Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT

Aviation Occurrence Investigation AO-2007-024

Final

In-flight engine failure 56 km south-south-west of Newman aerodrome, WA 13 July 2007

VH-NXK

Boeing Co. 717-200

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Figures 5 and 6 Rolls Royce Deutschland Ltd & Co.

Abstract

On 13 July 2007 at about 1420 Western Standard Time, a Boeing Company 717-200 aircraft, registered VH-NXK, was being operated on a scheduled passenger service from Newman, WA to Perth, WA, when the right engine failed during the climb to cruise. The flight crew disconnected the autopilot, actioned the *Engine Fire/Severe Damage* checklist, and commenced decent to flight level 140. The flight crew broadcast a PAN to air traffic services and advised the cabin crew and passengers that the aircraft would be returning to Newman Aerodrome. The aircraft landed safely at Newman Aerodrome.

The operator's maintenance organisation carried out an internal inspection of the failed engine and found that all the blades on the high pressure turbine stage disc had been sheared off.

A subsequent investigation by the engine manufacturer revealed that a high pressure turbine stage 1 blade had separated from the blade disc below the blade platform due to low-cycle fatigue causing the remaining HPT1 blades to separate from the disc. This led to the subsequent engine in-flight shutdown. This failure was similar to a number of previous engine failures that have occurred since November 2003.

The engine was removed from the aircraft for shipment to the engine manufacturer for investigation and repair. A serviceable engine was fitted and the aircraft was returned to service.

At the time of the incident the aircraft operator was engaged in replacing all the LIP 3 standard of HPT1 blades in their fleet engines with the new HPT1 blade

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 organisations.

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

Note: *The ATSB did not conduct an on-site investigation of this occurrence. This report is based on information provided to the ATSB by the operator and other parties.*

History of the flight

On 13 July 2007 at about 1420 Western Standard Time[1], a Boeing Company 717-200 aircraft, registered VH-NXK, was being operated on a scheduled passenger service from Newman to Perth, WA, with seven crew and 86 passengers on board. During climb through 14,000ft (FL140), the crew heard a loud bang, felt vibration through the airframe and noticed a difference in engine noise.

The right engine's cockpit instrumentation showed a decrease in engine pressure ratio and engine shaft speed, and a high engine turbine gas temperature. A compressor stall had also been indicated on the flight deck engine and alert display (EAD) panel. The flight crew disconnected the autopilot, actioned the *Engine Fire/Severe Damage* checklist and commenced decent to FL140.

The flight crew broadcast a PAN[2] and advised the cabin crew and passengers of the engine shutdown, then returned the aircraft to Newman aerodrome.

The operator's maintenance organisation carried out an internal inspection of the failed engine and found that all the blades on the high pressure turbine stage 1 (HPT1) disc had sheared off (Figures 1 and 2).

The engine was removed from the aircraft for shipment to the engine manufacturer for investigation and repair. A serviceable engine was fitted and the aircraft was returned to service.

1 The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST) as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) + 8 hours.

2 Radio broadcast indicating uncertainty or alert.

Figure 1: High pressure turbine stage-1 blade damage

Engine information

The aircraft entered service with the current operator in late 2005 and was fitted with two Rolls-Royce Deutschland BR715-A1-30 turbofan engines.

