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Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Aviation Occurrence Report – 200501189

Final

In-Flight Engine Failure and Shut-Down
Boeing 717-200
148 km NNW Launceston TAS

18 March 2005

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Abstract

Boeing Company 717-200 aircraft, VH-VQB, was operating a scheduled passenger service from Launceston, Tasmania to Melbourne, Victoria when the right (number-2) engine failed during the climb to cruise altitude. After securing the failed engine, the flight crew declared a PAN condition and continued the flight to Melbourne where the aircraft landed uneventfully.

Examination of the failed BR715-A1-30 engine by the operator's maintenance staff and subsequently by the engine manufacturer under the supervision of a representative of the German Federal Bureau of Aircraft Accident Investigation (BFU), confirmed a mechanical failure within the engine high-pressure turbine section. The failure was traced to the fatigue fracture and loss of a single stage-1 high-pressure turbine blade, with the resultant cascading mechanical damage to the downstream turbine elements and the initiation of a high-temperature titanium metal fire within the high-pressure compressor stages.

Characteristics of the failed turbine blade fracture surfaces indicated that a high-cycle (vibratory) loading environment had contributed to the development of the fatigue cracking that led to the blade loss. A significant contributor to the magnitude of the vibratory blade loading was the extent of trailing edge erosion and metal loss exhibited by the turbine nozzle guide vanes (NGV). Those vanes progressively degrade in service due to the effects of oxidation and thermal cycling and are typically removed from service once the erosion and damage exceeds serviceable limits. While not evident during the examination, it was suspected that pre-existing blade mechanical damage may have acted in concert with the vibratory loads to initiate cracking.

Following the investigation, the manufacturer implemented several changes to the maintenance regime for the BR715 engine, including monitoring of the P30 engine parameter that reflects the level of NGV erosion and the mandatory replacement of eroded NGV segments that may otherwise have been repaired and returned to service.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. 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. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and findings. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. 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.

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau is pleased to report positive safety action in its final reports rather than make formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

FACTUAL INFORMATION

History of the flight

At approximately 2245 local time on 18 March 2005, a Boeing 717-200 aircraft, registered VH-VQB, was operating a scheduled passenger service from Launceston, Tasmania to Melbourne, Victoria. Passing FL220 (22,000 ft) on climb, the crew heard a single loud bang from the right (number-2) engine and felt the aircraft yaw to the right. With instruments indicating a rapid increase in exhaust gas temperature and a drop in turbine speeds, the flight crew actioned the 'Engine Fire/Severe Damage' checklist, declared a PAN condition to air traffic services and advised the cabin crew and passengers that the right engine had failed, but a normal approach and landing could be expected. As Launceston aerodrome was operating as a Mandatory Broadcast Zone (MBZ) at the time of the failure and emergency services were unavailable, the flight crew continued the flight to Melbourne, where an uneventful one-engine-inoperative approach and landing was made.

Preliminary inspection by the operator's maintenance staff revealed evidence of a mechanical failure within the high-pressure turbine section of the right engine. As a result, the engine was removed from the aircraft and after discussions with the Australian Transport Safety Bureau (ATSB), the engine was transported to the manufacturer's maintenance facility in Berlin, Germany, where a disassembly, examination and analysis was carried out under the supervision of a representative of the German Federal Bureau of Aircraft Accident Investigation (BFU).

Engine information

The aircraft was fitted with two Rolls-Royce Deutschland BR715 A1-30 turbofan engines. The failed engine (serial number 13187) had operated for 11,073 hours and through 9,380 cycles since new; accruing 8,129 hours and 6,699 cycles following the last workshop visit in January 2002. During that visit, the engine was converted to 'life improvement package' (LIP) standard, including the replacement of both stage-1 and stage-2 high pressure turbine (HPT) rotor assemblies. At that time, 14 of the original stage-1 HPT nozzle guide vane (NGV) segments were returned to service and 6 were replaced with new items as a result of excessive trailing edge erosion.

In August 2004 at 9,327 hours / 8,050 cycles, a routine maintenance inspection found further damage to the trailing edges of three, stage-1 HPT NGV's. With the damage assessed as being within the aircraft maintenance manual (AMM) limits, the engine was released for further service and re-examination at the next scheduled inspection. It was not indicated whether the damaged NGV segments were the original or new items replaced in the January 2002 workshop visit.

