Australian Government
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ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Technical Analysis 23/2006

Final

High Pressure Turbine Blade Fracture
CFM56-3C1
Engine Test Cell, 7 July 2004

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

Published by: Australian Transport Safety Bureau
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DOCUMENT RETRIEVAL INFORMATION

Report No.	**Publication date**	**No. of pages**	**ISBN**
TA2006/23	15 June 2006	14	1 921092 56 4

Publication title

High Pressure Turbine Blade Fracture, CFM56-3C1, Engine Test Cell. 7 July 2004

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Abstract

During the performance testing of a CFM56-3C1 engine (engine s/n 725274) in an engine test cell, 7 July 2004, a severe shift in the engine exhaust gas temperature was observed when the engine was operated at take-off power. Subsequent borescope inspection revealed that sections of two adjacent high-pressure turbine (HPT) blade airfoils had broken away. Examination of the blades revealed that blade s/n GSH81 fractured through the blade airfoil section as a result of fatigue crack growth. Fatigue cracking initiated in the fourth internal rib from a planar defect created by intergranular oxidation. The loss of material from the leading edge of the adjacent blade, s/n 331R5, was a secondary event.

HPT blade fracture control depends on the prevention of intergranular oxidation that creates defects that allow fatigue crack propagation to occur under the thermal and alternating stress conditions imposed on a blade.

Variability in the nature of defects created by intergranular oxidation may be related to variations in the grain structure of other blades of the same design and the effectiveness of oxygen diffusion barriers at the surface of the internal ribs in the blades.

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).

1 CFM56-3 HIGH PRESSURE TURBINE BLADE FRACTURE, P/N 1475M35P01, S/N GSH81

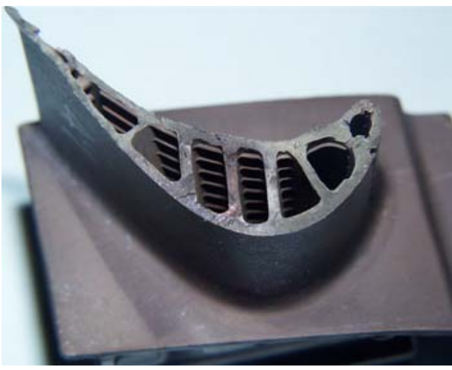
1.1 Introduction

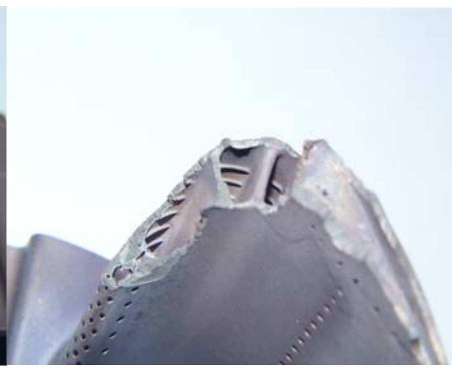
During the performance testing of a CFM56-3C1 engine (engine s/n 725274) in an engine test cell, 7 July 2004, a severe shift in the engine exhaust gas temperature (EGT) was observed when the engine was operated at take-off power. Subsequent borescope inspection revealed that sections of two, adjacent, high pressure turbine (HPT) blade airfoils had broken away.

The engine had been subjected to a full performance workscope, which included a recondition workscope of the HPT rotor engine module unit.

Because the HPT blade failures occurred while the engine was not attached to an aircraft, it was not a reportable occurrences under the TSI Act 2003. However, because of the nature of the failure and its potential threat to thrust system reliability, the ATSB conducted an investigation under the TSI Act in concert with the operator and General Electric (GE). The ATSB investigation was limited to a non-destructive examination of the physical evidence. General Electric completed a destructive examination of the HPT blades.

Figure 1: The damaged blades among the HPT blade set removed from engine 725274 (Operator photographs)





Blade 49 (s/n GSH81) Blade 48 (s/n 331R5)

1.1.1 HPT Blade History

Blade s/n GSH81, p/n 1475M35P01, total time in service 24350 hours, 14373 cycles.

Repair status M1CN2 (1st 'mini' tip repair using Rene 142 weld filler), previous repairs G18 (1st 'full' repair using Rene 80 weld filler), G22 (2nd 'full' repair using Rene 142 weld filler)

