



Australian Government

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 does not investigate for the purpose of apportioning blame or to provide a means for determining liability.

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

When the ATSB issues a safety recommendation, the person, organisation or agency must provide a written response within 90 days. That response must indicate whether the person, organisation or agency accepts 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.

© Commonwealth of Australia 2012

In the interests of enhancing the value of the information contained in this publication you may download, print, reproduce and distribute this material acknowledging the Australian Transport Safety Bureau as the source. However, copyright in the material obtained from other agencies, private individuals or organisations, belongs to those agencies, individuals or organisations. Where you want to use their material you will need to contact them directly.

Australian Transport Safety Bureau
PO Box 967, Civic Square ACT 2608
Australia

1800 020 616

+61 2 6257 4150 from overseas

www.atsb.gov.au

Publication Date: 16 April 2012

ISBN 978-1-74251-254-9

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

ATSB TRANSPORT SAFETY

Aviation Occurrence Investigation A0-2010-066

Final

Uncontained engine failure and air turn-back Near San Francisco Airport, USA 30 August 2010

Abstract

On 30 August 2010 at approximately 2330 Pacific Daylight Time, a Qantas Boeing 747-438 aircraft, registered VH-OJP, departed San Francisco International Airport on a scheduled passenger service to Sydney, Australia. As the aircraft passed through 25,000 ft, the aircraft's number-4 engine failed, resulting in the puncturing of the engine casing and nacelle and the release of debris. The engine was shut down and the flight crew returned the aircraft to San Francisco International Airport. There were no injuries.

An investigation conducted by the engine manufacturer found that the engine failure was initiated by the fatigue fracture of a single stage-2 low pressure (LP) turbine blade. The ensuing rotor imbalance caused the LP turbine bearing to fail, which ultimately resulted in the uncontained release of debris.

As a result of this occurrence, the engine manufacturer released non-modification service bulletins NMSB72-AG729 and NMSB72-AG800; instructing operators of RB211-524 engine variants to fit a more robust LP turbine bearing, so as to reduce the likelihood of catastrophic engine failure resulting from rotor imbalance.

FACTUAL INFORMATION

History of the flight

On 30 August 2010, at approximately 2330 PDT¹, a Qantas Boeing 747-438 aircraft, registered

VH-OJP, with 213 passengers and 18 crew, departed San Francisco International Airport for a scheduled passenger service to Sydney, Australia.

Around 15 minutes into the flight, as the aircraft climbed through 25,000 ft above mean sea level, severe vibrations were felt through the aircraft. Cockpit indications received by the flight crew were consistent with severe damage to the number-4 engine; however, there were no indications of an engine fire. The flight crew completed the appropriate non-normal checklist items (NNC)², and after the engine was shut down, requested a return to San Francisco International Airport (the nearest available airport). They did not declare an emergency at that time.

When contacted, the cabin crew reported that sparks and flames were emanating from the number-4 engine exhaust. One of the flight crew then confirmed this observation, but reported the situation 'not too bad'.

Regardless of airspeed changes made by the flight crew as directed by the NNC, significant airframe vibrations continued for the remainder of the flight.

The crew obtained a clearance for the aircraft to enter a holding pattern at 20,000 ft, where 70,000 kg of fuel was jettisoned over a period of about 34 minutes to bring the aircraft under maximum landing weight.

¹ Pacific Daylight Time (PDT) was Coordinated Universal Time (UTC) – 7 hours.

² The operator's Flight Crew Operations Manual contained a series of checklists for dealing with 'non-normal' conditions – that is, conditions outside normal operating parameters – such as an engine failure.

A PAN³ radio call was made by the flight crew on completion of the fuel jettison, and clearance obtained to return to San Francisco, where emergency services were requested to be on standby.

The aircraft landed without incident on runway 28R at approximately 0050; holding on a taxiway while the engine was inspected by emergency services. The aircraft subsequently proceeded to the gate for passenger disembarkation. At this time, the flight crew were informed by ground personnel that 'holes' were present in the number-4 engine nacelle.

There were no reported physical injuries to passengers or crew.

