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SAMPLE REPORT No. 2

TEST ITEM:

LP TURBINE BLADES, FROM A TURBOFAN ENGINE, FITTED TO A LARGE PASSENGER AIRCRAFT

TEST PERFORMED:

FAILURE ANALYSIS

1. INTRODUCTION

A. On 25 May 2007, the captain of the subject aircraft reported vibration from the no.1 engine, during climb. Subsequent examination of the engine revealed damage to the trailing edges of two low pressure (LP) turbine blades (figure 1). No evidence of damage elsewhere in the engine was reported.

B. An earlier occurrence of vibration on the same engine was reported on 22 May 2007. Subsequent investigations by maintenance staff did not determine the cause and the engine was declared serviceable after a test run. It is not known if the LP blades were examined at this time.

C. The two damaged LP blades (S/N C6395 and C6406) were submitted to *ms4i* for examination, in order to:-

(1) gain more information on the object which caused the damage and

(2) estimate the number of flight cycles which had elapsed since its occurrence.

D. At the time the damage was discovered, the engine had endured 11,282 hours in 2,565 flight cycles, since new. It is believed that the engine had never been disassembled, prior to the removal of the two damaged LP blades.

2. WORK CARRIED OUT

A. Visual Examination

(1) The two damaged blades were subjected to a detailed examination, in the as received condition, using a stereomicroscope.

B. Fractography

(1) The transverse crack present on blade C6406 (figure 8) was opened by deliberate overloading, in order to reveal the crack surfaces. Examination with a stereomicroscope revealed a small region of fatigue crack growth, located at the root of the transverse crack (figures 12 to 14). This region was sectioned from the remainder of the blade, to facilitate insertion into the chamber of a scanning electron microscope (SEM). The removed crack surfaces were cleaned by the repeated application and removal of replication tape. They were then examined in the SEM, at magnifications up to x5000.

C. **Energy Dispersive X-Ray (EDX) Spectroscopy**

(1) A section of the surface of blade C6406, which showed an imprint of a foreign object (figures 9 and 17), was inserted into the chamber of an SEM. The chemical composition of dark deposits, left by the foreign object, was determined by EDX analysis. Similar analysis was also performed on the original blade surface, for comparison.

3. RESULTS

A. **Visual Examination**

(1) On both blades, the damage had occurred at approximately the ¾ span position, at the trailing edge (figures 2 to 5).

(2) ***Blade C6395***

(a) This blade had suffered impact, directly on the trailing edge itself (figures 6 and 7), resulting in a roughly semi-circular indentation. The blade alloy had been locally deformed from the convex, towards the concave face. This was consistent with impact by a hard, solid object, during engine running.

(b) Traces of solid, foreign material were present at the impact site (figure 6). These were most likely associated with the foreign object, which had caused the damage.

(3) ***Blade C6406***

(a) This blade had also suffered impact by a hard foreign object. A rectangular imprint indicated that the impact site was located on the convex surface, approximately 5-15mm inwards from the trailing edge (figure 8). The trailing edge, itself was comparatively undisturbed.

(b) The imprint detailed at 3.A.(3)(a) above, was delineated by traces of foreign material, associated with the object which had caused the damage (figure 9). The dimensions of this imprint, coupled with those of the damage found on blade C6395, suggested that the damage may have been caused by a cylindrical object, approximately 10mm long by 5mm diameter.

(c) The impact had resulted in cracking of a cruciform nature on the convex surface (figure 8). The spanwise branches of the cracking coincided with the boundaries of the solid trailing edge and the hollow core regions of the aerofoil. The transverse branches of the cracking extended for approximately 25mm, normal to the major axis of the aerofoil. Deformation of the blade alloy was again consistent with the impact having occurred during engine running.

B. Fractography

(1) On blade C6406, the majority of the transverse crack surface area was composed of intergranular fracture, with clearly visible dendritic outlines (figures 11 and 12). This was consistent with high energy, overload fracture, occurring at elevated temperature. A very light covering of oxidation and combustion products was present on the crack surfaces. This indicated that a short period of engine running had ensued, after the occurrence of the impact damage.

(2) A small, thumbnail shaped region of fatigue crack growth was present, located at the tip of the overload crack detailed at 3.B.(1) above (figures 12 to 14). The curvature of arrest markings indicated that the fatigue crack had originated from the overload crack. Stable fatigue crack growth had progressed only for a distance of approximately 1mm.

