THE EFFECT OF NUMBER OF BLADES ON TURBINE CASCADE BLADE PERFORMANCE BY USING 3D CFD

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DECLARATION

I declare that this project report entitled “The effect of number of blades on turbine cascade blade performance by using 3D CFD” is the result of my own work except as cited in the references

Signature : ....

Name : ....

Date : ....

APPROVAL

I hereby declare that I have read this project 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-Fluids) with Honours.

Signature :. ....

Name of Supervisor : ....

Date : ....

DEDICATION

I would like to dedicate this thesis to my parents

ABSTRACT

Gas turbine engines considered as a huge machine with applications in propulsion and for power electric generation. The main parameter that considered in designing the gas turbine engines are the efficiency of turbine blades performance inside the engine. The NACA 8412 airfoil is used to simulate the blade's cascade and was obtained from the UIUC Airfoil Coordinates Database as a supercritical airfoil**.** The airfoil is generated into the SOLIDWORKS with specific geometric of the turbine blade profile. The Fluent was used to simulate the cascade for 3 blades, 5 blades, 7 blades and 9 blades. The result for drag coefficient, C_D and lift coefficient, C_L is obtained after the simulation. The pressure distribution and velocity distribution in terms of pressure contour and velocity streamline for all cascades are also obtained. The graph of lift coefficient is decreased because all the cascades have the negative lift coefficient due to the high static pressure is occurred at the upper side of the cascades. Cascade efficiency obtained shows that the bigger the number of blades, the higher the value of efficiency but it is decrease after the 5 blades. Efficiency for 3 blades obtained lowest which produced 66.25% but for 5 blades obtained highest which produced 80.36%. Cascade with 5 blades produced the optimum efficiency for the cascade performance. The result of cascade performance efficiency explained the linear turbine cascade for 5 blades are good to use because it has minimum losses in terms of tip clearance flow losses and blade surface losses. This linear turbine cascade can minimize the fuel consumption and produce the optimum power output when applying to the real gas turbine engine due to its highest efficiency.

ABSTRAK

Enjin turbin gas dianggap sebagai mesin besar dengan aplikasi dalam pendorongan dan untuk penjanaan kuasa elektrik. Parameter utama yang dipertimbangkan dalam mereka bentuk enjin turbin gas adalah kecekapan prestasi bilah turbin dalam enjin. NACA 8412 aerofoil digunakan untuk mensimulasikan lata bilah dan diperoleh daripada Pangkalan UIUC Airfoil Koordinat sebagai lelayang genting lampau. Aerofoil dihasilkan di dalam proses SOLIDWORKS berdasarkan geometri tertentu profil bilah turbin. Proses Fluent digunakan untuk mensimulasikan lata untuk 3 bilah, bilah 5, 7 bilah dan 9 bilah. Hasil untuk pekali seretan dan pekali daya angkat diperolehi selepas simulasi. Taburan tekanan dan taburan halaju dari segi kontur tekanan dan halaju arus untuk semua lata juga diperolehi. Graf pekali daya angkat semakin berkurang kerana semua lata mempunyai pekali daya angkat negatif akibat tekanan statik tinggi berlaku di sebelah atas lata. kecekapan Lata diperolehi menunjukkan bahawa lebih besar bilangan bilah, semakin tinggi nilai kecekapan tetapi ia adalah penurunan selepas 5 bilah. Kecekapan untuk 3 bilah diperolehi rendah yang menghasilkan 66,25% tetapi untuk 5 bilah diperolehi tertinggi yang menghasilkan 80.36%. Lata dengan 5 bilah hasilkan kecekapan optimum untuk prestasi lata. Hasil daripada kecekapan prestasi lata menjelaskan lata turbin linear untuk 5 bilah adalah baik untuk digunakan kerana ia mempunyai kerugian minimum dari segi kerugian aliran pelepasan tip dan kerugian permukaan bilah. Lata turbin linear ini juga boleh mengurangkan penggunaan bahan api dan menghasilkan keluaran kuasa optimum apabila digunakan terhadap enjin turbin gas sebenar kerana kecekapannya yang tertinggi.

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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
NACA	National Advisory Committee for Aeronautics
TET	Turbine Entry Temperature
CAD	Computer-aided Design

LIST OF SYMBOLS

C_D	=	Drag coefficient
C_L	=	Lift coefficient
n_D	=	Efficiency of turbine cascade performance (%)
α_m	=	Mean flow angle (°)
α_1	=	Air inlet angle (°)
α_2	=	Air outlet angle (°)

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Gas turbine engines considered as a huge machine with applications in propulsion and for power electric generation. The gas turbine engines built in 1940s with allowed cycle efficiencies around 17 percent. Effort was made to improve the gas turbine cycle efficiency and can be separated into three areas which are raising the turbine inlet temperature, increasing the efficiencies of the turbo machinery parts and adding more modifications to the basic cycle (Björkman, 2013). The gas turbine efficiency is directly connected to the inlet temperature of the turbine and it must use the higher inlet temperatures to improve performance.