Commencement of the investigation

Upon receiving notification of the occurrence, two Australian Transport Safety Bureau (ATSB) investigators travelled to San Francisco to commence an investigation into the event. As the engine failure occurred over international waters, responsibility for the investigation fell to the State of (aircraft) Registry under the provisions of Annex 13 to the Convention on International Civil Aviation (ICAO Annex 13). Once on-site, investigators conducted a preliminary examination of the engine and aircraft, in conjunction with representatives from the aircraft operator and engine manufacturer.

Aircraft information

The Boeing 747-438 aircraft, serial number 25545, registered VH-OJP, was manufactured in 1992 and first registered in Australia at that time.

Aircraft propulsion was generated by four Rolls-Royce RB211-524G2-T, high bypass, three-shaft, turbofan engines.

Damage to the aircraft

The number-4 engine had ruptured through the left and right sides of the turbine case and fairings, producing a large perforation in the right side of the engine nacelle (Figures 1 and 2) and

several smaller punctures through the left side (Figure 3).

Figure 1: Right side of number-4 engine



Debris ejected through the hole in the right side (outboard) of the engine had impacted the underside of the wing, producing superficial nicks and scratches to the wing skin. There was a puncture through the composite, leading-edge, variable-camber flaps and the associated torque tube was slightly bent. Operation of the flaps was not affected.

Figure 2: Perforation in the engine nacelle, right side



3 An internationally-recognised radio call announcing an urgency condition which concerns the safety of an aircraft or its occupants, but where the flight crew does not require immediate assistance.

Figure 3: Punctures in nacelle, left side



There was no airframe damage inboard of the number-4 engine. Despite the several small punctures in the left (inboard) side of the engine, the released debris did not have sufficient energy to contact the fuselage.

Engine disassembly

After removal from the aircraft, the engine was shipped to an overhaul facility in Hong Kong for systematic disassembly and inspection. ATSB investigators and representatives from the engine manufacturer, aircraft operator and airframe manufacturer oversaw the examination.

Figure 4 presents the subject engine with the fairings removed. During the early stages of the examination, it was evident that the internal turbomachinery had been significantly disrupted, with extensive damage sustained by the intermediate-pressure (IP) and low-pressure (LP) turbine rotors

(Figure 5). Figure 6 shows the general layout of the RB211-524 engine and Figure 7 shows the turbine section in detail.