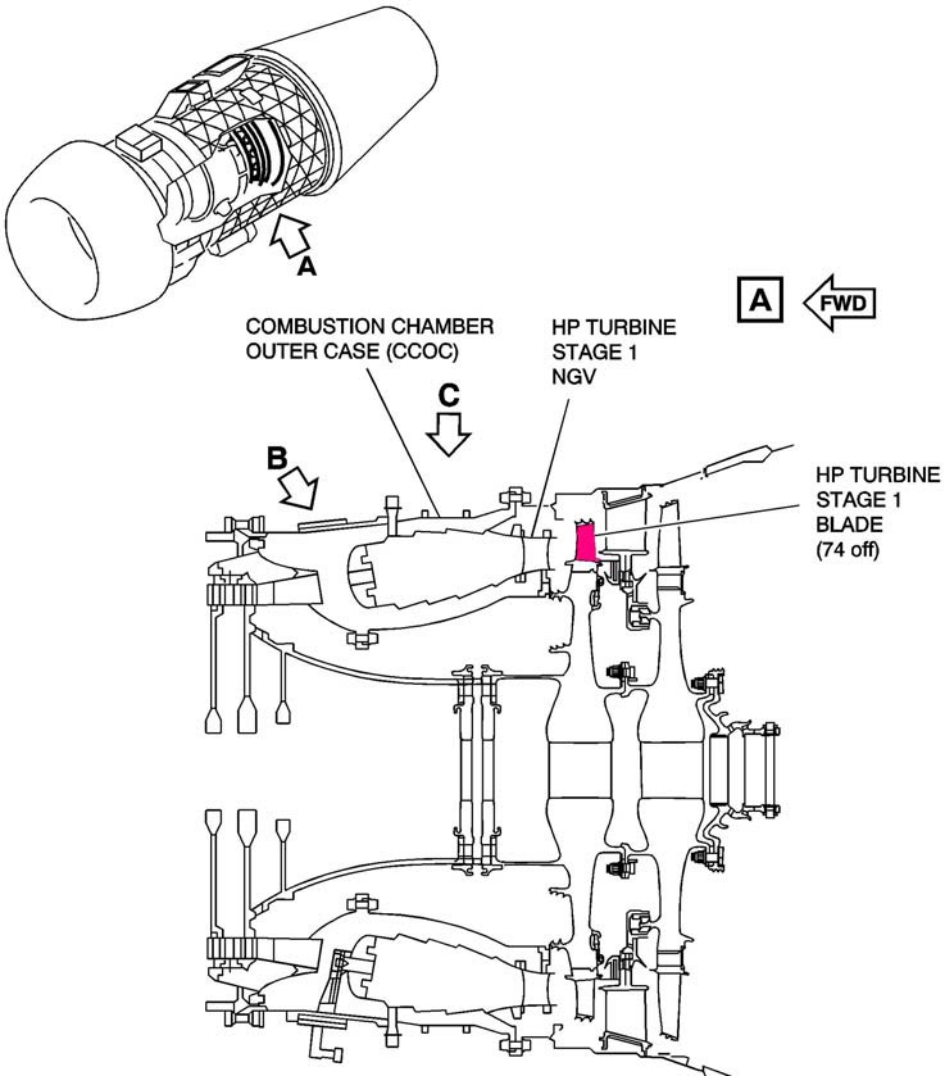
The failed right engine, serial number 13286, had completed 11,058 hours and 8,712 cycles[3] since new (CSN).

The engine had accrued 6,824 hours and 5,179 cycles since the last workshop visit on 3 December 2003. During that visit, the HPT1 blades were replaced with a new standard of blade as part of the engine upgrade to the life improvement package 3 (LIP 3)[4].

3 One cycle is the period from engine start-up, aircraft take-off, aircraft landing, to engine shut down.

4 The life improvement package 3 (LIP3) was a suite of high pressure turbine modifications that included the installation of high pressure turbine blade part number BRH20351. The engine manufacturer introduced the package through service bulleting BR700-72-100801.

