AN INVESTIGATION OF TURBINE BLADE FAILURE IN AIRCRAFT TURBINE ENGINES

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"I have read this literary work and that in my opinion it is fully adequate,
in scope and quality, as a masterpiece for the degree of
Bachelor of Mechanical Engineering (Structure & Material)"

Signature	: ....
Supervisor's Name	: ....
Date	: ....

"I declared that this project report entitled "An Investigation of Turbine Blade Failure in Aircraft Turbine Engines" is written by me and is my own effort except the ideas and summaries which I have clarified their sources."

Signature : ……………………………………

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Date : ……………………………………

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ABSTRACT

In modern aviation, the aircraft turbine engines are considered to be highly reliable in that failures in services are rare. However, research and improvement to the aircraft component seems to be the endless process to avoid the failure during operation of an aircraft engines. This is due to the safety of passengers. Aircraft turbine blades would damage after several years of operation. This blade is identified the most likely component to be failed due to the operating conditions at elevated temperature. The blades profile and behavior need to be understood to overcome these problems. So, this project deals with some mechanical analysis by simulation to find the possible reason of the failure. With the helps of MSC Nastran/Patran software package, a few simulations of finite element analysis will be done with the best simulation will be choose for further analysis. The results of maximum stress by simulation then will be compared to the theoretical values that determined by manual calculation. From the analysis, the maximum stress obtain is 647 MPa while the maximum deformation is 1.13 mm. There are two possible causes of the failure of the aircraft turbine blade which are creep rupture and thermomechanical fatigue.

ABSTRAK

Dalam dunia penerbangan moden, enjin turbin kapal terbang dianggap amat boleh dipercayai memandangkan kegagalan dalam perkhidmatan adalah jarang berlaku. Walau bagaimanapun, kajian dan penambahbaikan terhadap komponen kapal terbang adalah merupakan satu proses yang berterusan untuk mengelakkan kegagalan ketika operasi sesebuah enjin kapal terbang. Ini adalah kerana ia melibatkan keselamatan penumpang. Bilah turbin kapal terbang akan rosak setelah beberapa tahun beroperasi. Bilah ini dikenalpasti sebagai komponen paling terdedah kepada kegagalan disebabkan oleh keadaan operasi pada suhu yang amat tinggi. Ciri-ciri dan sifat bilah turbin ini perlu difahami untuk mengatasi masalah tersebut. Jadi, projek ini adalah berkaitan analisis mekanikal secara simulasi untuk mengenalpasti punca yang mungkin menyebabkan kegagalan. Dengan bantuan pakej perisian MSC Nastran/Patran, beberapa simulasi analisis unsur terhingga akan dilakukan terhadap bilah turbin dengan memilih satu simulasi terbaik untuk dianalisis dengan lebih lanjut. Keputusan tegasan maksimum yang terhasil dari simulasi kemudiannya akan dibandingkan dengan nilai teori yang diperolehi melalui pengiraan manual. Berdasarkan dapatan kajian, nilai tegasan maksimum adalah 647 MPa manakala anjakan maksimum adalah 1.13 mm. Terdapat dua kemungkinan punca kegagalan bilah turbin pesawat iaitu perpecahan rayapan dan kelesuan terma-mekanikal.

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LIST OF SYMBOLS

k	=	Elemental stiffness matrix
U	=	Displacement vector
F	=	Elemental load vector
K	=	Global stiffness matrix
γ'	=	Gamma prime
γ	=	Gamma
E	=	Young Modulus, Pa
v	=	Poisson's ratio
ρ	=	Density, kg/m^3
α	=	Thermal expansion
K	=	Conductivity, W/mK
M	=	Bending Moment, N.m
F	=	Force
σ_{max}	=	Maximum Stress, Pa
I	=	Moment of inertia, m^4

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The crash of an aircraft during operation may cause by several factors and this includes the failure of its turbine blade. In a research by Carter (2005), unlike automobile engines, aircraft engines run at high power settings for extended periods of time. As a general review, the engine runs at maximum power for a few minutes during taking off, and then power is slightly reduced for climb, and then spends the majority of its time at a cruise setting, that is about 65% to 75% of full power. The power of an internal combustion reciprocating or turbine aircraft engine is rated in units of power delivered to the propeller (typically horsepower). This is actually torque multiplied by crankshaft revolutions per minute (RPM). The propeller converts the engine power to thrust horsepower (thp) in which the thrust is a function of the blade pitch of the propeller relative to the velocity of the aircraft.

