so to minimise the likelihood of an additional failure, the operator campaigned the modification schedule on five mid-life engines to lower the risk profile of the unmodified engines in service.

As an additional safety precaution, and at the expense of reduced engine efficiency, the operator opted to maintain the maximum allowable clearance between the HPC stage 1, blade tip and the compressor case on all its engines, to further reduce the likelihood of blade tip rubbing.

To date, the operator has not experienced any HPC stage 1 blade root failures on post SB72-F002 modified engines. However, the second operator had experienced one post SB72-F002 modified engine failure in its fleet. That operator utilised the normal operating clearance between blade tip and rotor disc after SB72-F002 was embodied.

ANALYSIS

Although the failure of the high pressure compressor (HPC), stage 1, blade root failures on RB211-524 (–T) engines, was limited to only two operators, those operators represented 49 percent of the world fleet of RB211 engines.

The mechanism of the failures was understood as being stress cracking in the blade root, as a result of blade tip rubbing due to high pressure (HP) case distortion. The specific conditions that led to the failures and why only two operators had experienced these failures has not yet been identified, but may be attributed to a combination of operational and engine/airframe specific elements.

The exact time of the blade tip rubbing and subsequent cracking event could not be determined. The inclusion of service bulletin SB72-F002 appeared to have reduced the likelihood of these failures. However, the failure of a post-modified engine experienced by the other operator would indicate that tip rubbing conditions can still occur. The absence of failures on post-modified engines with this operator would indicate that the inclusion of maximum operating blade tip clearance may be sufficient to prevent such failures.

Although the operator accelerated its maintenance program for embodiment of SB72-F002 throughout its fleet, the statistical projection was that the operator may experience one additional failure prior to total fleet modification. As the precursors to the HPC case distortion and resulting blade tip rub are not yet fully understood, prevention of that failure cannot be assured.

FINDINGS

From the evidence available, the following findings are made with respect to the in-flight engine failure on Boeing 747 aircraft registered VH-OJM and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- Blade tip rub lead to cracking and subsequent failure of the high pressure compressor (HPC) stage-1 blade.
- The engine did not have the engine manufacturer's service bulletin SB72-F002 embodied at the time of the incident.

Other safety factors

- It was not possible to identify failure precursors or predict potential failures.
- The completion of modification to the operator's entire fleet of engines is not expected until 2010.
- There is a statistical probability of another failure within the operator's fleet before the entire fleet modification program is completed

SAFETY ACTION

Aircraft operator

As a result of this incident the aircraft operator implemented the following safety actions:

- Accelerated the embodiment of Service Bulletin SB72-F002 within its fleet to minimise the risk of further failures.
- Gave consideration to the mid-life criticality of the engines when prioritising modification embodiment within the fleet.
- Maintained the maximum operating clearance between the blade tips and the rotor disc on all post service bulletin SB72-F002 modified engines.

Engine manufacturer

The engine manufacturer released service bulletin SB72-F002 to address these failures. The subsequent failures experienced by two operators resulted in the engine manufacturer conducting further extensive testing and research into the failures. At the time of release of this report, that work is continuing.