Figure 2: High pressure (HP) turbine stage 1 disc and blade position

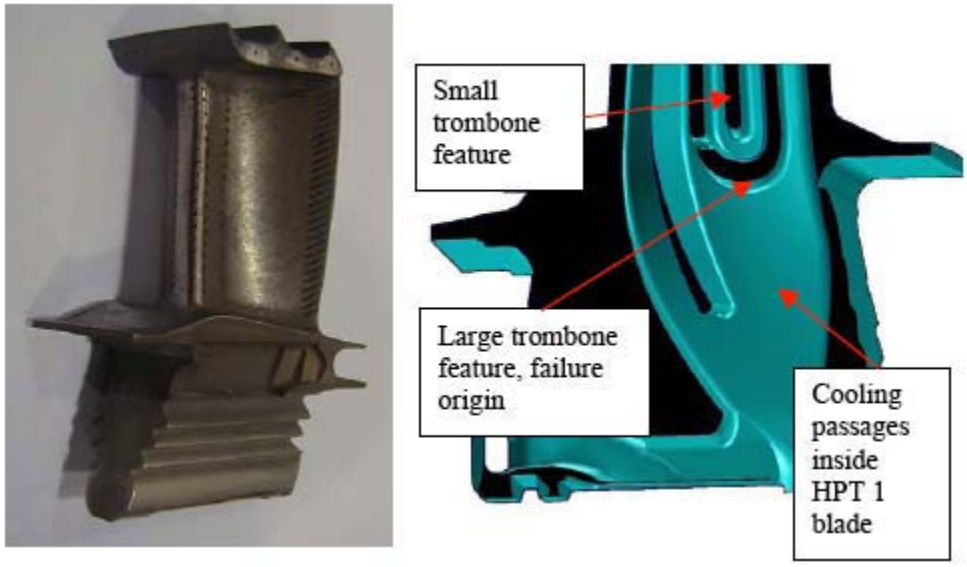


On 16 November 2004, following a series of failures of the LIP 3 HPT1 blade, the engine manufacturer introduced a modified LIP 3 HPT1 blade with the issue of service bulletin BR-700-72-101467. The service bulletin recommended that all LIP 3 HPT1 blades from those engines, prior to engine serial number 13419, be replaced with modified HPT1 blades as there was a possibility of cracking occurring at the bottom trombone fillet radius on the blades due to low-cycle fatigue[5] (Figure 3). This cracking could result in a blade failure during engine operation and result in the remaining HPT1 blades being sheared off.

The engine manufacturer recommended that the blade replacement be carried out at the earliest opportunity.

5 Repeated cycling (the completion of one repetition from low speed to high speed to low speed) stresses the rotating component material. This low-cycle fatigue (LCF) effect can result in the initiation of cracks in the higher stress regions of the component, typically near bolt holes, blade slots, or other complex geometric features, which eventually leads to failure.

Figure 3: Intact LIP 3 HPT1 blade (left). Blade internal cooling passage showing trombone feature (right)



There was no mandatory requirement for the current aircraft operator to have a planned program for replacement of the LIP 3 HPT1 blades with the modified blades. However, the service bulletin was entered in the operator's maintenance planning system.

On 3 June 2005, the engine manufacturer issued service bulletin SB-BR700-72-900361[6] detailing an on-wing ultrasonic inspection of the LIP 3 HPT1 blades to find potential internal cracks. The service bulletin stated that compliance should be accomplished when aircraft scheduled maintenance allowed access and time to do the ultrasonic inspection. The inspection would identify defective blades and prevent further HPT1 blade losses due to low-cycle fatigue cracking. There was no recommended cycle or time requirement for completion of the initial inspection, or any recommended re-inspection requirement. Revision 1 of the service bulletin was issued on 16 September 2005 and did not alter the recommended compliance requirements.

On 2 November 2006, a new HPT1 blade was released with Service Bulletin SB-BR700-72-101579 as a replacement for the modified LIP 3 blade issued with SB-700-72-101467. The new blade was also a replacement for the LIP 3 HPT1 blade. The current operator planned to replace all the LIP 3 and modified HPT1 blades fitted to their fleet engines with the new HPT1 blades at their next shop visit. The blade replacement program for the fleet was planned for completion by August 2008.

Revision 2 of the ultrasonic on-wing inspection service bulletin was issued on 7 June 2007 and introduced a recommended completion of on-wing ultrasonic inspections within 5,000 cycles since installation of the affected blades or 1,500 cycles since the last inspection. The inspection was to be repeated at intervals of 1,500 cycles. Where an engine had already exceeded either of these cycle times at

6 BR 700 Propulsion System Service Bulletin (SB-BR700-72-900361) engine – high pressure turbine blades Ultrasonic Inspection dated June 03/05.

the time of receipt of the service bulletin, it was recommended that the inspection be accomplished at the next scheduled maintenance, but not later than 1,000 cycles.