(3) When examined in the SEM, fatigue striations were evident on the fatigue crack surface (figure 16). The striation spacing showed a distinct periodicity, with groups of widely spaced striations interposed by groups of more narrow spacing. It was considered that this periodicity could be correlated to flight cycles in the following manner:-

(a) Individual striations were caused by vibrations in the blade, with each rotation of the turbine shaft.

(b) The groups of widely spaced striations occurred during periods when the engine was under heavy load, such as takeoff and climb. The groups of more narrow striations occurred during cruise and descent, when the load on the engine was reduced.

(c) It follows from (a) and (b) above that the distance from the beginning of one group of wide striations to the beginning of the next would correspond to a single flight cycle (figure 16).

(4) By counting groups of fatigue striations, it was estimated that the period of stable crack growth lasted for between 15 to 30 flight cycles. It was not possible to be more precise in this determination, since periodicity in striation spacing could not be resolved for the first 0.5mm of crack growth. Data for this region had to be extrapolated from measurements taken from the second 0.5mm of crack growth.

C. <u>Energy Dispersive X-Ray (EDX) Spectroscopy</u>

(1) The EDX spectra obtained from the foreign deposits and the original blade surface are shown in figure 17. The deposits were found to be composed of a compound rich in copper.

4. DISCUSSION

A. It was considered most likely that the damage present on the subject LP blades was the result of impact by a hard, cylindrical object, during engine running. It was estimated that this object was approximately 10mm long by 5mm diameter. It impacted blade C6395 directly on its trailing edge and was then deflected onto the convex surface of blade C6406, close to its trailing edge. This theory is supported by:-

(1) The locations and dimensions of the impact sites (3.A.(2)(a) and 3.A.(3)(a)).

(2) Regions of foreign material, present on the damaged blades (3.A.(2)(a) and 3.A.(3)(a)).

(3) The direction of deformation of the blade alloy (3.A.(2)(a) and 3.A.(3)(c)).

(4) The dendritic, intergranular nature of the fracture surfaces (3.B.(1)).

B. EDX analysis of foreign deposits found at the impact site showed that they were rich in copper. This indicated that the object which caused the damage was either rich in copper or was coated with a copper rich substance.

C. Engine running exerted significant centrifugal stresses on the blade aerofoils. The transverse, overload crack on blade C6406 magnified these stresses at its tip, resulting in the onset of fatigue crack growth. It was assumed that this occurred almost immediately after the impact, due to the large stress concentration associated with the overload crack. Fatigue striation counting showed that the period of stable crack growth lasted for between 15 and 30 flight cycles, before the blade was removed from service. During this period, the crack extended for a distance of only 1mm.

5. CONCLUSIONS

A. The damage on the subject two LP blades was consistent with impact by a hard, foreign object, during engine running. It was considered likely that this object was cylindrical in shape and measured approximately 10mm long by 5mm diameter. The object was either rich in copper or was coated with a copper rich substance.

B. Fatigue crack growth was present at the tip of the overload crack, which had been caused by the impact damage. It was assumed that the onset of fatigue crack growth occurred immediately after the impact, due to the large stress concentration associated with the overload crack. Fatigue striation counting indicated that the impact damage had occurred approximately 15 to 30 flight cycles before the engine was removed from service on 25 May 2007. During this period, the crack extended for a distance of only 1mm.

Figure 1 - The two damaged blades, in situ on the LP turbine disc (photograph supplied by customer).