Figure 4: Engine serial number: 13247

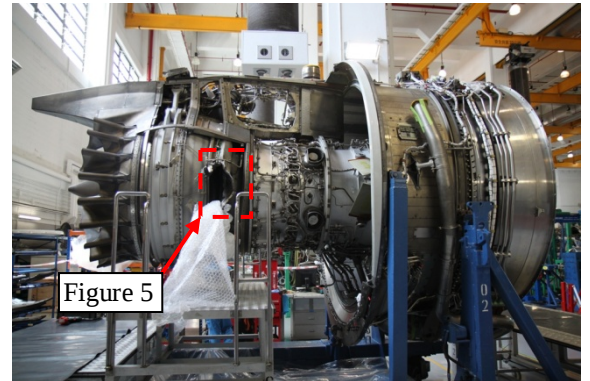


Figure 5: IP and stage 1 LP turbine discs

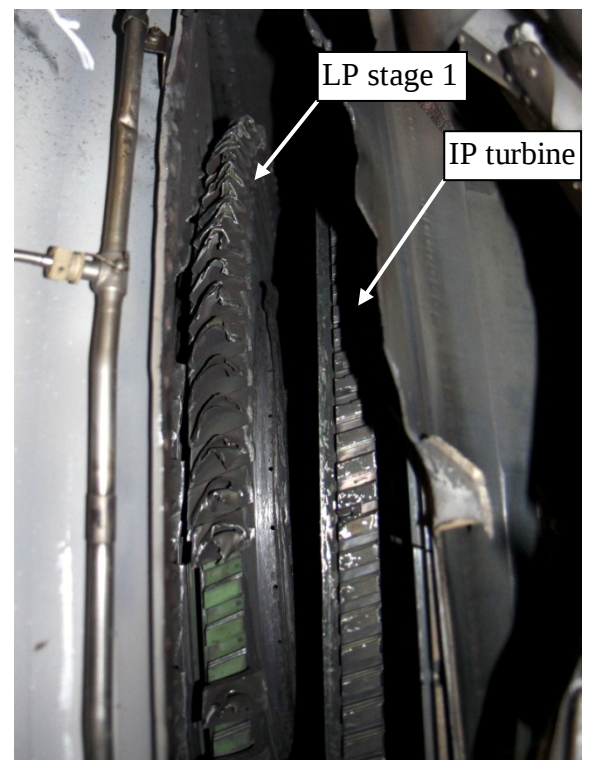


Figure 6: RB211-524 engine

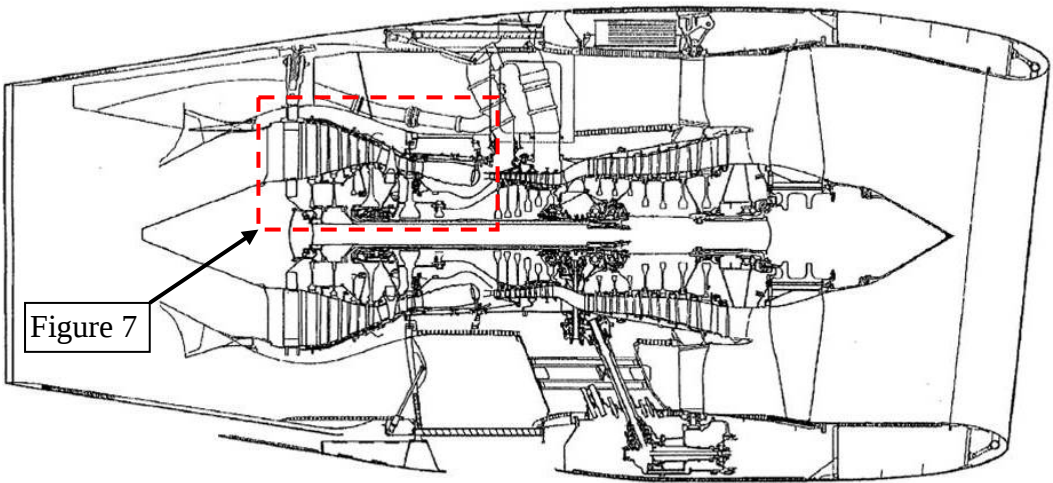
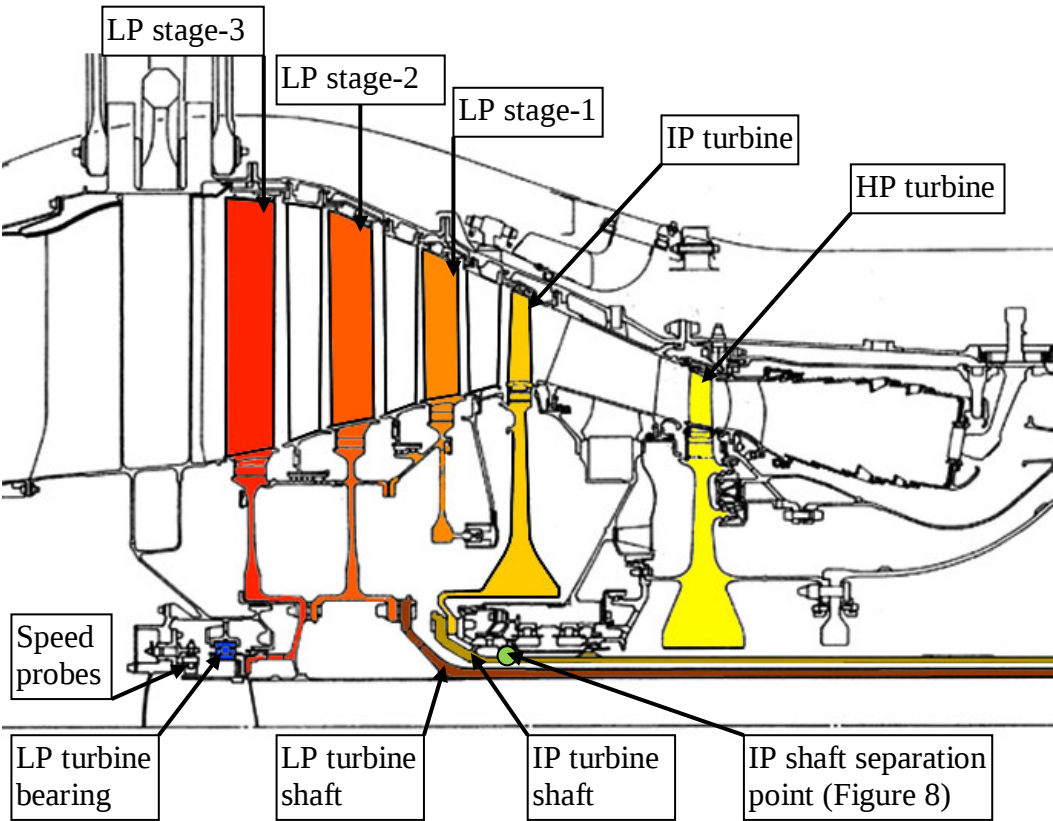