The aircraft operator confirmed there had been no known bird ingestion events since the engine was returned to service after the January 2002 workshop visit.

Recorded data

The aircraft was fitted with a Honeywell Solid State Flight Data Recorder (SSFDR) Part Number 980-4700-042. The operator provided the ATSB with approximately 11¾ hours of data downloaded from the FDR comprising the incident flight and six previous flights. The cockpit voice recorder (CVR) from VH-VQB was not downloaded.

Failure event

Examination of the FDR data revealed that about ten minutes after takeoff from Launceston airport and while climbing through 22,382 ft, the right engine of Boeing 717-200, VH-VQB indicated a '*surge'* condition (figure 1). At this time, both the commanded and indicated engine pressure ratios (EPR) were 1.48, fuel flow was 2,000lbs/hr, N1 and N2 were 91-92% RPM, and exhaust gas temperature (EGT) was 706-724°C. Following the surge indication, the right EPR, fuel flow, N1, N2 and oil pressure decreased abruptly. At the same time, the right engine EGT began to increase.

The commanded EPR on the right engine was reduced to 1.24, 45 seconds after the surge condition, and to 0.8, 32 seconds later. The EGT continued to increase and passed through 1,141°C[1] about 73 seconds after the engine surge indication; remaining above that level for 82 seconds, until the selection of the right engine fuel switch to the OFF position.

Following the engine shutdown, the aircraft leveled off at about 22,400 ft, before climbing to a cruise altitude of FL240, and later descending to FL200 for the remainder of the flight to Melbourne.

Vibration

Data from the flight recorder showed that the right engine HPT vibration levels had been consistently higher than the left engine levels prior to the incident (figures 2 and 3) and during the previous six flights. This was particularly evident during the climb and descent phases of the flights (figure 3) and reached a peak three flights prior to the incident flight. The right engine vibration levels had not, however, reached a high enough value to generate a vibration level exceedance warning at any time during the flights from which data was available. Analysis by the manufacturer indicated that prior to and leading up to the failure, the vibration levels of both aircraft engines were within the bounds of normal operation, with the left engine presenting particularly low vibration levels.

Information from the aircraft manufacturer indicated that engine vibration monitoring (EVM) system that records the vibration data displayed in the cockpit and recorded to the flight data recorder, does not detect high frequency vibration modes such as would be associated with degradation of the nozzle guide vane assembly. The system was designed to monitor 'once per revolution' vibration.

1 The limit of upper measurement for the EGT parameter.

Performance data

The manufacturer's review of engine performance data[2] following the January 2002 workshop visit and LIP conversion found that over the subsequent life of the engine, the compressor exit delivery pressure (P30) had reduced by four percent. The manufacturer indicated that engine parameter P30 provided an indication of the stage-1 HPT NGV condition, with a reduction in P30 caused by the opening of the NGV throat area from the degradation and loss of NGV trailing edge material.

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2 Aircraft Communication and Automatic Reporting System (ACARS) data, received and processed by Data Systems and Solutions LLC (DS&S).

Figure 1: **incident_flight_2_zoom.plt – 200 second period during time of engine shutdown showing recorded values of barometric corrected altitude, engine EPR (actual, commanded and reference), engine EGT and right engine fuel flow/ fuel switch position.**

