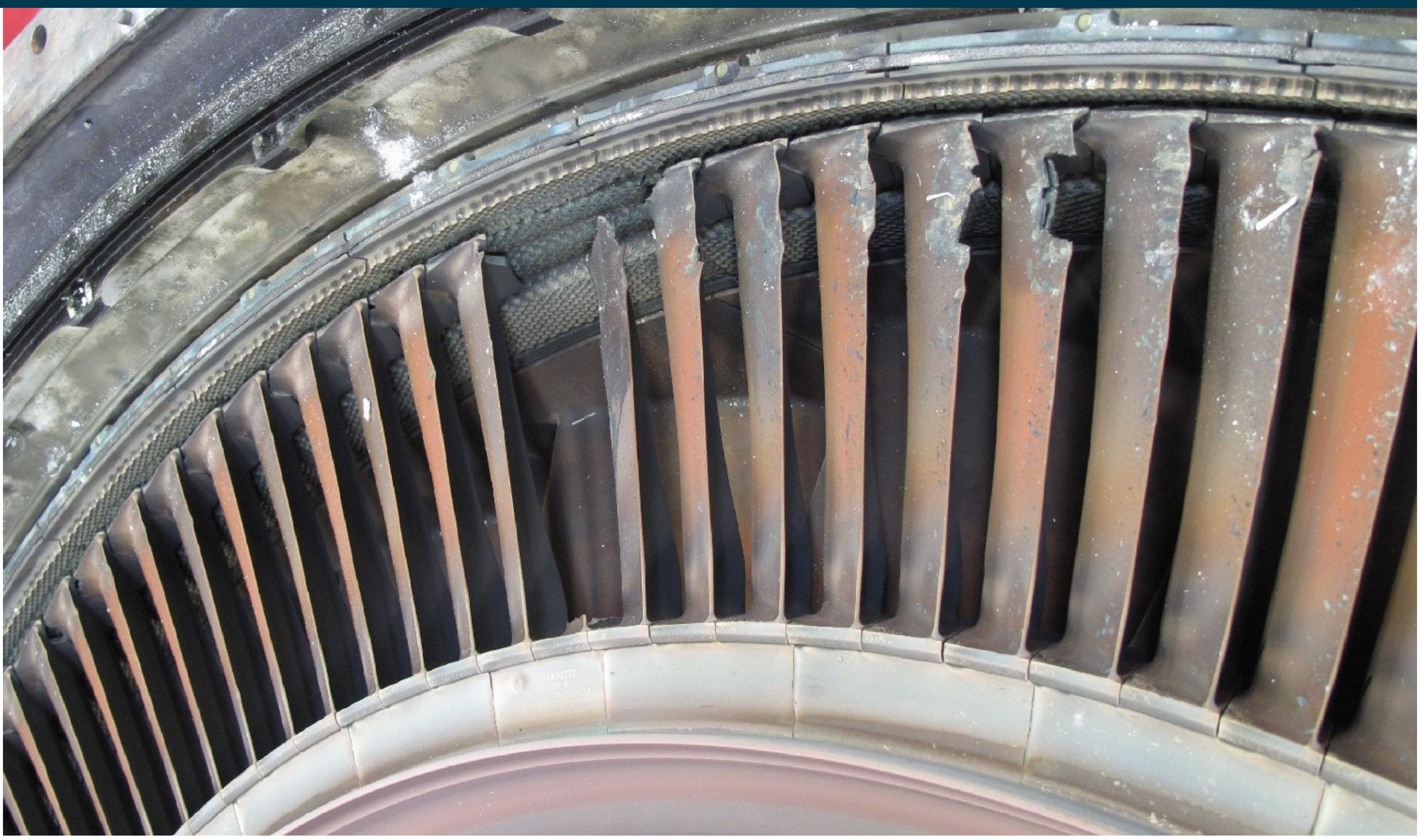
Australian Government
Australian Transport Safety Bureau

In-flight engine malfunction – Boeing 747-438, VH-OJH

100 km south-east of Bali International Airport, Indonesia | 9 May 2011



Investigation

ATSB Transport Safety Report
Aviation Occurrence Investigation
AO-2011-062
Final

Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation

AO-2011-062

Final

In-flight engine malfunction 100km south-east of Bali International Airport, Indonesia – 9 May 2011 Boeing Co 747-438, VH-OJH

