"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal Fluid)"

Signature : Juhari Ab Razak
Name of Supervisor : ……………………
Date : 15.12.2005

JUHARI BIN AB RAZAK
Pensyarah
Fakulti Kejuruteraan Mekanikal
Kolej Universiti Teknikal Kebangsaan Malaysia
Karung Berkunci 1200
75450 Ayer Keroh, Melaka.

A STUDY OF COMPLEX FLOW PROBLEM ON THE AERODYNAMIC OF COOLED TURBINE BLADE

NOR AZNIZAN BIN CHE YA

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Faculty Of Mechanical Engineering
Kolej Universiti Teknikal Kebangsaan Malaysia

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DECLARATION

" I hereby the author, declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged"

Signature : ………………………
Author Name : NOR AZNIZAN B. CHE YA
Date : 15/12/2005

DEDICATION

"To my beloved parents Mr. Che ya and Madam Johara and all my families and friends."

ACKNOWLEDGEMENT

In the name of ALLAH, the Most Gracious, Most Merciful. Praise be to ALLAH, The Cherisher and Sustainer of the World; Most Gracious, Most Merciful; Master of the Day of Judgment.

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ABSTRACT

In this thesis, there are have five main chapter specifically the introduction in the first chapter. In this chapter, there including the problem statement of the project, the objective of the project and scope of the project. In this chapter, also include the introduction about this project. In chapter two, it is about the literature review that has been done in doing this project from the textbook and the journals. In chapter three, it is about the turbine blade-cooling concept, turbine blade cooling design and also about turbine blade cooling method.

In chapter four, it is about the methodology for the simulation of the flow on the blade in the CFX-5. The flow on the blade had been simulated and the result about temperature, pressure and the velocity of the flow had been noticed. And the last chapter in this thesis is in chapter five, this chapter is about the result and discussion that had been done in this project.

ABSTRAK

Di dalam tesis ini terdapat lima bab penting iaitu pengenalan didalam bab satu. Di dalam bab satu ini ia menceritakan tentang pernyataan masalah yang terdapat dalam tajuk yang telah dipilih. Selain itu di dalam bab satu ini juga menceritakan tentang objektif dan skop kajian yang akan dilakukan nanti. Dan pada akhir bab satu ini ia menceritakan tentang kaedah yang dilakukan dalam menjalankan kajian. Di dalam bab dua pula, ia menceritakan tentang kajian ilmiah yang dicari dari buku-buku teks yang berkaitan dan juga dari jurnal-jurnal yang dicari di halaman internet. Di dalam bab ketiga pula, ianya menceritakan tentang kajian yang dilakukan terhadap sistem-sistem penyejukan yang ada untuk menyejukkan bilah turbin, terdapat beberapa kaedah yang boleh digunakan untuk menyejukkan bilah turbin. Semua kaedah tersebut dijelaskan didalam bab ini.

Di dalam bab yang keempat pula, ianya menjelaskan tenatng kaedah yang telah dijalankan dalam menjalankan simulasi terhadap aliran udara ke atas bilah turbin dengan menggunakan perisian CFX-5. Dan bab terakhir adalah bab kelima iaitu keputusan telah didapati setelah menjalan kajian. Di dalam bab ini ianya menceritakan tentang keputusan yang telah didapati seperti suhu, tekanan dan halaju aliran yang dikenakan keatas bilah turbin.

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Symbol	**Definition**
A_c	: Axial chord length
C	: Chord length of the blade
h	: blade height
M	: blowing rate or mass flux ratio ($\rho_j U_j / \rho_\infty U_\infty$)
T_{aw}	: adiabatic wall temperature
T_∞	: mainstream temperature
T_j	: injection temperature
U_{in}	: inlet velocity
U_j	: injection velocity
U_∞	: mainstream velocity
η	: film cooling effectiveness
Θ	: injection angle
μ	: dynamic viscosity
ρ_j	: density of cooling air
ρ_∞	: density of mainstream

CHAPTER 1

INTRODUCTION

1.1 Introduction

Gas turbine engines provide an efficient and reliable means of power production for both aircraft propulsion and power plant applications. For maximum efficiency of a gas turbine engine, the temperature of fluid (air) entering the turbine from the combustion chamber should be as high as possible without damaging the turbine section components such as the blades.