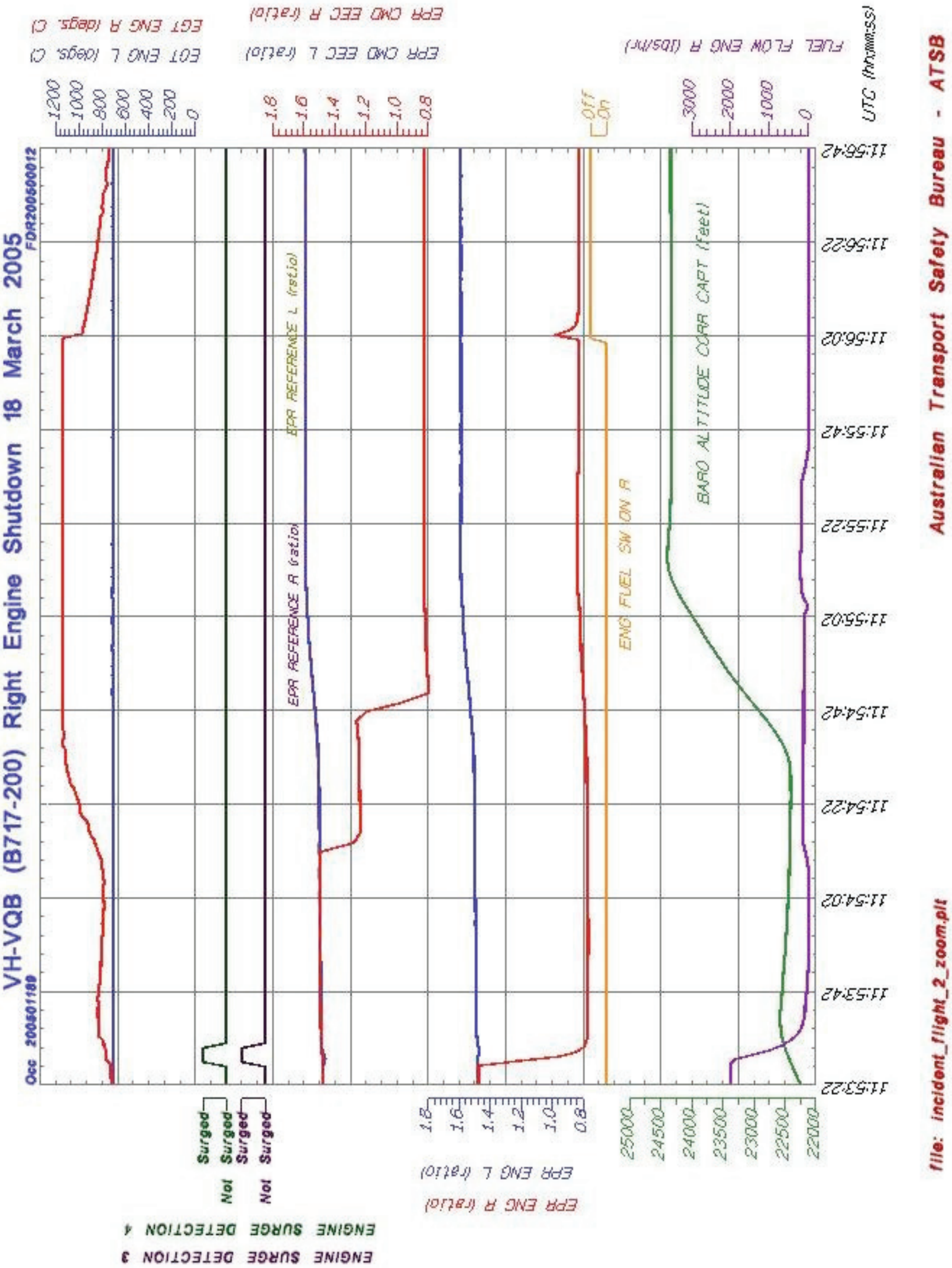


Figure 2: ***incident_flight_vibration.plt* – 20 minute period leading up to and including engine shutdown showing the recorded values of barometric corrected altitude, pitch angle, roll angle, engine out R, engine vibration levels (LPT and HPT) and engine vibration hi exceedance (LPT and HPT).**

