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ATSB TRANSPORT SAFETY REPORT
Aviation Occurrence Investigation AO-2009-069
Final

In-flight engine malfunction and air turn-back 120km SW of Brisbane Airport 10 November 2009

Abstract

On 10 November 2009 at around 1900 EST, a Boeing Company 737-467 aircraft, registered VH-TJY, departed Brisbane Airport, Queensland for Melbourne, Victoria. As the aircraft was climbing through 24,000 ft, the flight crew observed abnormal indications associated with the right engine. The aircraft was returned to Brisbane where it landed without further incident.

Engine disassembly and inspection revealed significant damage to the stage-1 low-pressure turbine (LPT). Analysis of the stage-1 LPT blades showed that some blades had sustained levels of thermally-induced microstructural degradation, which may have affected the creep resistance of the alloy and resulted in the blades being susceptible to failure by creep rupture.

Creep rupture was identified as the likely failure mechanism in previous stage-1 LPT blade failures in this engine type investigated by the Australian Transport Safety Bureau and the engine manufacturer. As a result of this occurrence and at the time of writing this report, the engine manufacturer is revising service bulletin SB 72-1113 to expand the range of blade manufacturing batch numbers that had previously been identified as being predisposed to creep-related failure. Blades in the identified batches are to be withdrawn from service as soon as they are next removed from the engine.

FACTUAL INFORMATION

History of the flight

On 10 November 2009 at around 1900 Eastern Standard Time[1], a Boeing Company 737-467 aircraft, registered VH-TJY, departed Brisbane Airport, Queensland on a scheduled passenger service to Melbourne, Victoria. At approximately 1930, as the aircraft was climbing through 24,000 ft, the crew reported hearing a loud thump from the right side of the aircraft, accompanied by a rise in exhaust gas temperature (EGT) and engine vibrations outside of normal limits.

The crew retarded the right engine thrust lever and the engine indications returned to normal levels. At this time, a non-normal checklist for engine limit / surge / stall was also completed. The aircraft was returned to Brisbane and landed without further incident. As a precaution, the right engine was shut-down during taxi.

Preliminary borescope inspection by the operator's engineering staff revealed significant damage to the low pressure turbine (LPT) assembly. The CFM56-3C-1 engine (Figure 1) was subsequently returned to an overhaul facility in Melbourne, Australia for disassembly and inspection, overseen by Australian Transport Safety Bureau (ATSB) investigators.

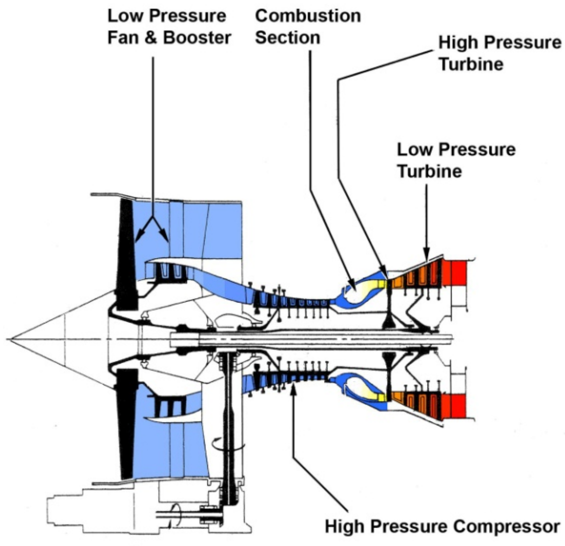
1 The 24-hour clock is used in this report to describe the local time of day, Eastern Standard Time (EST), as particular events occurred. Eastern Standard Time was Coordinated Universal Time (UTC) +10 hours.

Figure 1: Right engine from VH-TJY

Engine examination

The CFM56-3C-1 is a high-bypass, dual-rotor, axial-flow, turbofan engine (Figure 2). Separation of the LPT major module (Figure 3) revealed that all of the stage-1 LPT blades had fractured between the blade platform and mid-span (Figure 4).

Figure 2: Cross-section of CFM56-3 series engine



There was no significant damage upstream of the stage-1 LPT disk. Damage to the downstream LPT components was consistent with passage of the liberated blade debris.

Most of the stage-1 LPT blades exhibited significant cracks, nicks and dents consistent with multiple impacts from the blade debris. The surrounding air seal also exhibited extensive associated damage. Many of the blades showed a degree of bending opposite to the direction of rotation, consistent with a cascading collapse of the blade set. There was no evidence of blade melting or distortion that might have been indicative of an extreme overtemperature event.