Turbine blade is a major and a very important part in a turbine. It is one of the most critical mechanisms in turbine system. Thus, the condition of the blade is an important criterion due to the efficiency and the performance of the turbine. Turbine blades are exposing directly to these extremely high temperatures. The high temperature regard for high efficiency have a disastrous effect on turbine blade life and any problems or damages regarding to the blade will affecting the overall performance and efficiency of the turbine.

To cope with these temperature problems, the blade must be providing with a proper cooling system through out the operating system. The turbine blade cooled that found today modern gas turbine engines represent very complex heat exchangers of specific aerodynamic shape and strict structural integrity.

1.2 Problem Statement

Turbine blade is one of the most critical parts in turbine system. The blades are expose directly to the extremely hot gases. This will cause change in microstructure due to temperature involve effecting strength of material, life cycle and the complex flow in the blade. An effective cooling method is needed to reduce this problem.

1.3 Project Objective

The objectives of this research are as follow:

1. To study the complex flow on the aerodynamic of cooled turbine blade.
2. To study the types of blade cooling system in gas turbine blade.
3. To learn and use advanced data acquisition and data processing techniques.

1.4 Project Scope

This research is supposed to be carry out through the scope mentioned below:

1. Study on the types of blades cooling system.
2. Use the CFX software to simulate the flow on the cooled turbine blade
3. Gathering all the data required.
4. Analysis all the data.

1.5 Methodology of Research

This research is carried out through of this method:

1. Carried out literature study on turbine and the blade and study all information required regarding to the objective of the research.
2. Determine all the problems concerning to the turbine blades cooling and this is suppose to involve the literature study and research.
3. Collect the present information available concerning to turbine blades cooled.
4. Study and determine the appropriate and effective method to overcome the discovered and existing problems.

CHAPTER 2

LITERATURE REVIEW

2.1 Gas Turbine and Turbine Blade

The gas turbine used in power plant can be classified as the heavy duty gas turbine. This type of gas turbine is such a huge and heavy in size. The requirement of modern gas turbine has been increased continuously. The requirement of high firing temperature, long life, better corrosion and oxidation resistance, etc. In order to achieve better performance have turn the turbine blade technology into a dynamic and competence field.

Turbine blades are one of the most important in a gas turbine power plant. These are components across which flow of high pressure gases takes places to produce work. A blade can be defined as the medium of transfer of energy from the gases to the turbine rotor.

The blade as an entity is subjected to a large number of forces, some are inevitable and some are caused by the rotation of blade. The blade is subjected to forces in the three directions.

i. The rotor driving forces along the radial direction,
ii. Axial forces caused by the gas flow,
iii. Forces acting normal to the turbine shaft due to the centrifugal forces.

Further, the blade is subjected to differential thermal stresses, erosion-corrosion and a host of other hostile parameters hampering its smooth functioning.

Turbine blade has been classified as one of the most critical part in turbine system due to the high inlet temperature of about 600°C - 1300°C. The inlet temperature is base on the type and size of the turbine. The high inlet temperature is to ensure the turbine operate at higher efficiency, can achieve more power and power density in the modern gas turbine.

The design of high efficiency, highly cooled gas turbine is achieve through the orchestrated combination of aerodynamics, heat transfer, mechanical strength and durability, and material capabilities into a balanced operating unit.

Blade tips are comprised of extended surfaces at the furthest radial position of the rotating blade, which are exposed to hot gases on all sides, typically difficult to cool, and subjected to the potential for wear against the outer shroud flow path. The blade tips operate in the transitional environment between the rotating airfoil and the stationary flow path casing, which experiences the extremes in most fluid-thermal conditions within the turbine.

