

## SECTION XVI. MÉCANIQUE GÉNÉRALE ET GÉNIE MÉCANIQUE

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### DAMAGE AND LIFE ANALYSIS OF HIGH-PRESSURE TURBINE BLADES

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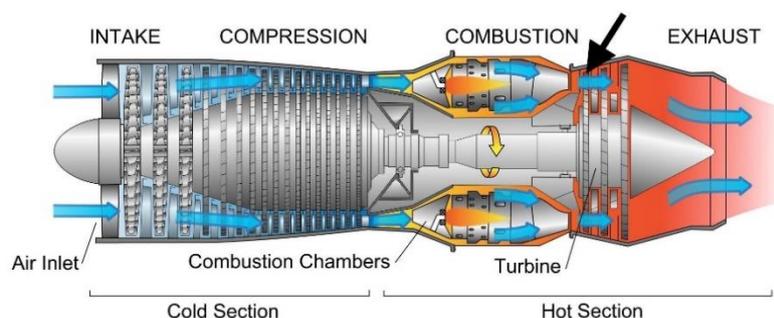
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#### INTRODUCTION

The aeroengine is a highly complex and precise thermodynamic machine. As the heart of the aircraft, it is not only the driving force for aircraft flight but also an important driving force for the development of aviation. Every important change in the history of human aviation is related to the technological progress of aero engines. After more than a hundred years of development, aeroengine have developed into mature products with extremely high reliability.



Gas turbines by their nature always work under extreme conditions and the high-pressure turbine blade has the greatest loading in the gas turbine system. The arrow in figure 1 shows the position of the high-pressure turbine blade which is nowadays made by single crystal casting and directional solidification technology [1]. It has extremely demanding requirements on their materials and manufacturing processes. Modern HP turbine blades are manufactured to incorporate internal cooling channels through which cooler air, bled from the high-pressure compressor is passed to reduce the blade metal temperature compared to the combustion gas turbine inlet temperature. The new engine developed for the fourth-generation fighter will be equipped with ceramic matrix composite blade with more outstanding high-

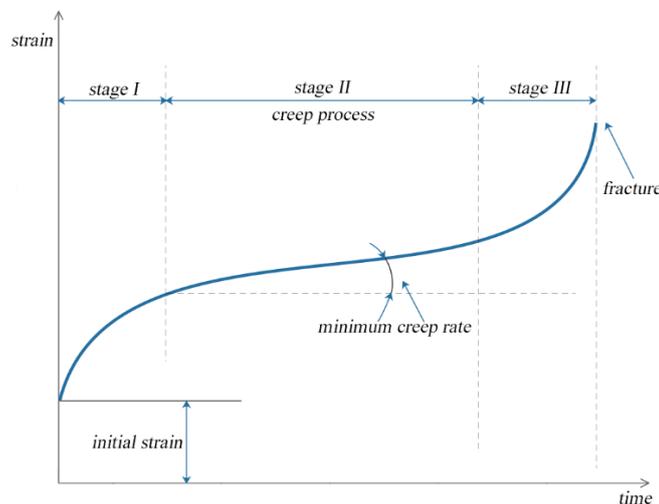
temperature performance [2]. While pursuing high-performance aero-engines, the working environment of high-pressure turbine blades has become increasingly harsh. Therefore, the service life of the high-pressure turbine blades directly determines the performance and quality of the aero-engine.

### THE DAMAGE OF HIGH-PRESSURE TURBINE BLADE

The general failure modes of engine turbine blades are in the following categories: (1) Failure due to external factors, such as corrosion, oxidation and external body damage. Due to the randomness of external factors, it is difficult to predict such failures. (2) Direct failure during operation. Thermal and mechanical loads acting on the turbine blades causing both elastic and plastic strains in the blade. Local plastic strains can induce micro-cracking at geometrical stress concentration features and excessive temperature can induce microstructural stability such as coarsening or dissolution of strengthening precipitates. The main failure mechanisms include creep, mechanical fatigue and thermal fatigue.

When the high-pressure turbine blade is exposed to a high temperature environment above 1000 degrees Celsius, thermal fatigue and creep are the main failure modes, and by contrast, mechanically sourced low-cycle fatigue failure is relatively small [3]. Creep is the progressive accumulation of plastic strains and associated microstructural damage such as grain boundary voids and cracking. Creep strain rate is an exponential function of temperature. When the temperature increases, the creep strain rate increases, as atomic diffusion is a significant contributor to the various creep sub-mechanisms. In practice, creep is affected by many factors such as temperature, stress, and endurance time.

When the blade metal temperature is over half the melting point of the material, creep will start to become significant and progressively accelerate. Creep is the primary failure mode under the typical high temperature and loading working environment of high-pressure turbines blades.



Creep can be divided into multiple stages as shown in figure 2. Generally, the lower the temperature and stress, the lower the creep strain rate of the secondary stage, which is steady state, the longer the whole creep life of the component.

### LIFE ASSESSMENT METHOD

Assessing the creep life of subcomponents of gas turbine engines is a very complicated process. Therefore, we must first establish a simple and accurate turbine

blade creep life model. The Larson-Miller empirical equation is one of the famous time-temperature parameter equations. Although only the temperature, stress and time parameters are used to estimate the life, and some assumptions are adopted, there is still sufficient accuracy in practical applications [4]. The equation is as follows:

$$L_{pm} = T(\lg t_r + C)/1000 \quad (1)$$

Where:  $T$  is temperature;

$t_r$  is the time to rupture;

$C$  is a constant (usually 20);

$L_{pm}$  is the Larson-Miller parameter.

So, the time to rupture is:

$$T_r = 10 \left( \frac{1000L_{pm}}{T} - 20 \right) \quad (2)$$

Assuming that the  $L_{pm}$  of the material is 35 and the temperature of the material is 1010K. According to the above formula,  $t_r$  is 10000h. It can be estimated that if the temperature of the material is reduced by 15K, the creep life will be doubled.

### CONCLUSION

The quality and service life of the high-pressure turbine blades directly determine the performance of the aero-engine. Common failure modes for engine turbine blades are corrosion, oxidation, and damage to the outer block. There may also be elastic and plastic strains due to thermal and mechanical loads acting on the high-pressure turbine blades. When high-pressure turbine blades are exposed to high temperatures above 1000 degrees Celsius, thermal fatigue and creep are the dominant failure modes. It is estimated that if the operating temperature of the high-pressure turbine blades is increased by 15K, the creep life will be doubled.

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