Released in accordance with section 25 of the *Transport Safety Investigation Act 2003*

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SAFETY SUMMARY

What happened

On 9 May 2011, a Qantas Airways Limited Boeing 747-400 aircraft, registered VH-OJH, was enroute from Sydney, NSW to Singapore, when during climb from 36,000 ft to 38,000 ft, the crew noted abnormal indications from the No.4 engine. The indications included an increase in both the exhaust gas temperature and vibration levels. The flight crew reduced the engine's thrust, however the vibration continued near maximum levels and the engine was subsequently shut down.

The aircraft continued to Singapore for a safe landing and disembarkation of the passengers and crew.

What the ATSB found

The increase in the exhaust gas temperature and vibration from the No.4 engine was a direct result of the failure and separation of a single intermediate-pressure turbine blade. The turbine blade had fractured following the initiation and growth of a fatigue crack from an origin area near the blade inner root platform. Detailed modelling and analysis was undertaken by the engine manufacturer following the occurrence, and while the root cause for the IP turbine blade failure was not fully identified at the time of this report, it was considered that the wear and loss of material from the turbine blade outer interlocking shrouds had reduced the rigidity and damping effects of the shroud and may have contributed to the high-cycle fatigue cracking and failure. The manufacturer has advised that they are continuing work to understand the underlying mechanism of the failure and will advise the ATSB if any further information is obtained.

What has been done as a result

The engine manufacturer issued non-modification service bulletin (NMSB) 72-G739 in October 2011, which instructed operators to perform a once-around-the-fleet inspection of IP turbine blades for missing shroud interlock material. Accomplishment of this task was recommended by June 2012, taking advantage of any earlier planned maintenance opportunities. The operator indicated that they had completed inspections across the fleet with no instances of excessive wear identified.

Safety message

Operators and maintainers of Rolls-Royce RB211-524 engines are alerted to the potential for wear and degradation of the intermediate-pressure turbine blade interlocking shrouds, with the possibility that this mechanism, if not detected and addressed, could lead to turbine blade cracking and loss. Service experience has shown, however, that the probability of an intermediate-pressure turbine blade failure (from any mechanism) is extremely low, with only three reported occurrences across the RB211-524 engine operating history. While blade separation will likely cause malfunctions necessitating an in-flight engine shut down, the associated risks to the safety of continued flight are minor, in the context that such failures are very likely to be contained (i.e. no liberated debris) and procedures for managing engine failures in transport-category aircraft are detailed and effective.

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Acknowledgements

Figures 2 & 3 were modified from Rolls-Royce maintenance documentation
Figure 5 was provided to the ATSB from Rolls-Royce following the engine disassembly in Hong Kong.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

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 identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, 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 initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes appropriate, or to raise general awareness of important safety information in the industry. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, current risk controls and organisational influences.

Contributing safety factor: a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Risk level: the ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

Safety action: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

FACTUAL INFORMATION

History of the flight

On 9 May 2011, at approximately 0605 Coordinated Universal Time (UTC[1]), a Qantas Airways Limited Boeing 747-438 aircraft, registered VH-OJH (OJH), departed Sydney, NSW on a scheduled passenger service to Singapore. At 1131 UTC, approximately 100 km south-east of Bali International Airport, all engine thrust levers were advanced and the aircraft began a climb from flight level[2] (FL) 360 to FL 380. Following initiation of the climb, the flight crew noticed that the No. 4 engine exhaust gas temperature (EGT) had increased rapidly to 850 °C. The thrust lever for the No. 4 engine was then retarded, until the EGT was brought within the normal limits. Subsequently, the flight crew noted that the N2[3] vibrations for that engine remained at approximately 3.5 units, well above normal operating level, and as such, they elected to shut the engine down. Air Traffic Control (ATC) was informed and the aircraft was descended to FL 340. The flight continued to Singapore without further incident, and a normal landing and disembarkation of passengers followed.

Post-flight engine examination

Examination of the No.4 engine following landing found:

- the fan and low-pressure (LP) turbine rotated freely
- the LP turbine stator exhibited damage
- the master, high-pressure/intermediate-pressure (HP/IP) turbine and external gearbox magnetic chip detectors (MCD) showed evidence of debris, while the LP turbine and location bearing MCDs were clean. There was also metallic debris visible in the tail pipe.