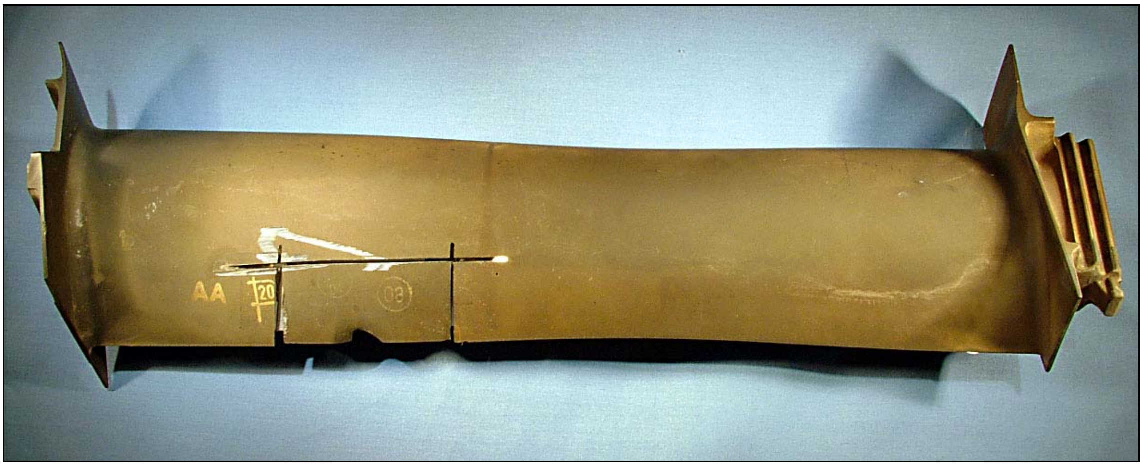


Figure 2- Blade C6395, convex side. The sectioning had been performed during an earlier investigation, at another laboratory.

Figure 3 - Blade C6395, concave side. The sectioning had been performed during an earlier investigation, at another laboratory.

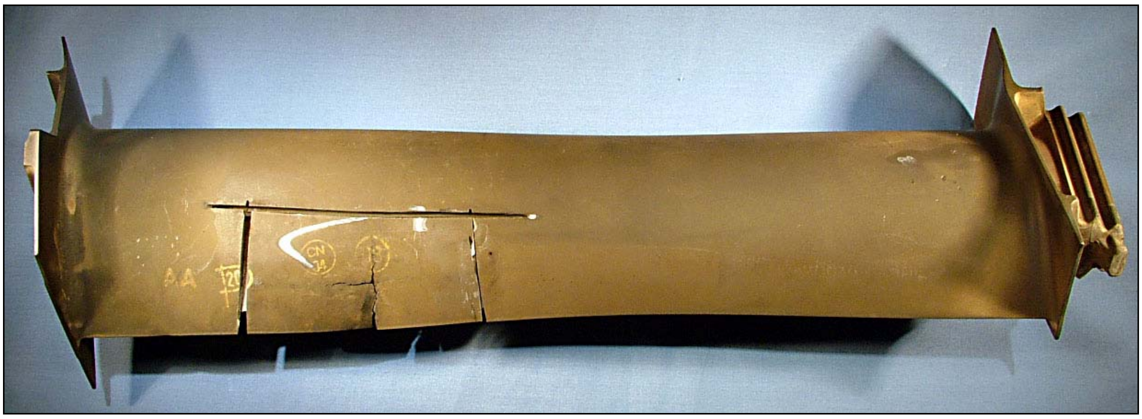


Figure 4 - Blade C6406, convex side. The sectioning had been performed during an earlier investigation, at another laboratory.

Figure 5 - Blade C6406, concave side. The sectioning had been performed during an earlier investigation, at another laboratory.