Table 1: Service bulletin sequence

BR-700-72-101467, issued 16-11-2004	Introduced a modified HPT1 blade to replace the LIP 3 HPT1 blade
SB-BR700-72-900361, issued 3-6-2005	Introduced on-wing ultrasonic HPT1 Blade inspection to prevent further blade failures
SB-BR700-72-900361-1, issued 16-9-2005	To satisfy EASA compliance
BR700-72-101579, issued 2-11-2006	Introduced a new HPT1 blade to replace the LIP 3 and modified LIP 3 HPT1 blades
SB-BR700-72-900361-2, issued 7-6-2007	Introduced initial and reinspection times for the on-wing ultrasonic inspection

A check of the operator's records for engine serial number 13286 revealed that on 6 July 2005, the engine had undergone an on-wing ultrasonic non-destructive inspection of the LIP 3 HPT1 blades at the previous operator's facility. This was performed at a blade life of 3,357 CSN, with no indications of cracking.

On 25 June 2007, the current operator entered revision 2 of service bulletin SB-BR700-72-900361 into the maintenance planning system against the engine for action. As the engine LIP 3 HPT1 blades had completed 5,099 CSN, the current operator scheduled the engine for another ultrasonic blade inspection to be completed at 6,099 CSN, being 2,742 cycles since the last inspection.

Aircraft operator fleet status

At the time of this investigation, the current operator had two aircraft with the LIP 3 HPT1 blades fitted to both engines. These blades were under half the life recommended to remain in service and had undergone successful on-wing ultrasonic inspection. The Rolls Royce time limits manual TLM 05-10-02-800-001 lists the LIP 3 HPT1 blade as having a service life of 15,971 cycles.

There were also four engines undergoing shop visits that were fitted with LIP 3 HPT1 blades and nine other engines on aircraft with the same blades fitted. The engines remaining in service fitted with LIP3 HPT1 blades were undergoing ultrasonic inspection to comply with revision 2 of SB-BR700-72-900361.

Recorded data

The Australian Transport Safety Bureau (ATSB) examined the flight data recorder (FDR) information for the occurrence flight and found that the right engine had surged as the aircraft climbed through FL150.

The engine pressure ratio (EPR) and engine rotational speed indications decreased rapidly, while the turbine gas temperature (TGT) increased up to a maximum recorded temperature of 1,149°C and then remained at 1,148°C for the next 10 seconds, before decreasing (Appendix A). It is likely that the TGT reached a higher value than that recorded, however the aircraft systems did not record above 1,149^{o}C. The high pressure turbine vibration values for the right engine increased from 0.3 units before the failure to 1.3 units after the engine failure.

FDR information for previous flights, including the incident flight, comprising 17 landings and 16 complete sectors was analysed. Engine parameters for the high pressure turbine (HPT) vibration, low pressure turbine (LPT) vibration, oil pressure and oil temperature were plotted and examined. No significant differences were observed in the data recorded over that period relating to vibration of either engine.

From the examination of the FDR data, it was determined that prior to the engine failure, no anomalies were observed in the performance of the right engine and the parameters for both engines had been in close agreement.

Engine examination and repair

The aircraft operator removed the engine and shipped it to the engine manufacturer in Germany for detailed examination. That examination was conducted under the supervision of a representative of the German Federal Bureau of Aircraft Accident Investigation (BFU[7]), on behalf of the ATSB.

The engine examination showed that one HPT1 blade, serial number 053706508 at position 22, had separated from the blade disc below the blade platform as the result of an internal fracture. The engine manufacturer determined that this was the reason the remaining HPT1 blades had separated from the disc just above the blade platforms (Figure 4) and for the subsequent engine failure.

