FINAL ASSESSMENT COVER PAGE - 2022/23

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Date: 22/05/2023

1 MQ1

1.1 i

The times are different for the turbines because an aero engine has a defined place to stop and, an aircraft can only carry so much fuel. An IGT will always generate power as long as it is needed, so there is no reason to stop it other than this and maintenance. An IGT can have a higher temperature, because denser materials can be used. In an aircraft, the higher weight of a more thermally resistant material has a penalty. On the ground for an IGT, this is not the case. This allows it to run higher temperatures.

1.1.1 a

The aero engine will clearly have a peak temperature of up to 1120°, and a typical cruise temperature of around 870°. Because gas turbine blades are commonly hollow with cooling ducts, the actual surface temperatures are likely lower, with the core of the blade being even cooler than the surface. This will lead to thermal gradients in the blade, likely leading to warping. There will be significant tangential loads as the blades develop significant amounts of lift to extract energy from the flow. These tangential loads will lead to a large bending moment at the root. Radial accelerations are also likely high due to the high angular velocity. Axially, force s are likely low because the blades are optimised for an ideal lift to drag ratio. These forces are likely fairly constant, as thrust demands will stay mostly constant.

1.1.2 b

For the IGT, temperatures are obviously higher for the majority of their life. They are also likely to have interior cooling. The velocities are likely similar but higher, meaning the loads will also be similar but higher. Due to erratic demand on the national grid, and the unreliability of other sources, there will likely be higher angular accelerations, and these will happen more frequently.

1.2 ii

1.2.1 a

An aero engine will likely want a high T_m. The lower the operating tempearture is relative to the melting point, the slower creep progresses. The creep will likely be in the high or low temperature creep regions due to the high stress, meaning plasticity will be dominant.

Stress relaxation isn't a factor here, as the blades lengthen stress will increase. The microstructure should be constant at high temperature. This means that ageing processes can't be used, because the high operating temperature will cause material properties to change while the blade is in operation. Any martensite or bainite would disappear as there is enough time for the material to reach equilibrium.

Grain boundaries should be avoided, these lead to higher diffusional creep, and grains can shear past eachother. If the microstructure changes, failure at brain boundaries is likely to occur.

If the engine was running at a rich condition, there would be very little free oxygen, if any. This would mean that oxidation wouldn't be an issue. This is the case for some of the operating life. Fuel economy dictates that the engine should be run lean sometimes. This means high temperature and lots of oxygen, so plenty of oxidation. For this reason, the alloy should be resistant to oxidation. Weight should also be minimised, so as not to hinder the aircraft.

Chromium could be added to create a coherent oxide layer. This will prevent further oxidation. In addition, because chromium oxide is a ceramic, this adds more protection from thermal loads. Tungsten can be added to increase the melting point and therefore reduce creep.

1.2.2 b

Lost wax processes could be used to get a cast blade with a very fine surface finish. Directional cooling should be employed, as this will allow for the final product to be made of a single crystal.

Plasma jet processes should be avoided, because the surface finish is suboptimal. This will lead to the turbine being less efficient. In addition, it can only work in line of sight. This is less of an issue if the blades and the disk are manufactured separately, but if a blisk (blade and disc in one piece) is used instead, the geometry will likely be too complex to do this effectively.

1.3 iii

The edges of the disc are most likely to experience fatigue. The root fixing has lots of small radii, leading to stress concentrations. If the disk is unbalanced, the largest forces from this will be at the edges of the blade, meaning high fluctuating stresses.

Oxidation fatigue may be a component as it is possible that hot gases could enter this region. This can initiate fatigue and increase crack rates, but only along grain boundaries. It is also frequency dependant. Advisories could be given to the engine operator to avoid running the engine at certain speeds to avoid these frequencies, and if the disk is also made of one crystal, there will be no grain boundaries meaning this is less of an issue.

Creep generally increases the rate of fatigue failure. The high temperature at the rim of the blade means that creep is probably a factor here too.

1.4 iv

Given in question: $a_i = 1.5 \times 10^{-3} m$
$\sigma_{min} = 25 \times 10^6$
$\sigma_{max} = 550 \times 10^6$
$K_{IC} = 125 \times 10^6 Pa\sqrt{m}$
$A = 7.35 \times 10^{-9}$
$m = 2.5$
$Q = 1.2$
Calculated:

$$\Delta\sigma = \sigma_{max} - \sigma_{min} = 525 \times 10^6 Pa$$

Find the critical crack length from the fracture toughness and the maximum stress. The maximum stress is used instead of the minimum or range of stresses because this is when, if ever, the material will fail.

$$a_{crit} = \frac{\left(\frac{K_{IC}}{Q\sigma_{max}}\right)}{\pi} = 0.01142m$$

This comes from integrating $\frac{da}{dN_f} = A^m$. ΔK has been expanded out.

$$N_f = \frac{\left[\frac{a^{1-\frac{m}{2}}}{1-\frac{m}{2}}\right]_{a_i}^{a_{crit}}}{A(Q\Delta\sigma\sqrt{\pi})^m} = 26.41 flights$$

Using a safety factor of 1.25, this means 21 flights are probably safe. Obviously, the fewer flights, the safer. This does lead to more costs to the airline, so they want to maximise the life that can be found from the engine.