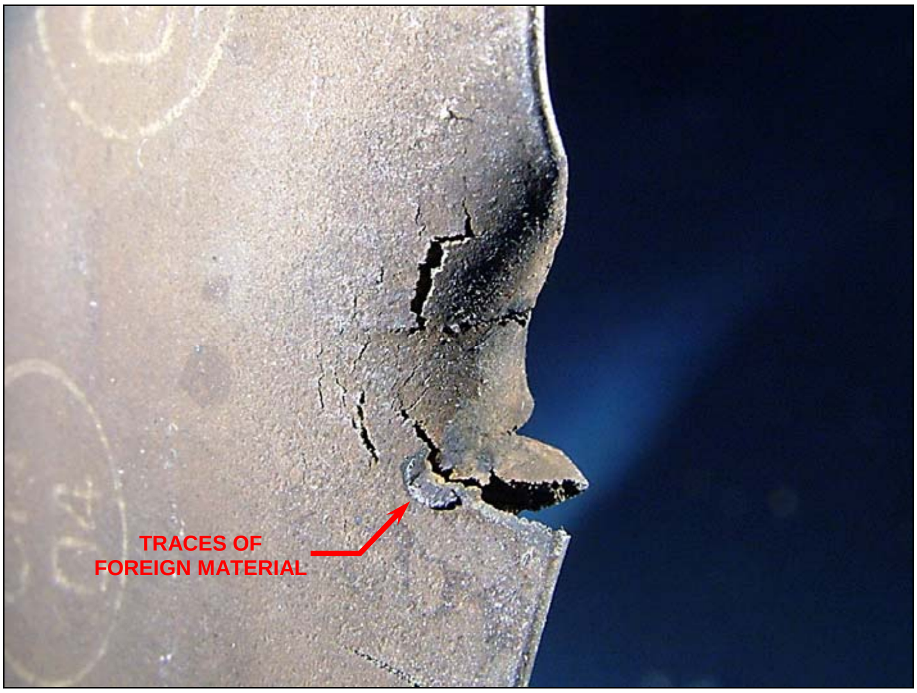


Figure 6 - Blade C6395, convex side, trailing edge. Impact damage directly on the trailing edge has resulted in a roughly semi-circular indentation. Traces of foreign material, most likely associated with the impacting object, is present on the surface of the blade.

Figure 7 - Blade C6395, concave side, trailing edge. Deformation of blade material, caused by impact with a foreign object.

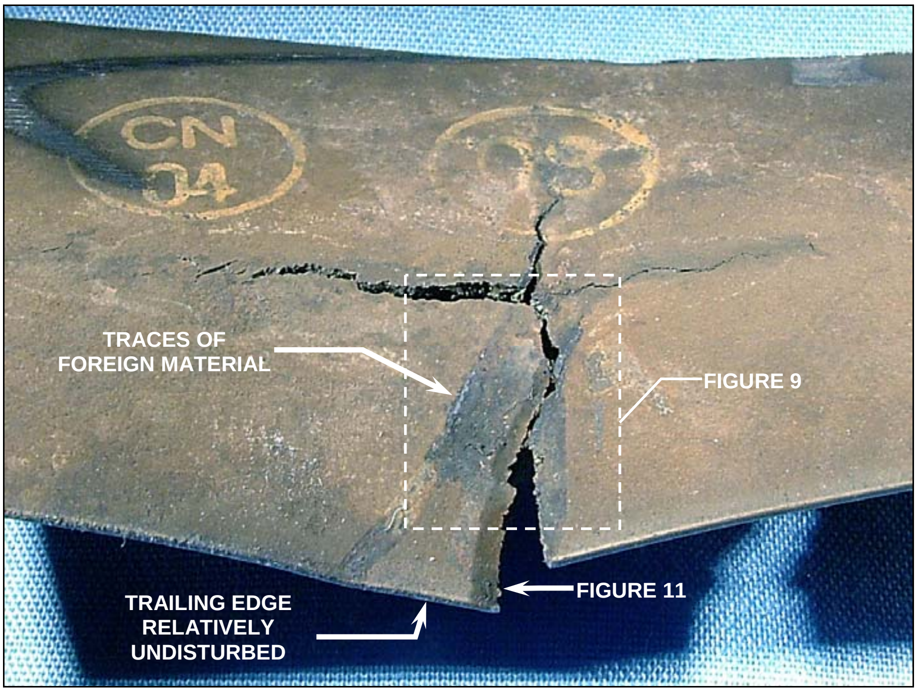


Figure 8 - Blade C6406, convex side, trailing edge. Imprint and traces of foreign material indicate impact by an elongated foreign object a short distance from the trailing edge. Note that the trailing edge itself is comparatively undisturbed.

Figure 9 - Blade C6406, convex side, trailing edge. Close view of the region indicated in figure 8. Traces of foreign material left by the impacting object.

Figure 10 - Blade C6406, concave side, trailing edge. Note the jagged, intergranular nature of the cracking.