Figure 4: Damage to high pressure turbine stage 1 rotors

7 Bundesstelle für Flugunfalluntersuchung (BFU).

The engine manufacturer concluded that the blade failure had developed through low-cycle fatigue cracking similar to that of a number of other occurrences since November 2003 (see Previous events below).

The fracture surface of the blade contained multiple sites of crack initiation at the inner shank wall on the pressure side of the blade (Figures 5 and 6). The crack origin area was located directly adjacent to the internal trombone radius (Figure 3). The crack initiation was considered to be due to an increased thermo-mechanical stress level. However, the engine manufacturer reported that the crack mechanism in the LIP 3 HPT1 blade was not yet fully understood.

The engine manufacturer's technical report on the blade release dated 4 October 2007 stated that new standards for the HPT1 blades (SB72-101467/SB72-101579) with an increased trombone radius were being introduced to the fleet as part of a planned shop visit program. The report also stated that all engines with an earlier standard of the HPT1 blade were planned to be retrofitted by the end of 2008.

The report also stated that ultrasonic inspection carried out on this engine at a blade life of 3,357 cycles was:

> determined to be too early to correlate to this event and that the scheduled reinspection of this engine was not in time to avoid this event.

Figure 5: HPT stage 1 blade, position 22 showing overview of the blade pressure side where the crack initiation occurred

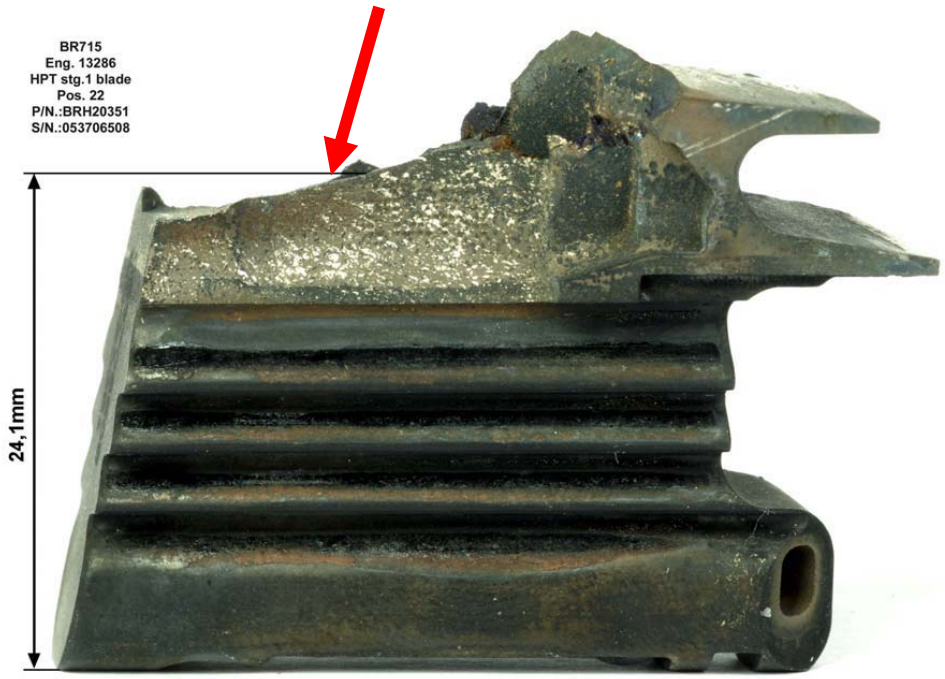
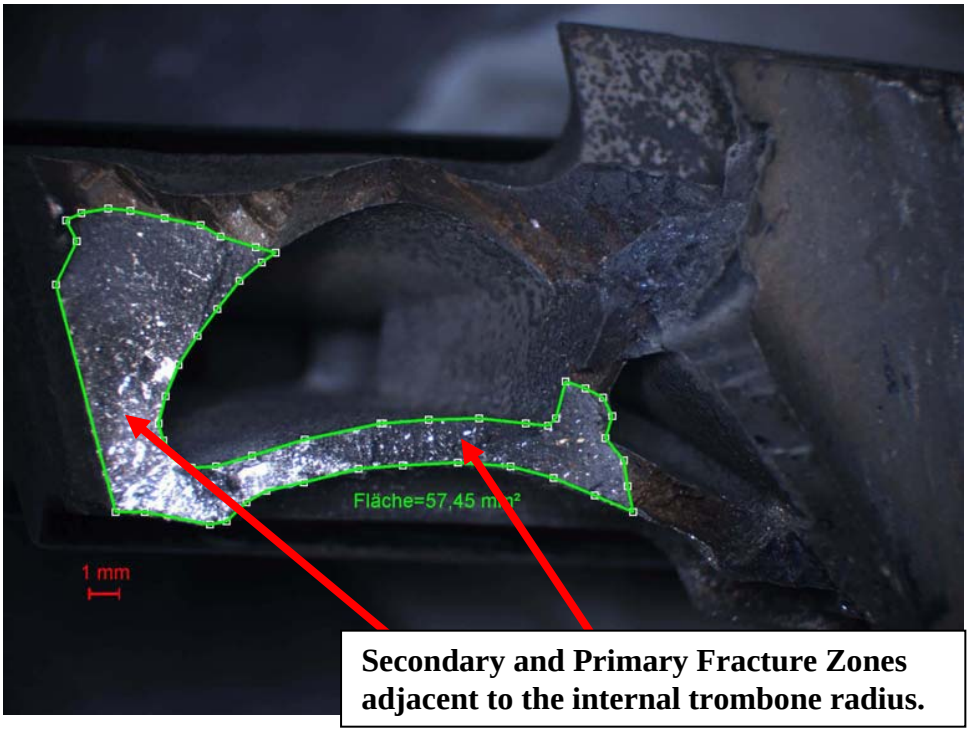