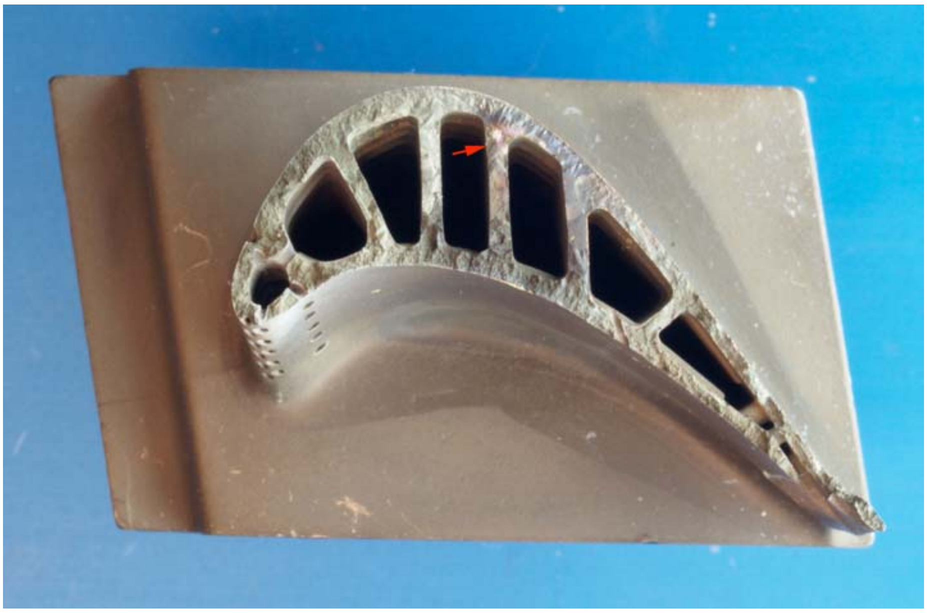
Blade s/n 331R5, p/n 1475M35P01, total time in service 33436 hours, 19589 cycles.

Repair status M2CNR2 (2nd 'mini' tip repair using Rene 142 weld filler, including coating rejuvenation), previous repairs G1A8 (1st 'full' repair using Rene 80 weld filler), M1G2 (1st 'mini' tip repair using Rene 142 Rene weld filler).

1.2 Physical Evidence

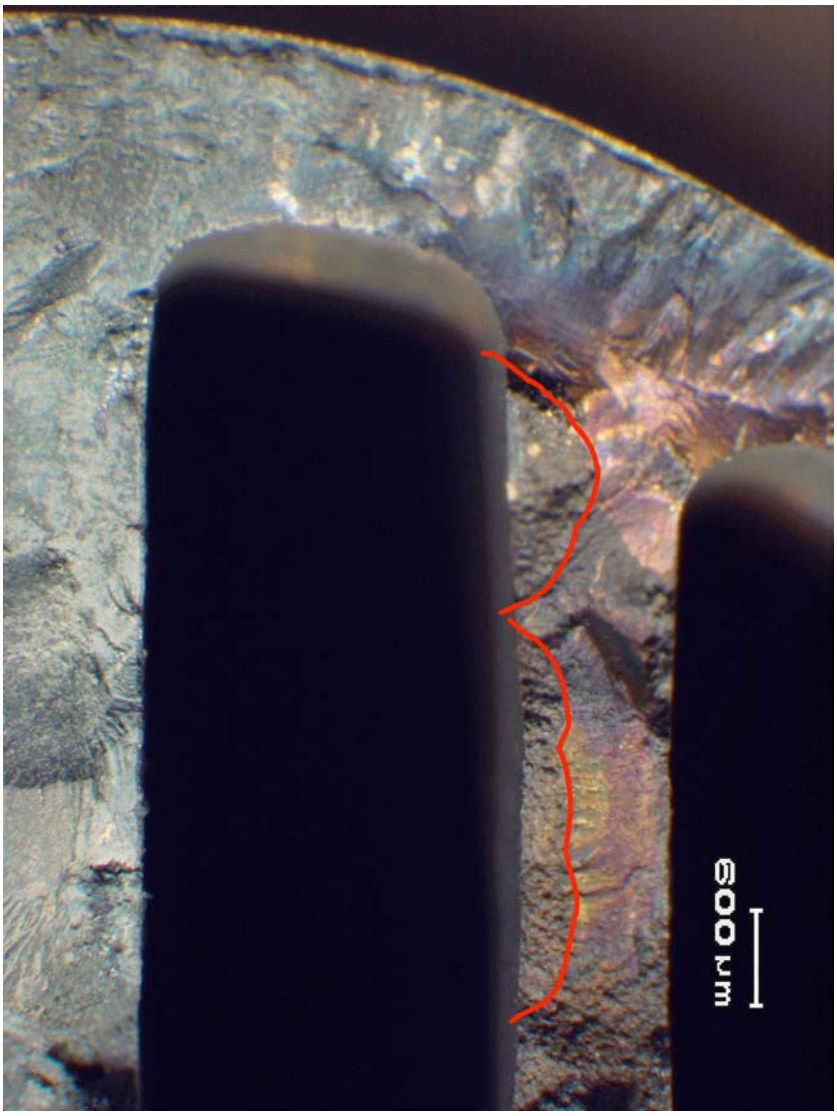
Examination of the blades revealed that blade s/n GSH81 (no. 49) fractured through the blade airfoil section as a result of fatigue crack growth. Fatigue cracking initiated from a planar defect in the fourth internal rib (ribs numbered from the leading edge), see figures 2 and 3. The loss of material from the leading edge of the adjacent blade (blade s/n 331R5, no. 48) was clearly a secondary event.