Modern gas turbine engines for aviation applications are generally considered to exhibit a high level of reliability, and failure rates are considered low. In reality, this perception is incorrect; with component rejection for incipient failure symptoms during overhaul is quite high. However, the situation is controlled by the rigid inspection team which the engines are exposed, and undergoes very strictly inspection. This is also to ensure that almost all failures are detected in the early stage, and are removed from service for replacement or refurbishment before failure actually occurs. Therefore, it lead to a low rate of actual failure in service occurs.

1.2 OBJECTIVES

This project implemented with aim to study and analyze problem those related to the failure of turbine blade. The other objectives that contain in this project are:

i. To model the blade based on the actual dimensions used in aircraft turbine engine.
ii. To simulate the blade using MSC Nasran/Patran software and investigate the failure of the turbine blade.

1.3 SCOPES

The scope of study for this project is to analyze the failure of turbine blade by using the appropriate software. Other aspects that also include are:

i. Modeling the blade for aircraft turbine engine model JT8D based on the actual dimension.
ii. Simulate the blade using MSC Nasran/Patran by using different meshing which is coarse and fine mesh.
iii. Analyze the data obtained and compare to the theoretical value.

1.4 PROBLEM STATEMENT

The blade use in aircraft turbine would damage after several years of operation. A major risk in modern aviation is the failure of aero engine turbine blades at very high rotating speed. According to Cowles (1996), the blade is the component that is most likely to be failed due to high cycle fatigue. The failure of turbine blade in aircraft engine could cause aircraft crash. Several cases of aircraft crash recoded in every years. This should be taken seriously and need to be avoided due to the safety of passengers life. So this project deals with some analysis to find the possible reason of the failure.

Year after years, the engineer and designer have done research on the causes of failure of this aircraft turbine blade. A lot of experiment and examination on the blade behavior have been carried out to determine the causes of failure and the way to preventing it. The simulation using finite element method software package seem to be the most effective way due to the accuracy of the results and the cost saving.

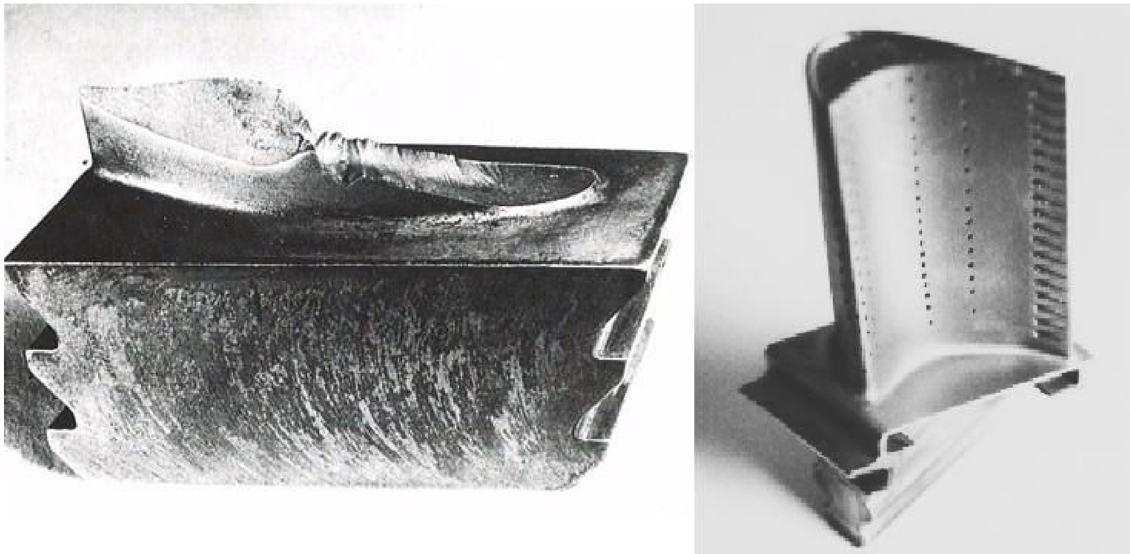

Figure 1.1: Failure turbine blade

(Retrieved from: www.lifepredictiontech.com)

The Figure 1.1 above shows the example of failure turbine blade. In order to prevent the problem, the engineer and designer have the option by using several appropriate software packages that related to the finite element analysis. As in this research, the use of MSC Nastran/Patran software will be very helpful in order to simulate and analyze the aircraft turbine blade to find the critical area of the failure, maximum displacement of the blade when exposed to the pressure, and the maximum stress that act on the blade. Theoretical calculation will be use to validate the result obtained from the simulation.