Initial borescope inspection findings showed that a single IP turbine blade had fractured through the lower airfoil section, in the region adjacent to the root platform. The root section remained within the turbine disc. The borescope inspection also revealed evidence of outer shroud loss on the adjacent blade.

The engine was removed from the aircraft and sent to Hong Kong Aero Engine Services Limited (HAESL) for disassembly and further examination. The work was undertaken under the supervision of an Australian Transport Safety Bureau (ATSB) accredited representative from the Hong Kong Civil Aviation Department, and a representative of the engine manufacturer.

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1 Coordinated Universal Time (abbreviated UTC) is the time zone used for civil aviation. All times used in this report are in UTC.

2 At altitudes above 10,000 ft in Australia, an aircraft's height above mean sea level is referred to as a flight level (FL). FL 380 equates to 38,000 ft.

3 In a 3-spool turbine engine, N1 refers to the LP shaft speed, expressed as a percentage of the maximum rated speed. N2 and N3 refer to the IP and HP shaft speeds respectively.

Recorded information

The recorded data from OJH included information from a number of previous flights. The ATSB's examination of the data from the occurrence flight confirmed the flight crew's recount of events. The following sequence of events was established primarily from information included on the flight data recorder (FDR), with a plot of the relevant parameters shown at Figure 1.