Figure 2: Blade GSH81 fracture



The site of fatigue initiation is arrowed

Figure 3: Photomacrograph of the planar defect at the site of fatigue crack initiation



The extent of the planar defect extending from the face of the fourth internal rib is delineated, approximately, by the red line.

Scanning electron microscopy revealed that the 'planar defect' exhibited a more heavily oxidised surface when compared to the region of fatigue crack growth, see figures 4 and 5.

Figure 4: Scanning electron micrograph showing the differences in the fracture surface morphology between the planar defect and the fatigue crack surface

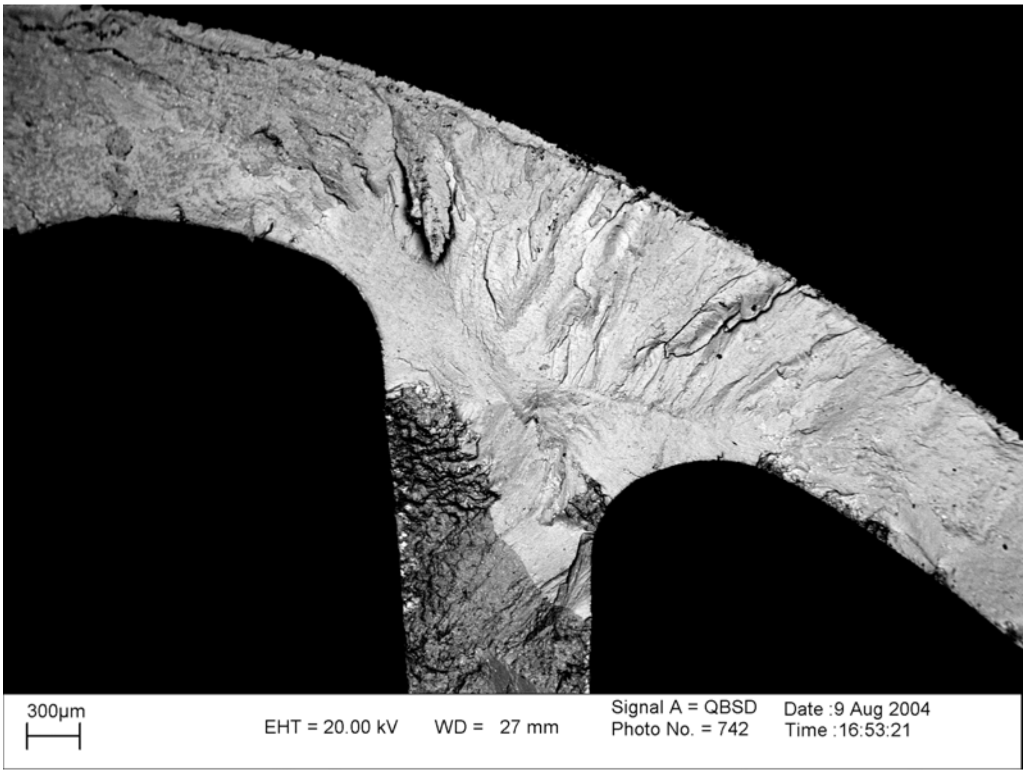
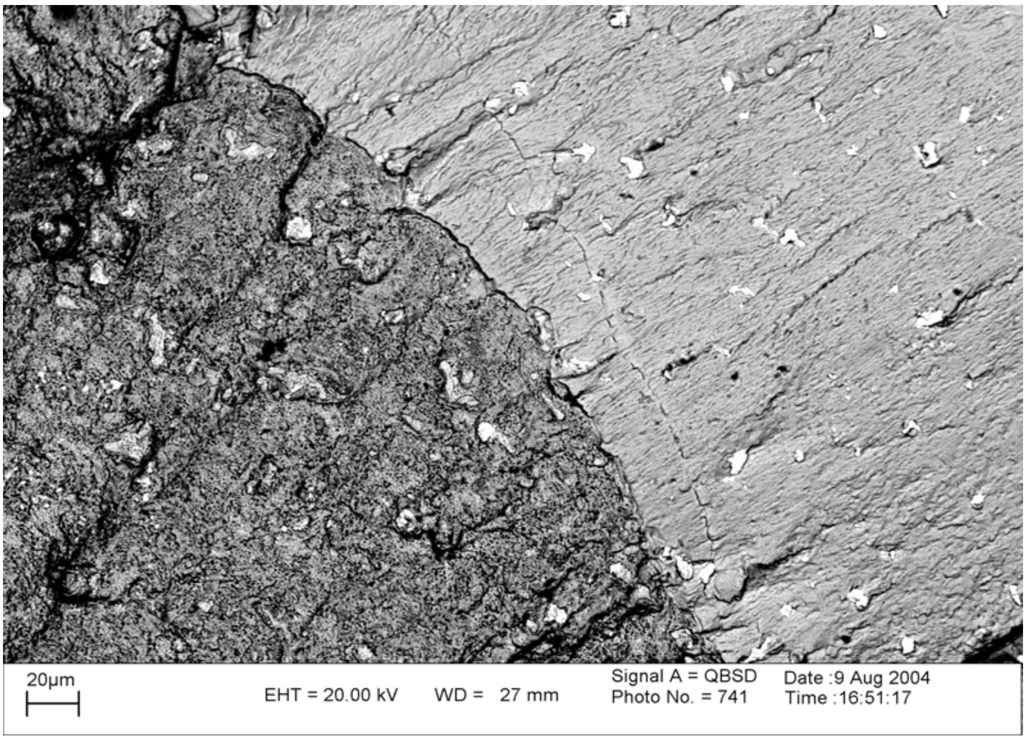


