The Fracture Analysis of Turbine Rotor Blade

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Abstract. Failure of aeroengine Turbine Blade in Wing seriously threatens Flight Safety. We used the emergence and development of blade cracks to discuss the causes of blade fracture. The results show that due to intergranular oxidation, alloy dilution, and thermal stress, fatigue crack spreads through the blade and results in blade fatigue fracture. During blade usage and maintenance, we avoid over usage and overheating of the engine to decrease time of maximum capacity usage.

Introduction

Turbine blade is one of the most important components of the plane engine. The turbine blade spins at a fast speed and endures centrifugal load, thermal load, Aerodynamic load, vibration load and takes on high temperature, high pressure gas impact. The start, stop, acceleration and deceleration of engine operation, enforces a wide range of temperature and stress on the turbine thus wear and tear accumulates. Turbine blade failure modes include: high cycle fatigue, low cycle fatigue, creep / fatigue, thermal fatigue, high temperature damage, and external damage. The fatigue failure of turbine blade is accompanied by creep failure at high temperature.[1]

At present, the research on failure modes of turbine blades is mainly carried out by using standard specimen or real turbine blades to simulate the working conditions of turbine blades [2-3]. Using experimental data, turbine blade simulation is often used to predict the working life of turbine blades [4-6]. It is rare to observe and analyze the breakage phenomenon of turbine blade in practical use of turbine engine.

An engine’s high pressure turbine blade cracked during flight. We used this engine’s turbine blade to study and discuss the causes of failure. The turbine engine document shows that the engine had been working for 28917 hours, 37985 load cycles, cumulative. The blade had been repaired 5 times and after the fifth repair had accumulated 1986 hours, 2905 load cycles.

Study on Fractured Blade

Macro analysis on the blade fracture

Figure 1. Convex surface of failed blade.                                        Figure 2. Concave surface of failed blade.

Figure 1 and 2 shows the fractured blade.[7]. The measurement for the front of the blade is approximately 79 mm. from the picture, we can see that the lost part of the blade is at the top corner of
the exhaust edge. The fault surface on the side of the exhaust edge is perpendicular to the exhaust edge, and the lost area is approximately 13 by 16mm$^2$.

As shown in Figure 3 and 4, the oxidation damage and warping are obvious, especially on the convex surface of the blade. Since the back of the blade is usually thinner, we think that the warping is due to the heat damage.

**Micro Analysis on the Blade Fracture**

We studied the fracture using an electric microscope, especially on the germinating and spreading regions of the broken blade. Figure 5 shows observed areas. The fracture was categorized into several areas.

From Figure 5 and 10, we can see:
1) Area 1 is light in color. Figure 7 shows area 1 surface is rough, a characteristic of an instant crack.

2) Area 2 is dark in color, as shown in Figure 5. The surface of the fracture surface is severely oxidized for a long time, and there have been many corrosion residues. It is proved that the corrosion time is longer, and it is the fatigue initiation zone. We think intergranular oxidation and alloy dilution cause the formation of fatigue cracks in the area. Under Area 2, The inner surface of the cavity 6 shows multiple fractures, as shown in Figure 8.

3) Area 3, cavity 6, cavity 7 and rib fracture area has light oxidation damage. From Figure 9, we observed Area 3 fatigue belt, a typical area of fatigue crack expansion. Fatigue crack passes through blade inner surface and blade basin surface to reach the back of the blade and arrives at the second stage of fatigue crack, which quickly expands horizontally and vertically from the back of the blade to the front.

4) Area 4 suffered from light oxidation. This is an instant crack area.

5) There are serious oxidizing points in area 5. These points are the source of fatigue crack.

Discussion

From the macro and micro observation of the fractured blade, we conclude the sequence of blade malfunction (as shown in Figure 11).
First the unprotected inner surface of cavity and rib suffers intergranular oxidation and alloy dilutions thus fatigue crack starts. These areas (Area2, 5) are the source of fatigue crack. The exhaust edge of the blade is relatively thin, and partially cracked blade endured heat damage and warping, and thus damages top coating of the blade and encourages further intergranular oxidation and alloy dilution to create fatigue crack. In total, 3 areas are the source of fatigue, the first stage of fatigue crack.

During continued use of the blades, small fatigue crack (Area 2) passes through inner surface of the blade basin and horizontally reaches the convex of the blade. Quickly the cracks extend to the front and the tail of the blade, stage two of the fatigue crack.

Last, due to the extension of the fatigue crack. Strength of the blade decreases and the frequency of self-vibration is altered. As external vibration and blade’s self-vibration become synchronized, the turbine blade fractures.

Conclusion

1) fractured turbine blade has standard composition. No noticeable material and workmanship defects were observed. The malfunction of the blade is not the result of external damages, material defect, nor repair process.

2) The start and stop of the engine cycle creates strong impact, causes the start of the cracks along blade inner surface and rib. The cracks extend due to cycle load. The self-vibration frequency changes and causes the failure of the blade. The crack surface is consistent with high cycle fatigue crack surface, thus we conclude high cycle fatigue is the cause of the cracks.

3) We advise during blade usage and maintenance, avoid over usage and overheating of the engine to decrease time of maximum capacity usage. Under the permitted condition of take-off, reducing take-off thrust to decrease turbine blade centrifugal load, thermal load. Enhance turbine blade bore-scope inspection quality to find the start of the cracks and ensure the safety of the flight.

References