The cooled turbine blades found today's modern gas turbine engines represent very complex heat exchangers of specific aerodynamic shape and strict structural integrity. The blade tip region is arguably the most three-dimensional portion of the blade in terms of hot gas flow interaction, coolant delivery, and geometry. Issues which challenge the best turbine designers include:

i. The blade tip is subjected to extremes in convective heat transfer loads.
ii. An extremely complex flow with periodic unsteadiness and leakage flow.
iii. Blade tip thermal gradients can result in high thermal stresses and cracking.
iv. Aerodynamic and thermal boundary conditions change during short transient.
v. Blade tip weight directly impacts the blade root stresses, LCF life and creep.
vi. Increased blade tip cooling represents a chargeable flow penalty on the cycle.

vii. Film cooling adds further complexity or constraint in many factors.

CFD heat transfer predictions are becoming very attractive and cost effective means for designing blade tips, but this still requires closure of the present turbulence modeling issue. Though method such as Large Eddy Simulation may help to bridge the CFD needs, there remain many areas requiring research and development to allow a full understanding of turbine blade tips. To date, now have only engine experience to describe the effects of tip film coolant mixing fundamentals, both on blade tips as well as on the airfoil surfaces near the tip. The ability to predict blade tip heat transfer also rests on a better understanding of the hot gas migration and temperature profiles present in the many types of combustion-turbine systems. The understanding of how heat transfer coefficient and film effectiveness change as the blade tip are altered in services is a wholly unexplored area. As such, information becomes more plentiful, innovative solutions will be required to extend blade tip life.

2.2 Unsteady Wake Flow Behind Turbine Blade

The main effort was devoted to the performance of steady and unsteady wake pressure measurements and to the investigation of the effect of the wake vortex shedding process on the blade suction side pressure distribution. The wake measurement were performed at a trailing edge distance X/Dte = 2.5 with a four-sensor probe carrying a modified kiel-type total pressure probe and a shielded thermocouple probe for the steady state measurement on one side and a fast response cold-wire temperature probe and a kulite pressure probe for the unsteady measurement on the other side. The phase lock averaging procedure for the unsteady pressure and temperature measurement proved to be very difficult. The outer wake regions are dominated by the suction and pressure side vortex shedding processes, respectively, and are characterized by very high correlation coefficient. The wake centre region is affected by the shedding process from both sides (the frequency changes from ~7.5 kHz to ~15 kHz) and is characterized by rather poor correlation coefficients.

2.3 Unsteady Flow Visualization

A part from the huge centripetal forces on turbine blades, hot spots around blades can peak at temperature above 2000K, creating thermal fatigue that can cause blades to snap off. Controlling the temperature across the blade can reduce creep significantly. Experimentation and simple CFD analysis have not provided sufficient insight into the flow condition inside turbine engine, but now codes developed by the Turbomachinery Group of Qinetiq, combined with Fieldview visualization software marketed and supported by simulation technology enabled engineers to visualize the development of hot spots. If the CFD analysis of unsteady flow adds 50% to blade life and inspection are reduced, over and above any increase in efficiency. CFD analysis also allows 'what if' scenarios to be undertaken before the detailed development work and subsequent manufacture. 3D CFD programmed can be used to predict heat transfer and the effectiveness of cooling strategies.

2.4 Finite Element Method Project Heat Transfer In A Turbine Blade

In the first stages of a turbine, the blades are subjected to a high temperature flow due to the hot gas produced in the combustor. Turbine blades are often internally cooled by pumping low temperature air through the blades in passage. In this project, we will simulate the heat transfer in an internally cooled turbine blade using a finite element discretization.