Figure 3: LPT stage 1 rotor disk and blades

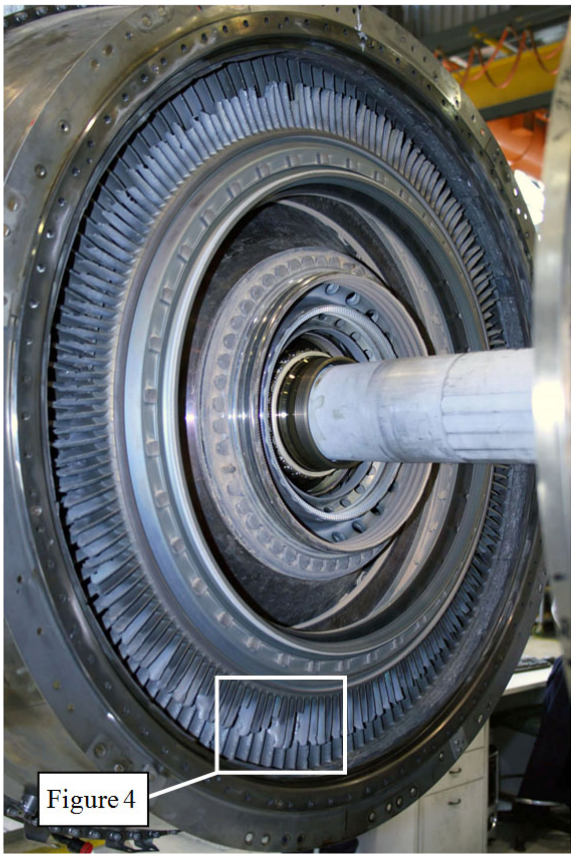
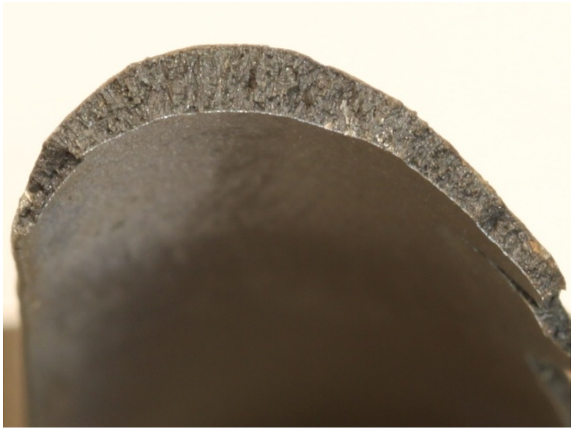


Figure 4: LPT stage 1 blades

LPT blade examination

The stage-1 LPT disk contained 174 blades, all of which exhibited semi-crystalline fracture surfaces, typical of overload fractures and consistent with the secondary fractures associated with impacts from blade debris (Figure 5). There were no indications of progressive failure or pre-existing defects on any of the blades.

Figure 5: **Typical appearance of blade fracture surfaces**



A yellow-green surface colouration observed on some of the blades was attributed to a protective aluminide coating applied during a previous blade repair.

The blade manufacturing batch numbers contained a two letter prefix, followed by a series of 5 or 6 numbers. Of the installed blades, 168 had either a 'JB', 'RB' or 'DL' prefix and several of those blades were selected for sectioning and microstructural examination (Table 1).