The power of performance characteristic for turbines and compressors are decreased because of the bad efficiency of the turbomachinery components and its design. The development and usage of advanced computer software and finite element software such as ANSYS Fluent made it possible to design components with minimal aerodynamically losses (Björkman, 2013). A modern gas turbine is a complicated machine with many components and can be simplified into three major parts which are a compressor, a combustion chamber and a turbine (Cengel & Boles, 2011). An illustrated view of the stages in a gas turbine is shown in Figure 1.1.

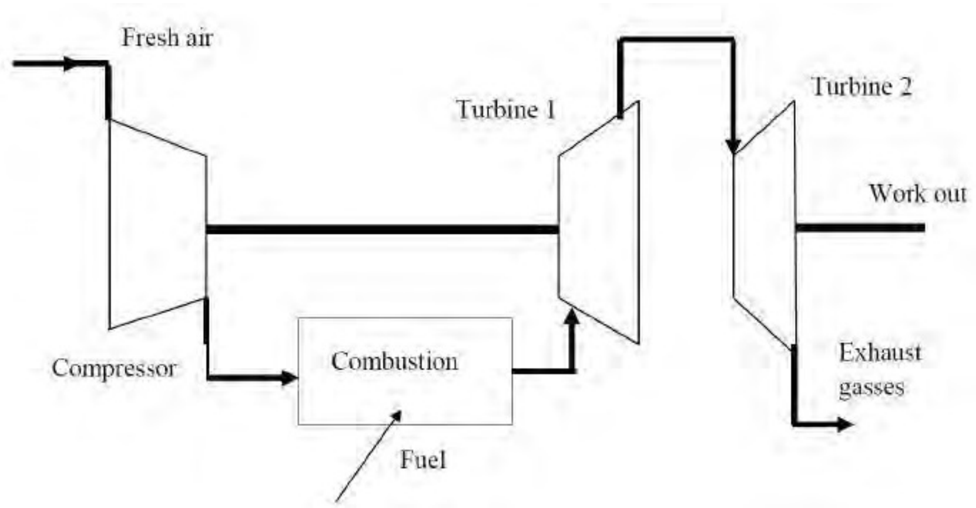

Figure 1.1: Schematic view for a gas turbine machine (Cengel & Boles, 2011)

Based on Figure 1.1, the compressor compresses the incoming air which enters the combustion chamber. The fuel is added at combustion chamber and ignites together with the compressed fluid. The exhaust gases enter the turbine with the high velocity and high temperature. The turbines are divided into two sets where the first set drives the compressor as it is connected on the same shaft and the other one set is connected on an output shaft which work is delivered and it can be connected to an application which needs the power. This is explained the application in the industrial sector of gas turbine engine (Cengel & Boles, 2011).

For the airfoil terminology theory, when an airfoil body moves through a fluid, it will generate and produce aerodynamic force which produced the lift and drag. The curvature on the airfoil is combined with the angle of attack to create results in a pressure difference between the upper and the lower surface of the airfoil. The pressure difference shows that the average velocities on the upper and lower surface are in different variable (Cengel & Boles, 2011).

The suction side always has lower static pressure occurred in a higher velocity compared to the pressure side which the static pressure is higher and the velocity is lower condition. The chord line variable is connecting with the leading part and trailing edge part in straight line condition. The angle of attack is the angle between the chord line to the free stream of velocity direction. The illustration of terminology for airfoil component is shown in Figure 1.2 (Björkman, 2013).

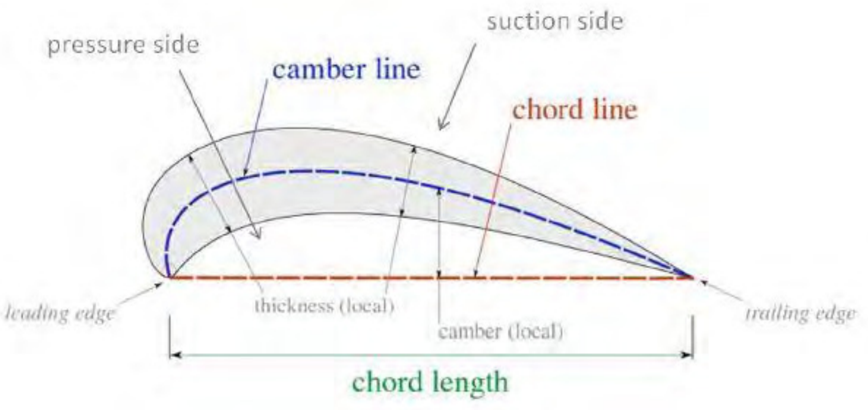

Figure 1.2: Conceptual of airfoil terminology (Björkman, 2013)