2.5 Multidisciplinary Design Optimization Of Film-Cooled Gas Turbine Blades

A multiobjective optimization procedure with the integration of aerodynamic and heat transfer has been developed for the design of gas turbine to achieve efficient film cooling. Three different formulations are used to study the design problem. In the first one, the average blade temperature is chosen as the objective function to be minimized. In the second one, the maximum blade temperature is chosen as the objective function to be minimized. In the third formulation, the blade average and maximum temperatures are chosen as objective functions. The CFD code, RVCQ3D, is used to solve for the flow field outside the blade and the finite element method is used for the heat transfer analysis in the blade interior. Film cooling is incorporated by appropriately changing the boundary conditions on the surface of the blade at the nodes where film cooling holes exist.

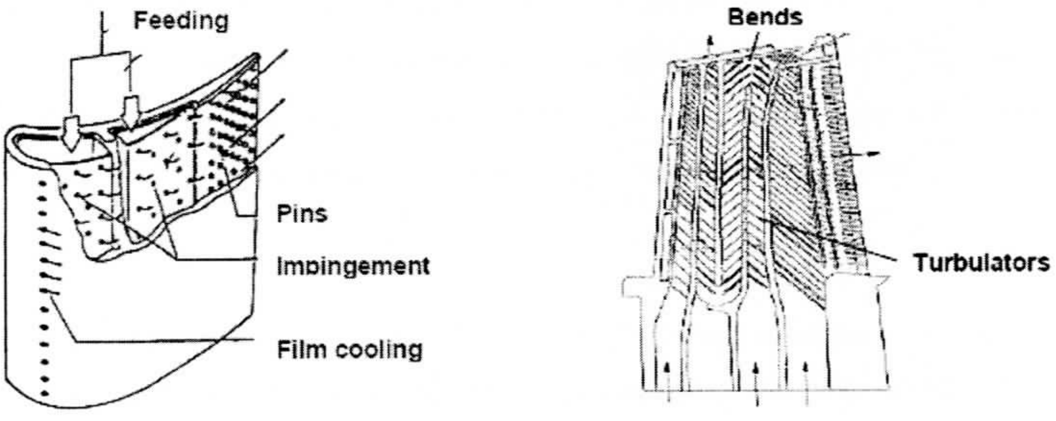
2.6 Heat Transfer Technology for Internal Passages Of Air Cooled Blades For Heavy Duty Gas Turbines

The need for cooling gas turbine has steadily increased because of the increasing differences between turbine inlet temperature and allowable material temperature. Compared to the heat transfer requirement for an aero-engine, the cooling of blades for industrial gas turbine differs in some aspect. The most important differences are firstly that blades for heavy-duty gas turbine, because of there much bigger dimensions, are subjected to much higher Reynolds numbers in the internal cooling passages. Secondly, the larger size of the blades and also the internal passages gives much more freedom for designing the shape of cooling features inside the blade which have to be casted in.

For vanes, impingement cooling is use very often together with pins and turbulators. For rotating blades mostly, turbulators are preferred together with pins in order to efficiently cool the blade. Both cooling schemes can use additionally film cooling if the external hot gas temperature is to high for cooling the blade only by internal convection. The external heat transfer of the blade provides the boundary condition for the internal cooling problem.

In blades of a real gas turbine complex geometries have to be used for the cross section of coolant passages because of constraint given by stress analysis, aerodynamics and manufacturing. This requires some sort of component tests for the heat transfer of the designed blade at the end. Such tests can be done for heavy duty gas turbine by using large scale models, as the one shown in figure, where the transient liquid crystal method has been used for measuring the heat transfer inside the blade. The large scale tests mentioned above are further be used for evaluating and improving CFD tools.

Several innovative developments for the internal cooling design of industrial gas turbine have been thought of in newer past. One is the use of steam as the working fluid for the internal cooling loop. Another innovative development is to use 3D shaped turbulators to locally influence heat transfers in the internal channels of industrial gas turbines.