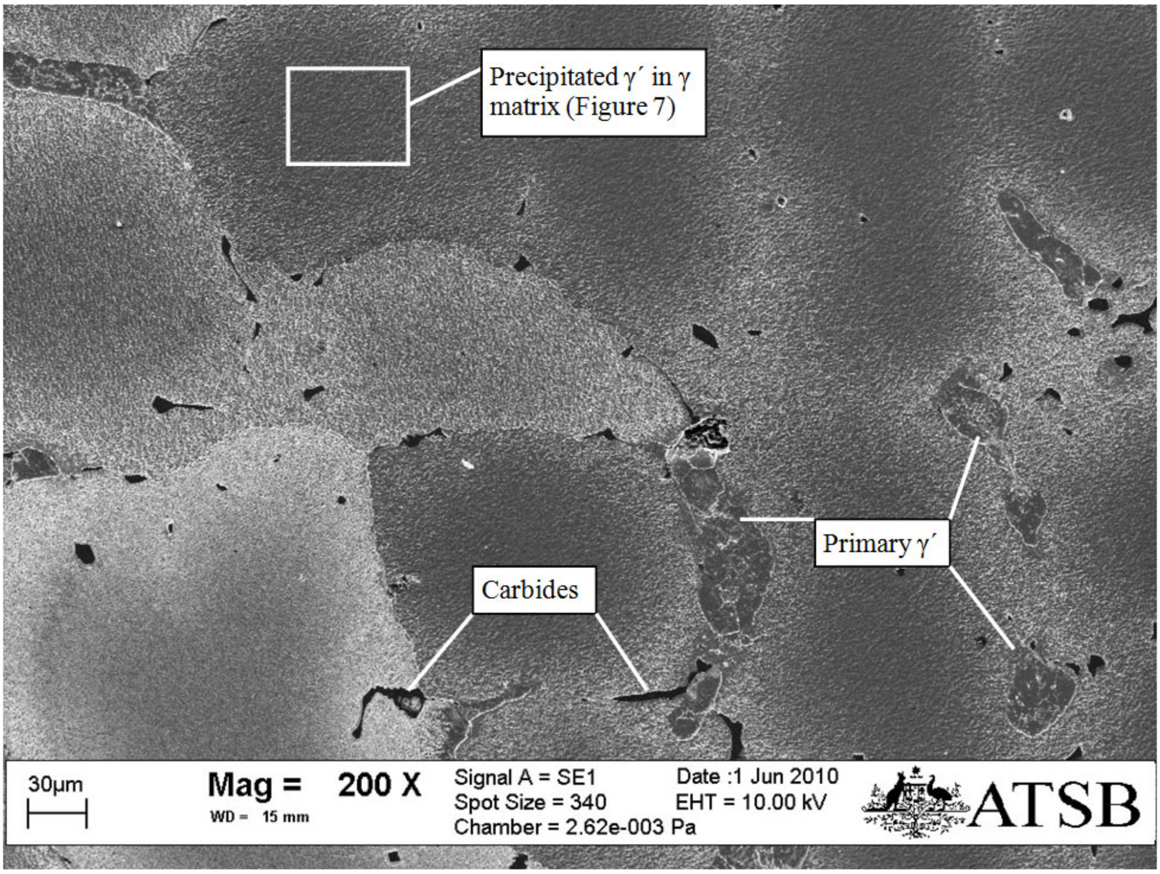
Table 1: **Stage-1 LPT blade manufacturing batch numbers selected for microstructural examination.**

DL223451	JB80489
DL223453	RB16870
DL223452	RB16875
JB80461	RB16878

The blades were sectioned transversely (from leading to trailing edge) through sections at the fir-tree root and at the approximate blade airfoil mid-span position. Microstructures of these blades were compared to those of a selection of exemplar, used blades from the aircraft operator's unserviceable stock.

Baseline microstructures (representative of the as-cast part) of all blade root sections featured a finely-dispersed gamma-prime (γ') precipitate within a gamma (γ) matrix containing a dispersion of larger primary γ' islands and carbide particles (Figure 6).

Figure 6: **Typical turbine blade root, baseline microstructure (Kalling's No.2 etch, 200x mag)**



Airfoil section microstructures from the 'RB' and 'JB' prefixed blades exhibited a degree of thermal degradation in the form of γ´ coarsening and coalescence, when compared to the baseline (root) microstructures of the same blades (Figures 7 and 8), as well as some grain boundary γ´ re-precipitation. Similar degrees of γ´ coalescence were noted in the exemplar blade microstructures. The 'DL' blade airfoil sections were similar in microstructural appearance to the blade roots and did not exhibit any coalescence.

There was no information available detailing the level of thermal degradation necessary to produce an in-service failure during normal engine operation.

Figure 7: Microstructure through blade root showing finely dispersed γ´ (Kalling's No.2 etch, 2000x mag.)

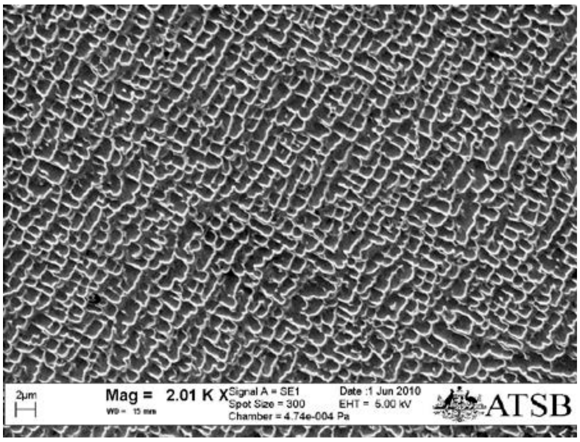
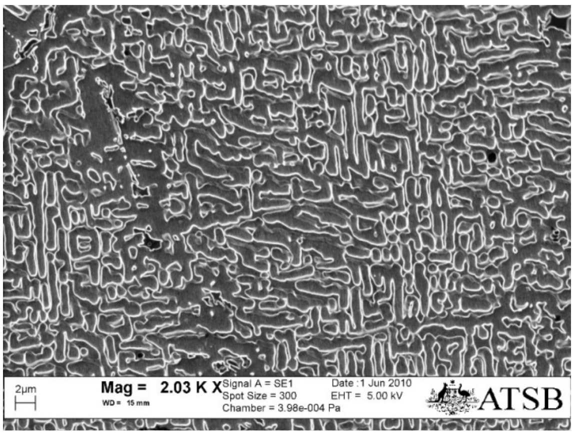