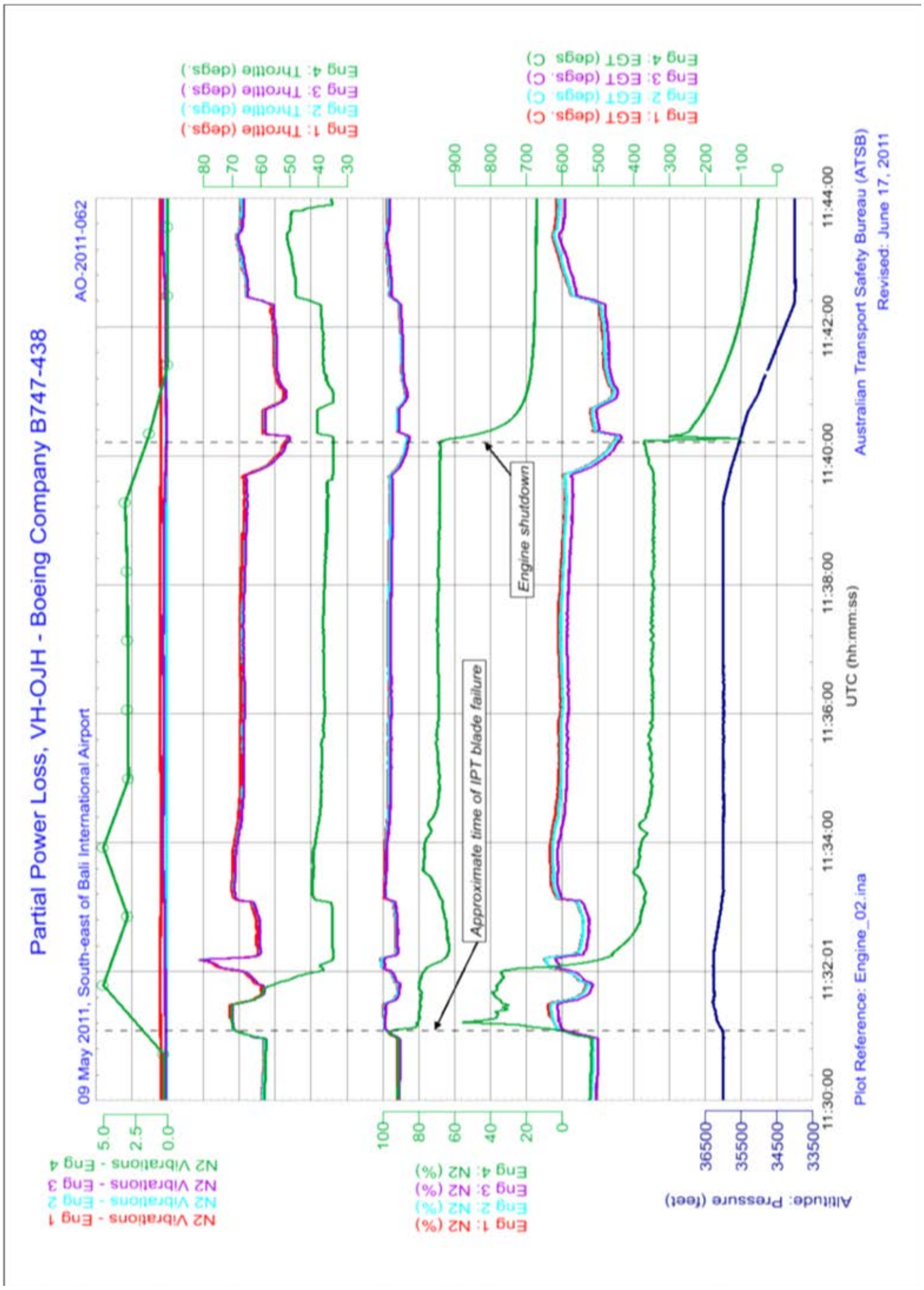
Sequence of events

- OJH departed Sydney Airport at approximately 0600.
- At 1131:00, all engine thrust lever angles were advanced and the aircraft began to climb. This was accompanied by an increase in N1, N2, N3 and EGT.
- Shortly after, at 1131:07 the N1, N2 and N3 values for the No.4 engine started to decrease with no associated change to the thrust lever movement, while the EGT continued to increase at a faster rate than the other engines.
- The EGT for engine No.4 reached its peak value of 880 °C at 1131:14.
- The aircraft levelled off at 36,250 feet pressure altitude at approximately 1131:30. At 1131:48, and for a duration of approximately 24 seconds, the No.4 engine thrust lever was reduced to flight idle while the other engine thrust levers were advanced to 80°.
- No.4 engine vibrations were recorded at 5 units (full scale) at 1131:49 and high vibrations continued to be recorded for the following 7 samples (recorded at intervals of 64 seconds)
- At 1139:19 the aircraft initiated a descent to FL340 and the No.4 engine was shut down at 1140:14.
- The aircraft touched down at Singapore Changi Airport at 1341:58.

Examination of the flight data showed that the N1, N2, N3 and EGT values for all engines were matched until the incident.

The FDR data from the previous three flights was examined, with the operation of all engines appearing normal. No parameter changes that may have been precursors of the No.4 engine failure were noted.

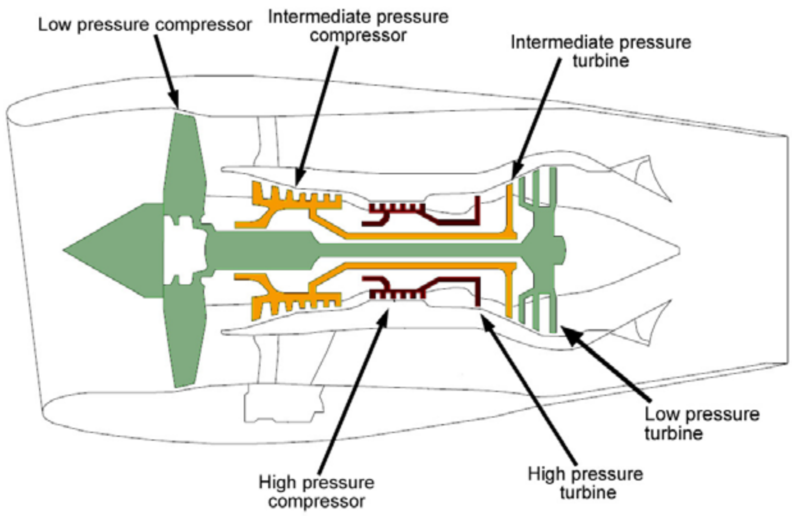
Figure 1: FDR plot showing increase in No.4 engine EGT and N2 vibrations



Engine examination

Aircraft propulsion was generated by four Rolls-Royce RB211-524G2-T high bypass, three rotor turbofan engines (Figure 2).