CHAPTER 2

LITERATURE REVIEW

The literature review consists of numerous aspect of analysis regarding to the investigation of turbine blade failure in aircraft engine produced by various person either individual or group. The research made by them involved here as a reference that really helpful to this project.

2.1 Causes of Failure

J. Hou et al. (2002) stated that blade failures can be caused by a number of mechanisms under the turbine operating conditions of high rotational speed at elevated temperature. In general, blade failures can be grouped into two categories that are fatigue; including both high (HCF) and low cycle fatigue (LCF) and the second is creep rupture. In the conclusion section he state that the likely cause of blade failure is considered to be a mixture of LCF and HCF as a consequence of blade tip or casing rub strap impact.

By using finite element method, the maximum stress in the blade under normal steady state conditions occurs at the top firtree in the acute trailing corner, and that stress level is low. This indicates that centrifugal load, thermal expansion and gas pressure during steady state operation do not have a significant influence on crack initiation at the top firtree in the acute leading corner, although they do determine the mean stress values.

S.-g. Kim et al. (2008), in their analysis of failure in J85 engine turbine blades stated that after observing the engine exterior upon landing, cracks and deformations were found in many parts including the fuel inlet manifold and the afterburner fuel manifold. After removing parts and carrying out SEM analysis on cracked parts, the problem was found to be secondary cracks due to overstress.

They also mention about the engine vibration and external parts damage were caused by fragments created when the seven blades suffered fractures 1/3 of the way down from the tip as identified on 2 of the first stage turbine rotor blades resulting in damages to parts of the other 66 blades. The first stage turbine blades, where the initial failure occurred, suffered failure because over the long operating time, the coating peeled off due to high temperature air on the concave side surface, followed by direct exposure of the base metal to high temperature resulting in creep rupture.

T.J Carter (2005) in the research about common failures in gas turbine blades stand with the opinion that there are three probable damage mechanisms affect turbine blades, these being mechanical damage through either creep or fatigue and high temperature corrosion. The use of light alloys for the high temperature sections of the engine is not feasible since they cannot generally be design to give acceptable creep properties at the high temperatures needed for efficient turbine operation. In the case of aluminium alloys, the operating temperature is above the melting point. For the most parts, nickel base alloys are use and the weight penalty is accepted. Under normal conditions, blades should never be operated at excessive temperatures for long enough periods to cause microstructural damage.

All turbines blade and sometimes the high pressure stage of compressor blades are subjected to creep as a natural consequence of operating at high temperatures and stresses, and creep is eventually the life limiting process for all blades so exposed. The turbine blades are exposed to strongly oxidizing conditions and the gaseous combustion products contain element such as sulphur, vanadium or even lead and bromine from the fuel at very high temperatures.

E. Silveira et al. (2008) in the journal of study on the root causes for the premature failure of an aircraft turbine blade conclude that the failure of the first blade was attributed to thermal-mechanical fatigue with a significant contribution of creep. This fracture was initiated at one of the cooling holes. Moreover, a noticeable number of elongated particles, whose analysis points were to identify them as brittle intermetallic phases were, observe in this blade. This is a new factor which promotes the failure.

The other blades of the set failed by the impacts were produced by the broken fragments of the first failed blade. These blades exhibited much finer carbides and were not detected in the presence of intermetallic phases. It was postulated that without the premature failure of the first blade, these could have continued service for longer time.

H. Tang et al. (2008) carried out an analysis about fretting fatigue failure of an aero engine turbine blade that focused on two blades which had caused shutdown of an aircraft engine. He stated that apparently the fracture mechanism of blade 1 was high cycle fatigue. The fatigue was attributed to a V-shape notch defect which might be produced by fretting wear. In addition there are some fretting pits and fretting cracks on the surface of blade 1. Therefore it confirms that the failure mechanism of turbine blade 1 was fretting fatigue.

The fretting wear happen at the contact region between the serration of blade and dovetail slot of turbine disk because work environment at there was subject to fretting wear. Generally turbine blade and turbine disk should be assembled with little clearance for the demand of elongation of turbine blade when engine work. This turbine blade will endure centrifugal force and the balance of centrifugal bend moment and aerodynamic bend moment should be kept. Once the balance was broken for some reasons turbine blade would prefer to fracture at one side of root.