Figure 7: RB211-524 turbine section



Disassembly of the LP/IP turbine module revealed the LP turbine bearing, phonic wheel⁴ and speed probe assembly had been destroyed in the failure sequence.

The IP turbine shaft was severed towards the aft end and there was evidence of heavy rotational wear on the inner and outer surfaces (Figure 8). The damage was consistent with the shaft having contacted adjacent components, including the LP turbine shaft (Figure 9).

Figure 8: Composite image showing IP turbine shaft damage and separation

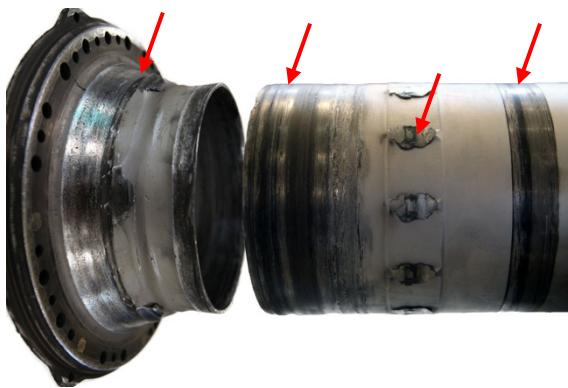


Figure 9: LP turbine shaft showing evidence of contact with IP shaft



All of the IP turbine blades had separated from the disc. Apart from a single stage-2 LP turbine blade that had fractured through the blade root (Figure 10), all blades from the three LP turbine stages had either fractured through the airfoil section or separated entirely from the disc. The

stage-2 LP blade fracture surface showed two distinct morphologies; consistent with high-cycle fatigue crack progression followed by ductile overstress fracture (Figure 11). The origin of the fatigue crack was at the trailing-edge corner of the blade root, between the blade platform and fir tree.

Figure 10: Stage-2 LP turbine disc showing fractured blade root



Figure 11: Stage-2 LP turbine blade root. Fatigue crack origin arrowed



Engine Information

The number-4 engine, serial number 13247, was configured as an RB211-524G2-T-19/15. The last overhaul was completed in May 2009 and the engine had accumulated 5,059 hours and 518 cycles since overhaul, which was within the IP/LP turbine module build target of 26,000 hours and 3,000 cycles.

At the time of the last overhaul, the LP turbine roller bearing (part number LK30313, serial number PBC019) was inspected as per the engine maintenance manual and subsequently refitted to the engine. The bearing had accumulated 71,885

⁴ A geared wheel that induces an electric current in the adjacent speed probe by varying magnetic flux. The magnitude of the current generated gives an indication of engine speed.

hours total time in service (TTIS) and 9,026 cycles since new (CSN).

Also at the time of the last overhaul, the set of 68, stage-2 LP turbine blades (P/N: UL20899) were overhauled at an approved blade repair station and refitted to the engine. The blades were estimated to have accumulated around 80,000 hours TTIS and 10,000 CSN. Physical, dimensional and crack inspections were conducted as part of the overhaul process.

Both the LP turbine bearing and turbine blades were maintained according to standards published in the engine maintenance manual. Neither part had a specified maximum service life and were maintained on-condition⁵.