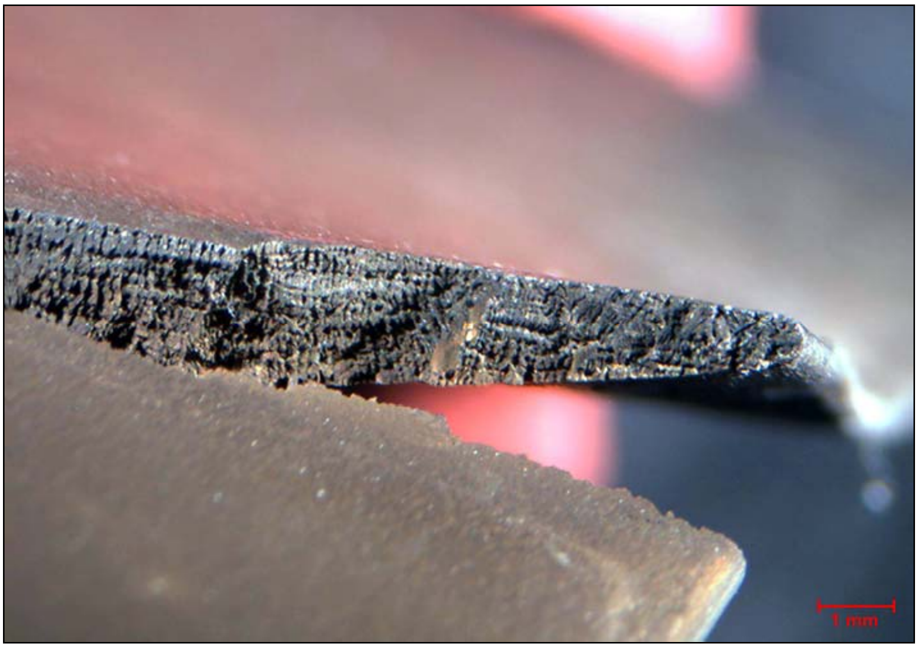


Figure 11 - Blade C6406, trailing edge, close view on the fracture surface indicated in figure 8. Dendritic outlines clearly visible on the fracture surface indicate intergranular fracture. Combustion products and only very light oxidation are also evident.

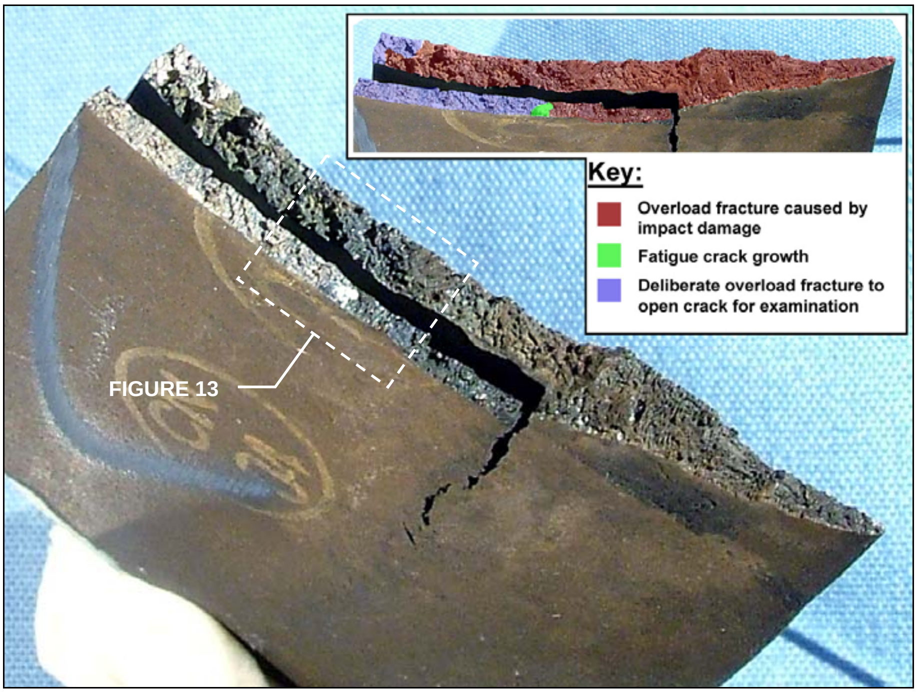


Figure 12 - Blade C6406. The transverse crack shown in figure 8 has been broken open, to allow examination of the crack surfaces. The inset shows the fracture mechanisms of the different regions of the crack surface.