2.2 Method of Analysis

J. Hou et al. (2002) in the journal titled an investigation of fatigue failures of turbine blades in a gas turbine engine by mechanical analysis utilized a non-linear finite element method to determine the steady state stresses and dynamic characteristics of the turbine blade. The steady state stresses and dynamic characteristics of the blade were evaluated and synthesized in order to identify the cause of blade failures. A 3D finite element model of a blade and a sector of the disc were created, consisting of 80,000 solid elements. Ten-noded tetrahedral elements were used to mesh both the blade and disc due to complexity of the geometry. The global mesh density was chosen to minimize discretisation errors in the failure region.

E. Silveira et al. (2008) stated that the first step in their study consisted in a visual examination of the whole sets of blades, dedicating the principal attention to their fracture surfaces but without forgetting other aspects which could help identifying the origin or the operating mechanism. This labour was mainly carried out by the naked eye but it was completed with the help of a small stereoscopic microscope (X50). Once this visual examination was finished the fracture surfaces of the blades were cut to allow their fractographic analysis in the scanning electron microscope. This fractographic analysis allowed defining the most plausible origins of the failure and selecting those zones where the metallographic samples would be obtained.

S.-g. Kim et al. (2008) also used the same method as the above which involving the visual examination, fractographic analysis and metallographic analysis, however in addition of analysis of coating. To verify the overheating mechanism of the first stage turbine rotor blade concave side, the blade concave side and the coating layer of the non-discolored convex side were observed through scanning electron microscope (SEM).

2.3 Blades Material

In a research (Lisa 2007) the majority of gas turbines blades are made from nickel-based alloys. However current running temperature of the gas turbine (1350°C) is often in excess of the melting point of these Nickel alloys (1200~1315°C). Gas turbines obviously require protection to prevent the nickel alloy melting at high temperature but also require protection to prevent corrosion at high temperature.

J. Blackford (2000) state that turbine blades made by nickel base superalloy (Ni-base Superalloy). The Ni-base superalloy has high creep resistance thought to be due to precipitation hardening. Development of new alloys is a combination of experimental work, modelling and black art. Further improvements are able, but the scope is limited as superalloys now operate at 85-90% of their melting point.

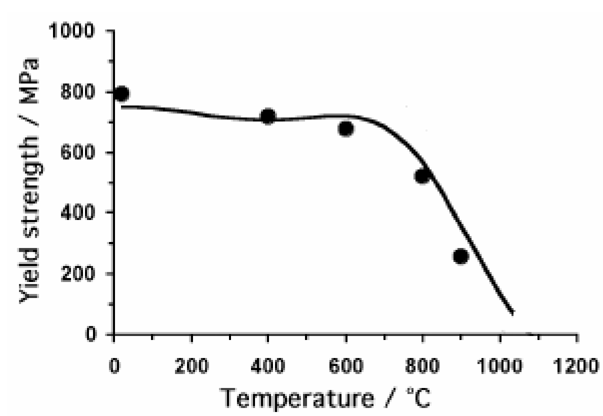

Figure 2.1: Graph of yield strength versus temperature for Ni-base superalloy.

In an abstract (V.A. Shulova et al. 1996) mention about the investigating the influence of uninterrupted and arc-pulsed ion implantation, high-power ion beam treatment and final annealing regimes on the chemical composition and phase-structural state of surface layers and on the surface properties of gas turbine engine compressor blades manufactured from refractory alloys.

Silviera E et al. (2008) stated that the use of nickel-base superalloys on various gas turbine components which operate under high temperature and high pressure conditions is widely extended. These alloys can work satisfactorily under load at temperatures near the melting point that is about 85% of this value in Kelvin degrees, figure which is clearly higher than those offered by alternative materials.

2.4 Blades Coating

Coatings are one of alternatives way to prevent blades from immediate corrosion that might shorten the life prediction of blades. G.W. Goward (1998) stated that increases in temperature are facilitated by improved structural design and airfoil cooling technology applied to higher strength-at-temperature alloys cast by increasingly complex processes, and coated with steadily improved protection systems. First stage turbine blades, the most critical components of gas turbines, made from nickel-base superalloys in various wrought and cast forms, and augmented by coatings, have been singularly successful materials systems for the past 50 years.