Vane

Rotating blade

Figure 2.1: Typical cooling features for stationary and rotating blades

2.7 Internal Blade Cooling & Conjugate Heat Transfer

Various techniques are employed to cool gas turbine blades; one such technique involves manufacturing blades with leading – and trailing edge cavities into which cooler air from the compressor is injected. CFD can provide key information such as the heat transfer rate, temperature distribution, maximum temperature, etc., for a particular design shape. CFD can aid in the design process by providing detail of the flow field to understand the basic flow physics and the effect of various parameters.

For internally cooled turbine blades, the thermal analysis requires the specification of thermal boundary conditions on the blade surfaces in contact with the hot gas (external to the blade) and the coolant (inside the blade cavity). However, fixing the boundary conditions on the external and internal blade surfaces leads to an inconsistent procedure. One needs to solve for the heat transfer in the fluid (by convection and conduction) and in the solid (by conduction) in a conjugate manner.

Several numerical approaches have been used for problems involving conjugate heat transfer. For example, use an iterative procedure which sequentially employs two different computer codes: one for the hot gas flow field and another for the blade temperature field; such a procedure can be unstable. A more robust approach is one where a single CFD code is used for a simultaneous solution in the fluid and solid phases.

In this research we have compute the coolant flow field (inside the blade cavity) along with heat transfer in the blade material while specifying the temperature on the outer (hot) walls of the blade.

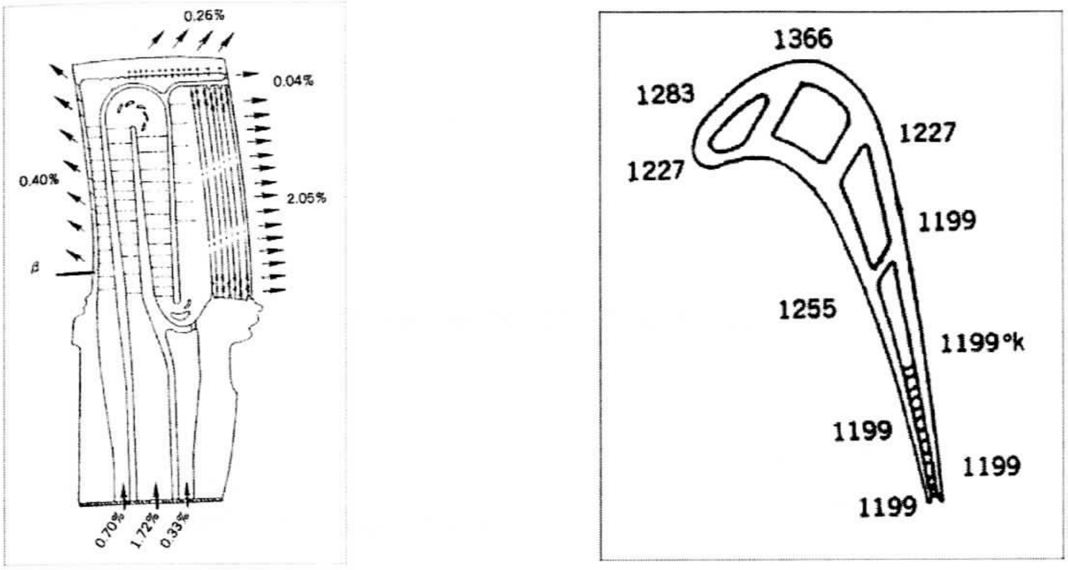


Figure 2.2: Schematic of a typical internally cooled gas turbine blade

2.8 Blades Cooling

The requirement of high gas temperature at turbine inlet to achieve greater performance has given various effects to the turbine blades. Even thought the advancement of the blading technology has raised the blades capabilities to withstand the high inlet temperature but the fixed and rotor blades of the first two rows are needed to be cooled. These blades are cooled with compressed air.

In actual gas turbine, there are normally three types of cooling methods utilized. These three cooling methods are:

a. Convection cooling
b. Jet impingement
c. Film cooling]

The working fluid used for these three types of cooling methods is compressor air.