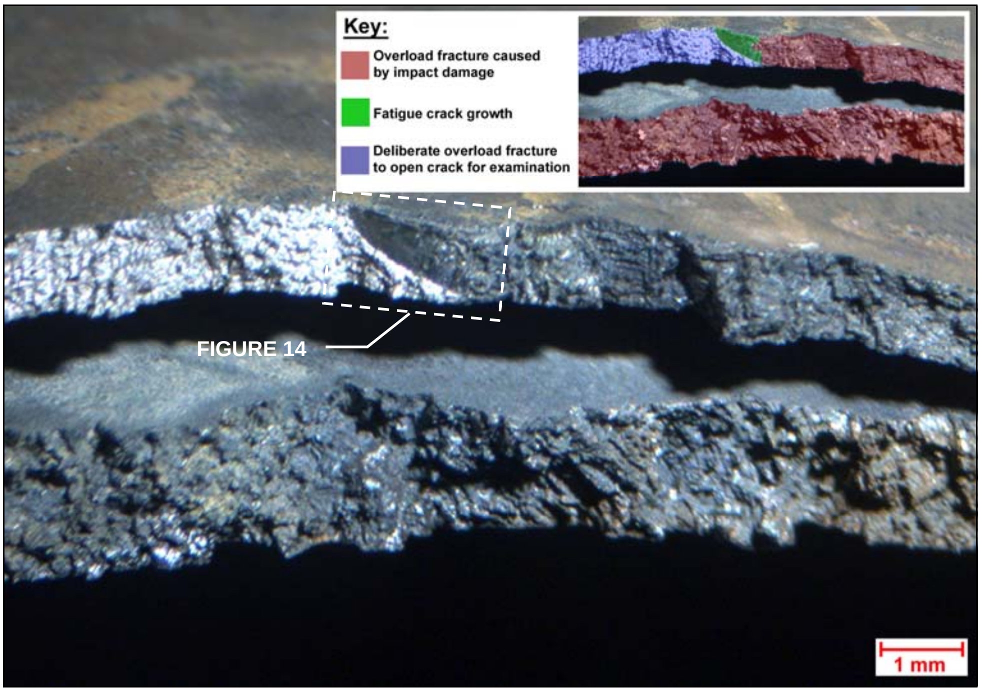


Figure 13 - Blade C6406, close view of the region indicated in figure 12 (note – this photograph shows the opposite crack surface to that shown in figure 12). The inset shows the fracture mechanisms of the different regions of the crack surface. Note the thumbnail shaped region of fatigue crack growth.

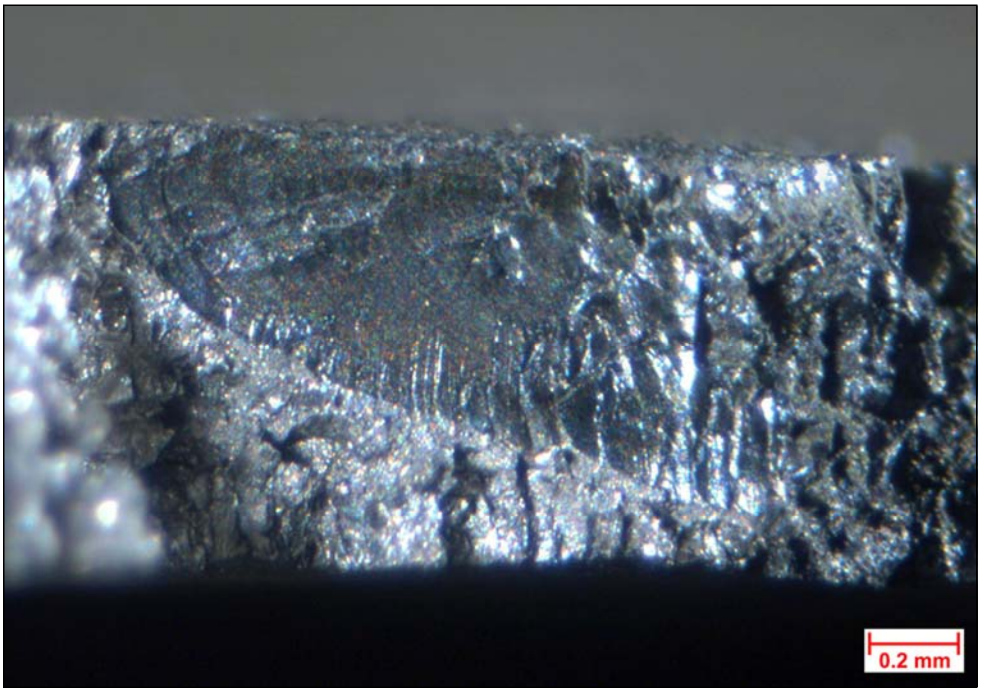


Figure 14 - Blade C6406, close view of the region indicated in figure 13. Shows the region of fatigue crack growth, originating from the overload crack which had been caused by impact damage.