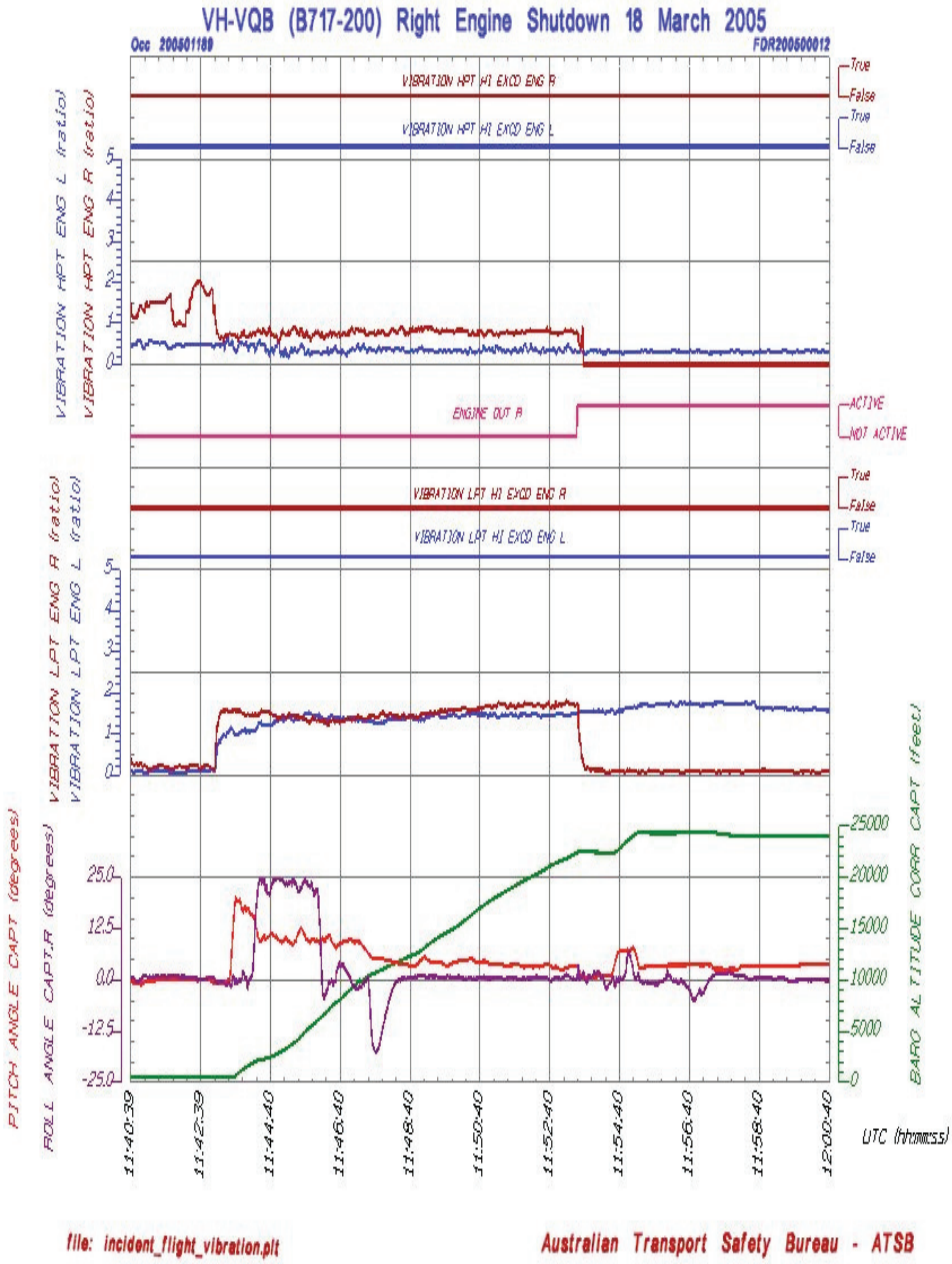
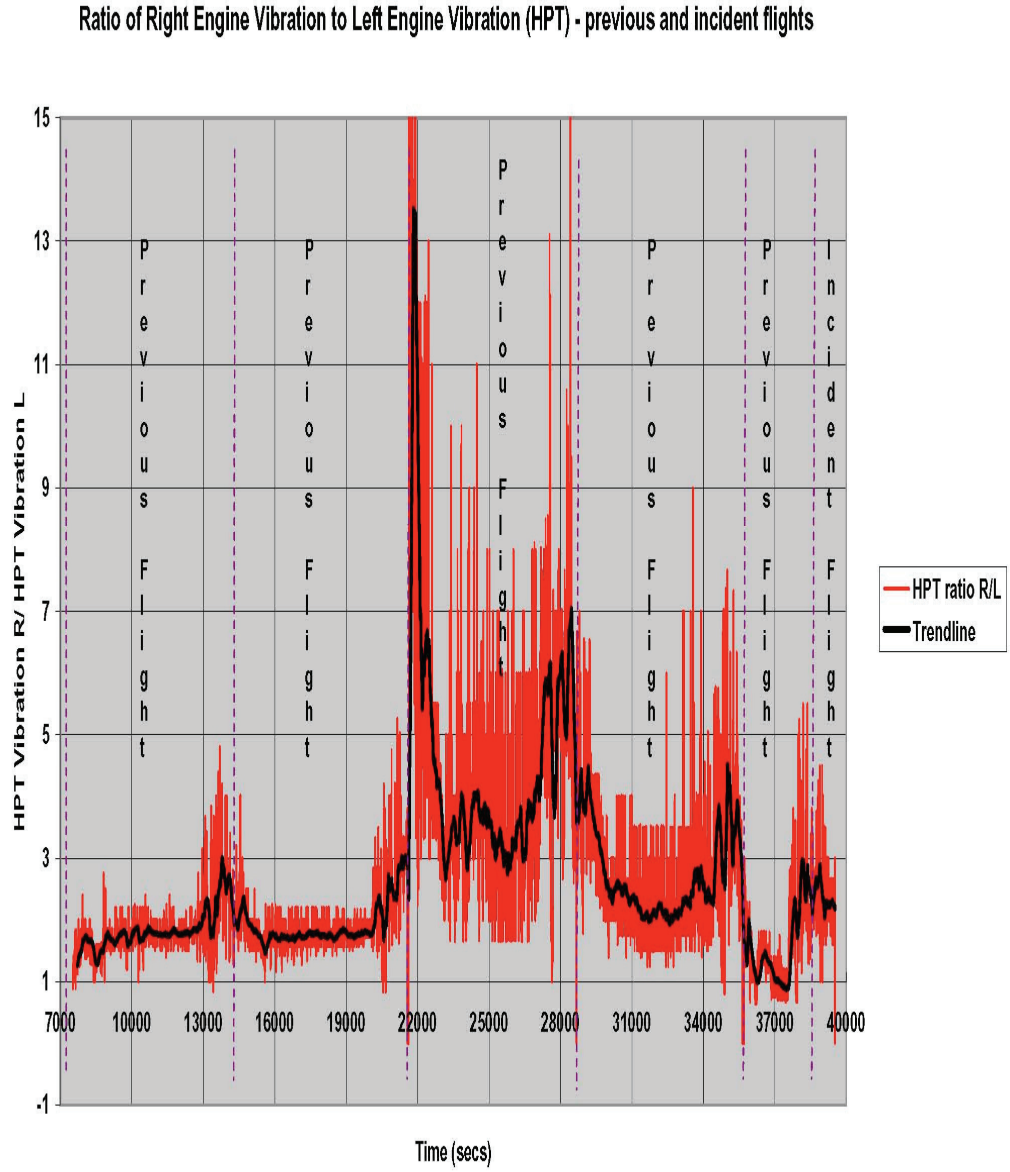