Figure 2: Schematic diagram showing the stages of an RB211 engine



Disassembly of the malfunctioning engine at HAESL revealed only minor damage to the internal componentry associated with the fractured IP turbine blade that was identified in the borescope inspection performed on-wing.

The fractured blade root was removed from the IP turbine disc and sent to the ATSB's Canberra laboratories for preliminary examination. The blade was then forwarded to the engine manufacturer in the United Kingdom, together with a number of other engine components recovered during the engine disassembly.

Engine history

At the time of the occurrence, the No.4 engine (engine serial number ESN13206) had accumulated 79,666 hours since new (TSN) and 10,048 flight cycles since new (CSN).

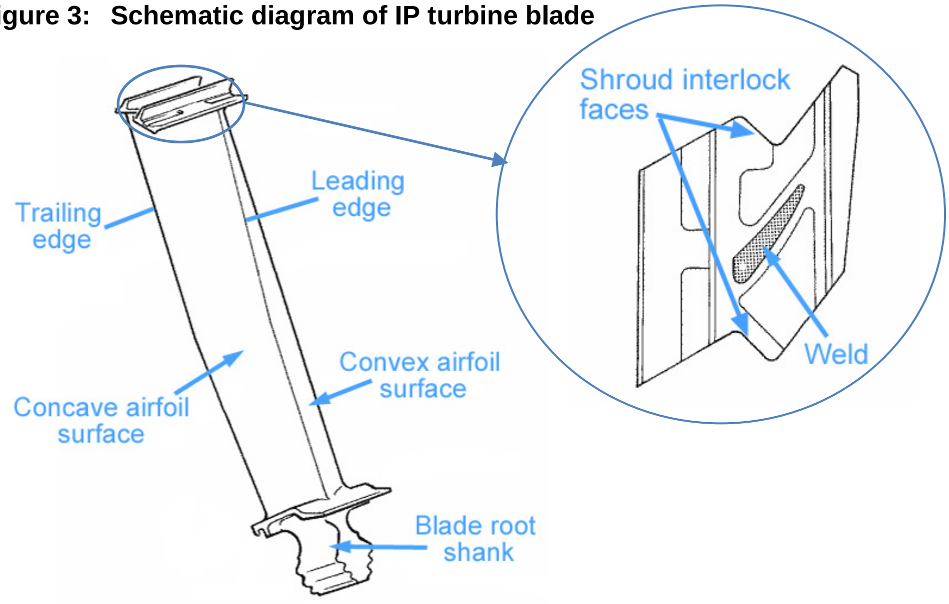
The last full refurbishment was on 24 February 2006, and the engine had accumulated 18,944 hours and 2,017 flight cycles since that time.

The last workshop visit for the engine was 30 flight cycles prior to the event, when the engine was removed from another aircraft (VH-OJT) following an air turn back event on 25 January 2011. At that time, the engine exhibited reducing oil quantities and high oil temperature during climb. Workshop analysis diagnosed a high speed gear box bearing failure, which was resolved by replacement of the gearbox and the engine was subsequently returned to service as the No.4 engine on OJH.

IP turbine blade examination

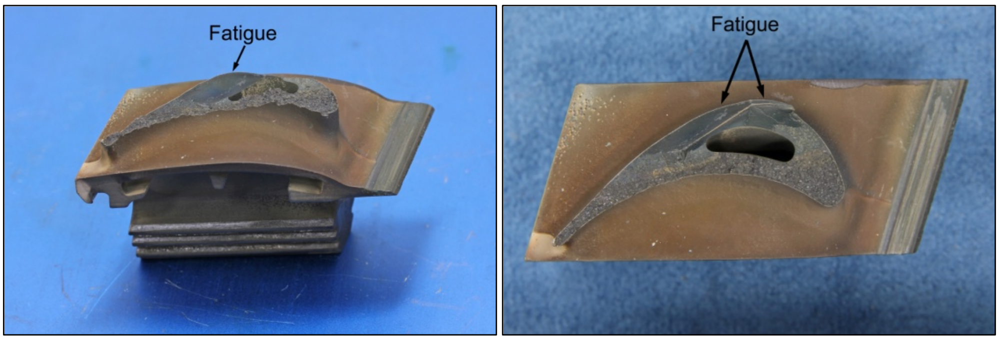
The fractured IP turbine blade, manufactured in May 1989, was identified as blade No.24 (disc post position), with serial number A01630-7 and part number UL21701. The blade had fractured approximately 5 mm (0.2 in) from the root platform.