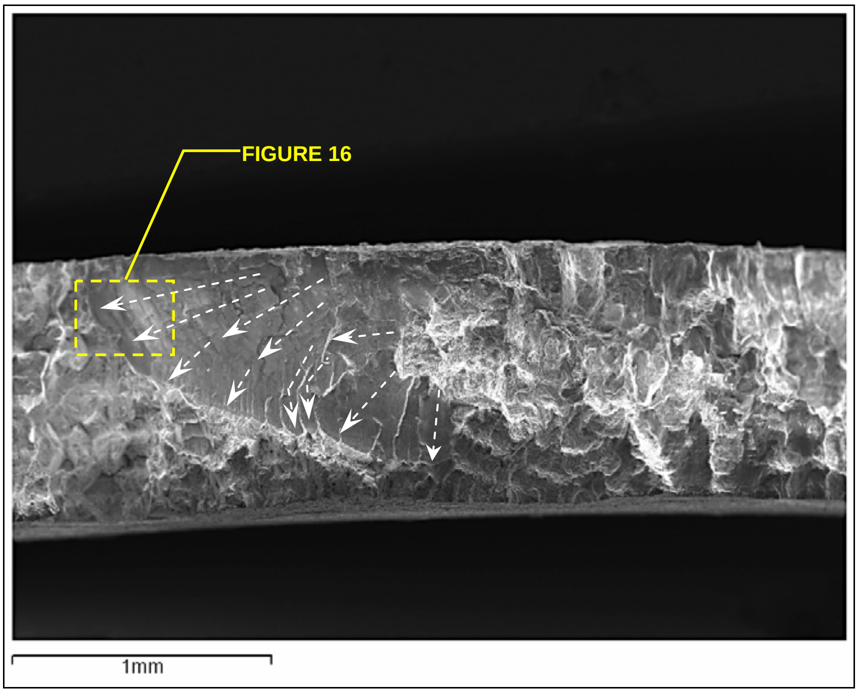


Figure 15 - Blade C6406, close view of the region of fatigue crack growth. Arrows indicate directions of crack growth, determined from the curvature of fatigue striations (secondary electron image).