Figure 3: **Ratio of right engine vibration to left engine vibration (LPT) previous and incident flights**

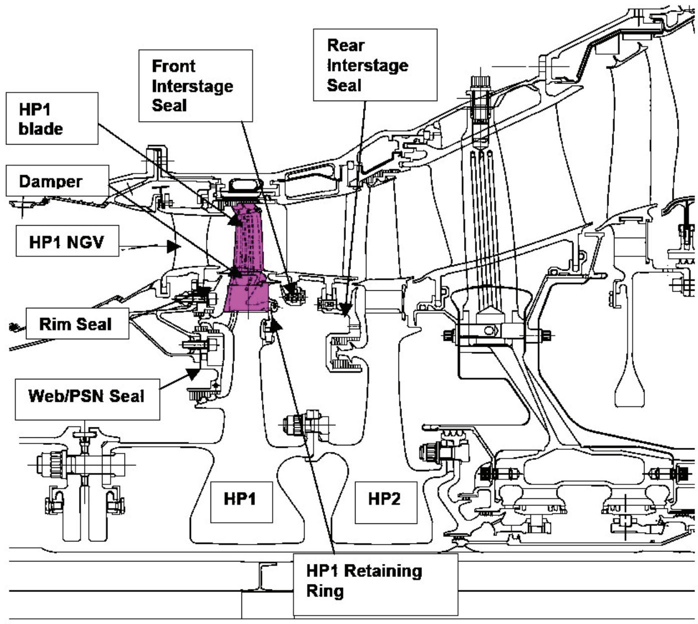


Engine examination

The engine disassembly and examination was carried out by the manufacturer under the supervision of a BFU representative acting on behalf of the ATSB. The findings of the examination were provided to the ATSB by way of a copy of the engine manufacturer's internal service investigation report[3].