Figure 6: HPT1 blade, position 22 showing primary and secondary fracture zone (trombone cracking)



Secondary and Primary Fracture Zones adjacent to the internal trombone radius.

Engine serial number 13286 was repaired at the engine manufacturer's facility in October 2007 by replacing the damaged engine combustion and high pressure turbine module with a module that incorporated the new HPT1 blade. The engine was returned to the operator.

Previous events

There had been a number of failures of HPT1 blades in BR700-715 engines fitted with the LIP 3 HPT1 blades, including as detailed in ATSB occurrence investigation report 200402948[8]. The HPT1 blade life on that engine was at 5,417 CSN. The engine failure was due to the release of a single HPT1 blade following the development of low-cycle fatigue cracking in its internal cooling passages. This was found to be caused by potentially excessive stress levels in the larger trombone radius feature within the blades' internal cooling passages.

The engine manufacturer also found that the thickness of the vaporised aluminium coating within the internal cooling passages was variable and difficult to predict. In certain operational conditions, dependent upon high strains in areas of stress concentration and local temperature, the coating could crack with subsequent growth into the coated (parent) material. The area from which the failure occurred was confirmed to be the most susceptible to this behaviour.

8 ATSB (2006) *Engine Failure, Boeing 717-200, VH-VQA, Near Melbourne, Victoria* (Aviation Safety Investigation Report No. 200402948). Available at: http://www.atsb.gov.au/publications/investigation_reports/2004/AAIR/aair200402948.aspx

Previous safety actions

A safety action from the previous investigation was implemented by the previous operator of these aircraft in Australia. There was a possibility of a double in-flight engine shut-down event occurring with both engines fitted with LIP 3 HPT 1 blades at a cycle time where failure had previously occurred. The engine manufacturer agreed to mitigate this risk by requiring operators with both engines affected to remove the higher cycle count engine and replace it with an unaffected engine.

Another safety action undertaken by the previous operator was to introduce the on-wing ultrasonic inspection of the LIP 3 HPT 1 blades fitted to the fleet engines.

Both of these safety actions were reported as being continued by the current aircraft operator.