Recorded information

The aircraft was fitted with the mandatory Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) as well as an optional Wireless Quick Access Recorder (WQAR) which is used by the aircraft operator for flight data and aircraft system monitoring. The FDR and CVR were downloaded at the ATSB's facilities in Canberra and a copy of the WQAR data was provided to the ATSB by the operator.

Data from the FDR and WQAR confirmed the sequence of events as detailed in the flight crew reports. The vibration level of the number-4 engine N1 reached 5 (maximum) and the exhaust gas temperature 780 degrees C. Although there were recorded abnormal engine indications associated with the failure event, there were no precursor indications leading up to the event that may have alerted the flight crew of an impending engine failure.

The FDR contained the most recent 25 hours of flight data. Number-4 engine data from previous flights showed no abnormal engine indications.

The CVR recorded data on a continuous-loop principle and retained the most recent 2 hours of audio information. Due to the duration of the return to San Francisco and aircraft ground operations after landing, the recording of the

failure event had been overwritten and as such, the CVR contained no pertinent information.

Engine manufacturer

A number of engine components were retained for testing and analysis by specialists from the engine manufacturer. That examination was overseen by representatives from the UK Air Accident Investigation Branch (AAIB), acting as Accredited Representatives to the investigation (State of Manufacture – Engines).

Engine failure sequence

The manufacturer's completed investigation findings were provided to the ATSB, where it was concluded that the engine failure was most likely the result of the following sequence of events:

- Fatigue failure and release of a stage-2 LP turbine blade resulted in secondary blade releases and causing engine imbalance.
- Imbalance in the engine overloaded the LP turbine roller bearing, which subsequently failed.
- Failure of the LP turbine bearing allowed the LP turbine shaft to orbit, contacting and eventually severing the IP turbine shaft.
- Separation of the IP turbine shaft allowed the IP turbine disc to overspeed slightly, losing its axial and radial location. The loss of location allowed the disc and blades to contact adjacent engine components, resulting in the blades being released from the disc (as per the design intent to prevent a disc burst). The entanglement of released blades and stage 1 LP turbine nozzle guide vanes resulted in the turbine casing rupture and release of debris.

LP turbine bearing

The mechanism of breakdown of the LK30313 LP turbine bearing could not be fully determined from examination of the bearing debris recovered from the engine.

Three standards of LP turbine bearing were available for installation on RB211 engines. The LK30313 and UL29651 bearings were of a two-piece, riveted roller-cage design. The FB500000 bearing comprised a single piece cage construction and had a significantly greater load carrying capacity than the two-piece cage design.

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

Due to supply continuity issues with the LK30313 and UL29651 bearings, in 1995 the FB500000 bearing was introduced (service bulletin SB-72-B540) as an optional alternative to the earlier parts.

Stage-2 LP turbine blade

Detailed examination of the turbine blade root found no evidence of material defects or other anomalies that may have contributed to the fatigue crack initiation. The manufacturer's finite element stress analysis showed that the fatigue crack origin coincided with the peak stress location within the blade.

The engine manufacturer's analysis of the circumstances contributing to the blade failure found that a flutter vibration phenomenon could contribute to reduced fatigue endurance of the stage-2 LP turbine blades at engine speeds above 100% N1⁶. Flutter stress levels were found to increase in an almost linear fashion up to the N1 operational limitation of 110.5%. The amount of accrued blade damage would therefore depend on the type of engine operation in addition to the blade service hours.

The stage-2 LP turbine blade part number UL20899 was superseded in 1992. Many high life blades remained in service after that time, as typically, only about 5% of the total engine inventory of stage-2 LP turbine blades would be replaced during any given engine overhaul.

Previous occurrences

The engine manufacturer reported that the failed stage-2 LP turbine blade from the event engine was the only stage-2 blade to have failed by a fatigue cracking mechanism in the RB211-524G/H-T service history (totalling around 40 million hours service over 23 years). However, there have been five IP turbine and two stage-3 LP turbine blade release events, all of which resulted in in-flight engine shut downs (one aborted takeoff). One of the stage 3 LP turbine blade release events, in 1995, resulted in breakdown of

the LP turbine support bearing, which was the riveted-cage design. IP/LP inter-shaft rub was observed as a result of the bearing breakdown, but there was no shaft separation.