Disassembly of the engine high-pressure turbine module (figure 4) revealed the fracture and loss of all blades from the aerofoil root section around the HPT1 disk. Impact damage was confined to the trailing edges of the HPT1 NGV segments, with the leading edges showing no evidence of foreign hard-object ingress. The HPT2 blades presented similar impact and forced rupture damage, with the HPT NGV segments showing leading-edge impact and thermal damage. All exposed surfaces throughout the high-pressure turbine exhibited heavy surface oxidation and metallisation deposits.

Figure 4: BR715-A1-30 engine high-pressure turbine section[4].



HPT1 blades

The characterisation of the HPT1 blade failures by the manufacturer's materials laboratory found one blade presenting clear evidence of transverse fatigue cracking above the aerofoil root transition, extending through approximately one-quarter of the blade cross section (figure 5). All other HPT1 blades showed the uneven fracture morphology typical of failure under impact overload conditions. Although damaged, the region of fatigue cracking appeared to have an origin towards the blade trailing edge cooling holes, with the subsequent propagation morphology being typical of crack growth under resonant vibratory conditions (High Cycle Fatigue, HCF). Impact and mechanical damage prevented any further characterisation of the origin region.

3 Technical Report No: O-TR0627/05-ISS01, 29-09-2005. Commercial-in-confidence.

4 References to HP1 and HP2 refer to stages 1 and 2 of the high-pressure turbine respectively.

Figure 5: Fractured HPT1 blade with annotations showing the growth of fatigue cracking.

HPT1 Nozzle guide vanes (NGV)

Despite the degree of mechanically induced damage, it was evident to the manufacturer that service-related thermal erosion damage had been sustained by the NGV aerofoil sections prior to the engine failure. After mapping the extent of the material loss, the manufacturer was of the opinion that the erosion would have been within the AMM limits at the time of engine failure, although it was acknowledged that high levels of trailing edge erosion can cause an appreciable increase in the level of vibratory stresses excited within the turbine blades. The manufacturer considered that the level of erosion presented by the engine HPT1 NGV segments would not, in itself, have been sufficient to induce a fatigue failure of a HPT1 blade from a trailing edge origin.

HPT1 Blade dampers

The first-stage high-pressure turbine blades incorporated integrated damper components seated in a pocket immediately below the blade platform. The design intent of the dampers was to modify the blades' vibratory excitation behaviour, reducing exposure to damaging high-cycle fatigue loading. Upon examination, the manufacturer noted that all HPT1 blades exhibited abnormal galling and adhesive wear within the damper pockets and on the damper external surfaces, suggesting anomalous operating conditions and a possible loss of damping behaviour as a result of the galling. Stress analysis carried out by the manufacturer to model the influence of blade dampening found that in the event that the blade dampener function became inhibited or lost during engine operation, fatigue cracking should not be initiated within the trailing edge cooling hole region.

HPT2 Components

All damage to the HPT2 bladed disk and nozzle guide vanes was consistent with the passage of fragmented materials from the stage-1 HPT and the internal temperature excursion.

HPT Casing

Although deformed and outwardly distorted in the circumferential region surrounding the first-stage disk, there was no evidence that the casing had been ruptured or that the containment of the rotating assembly had been compromised.

HP Compressor and combustor

Stages 3 through 10 of the high-pressure compressor had sustained blade tip melting and rounding, consistent with the effects of an internal titanium fire. Foreign object damage was not observed, nor were any indications of anomalous or uneven combustion conditions that could have provided an impetus for the excitation of blade resonance modes.

Blade failure mechanism

The engine manufacturer reported no previous instances of blade failure by HCF above the root platform and considered the event to be unrelated to the history of previous HPT blade releases that had developed from sub-platform cracking[5].

The manufacturer also considered that no single source of increased blade forcing and excitation, such as nozzle guide vane trailing edge erosion, blocked burners or ineffective dampers, would have produced the cracking and release of a HPT stage-1 blade in the manner experienced.