Based on the aerodynamic effects for gas turbines, the characteristics of the flow which occurs are affecting the efficiency of the gas turbine due to the energy losses. This situation is because of inviscid and viscous effects. To predict these losses, there are various types of experiments and simulations on cascades need to be done (Björkman, 2013).

A cascade testing rig consists of an inlet, a testing section and an outlet including the different geometry is used for simulation process for cascades. These parts will influence the nature of flow in simulation. Depending on the tests, the low or high-speed flow and type of power will influence on the design of the test rig. The aerodynamic effects which can occur are boundary layer separation, vortices and the influence of the walls boundary-layers close to the cascade (Björkman, 2013). For an example of a test section which a wind tunnel powered by a fan can be seen in Figure 1.3.

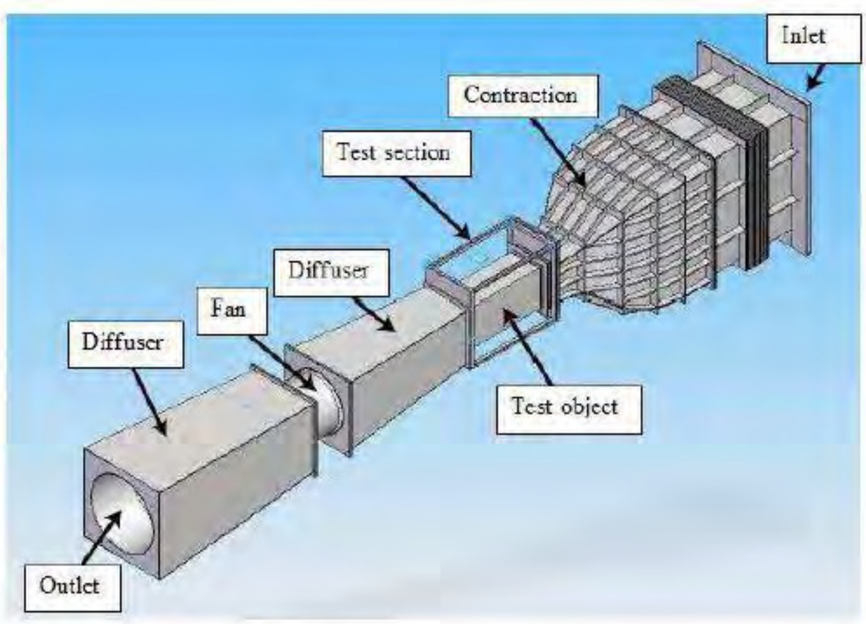

Figure 1.3: Wind tunnel schematic view for inlet, test section and outlet (Björkman, 2013)

The cascade in the tunnel consists of number of the same blades which are equally spaced and parallel to one another. The measurements are made in the centre region of the blades and it is important that the flow is periodic and repeats over several blade pitches (Björkman, 2013). For example, a linear turbine cascade component is shown in Figure 1.4 below.

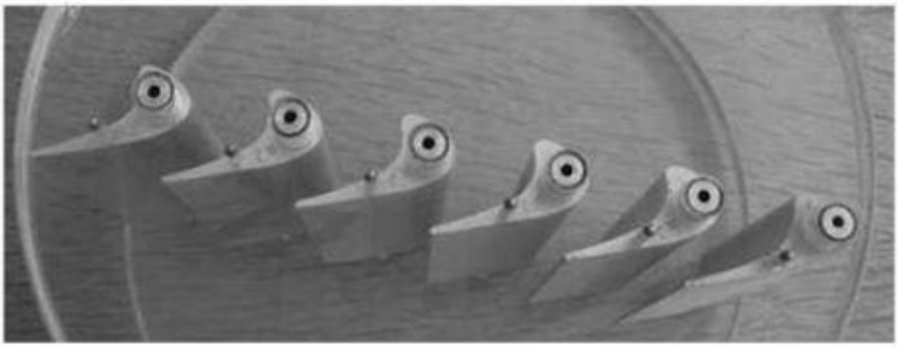

Figure 1.4: Linear cascade component for turbine (Björkman, 2013)

In simulation aspect, linear cascade has been scaled based on the theory and a series of three-dimensional numerical simulations are conducted on the geometric same cascade component with the CFD finite element software named ANSYS Fluent (Chen et al, 2015). Usually, a 3D Navier-Stokes equation flow solver was applied to stabilize flow and to support the flow situation at the linear cascade component. The program will mention the flow analysis results and performance of a turbine blade design. The main procedure and purpose of CFD element is used to investigate the flow in a linear cascade component. The CFD element analysis is becoming a part of required method for designing, testing and optimization of practical engineering systems (Pittala & Tafere, 2014).