Two occurrences of riveted-cage bearing damage were reported on older, RB211-524D4 engines, related to blade release events. However, the bearings did not completely break down and there was no inter-shaft contact.

There were therefore no previous occurrences of turbine shaft separation as a result of LP turbine bearing breakdown. There have also been no in-service issues related to the FB500000 bearing.

ANALYSIS

With respect to the engine failure, the ATSB concurred with the findings of the engine manufacturer, which indicated that the most likely sequence of events was initiated by the fatigue failure of a stage-2 LP turbine blade. The consequence of the turbine blade failure was increased by the subsequent LP bearing failure, which ultimately resulted in the uncontained engine failure.

FINDINGS

Context

From the evidence available, the following findings are made with respect to the uncontained engine failure on the Boeing 747-438 aircraft, registered VH-OJP, and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- High service time stage-2 LP turbine blades were susceptible to a reduction in fatigue endurance as a result of vibratory stresses sustained during operation at speeds close to the maximum. [*minor safety issue*]
- It was likely that as a result of the reduced fatigue endurance limit, a single stage-2 LP turbine blade fractured and separated from the LP disc during engine operation.
- LP turbine support bearings (part numbers LK30313 and UL29651) showed increased susceptibility to breakdown and collapse under

6 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.

vibratory stress conditions associated with LP turbine blade release. *[minor safety issue]*

- It was likely that vibratory stresses from the LP turbine blade loss resulted in the LP turbine support bearing collapse, allowing contact between the LP and IP turbine shafts.
- The IP turbine shaft severed as a result of contact between the IP and LP turbine shafts, which ultimately resulted in the uncontained failure event.

Other key findings

- Cockpit voice recorder audio of the engine failure event was not available to the investigation, as it had been overwritten as a result of the time elapsed during aircraft return and ground operations subsequent to the event.

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.

Rolls-Royce

LP Turbine support bearing breakdown

Safety Issue

LP turbine support bearings (part numbers LK30313 and UL29651) showed increased susceptibility to breakdown and collapse under vibratory stress conditions associated with LP turbine blade release.

Action taken

As a result of this occurrence and to minimise the risk of potentially hazardous complications associated with blade release events, the engine manufacturer released non-modification service bulletins NMSB72-AG729 for RB211-524G/H-T engines, and NMSB72-AG800 for RB211-524 'Classic' engines. The service bulletins instructed fitment of a more robust LP turbine bearing, part number FB500000, during the next maintenance visit where the turbine module is removed. At the time of writing, the FB500000 bearing had already been installed in over 68% of the RB211-524G/H & -T worldwide engine fleet.

High service time stage-2 LP turbine blades

Safety Issue

High service time stage-2 LP turbine blades were susceptible to a reduction in fatigue endurance as a result of vibratory stresses sustained during operation at speeds close to the maximum.

Action taken

The manufacturer is recommending that operators replace high service time stage-2 LP turbine blades.

Civil Aviation Safety Authority

CVR audio of the event was overwritten

Cockpit voice recorder audio of the engine failure event was not available to the investigation, as it had been overwritten as a result of the time elapsed during aircraft return and ground operations subsequent to the event.

Action taken

Although not directly related to this occurrence, on 25 March 2011 the Australian Civil Aviation Safety Authority (CASA) amended Civil Aviation Order (CAO) 82.5 'Conditions on Air Operators' Certificates authorising regular public transport operations in high capacity aircraft'. Section 12 of the amendment included a requirement for Air Operator Certificate holders to preserve for 30 days CVR or FDR records for immediately reportable matters such as engine failures.

SOURCES AND SUBMISSIONS

Sources of Information

The aircraft operator

The engine manufacturer

VH-OJP crew reports

References

Figures 6 and 7 courtesy of Rolls-Royce

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 aircraft manufacturer, the UK Air Accidents Investigation Branch (AAIB), the US National transportation Safety Board (NTSB), and the Civil Aviation Safety Authority (CASA).

Submissions were received from the aircraft operator, the engine manufacturer, the aircraft manufacturer, the UK Air Accidents Investigation Branch (AAIB) and the Civil Aviation Safety Authority (CASA). The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.