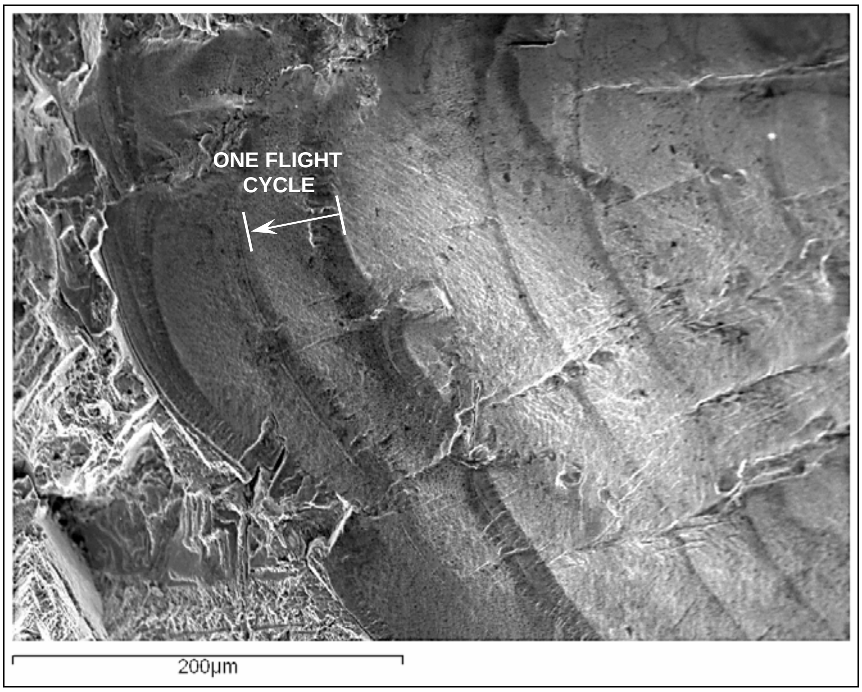
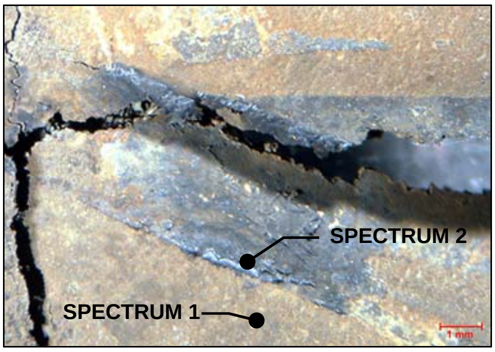
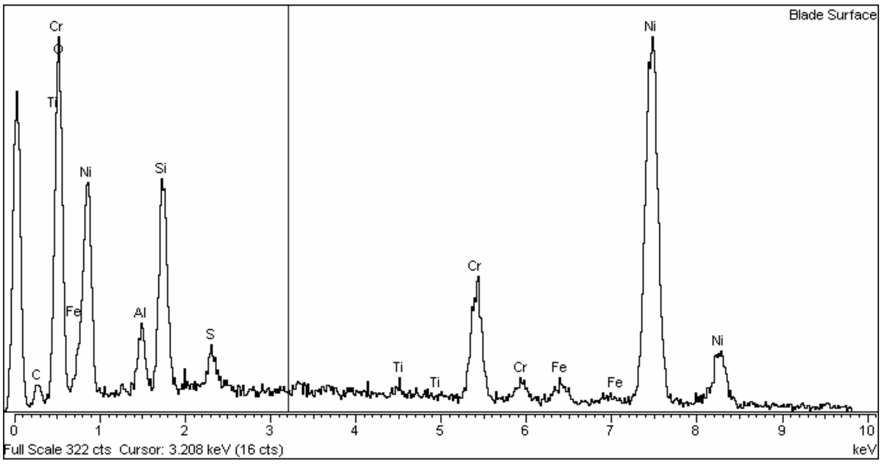
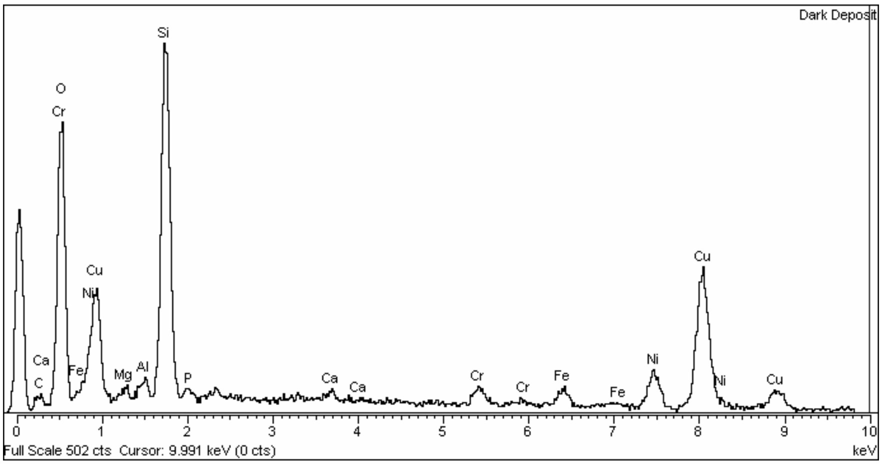


Figure 16 - Blade C6406, close view of the region indicated in figure 15. Shows groups of widely spaced striations interposed by groups of more narrow spacing. This periodicity in striation spacing was considered to correlate with flight cycles (secondary electron image).





Spectrum 1 – Blade Surface



Spectrum 2 – Foreign Deposit

Figure 17 - Comparison of EDX spectra taken from the blade surface and foreign deposits, associated with the impact site on blade C6406. "Spectrum 1" is typical of the blade alloy, with surface contamination by silicon, most likely the result of combustion processes. "Spectrum 2" shows that the foreign deposit was composed of a substance rich in copper.