ANALYSIS

General

The investigation established that the failure of the right engine resulted from the fracture of a single high pressure turbine stage 1 (HPT1) blade, resulting in the remaining HPT1 blades shearing off the blade disc. Examination of the remaining section of the released blade found that it had fractured as the result of low-cycle fatigue cracking in an area adjacent to the internal trombone radius. The failure mechanism was consistent with previous life improvement package 3 (LIP 3) blade failures in the HPT1 section of the BR700-715 engines. This type of blade failure was known to the engine manufacturer and the aircraft operator.

As there was no precursor to give an indication of a pending engine failure, the crew were unable to take any action to minimise the extent of engine damage. Data downloaded from the flight data recorder also showed the failure occurred suddenly. This is consistent with a previous blade failure event investigated by the Australian Transport Safety Bureau (see Footnote 8), signifying that a blade failure of this type could occur again to susceptible LIP 3 HPT 1 blades. The measures taken to prevent further LIP 3 HPT1 blade failures included blade replacement, and on-wing ultrasonic inspection.

Service bulletin compliance

Although not mandatory, the operator did comply with the engine manufacturer's service bulletin requirements for the on-wing ultrasonic inspections of the LIP 3 HPT1 blades. The change in the service bulletin compliance for revision 2 of the ultrasonic inspection service bulletin indicates that the engine manufacturer had found that a time parameter was necessary as a measure to prevent further HPT1 blade failures.

Although revision 2 of the blade ultrasonic inspection service bulletin required a reinspection of the HPT 1 blades, the engine manufacturer's report stated that the scheduled reinspection of this engine was not in time to avoid this event. However, the blade failure occurred only 77 cycles after revision 2 of service bulletin SB-BR700-72-900361 was entered against the engine in the maintenance planning system. Had the operator scheduled an earlier inspection, it is most unlikely that this would have been completed before the engine failure event.

The time period allowed by the engine manufacturer between the intial ultrasonic inspection of the blade and the engine failure was too great to detect indications of impending blade cracking and failure. The previous ultrasonic inspection service bulletin SB-BR700-72-900361, assumed that a single inspection would detect any blades that were susceptible to failure. If there had been a requirement for repetitive inspections with previous issues of the service bulletin, the potential for blade failure may have been detected prior to the engine failure.

FINDINGS

From the evidence available, the following findings are made with respect to the In-flight engine failure on board the Boeing 717-200 registration VH-NXK and should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- Internal low-cycle fatigue cracking lead to the high pressure turbine stage-1 blade failure and the subsequent engine in-flight shutdown.
- The time-period allowed between the ultrasonic inspection of the blade and the engine failure was too great to detect indications of blade cracking.