Figure 3: Schematic diagram of IP turbine blade



Fractographic analysis showed that the blade had failed following the growth of a low stress/high cycle fatigue crack that had originated on the convex (suction) side of the aerofoil (Figure 3) and propagated across a significant portion of the cross section prior to final release in tensile rupture (Figure 4). There were no discontinuities or other localised stress-raising defects identified in the crack origin areas.

Figure 4: Root section of fractured IP turbine blade no. 24



As part of the failure analysis, the manufacturer reviewed and examined all blades from the IP turbine and made the following observations:

- The blade set installed on ESN13206 at the 2006 overhaul was comprised of 64 new blades (part number UL39195[4]) and 62 old (previously refurbished) blades (part number UL21701).

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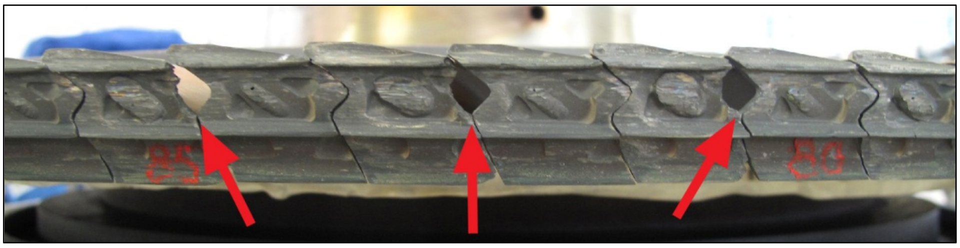
[4] Part number UL39195 had an improved airfoil surface finish and was introduced as part of an engine performance enhancement package.

- The repaired blades from the event engine exhibited evidence of thermal degradation of the microstructure.
- Radial height mismatch was visible between the old (repaired) and new blades.
- Some repaired blades had greater than expected quantities of weld (metal) on the shroud features as a result of earlier blade geometry restoration repairs. Repaired blade shrouds exhibited some variation in sectional thickness as a result of previous repairs or high-life distortion and wear.
- Evidence of greater than expected weld build up was observed at the repair locations, including the seal fins and shroud sides.
- A number of blade shrouds had reduced sectional thickness from previous wear and possibly from dressing during the repairs at the previous refurbishment.
- Most of the repaired blades had lost material from the outer shroud interlock feature where they had been rebuilt with weld metal.
- The shrouds and interlocks on the new blades were considered to be satisfactory.
- Significant loss of the rear interlock shroud was identified on blades 14, 81, 83, 85 and 106 (Figure 5).

Figure 5: Outer shrouds of blade 80 – 85 showing significant loss of material from the interlock feature (arrowed) *[image supplied by the manufacturer]*



Outer shroud interlocking feature wear

The outer interlocking shrouds are an integral feature of the blade design and serve to dampen blade motion during engine running. As the shrouds wear, the blades can become more susceptible to excitation (resonant vibration) in the flap and torsional modes.

Wear of the outer shroud interlocking feature occurs due to the relative movement between the blades as a result of the mechanical and vibratory forces during operation. If the area of contact is sufficiently large, the wear rate is relatively low and will have no detrimental effect during service between workshop visits. Radial height mismatch of the blades can promote greater wear rates, as the contact load at the blade interface will be distributed over a smaller area.

Of the five IP turbine blades that showed significant wear and loss of the interlocking shroud feature, three (blades 81, 83 and 85) were located diametrically-opposite the failed blade 24.

Blade repair scheme

During a full refurbishment of the IP turbine, all blades are removed, cleaned and measured, and may then be repaired prior to return to service. A combination of refurbished and new blades could be fitted to the turbine disc for continued service.

The IP turbine blades do not have a specified maximum service life and are maintained on-condition[5]. The repaired blades installed on ESN13206 had accumulated around 41,753 hours TSN and 4,475 CSN.

A review of the engine's maintenance documentation and a visit to the overhaul provider by the engine manufacturer found that the blades had been maintained in accordance with the standards published in the engine maintenance manual, 72-51-32 7RR Revision No. 67. Of interest to the investigation were the repair tasks related to blade creep[6] and the shroud interlock faces.