For generalization in this project, the suitable airfoil that act as turbine blade profile for turbine cascade is important to generate the good efficiency of cascade performance. This is to ensure the simulation process obtained the minimum losses in terms of blade surface losses and tip clearance flow losses in simulation. This project is involved the characteristic of gas turbine engine which act as tunnel and run at a high inlet temperature and high inlet velocity.

1.2 PROBLEM STATEMENT

The gas in the linear cascade in a gas turbine engine is subject to centrifugal forces. If there is no radial pressure gradient to counteract this centrifugal force field, a radial flow will take place. The radial flow has a detrimental effect on the boundary layers over the blades and may cause premature separation of the boundary layers with the accompanied bad results on the performance of the machine component. To overcome these consequences, a twist is given to the cascade blades (Tsien, 2012).

Moreover, this will make the lift force at the tip larger than at the root of the blade. It will produce the result of larger pressure rise across the linear cascade to the tip compared to the root. The pressure gradient obtained will be avoided the radial flow situation and it will ensure that the operation will be in a good operation for the machine. Furthermore, the magnitude of the velocity component for the twisted flow condition behind the cascade turbine blades need to be ensure at constant along the length of the blade when the total twist is a few degrees (Tsien, 2012).

The main parameter in the problem statement is consider the efficiency of turbine cascade performance. The losses in terms of blade surface losses and tip clearance flow losses need to be decreased. The advanced gas turbine engines operate at high temperatures (1200-1500℃) to improve thermal efficiency and power output, so the performance of gas turbine will increase. The increase in temperatures of gases, the heat transferred to the blades will also increase. This can cause the thermal failure. The good material of turbine blades need to use to keep their metal temperature with in allowable limits. This because the blades are rotating, so the flow of the coolant in the passages is altered.

The boundary condition of internal heat transfer in terms of input data need to be considered to create high compression at turbine blades to produce higher power output. The type of turbine blade profile must be suitable and good to obtain the optimum efficiency for turbine performance and minimize the fuel consumption. The selection for optimum angle of attack of turbine blade must be considered to maximize lift and minimize drag.

The good angle of attack can minimize the fuel consumption of the gas turbine machine because there has small resistance at the blades in terms of drag force. Throughout the optimum angle of attack of airfoil blades with the suitable inlet velocity and inlet temperature for working fluid, it can produce the good linear turbine cascade with the high efficiency of performance.

1.3 OBJECTIVE

The objective of this project is to obtain cascade performance data for turbine cascade blade with various numbers of blades.

1.4 SCOPE OF PROJECT

Based on the simulation and computerization, this project needs to use 3-Dimensional CFD software which is CFD ANSYS Fluent version 16.0 to simulate the fluid flow through the cascade blade. The investigation involved the fix turbine blade profile, fix incidence angle and fix inlet fluid flow velocity but with various case with the different number of blades. The blade used in this project is a supercritical airfoil which is NACA 8412 airfoil. The linear turbine cascades consist of 3 blades, 5 blades, 7 blades and 9 blades.

All these blades are twisted with a fixed angle and fixed angle of attack which provided from the journal. The angle of attack for the blades are 0° and for twisted angle of the airfoil blades are 36°. For the simulation process in CFD ANSYS Fluent software, it needs to use the Realizable K-epsilon in viscous model and Second Order Upwind scheme in solution methods. The Realizable K-epsilon is used because the air in the tunnel will be combined with the inlet temperature of working fluid then produced the high temperature of hot air and is sufficient to make the flow turbulence over the turbine blades. The Second Order Upwind scheme in solution methods are used because this scheme is more accurate and suitable to use for the meshing of the cascade models. The inlet velocity and inlet temperature of the working fluid used in ANSYS Fluent is 126 m/s and 728 K (455℃).

After completing the simulation process, the data for lift coefficient, C_L and drag coefficient, C_D will be obtained. The data will be used to calculate the efficiency of performance for all the linear turbine cascades with the required formula. The results of pressure distribution and the velocity distribution in terms of pressure contour and velocity streamline also obtained from the simulation. All these contours can be discussed the specific losses that occurred in the simulation to the linear turbine cascades in terms of blade surface losses and tip clearance flow losses.