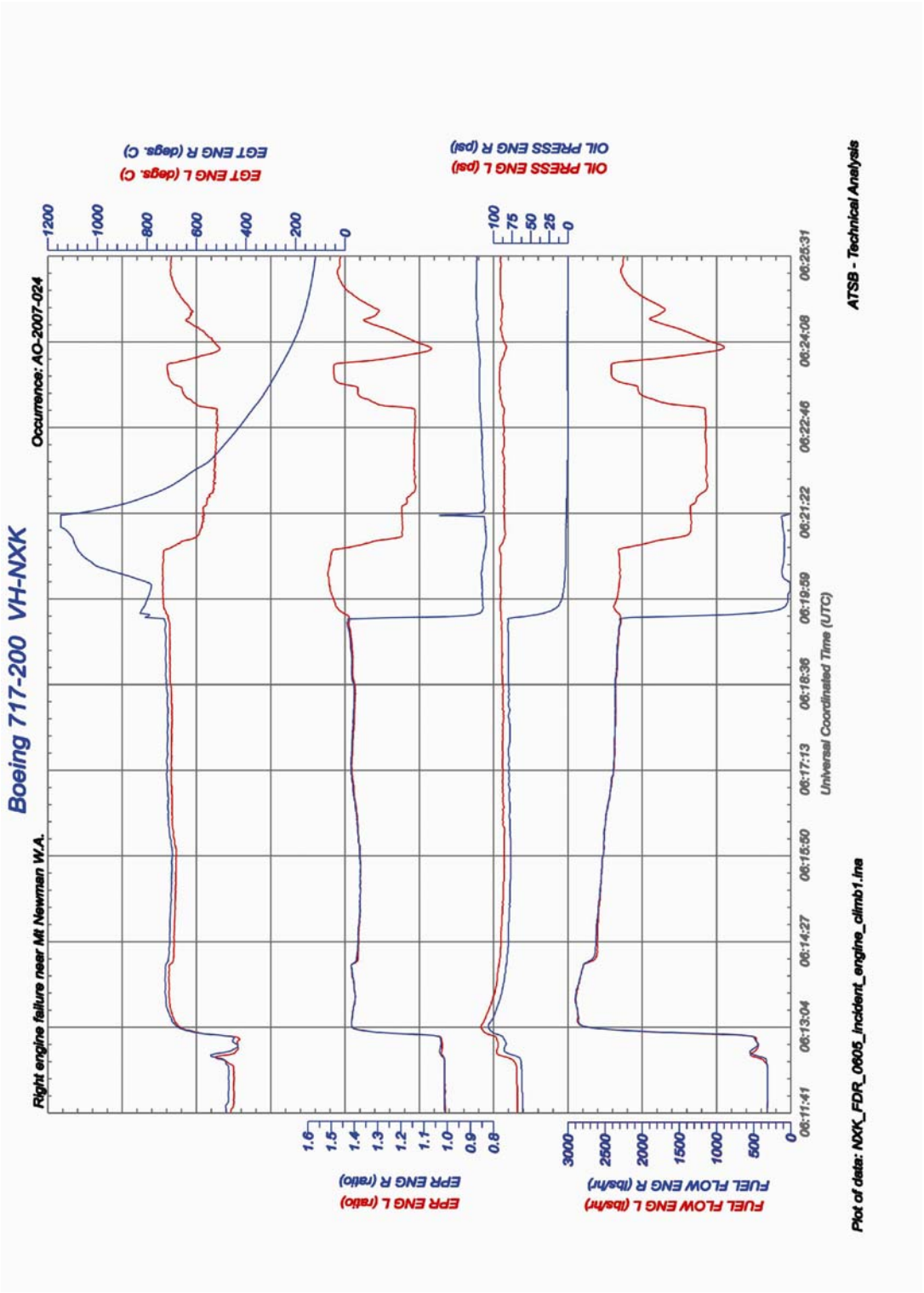
Other safety factors

- The life improvement package 3 (LIP 3) high pressure turbine stage-1 blades were known to be susceptible to low-cycle fatigue cracking in the region of the internal trombone radius.
- From the review of the recorded data, it was determined that, prior to the engine failure, no anomalies were observed in the performance of the right engine, and the parameters for both engines had been in close agreement.

Other key findings

- At the time of the incident, the aircraft operator was engaged in replacing all the LIP 3 HPT1 blades in their fleet engines with the new HPT1 blade.
- At the time of the incident, the aircraft operator had all engines in service fitted with LIP 3 HPT1 blades undergoing ultrasonic inspection in compliance with revision 2 of service bulletin SB-BR700-72-900361.
- The engine manufacturer planned for all engines with an earlier standard of the HPT1 blade to be retrofitted with the new HPT1 blade by the end of 2008.

APPENDIX A: FLIGHT DATA RECORDER PLOT



APPENDIX B: SOURCES AND SUBMISSIONS

Sources of information

The sources of information for this investigation included the:

- aircraft operator
- engine manufacturer
- accredited representative from the German Federal Bureau of Aircraft Accidents Investigation.
- Civil Aviation Safety Authority

Submissions

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

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

A submission was received from the aircraft operator. The submission was reviewed and, where considered appropriate, the text of the report was amended accordingly.