The manufacturer's prescribed maintenance task 72-51-32-220-082 was an inspection of the IP turbine blade shroud interlock faces. The faces are visually examined for damage or wear, and are rejected for continued service where such damage exceeds specified limits.

Technical variance TVF41601, *IP turbine blade – welding and machining of shroud interlock and non-interlock faces*, allowed damaged blades to have the interlock / non-interlock faces to be repaired by welding and machining. If the blades had undergone this repair, a 'delta 154' symbol was marked on the blade root. A number of blades had two such markings, which indicated that the blade had undergone two repairs to the shroud faces.

Maintenance sub-task 72-51-32-220-115 was an inspection for IP turbine blade axial creep. If the recorded creep was up to and including 0.020 in (0.5 mm) then the directive was to mark a 'delta 190' symbol on the blade root. If the measured creep was greater than 0.020 in (0.5 mm) and less than or equal to 0.035 in (0.889mm) then a 'delta 191' symbol was marked on the surface. Creep in excess of 0.889 mm required the blade to be rejected. The failed blade had been marked with a 'delta 190' symbol.

Information on the extent of the creep was then used in sub-task 72-51-30-440-051 for balancing of the IP turbine shaft, disc and blades. To limit the degree of radial shroud misalignment, a caution was included to require that all IP turbine blades were to be *part of the same creep band*. Blades with no markings and blades marked with a 'delta 190' could be fitted together, and blades marked with a 'delta 191' could be fitted together; however the two lots of blades were not to be mixed within a single IP turbine disc build.

In 2008, a new inspection task (72-51-200-003) was introduced to tighten the allowable levels of creep - limiting shroud curl/bow[7] and maximum creep length to 0.020 in (0.5 mm). Any blades that previously would have been marked as 'delta

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5 A preventative maintenance regime, where a determination of the continued serviceability of a component is based on appropriate periodic inspections.

6 Creep is a slow plastic deformation under prolonged load, which is accelerated at high temperatures.

7 Shroud curl/bow is the radial outward distortion and deformation of the forward part of the shroud. It is generally a result of a material creep mechanism, but may be exacerbated by thermal erosion (thinning of the shroud) or section reduction as a result of repair dressing.

191' would now be rejected for further service at overhaul. The build of ESN 13206 occurred at the overhaul in 2006, prior to the release of this task. The engine manufacturer indicated that these changes would result in increased levels of high-life blade rejection following inspection; reducing the total number of blades undergoing second and subsequent repairs.

Previous occurrences

The engine manufacturer advised the ATSB of three previous occurrences that involved the failure of an IP turbine blade.

- Event date: 27 September 2001, ESN13209, single IP turbine blade fracture (part number UL21701, serial number 45698-2)

  The fracture face displayed similarities in location and profile to the fractured blade from ESN13206. Blade creep was the determined cause; exacerbated by mixing of different aged blades within a set. TV211-38027 was subsequently issued, calling for the classification of blades into creep bands to prevent significant mismatch.

- Event date: 10 November 2004, ESN 13252, single IP turbine blade fracture (part number UL21701, serial number C45515-4).

  The blade fractured due to a fatigue crack in the aerofoil, which had initiated near the trailing edge approximately 15 mm above the root platform. The section of trailing edge that was thought to have contained the fatigue origin had been lost during the event. Exact cause could not be determined as there was significant mechanical and thermal damage to all other blades in the set.

- Event date: 2009, ESN13251, single IP turbine blade fracture (part number UL21701, serial number B6588720)

  The blade fractured from high cycle fatigue at approximately one-third span. A small casting inclusion was present below the surface in the region of crack nucleation and was considered as a possible contributing factor.

ANALYSIS

Engine malfunction

The in-flight malfunction of the No.4 engine of a Qantas Airways Limited Boeing 747-438 aircraft (VH-OJH) was the result of the failure of a single intermediate-pressure (IP) turbine blade. Blade failure stemmed from a low stress/high cycle fatigue crack that had initiated and propagated from the convex (suction) aerofoil surface. Metallurgically, the failed blade showed no localised discontinuities or material characteristics that could have contributed to the fatigue cracking sustained.