As a possible failure mechanism, the engine manufacturer proposed that a portion of an eroded HPT stage-1 NGV vane may have released and damaged the trailing edge of an HPT blade, which subsequently cracked under HCF conditions stemming from NGV deterioration and the stress-raising effects of the trailing edge damage.

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5 ATSB Occurrence 200402498, VH-VQA, 10 August 2004

ANALYSIS

Engine failure

The investigation established that failure of the right engine from VH-VQB resulted from the fracture and liberation of a single blade from the first-stage high-pressure turbine rotor. The impact of the released blade segment with the adjacent blades produced the rapid cascading overload fracture of all remaining blades in the stage and the heavy down-stream damage. The recorded EGT excursion for the 131 second period between the initial failure and fuel shut off was reflected in the level of oxidation and overheating damage of the turbine components. Metallisation and spatter over the HPT internal surfaces was a likely product of the HPC titanium fire and associated EGT excursion.

Blade failure

Failure of the HPT stage-1 blade was attributed to the initiation and growth of high-cycle fatigue cracking transversely through the blade lower aerofoil section. Damage to the trailing edge region precluded the characterisation of the fatigue origin and prevented the establishment of the manner in which the cracking initiated.

Blade cracking

The presence of a blade manufacturing flaw acting as a primary crack initiator was considered unlikely, given the appreciable service time and cycles that the blade had accrued. It followed therefore, that blade cracking had developed from isolated local blade damage or deterioration, or from anomalous operating conditions developing within the engine, exciting blades to levels of resonant vibration outside the design intent. The engine manufacturer concluded that in view of the absence of physical evidence and the results of stress analyses on the effects of increased blade excitation, it was unlikely that any single factor had acted in isolation to produce the cracking and failure sustained. The manufacturer proposed a possible scenario whereby increased vibratory excitation from the stage-1 NGV erosion acted in synergy with localised mechanical blade damage, to initiate blade HCF cracking. Although unsubstantiated by direct evidence, the ATSB agrees that NGV deterioration was a likely contributor to the development of blade cracking in this instance, having been known to have induced premature fatigue cracking and turbine blade failure in other engine types[6].

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6 ATSB Occurrence 200104983, VH-VEH, 11 October 2001

Vibration

The fretting damage exhibited by the HPT blade dampers was consistent with sustained exposure to elevated vibration levels associated with degradation of the HP NGV assembly. Damage to the blade dampers can lead to a loss of the normal vibration damping effect, thus allowing the development of greater blade resonant stress levels and predisposing the blades to high-cycle fatigue cracking.

FINDINGS

Contributing factors

The following factors were identified as significant to the development of the engine failure event.

- During engine maintenance in 2002, 14 of the original 20 HPT1 NGV segments were returned to service.
- The first-stage high-pressure turbine nozzle guide vanes of the BR715 A1-30 turbofan engine, like those of other comparably designed engines, are subject to trailing edge erosion and metal-loss during extended service, as a result of high-temperature oxidation and thermal cycling.
- The erosion and loss of material from the trailing edge of the HPT1 NGV segments produced an increase in irregular turbine blade forcing and subsequent vibratory excitation levels.
- Elevated high frequency blade vibration levels contributed to the development of fatigue cracking within the turbine blade aerofoil section.

SAFETY ACTIONS

As a result of investigations into the failure of the right engine from VH-VQB, the engine manufacturer has implemented the following measures to reduce the likelihood of future occurrences resulting from the same or similar contributory factors.

- Monitoring of the P30 engine parameter and requiring a borescope inspection of the HPT1 NGV assembly once the parameter decreases below 96.5 percent of initial values. A reduction in the P30 parameter provides an indicator of degradation and metal-loss within the NGV assembly.
- Changes to the maintenance requirements for the hot-section of the engine during routine or unplanned workshop visits, requiring the replacement of degraded HPT1 NGV segments that would otherwise have been repaired and returned to service.
- Design action to improve the robustness of the HPT1 NGV assembly and the functionality of the HPT blade dampers. Service bulletins SB-BR700-101579 and SB-BR700-101546 have been released to implement changes to the blade and NGV configuration aimed at reducing the potential for premature NGV degradation and enhancing blade vibration damper reliability.