Figure 8: Same blade as Figure 7. Airfoil microstructure showing γ´ coalescence (Kalling's No.2 etch, 2000x mag)



Blade Chemistry

A selection of blades from the batches listed in Table 1 was submitted for chemical analysis. In all instances, the chemistry was consistent with the IN-100 alloy from which the blades were produced. There were no significant variations in the chemistry of the blades tested.

Engine history

The 737-467 aircraft (S/N: 28151) was powered by two CFM56-3C-1 engines. At the time of the occurrence, the subject engine (S/N: 858322) had accumulated 36,087 hours and 21,927 cycles since new. The last engine workshop visit was in August 2006 for replacement of time expired, life-limited parts, including the LPT stage 1 disk (P/N: 301-331-126-0 S/N: BC769203). The engine had operated for 4,785 hours and 3,587 cycles since that time.

Low-pressure turbine blades were not life-limited components, and as such, the manufacturer placed no requirements on the recording of their operational history. The blades were maintained on-condition[2], including additional inspections as required by the aircraft maintenance manual for inadvertent engine operations above maximum limits (including EGT overtemperature events). Those blades exhibiting defects within allowable rework limits may be repaired and then returned to the operator's reserve of serviceable blades. Turbine disks may then be reassembled from a pool of new and repaired blades. Microstructural examination of the blade material was only required following overtemperature events where there was visible evidence of physical distortion or blade melting.

A review of the engine on-wing history, as provided by the aircraft operator, revealed that the subject engine had a history of exhaust-gas temperature (EGT) excursions. Five high EGT alert events during takeoff had been reported by the aircraft communications and automatic reporting system (ACARS) since the last workshop visit. EGT overtemperature events require maintenance action that is dependent on the maximum

2 A preventative maintenance regime, where a determination of the continued serviceability of a component is based on periodic visual, dimensional, or other appropriate inspections.

temperature reached, duration of the temperature excursion, phase of flight and number of exceedences. Records showed that the EGT excursion events for engine 858322 had been addressed where necessary.

Engine condition trend monitoring (ECTM) data for the months leading up to the occurrence showed no abnormal changes in the monitored parameters that may have indicated an impending failure event.

Recorded data

The aircraft was fitted with a quick access recorder (QAR) which records flight data on a medium which is easily accessible to the operator for the purpose of monitoring systems on the aircraft. The aircraft operator provided the ATSB with QAR data pertaining to the occurrence flight and the previous 14 flights.

The CFM56-3 engine is fitted with a vibration monitoring system comprising two engine-mounted accelerometers, each analysed for response at the engine's LP and HP shaft speeds. The accelerometer outputs are processed through signal conditioners to compensate for the vibrations from the speed/frequency of the engine. The vibration value is dimensionless and is the maximum of the LP and HP values from the two accelerometers. A maximum of 5 units can be displayed by the cockpit indicator.

A general analysis of the recorded flight data confirmed the details of the occurrence. While passing through 24,000 ft, the right engine LPT vibration level increased to approximately 3.5 units. The right engine thrust lever was retarded to 17 degrees, however the vibration level continued to increase gradually, reaching a peak of around 4 units. At the top of descent, both thrust levers were retarded to zero degrees, whereupon the vibration level decreased and stabilised at 2.5 units for the remainder of the flight.

Examination of the data from the previous flights showed no anomalous characteristics or possible indications of a developing engine problem.

Previous occurrences

In 2006, the ATSB investigated an in-flight engine malfunction and air turn-back involving a Boeing 737 aircraft fitted with CFM56-3C-1 engines (ATSB investigation number 200605620). In that occurrence it was found that a similar mechanical failure had occurred within the first stage LPT.

The investigation concluded that thermally-induced microstructural creep[3] damage had contributed to the failure of the stage 1 LPT blades and subsequent damage to the LPT module. During that investigation, the engine manufacturer reported that seven CFM56-3 engines had sustained stage-1 LPT failures between July 2006 and February 2007. It was concluded that creep rupture was the likely failure mode affecting all seven engines.