A number of the remaining blades from the IP turbine disc showed significant material loss from the outer shroud interlocks; particularly those on the diametrically-opposite side of the turbine disc from the failed blade. Although work by the engine manufacturer to substantiate the effects of shroud interlock wear is continuing, it is known that the wear and loss of this feature can reduce the rigidity and damping effects of the shroud; potentially predisposing the blades to undesirable resonant behaviours and the onset of high-cycle fatigue cracking.

Management of the potential for excessive shroud interlock wear has been effected by a series of changes to the inspection criteria for the acceptance and re-use of IP turbine blades during the engine overhaul process. To reduce the interlock surface stresses and thus wear potential, the engine manufacturer has further restricted the allowable mismatch in blade axial lengths within a disc build, and has tightened blade creep and distortion limits. The subject engine was last overhauled before the 2008 introduction of these new inspection criteria, and a current around-the-fleet inspection of the operator’s other engines overhauled before 2008 has not detected any further instances of unacceptable IP turbine blade shroud interlock wear.

FINDINGS

From the evidence available, the following findings are made with respect to the Boeing 747-438 in-flight engine malfunction and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factor

- A single intermediate-pressure turbine blade failed as a result of high-cycle fatigue cracking, producing high levels of vibration and the subsequent commanded shut-down of the No.4 engine.

Other safety factor

- Wear of the interlocking shrouds of the intermediate-pressure turbine blades had the potential to reduce the dampening effects of the feature, and may have led to the development of conditions suitable for fatigue cracking of the IP turbine blades. *[Minor safety issue]*

Other key findings

- The intermediate-pressure turbine blades were maintained on-condition and some blades had undergone multiple repairs in the region of the outer interlock shroud.

SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

Loss of outer shroud interlock surfaces

Minor safety issue

Wear of the interlocking shrouds of the intermediate-pressure turbine blades had the potential to reduce the dampening effects of the feature, and may have led to the development of conditions suitable for fatigue cracking of the IP turbine blades.

Action taken by Rolls-Royce PLC

Following the occurrence, the engine manufacturer issued non-modification service bulletin, NMSB 72-G739, on 6 October 2011. The NMSB directed a borescope inspection of the IP turbine blades to confirm that the interlocks were in an acceptable condition. It was recommended that the inspections be carried out before 30 June 2012. The service bulletin was re-issued on 11 July 2012 to include crack acceptance and re-inspection criteria.

The engine manufacturer advised that they were running a series of stress and modal analyses to look at the effect of a loss of the interlocking shroud feature on the system, in particular the stress in the IP turbine blades. The analysis was run with *fixed-fixed* and *fixed-free* configurations, representative of blades with full interlock functionality and with zero interlock functionality. It was reported that the fixed-fixed configuration showed good correlation to the certification tests which validated the model, and while the fixed-free test showed changes to the stress levels and distribution, it did not indicate a significant stress increase on the convex (suction) side of the aerofoil as likely in the occurrence event. The *fixed-half free* model analysis was completed in the second half of 2012; however the engine manufacturer reported that they remained unable to verify the mechanism that led to the IP turbine fracture. The manufacturer reported that they were committed to reaching a root-cause understanding of the failure, and ongoing work included a rig-based fatigue test that involved high-life service-run blades against new blades. It was thought that this would provide important material property data for service aged material with thermal degradation.

Analyses were also commissioned to assess the dual in flight shut down (DIFSD) risk for the fleet (which included both 747 and 767 aircraft). In respect of the IP turbine blade release, the DIFSD risk was a factor of 10^3 below the regulatory threshold of one such event in 1 billion (10^9) aircraft flight hours.

Action taken by Qantas Airways Limited

The operator indicated that they had completed inspections across the fleet in accordance with the requirements of NMSB 72-G739 with no instances of excessive wear identified.

APPENDIX A: SOURCES AND SUBMISSIONS

Sources of Information

The sources of information during the investigation included:

- Qantas Airways Limited
- Rolls-Royce PLC

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the aircraft operator, the engine manufacturer, the Civil Aviation Safety Authority and the UK Air Accidents Investigation Branch.

Submissions were received from the engine manufacturer. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

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Investigation

ATSB Transport Safety Report
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