Figure 5: Detailed view of the boundary between the planar defect and fatigue cracking



The region of fatigue crack propagation is to the right

Destructive examination of blade s/n GSH81 was conducted by GE. Metallographic sectioning and examination of the region associated with the planar defect provided evidence that the mechanism of defect formation was intergranular oxidation.

1.3 Evaluation

At the operating temperatures of turbine blades, oxygen in the environment will react with the elements of the blade alloy. Typically, this reaction occurs at the blade surface and an oxide scale is produced. This surface scale may act as a barrier to oxygen diffusion and prevent further oxidation. If the oxide scale formed does not provide a barrier to oxygen diffusion, through changes in the physical form of the scale or the cracking of the scale as a result of applied stresses, continued oxidation of the underlying alloy may proceed. When oxidation is allowed to continue unchecked, oxygen diffuses more rapidly along grain boundaries resulting in the selective oxidation and weakening of grain boundaries.

For the case of fatigue crack propagation from a defect created by intergranular oxidation, two issues need to be considered. Firstly, the effectiveness of oxygen diffusion barriers and secondly, the relationship between the critical stress intensity for fatigue crack initiation, under the prevailing loading/environmental conditions, and the size and orientation of the planar defect created by intergranular oxidation.

If the barrier to oxygen diffusion into the blade alloy remains effective throughout the operational life of the turbine blades, then the creation of planar defects in the turbine blade by intergranular oxidation is prevented.

GE manufactures an optional HPT blade, p/n 1475M35P02. A significant difference between the P02 blade and the P01 blade is the incorporation of an aluminide coating on blade internal surfaces. The oxidation resistance of the internal surfaces of the P01 blade relies on the oxide film created by the elements present in the blade alloy. Aluminide coatings provide a more effective barrier to oxidation under more severe operating conditions, for example, higher temperatures.

Fatigue crack propagation from a planar defect, such as a defect created by intergranular oxidation, is dependent on the magnitude of the alternating stresses created during operation and the size and orientation of the defect.

The size and orientation of defects created by intergranular oxidation is a function of the grain structure of the turbine blade. Blades with large grains combined with grain boundaries extending from the surface, normal to the blade axis, will favour the creation of large planar defects oriented normal to the blade axis if intergranular oxidation occurs.

Variations in blade grain structure may explain why there is a seemingly wide variation in blade behaviour. In the case of the blade set installed in engine 725274, the blade which fractured as a result of intergranular oxidation and subsequent fatigue crack propagation, had been in service for a significantly shorter period than the adjacent blade.

1.4 Findings

The fracture of high pressure turbine (HPT) blade p/n 1475M35P01, s/n GSH81, occurred as a result of intergranular oxidation at the surface of the fourth internal rib and subsequent fatigue crack propagation.

HPT blade fracture control depends on the prevention of the formation of an intergranular oxidation defect of a size and orientation that allows fatigue crack propagation to occur under the alternating stress conditions imposed on the blade. For the case of blade GSH81, the designed barrier to oxygen diffusion into the blade alloy failed and the nature of the grain structure in the blade allowed the formation of a large planar defect.

1.5 Safety Action

A review of the service history of 1475M35P01 blades found that no similar blade fractures had occurred since the 1475M35P01 design had been introduced. Two blade airfoil fatigue fracture events were found to be related to an abnormal vibratory condition induced by surrounding hardware factors.

The continued structural integrity of HPT blades depends on the prevention of intergranular oxidation at the internal surfaces of the blades. The nature of the planar defects created by intergranular oxidation from internal blade surfaces precludes the use of non-destructive inspection methods to detect defects and remove the blades from service prior to blade fracture.