The manufacturer's investigations into the previous failures identified a range of stage-1 LPT blade manufacturing batches as being predisposed to premature creep-related failure. There were no features or properties of the blade manufacture that identified the batches with this predisposition, but all of the failed blades produced in those batches were identified as having originated from the same raw material cast. In December 2007, the engine manufacturer communicated with operators regarding this issue and provided detail on the known range of suspect blades. Progressive revision of the suspect batch number ranges subsequently occurred, culminating in the release of service bulletin SB 72-1113 in July 2009. That service bulletin instructed that the stage 1 LPT blades within the specified batch ranges be removed from service as soon as they were next removed from the engine. The engine manufacturer was not aware of any further instances of creep-related stage-1 LPT blade failure between February 2007 and the subject occurrence in November 2009.

Some of the blades installed in engine serial number 858322 (the subject failed engine) were found to lie within the original suspect blade batch range identified by the manufacturer in December 2007, but were not listed in SB 72-1113.

ANALYSIS

The abnormal indications from the right engine of VH-TJY were as a result of mechanical breakdown of the stage-1 low pressure turbine (LPT)

3 Creep refers to the permanent deformation of a material under the influence of stress below the material's normal yield point.

assembly. Damage to the turbine blades was consistent with a cascading collapse of the turbine blade set, where an initiating failure event resulted in multiple consequent blade failures through contact with the circulating blade debris.

The investigation was unable to identify the exact initiating event that precipitated collapse of the LPT blades. Examination of the blades did not reveal any evidence of contributory blade defects or fatigue cracking. Although the microstructure of the LPT blades had undergone a degree of thermal degradation, it was not known how much degradation the material could sustain before it would result in an in-service failure.

Similar stage-1 LPT failure occurrences investigated by the engine manufacturer were all attributed to a creep rupture mechanism. Turbine blades experiencing creep-extension outside of normal limits could result in excessive interference between the integral blade shroud and mating stationary honeycomb seals, and lead to a collapse of the blade set (as sustained by engine 858322).

Nickel-based superalloy microstructures are primarily comprised of gamma-prime (γ') precipitate in a gamma (γ) matrix. The strength of these alloys and their resistance to creep is heavily influenced by the volume fraction, size and distribution of γ' precipitate. Thermally-induced microstructural degradation of the alloy, in the form of coalescence or coarsening of the small, finely dispersed γ' precipitate, may predispose the turbine blades to a creep-related failure. The degradation is a cumulative effect and progresses more rapidly with increasing temperature.

At the time of this event, it was not possible to quantify the service life of individual blades and their predisposition to creep-rupture.

FINDINGS

Context

From the evidence available, the following findings are made with respect to the abnormal engine event sustained by Boeing 737 aircraft VH-TJY on 10 November 2009, resulting in an air turn-back from approximately 120km south west of Brisbane Airport. The findings should not be read as apportioning blame or liability to any particular organisation or individual.

Contributing safety factors

- The in-flight malfunction of the aircraft's right engine was a result of a cascading rupture of the stage-1 LPT blades.
- Fracture of the stage-1 LPT blades was probably precipitated by thermal degradation of the blade alloy, resulting in excessive creep extension, tip shroud/seal interference and blade rupture.
- Material characteristics of some of the LPT blades installed in engine 858322 were consistent with a raw material manufacturing cast that had previously been identified as being susceptible to creep rupture *[minor safety issue]*.

Other key findings

- LPT blades do not have a manufacturer-prescribed service life and there is no requirement to record the service history of individual blades.

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.

CFM International

Safety Issue

Material characteristics of some the LPT blades installed in engine 858322 were consistent with a raw material manufacturing cast that had previously been identified as being susceptible to creep rupture *[minor safety issue]*.

Action taken by CFM International

As a result of this occurrence and at the time of writing this report, the engine manufacturer is revising service bulletin SB 72-1113 to expand the range of blade manufacturing batch numbers that had previously been identified as being predisposed to creep-related failure. Blades in the batches identified in the service bulletin are to be withdrawn from service as soon as they are next removed from the engine.

SOURCES AND SUBMISSIONS

Sources of Information

Aircraft Operator

Engine Manufacturer

References

I.E. Treager, *Aircraft Gas Turbine Engine Technology,* 3rd Ed. Glencoe Aviation Technology Series, McGraw Hill, 1999, Ohio USA.

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 National Transportation Safety Board.

Submissions were received from aircraft operator, the engine manufacturer and the Civil Aviation Safety Authority. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly