THE EFFECT OF NUMBER OF BLADES ON COMPRESSOR CASCADE BLADESPERFORMANCE BY USING 3D CFD

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in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "The Effect of Number of Blades on Compressor Cascade Blades Performance by using 3D CFD" is the result of my own work except as cited in the references

Signature : …………………………

Name : Siti Nurazeera binti Azli

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 Honour.

Signature : ....

Name of Supervisor: **Dr. Yusmady bin Mohamed Arifin**

Date : ....

DEDICATION

To my beloved mother and father

ABSTRACT

A compressor is one of the mechanical devices in gas turbine engine that compresses air to increases its pressure as well as changing its temperature. In order to design the efficient gas turbine engine, high efficiency of engine is required. Smoothness of airflow in gas turbine has an impact on engine performance. Compressor efficiency is one of the parameter should be considered to maintain that airflow. Hence, compressor blade design was play important role to obtain high efficiency of compressor. A computational investigation has been carried out on the effect of number of blade on 3-Dimensional of compressor cascade blade performance. In order to design the good performance of compressor cascade blade, higher efficiency of cascade is required. It is give benefit to the compressor efficiency, hence produce the efficient turbomachine. The study of flow field is analyzed with help of Computational Fluid Dynamics using the FLUENT software. The flow considered steady with inlet velocity of 30 m/s. NACA 65-206 chosen as blade profile with angle of attack of 10°. The compressor cascade blade is modelled by using SolidWorks software. The blade is twisted. The analysis has been made on different number of blade, namely 3, 5, 7 and 9 with fixed geometry and parameter. The performance of compressor cascade blade have been shown in results of pressure distribution, velocity profile, lift and drag coefficient, pressure different and cascade efficiency. The results have been shown in 2-Dimensional taken at four ratio of position plane. The pattern of velocity profile around the cascade blade and pressure distribution on the surface of cascade blade followed the Bernoulli's principle stated that the velocity on the suction side of airfoil higher than pressure side of airfoil. The acceleration of air creates the lower pressure system and vice versa. Thus, the pattern of pressure distribution is inversely to the velocity profile of cascade blade. Nine blade of compressor have the higher pressure different of inlet and outlet between the blade passages with value of 5.7095 Pa. In order to design the compressor cascade blade, maximum lift and minimize drag should be considered. As result of the effect of number of blade to the lift and drag, it is showed that lift coefficient is higher that drag coefficient for various number of blades. However, five blades of compressor have better result of efficiency of cascade and lift to drag ratio with 75% and 7.857, respectively. It is shown that the five blades of compressor have the best performance compared to the other number of blades.

ABSTRAK

Pemampat adalah salah satu daripada peranti mekanikal dalam enjin turbin gas yang memampatkan udara untuk kenaikan tekanan serta perubahan suhu. Dalam usaha untuk mereka bentuk enjin turbin gas yang cekap, kecekapan tinggi enjin diperlukan. Kelancaran aliran udara di dalam turbin gas mempunyai kesan ke atas prestasi enjin. Kecekapan pemampat adalah salah satu parameter yang perlu dipertimbangkan untuk mengekalkan aliran udara itu. Oleh itu, reka bentuk bilah pemampat adalah memainkan peranan penting untuk mendapatkan kecekapan pemampat yang tinggi. Kajian pengiraan perisian komputer telah dijalankan ke atas kesan bilangan bilah 3 Dimensi prestasi bilah pemampat lata. Untuk merangka prestasi baik bilah pemampat lata, kecekapan lata yang tinggi diperlukan. Ia memberi manfaat kepada kecekapan pemampat , dengan itu menghasilkan mesin turbo yang cekap. Kajian medan aliran dianalisis dengan bantuan Pengiraan Bendalir Dinamik menggunakan perisian FLUENT. Aliran dalam keadaan tetap dengan halalaju masuk 30 m/s. NACA 65-206 dipilih sebagai profil bilah dengan sudut serang 10º. Bilah pemampat lata dimodelkan dengan menggunakan perisian SolidWorks. Bilah adalah berpintal. Analisis telah dibuat ke atas bilangan bilah yang berbeza iaitu 3, 5, 7, dan 9 dengan geometri dan parameter yang tetap. Prestasi bilah pemampat lata telah ditunjukkan dalam keputusan pengagihan tekanan, profil halalaju, daya angkat dan pekali seretan, perbezaan tekanan dan kecekapan bilah lata. Keputusan telah ditunjukkan dalam 2 Dimensi di ambil pada empat kedudukan nisbah. Corak profil halalaju di sekeliling bilah lata dan taburan tekanan pada permukaan bilah lata adalah sejajar dengan prinsip Bernoulli yang menyatakan halalaju di bahagian sedutan airfoil lebih tinggi berbanding bahagian tekanan airfoil. Pecutan udara mewujudkan sistem tekanan yang rendah dan sebaliknya. Oleh itu, corak taburan tekanan adalah songsang dengan profil halalaju bilah lata. Sembilan bilah pemampat mempunyai perbezaan tekanan di antara tekanan masuk dan tekanan keluar yang tinggi dengan nilai 5.7095 Pa. Dalam usaha untuk mereka bentuk bilah pemampat lata, maksimum daya angkat dan minimum pekali seretan perlu dipertimbangkan. Sebagai hasil daripada kesan bilangan bilah terhadap daya angkat dan pekali seretan, ia menunjukkan bahawa daya angkat adalah lebih tinggi daripada pekali seretan untuk pelbagai bilangan bilah. Walau bagaimanapun, lima bilah pemampat mempunyai hasil kecekapan lata yang lebih baik dan nisbah daya angkat dan pekali seretan dengan masing-masing 75% dan 7.857. Ia menunjukan bahawa lima bilah pemampat mempunyai prestasi yang terbaik berbanding bilangan bilah yang lain.

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LIST OF SYMBOLS

			Unit
t	-	Thickness	m
a	-	Maximum displacement of camber from leading edge	m
b	-	Maximum displacement from the chord line	m
λ	-	Angle of attack	°
s	-	Spacing	cm
c	-	Chord length	cm
i	-	Incidence angle	°
C_L	-	Lift coefficient	-
L	-	Lift forces	$kg.m/s^2$
C_D	-	Drag coefficient	-
D	-	Drag forces	N
ρ	-	Density	kg/m^3
V	-	Velocity	m/s
l	-	Length	m
η	-	Efficiency	-

LIST OF ABBEREVATIONS

NACA	National Advisory Committee for Aeronautics
CFD	Computational Fluid Dynamics

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

A compressor is one of major part in a gas turbine engine other than turbine and combustor. It is function to increase the pressure of incoming air before it is enter the combustion section. This component is important to design as it is affecting the efficiency and performance of engine. Lebele-Awala and Jo-Appah (2015) have shown compressor work was increase 30 percent in increasing of ambient temperature for gas turbine power plant analysis. In manufacturing the gas turbine engine, high efficiency is required to obtain the best design of gas turbine engine which produced high thrust and good performance. Gas turbine engine, mostly used for power generation, is a combustion engine that can convert natural gas or other liquid fuels to mechanical energy which drives a generator to produces electrical energy. There are several parameters that affect aerodynamics performance of gas turbine including the compressor compression ratio, combustion inlet temperature and turbine inlet temperature. To achieve the efficient gas turbine, improvement in compressor blade design is essential since overall efficiency of the gas turbine cycle depends primarily upon the pressure ratio of the compressor. In development of the highly efficient axial flow compressor, the study of the two and three dimensional flow through a compressor cascade of aerofoil has played an important role.

Figure 1.1 shown the nomenclature of compressor blade, shaped in aerofoil. The dotted line indicated the camber line, or it is defined as skeleton of the aerofoil. A thickness, t is distributed over the camber line with the leading and trailing edge circles that finally form an aerofoil. 'a' is maximum displacement from the leading edge for maximum camber. 'b' is the maximum displacement from the chord line. Upper side of airfoil is known as suction surface while lower side is called pressure surface of airfoil.

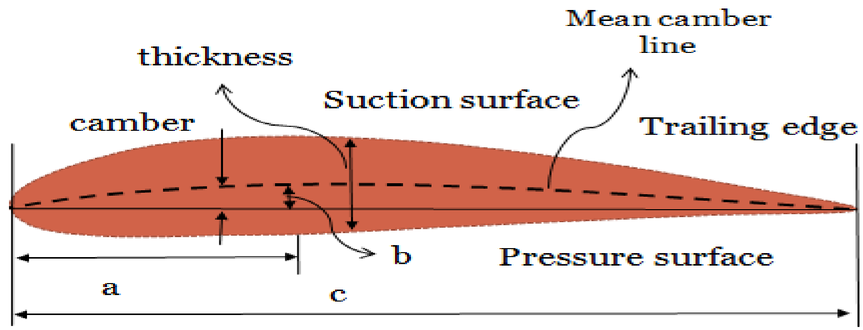

Figure 1.1 Basic nomenclature airfoil for NACA-65 (Pandey, *el at.*, 2012)

Compressor cascade blade, means by set of blades comprises a number of identical blades, equally spaced and parallel to one another defined in Figure 1.2. In modelling the blade profile, the cascade geometry is defined by the aerofoil specification such as angle of attack (λ), spacing (s), chord length (c) and incidence angle (*i*).

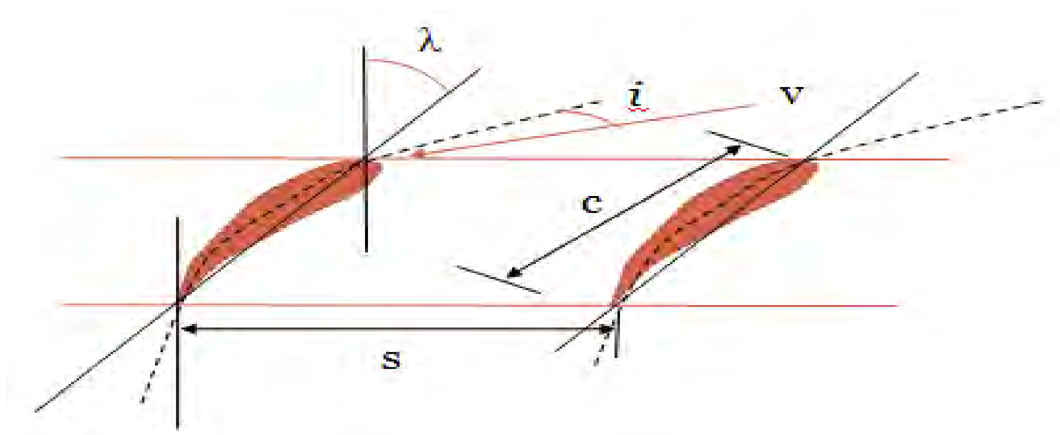

Figure 1.2 Geometrical of cascade airfoil for NACA-65 (Pandey, *el at.*, 2012)

1.2 PROBLEM STATEMENT

High efficiency is required in order to produce gas turbine engine in the most efficient manners. This is to minimize the fuel consumption in the process of converting the mechanical energy to produce the power, which engine efficiency is the ratio between work output and fuel energy input. Smoothness of airflow influenced the efficiency of compressor, means that design of the compressor in gas turbine engine has to be considered. This is to reduce the airflow losses due to friction and turbulence. Thus, shaped of aerofoils are play important role in the compressor to maintain the smoothness of airflow. Instead of incident angle and angle of attack that influence the efficiency, number of blades on compressor cascade blades also has an effect on the compressor performance. The performance of compressor cascade blade will be shown in result of pressure distribution, velocity profile, lift and drag coefficient, pressure different and efficiency of cascade at four position plane in 2-Dimensional for four case study with different number of blades.

1.3 OBJECTIVE

This study presents the investigation of the effect of number of blades on compressor cascade blades performance by using 3D CFD. The aim of this study is to obtain cascade performance for compressor cascade blade with various number of blades. The specific research questions are as follows:

i. How does number of blades affect compressor cascade performance?
ii. How does twisted blade affect the compressor cascade blade?

1.4 SCOPE OF PROJECT

The scopes of this project are:

i. The flow direction of compressor is parallel to the axial, called as axial flow compressor and the blade is twisted. The arrangement of blade in test section is linear.

ii. The geometry of blade such as angle of attack, blade profile, chord, angle of twist is fixed for four case study. Similar to the parameter setting in ANSYS such as velocity inlet, meshing and so on are fixed. The test section with dimension of $50\ \text{cm} \times 50\ \text{cm}\ \times 100\ \text{cm}$ was used. Thus, Reynolds number and Mach number are same with various numbers of blades.

iii. Realizable k-ε (epsilon) viscous model is used in this analysis and ANSYS Fluent code as the type of solver preference.

iv. Then working fluid is air at 15ºC and the flow is considered in steady state and incompressible flow.

v. The performance of cascade blade is shown in pressure distribution, velocity profile, lift to drag ratio, pressure different and efficiency of cascade. The losses of energy and 3D flow such as secondary flow are negligible.

CHAPTER 2

LITERATURE REVIEW

2.1 TURBOMACHINERY

2.1.1 Basic of Gas Turbine

Gas turbine has been used in aerospace and industrial applications in many years. Mostly, gas turbine engine drives for power generation and power aircraft. Figure 2.1 depict the gas turbine and how the device works. Development of gas turbine can be divided in two field of technology, namely steam turbine and internal combustion engine. Recent research on Gas Turbine (Hackert, 2014) has shown the first steam turbine was built by Sir Charles Parsons and on 1903, gas turbine thesis are established by Dr. Sanford Moss .Year by year, gas turbine is upgraded and it is accomplished to installed at Oklahoma for electric power generation purpose.

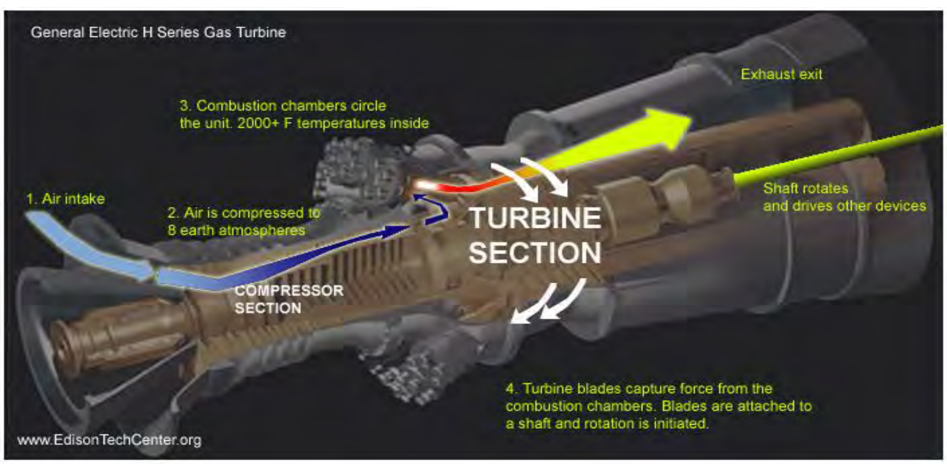

Figure 2.1 Gas turbine and devices work (source: Edison Tech Center website)

The compressor required the power provided by turbine to compress the air in the engine compressor. Turbine and compressor are the main component in the gas turbine. Otherwise the combustor, function to be combustion section by burning the large amount of fuel and air to release the heat. The turbine and compressor have different functional, where turbine was extracted the work from the flow while compressor was supplied the air at high pressure. In the other words, the inlet air at ambient pressure is compressed to obtain the air at high pressure.

2.1.2 Performance of Gas Turbine

Kurz (2005) stated that gas turbine performance is influenced with several ambient conditions such as ambient temperature, inlet and exhaust pressure losses, fuel, ambient pressure and relative humidity. The power turbine reduces as more work required to increase the pressure at higher temperature inlet. With increasing the temperature will lessen the pressure ratio of the compressor at constant speed. Therefore, component efficiencies in gas turbine have an effect on changes in the ambient temperature. As well as ambient pressure, this condition give impact on the power output when the air density is decreased resulting on the impact of operating the engine at lower ambient pressure. Other than that, it is found that increasing the tip clearances, changing in airfoil geometry and airfoil surface quality has major effect on compressor performance. Anoop and Onkar (2014) have shown that there is a change in specific work output, thermal efficiency and saving of fuel when the compressor inlet temperature decreased from 318K to 282K which is 10.12, 3.45 and 3.43 percent, respectively.

Arangi, *el at.* (2015) has analysed that the efficiency and power output has dependency on inlet air temperature of compressor. The compressor will produces high temperature of air as increasing of pressure. Low inlet temperature is advantages as it is give the maximum of efficiency and maximum of power output of gas turbine. Hence, the cooler is provided to lower the temperature also give the better performance in the gas turbine. Naeim, *el.at*. (2013) have been investigated the effect of ambient temperature on the performance of gas turbine power plant by comparing the ambient temperature for two years. The result shows variation of efficiency and electric-power output of gas turbines has an impact on electricity production, fuel consumption and plant incomes.

2.2 AXIAL FLOW COMPRESSOR

2.2.1 Introduction of compressor

Axial flow compressor as shown in Figure 2.2, where the air entering the axial compressor is parallel to the axis of shaft. Pressure ratio and temperature act as the basic parameter that measure the efficiency of gas turbine. Table 2.1 shows the axial flow compressor characteristic for two applications, namely industrial and aerospace. Both are used the compressor for power generation (Boyce, 2011). Axial flow compressor has an advantage of potential for higher pressure ratio, higher efficiency and larger flow rate possible at given frontal area.

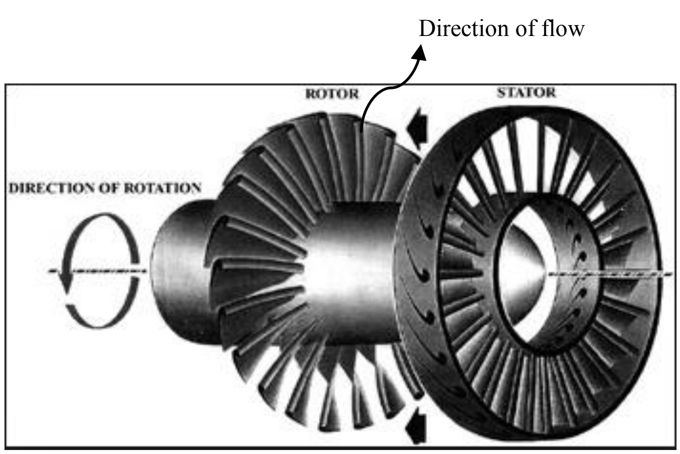

Figure 2.2 Isometric view of an axial flow compressor stage (source: IEEE website)

Table 2.1 Axial Flow Compressor Characteristic (source: Gas Turbine Engineering Handbook)

Type of Application	Type of Flow	Inlet Relative Velocity Mach Number	Pressure Ratio per stage	Efficiency per stage
Industrial	Subsonic	0.4-0.8	1.05-1.2	88% - 92%
Aerospace	Transonic	0.7-1.1	1.15-1.6	80% - 85%

According to Table 2.1, both type of application for gas turbine have different characteristic in term of type of flow, Mach number, pressure ratio and efficiency. This is because they depend on the gas turbine utilization as industrial more to generate electricity, while aerospace is for power aircraft.

2.2.2 Compressor cascade blades

Many scientists have done their research on cascade wind tunnel and publish their research. Some are collected as reference for this project. Compressor cascade blade profile was designed and it is analysed by Pradhapraj, *el at.* (2016).The model was designed based on two dimensional flows through a cascade of aerofoil study. Testing cascade model will provide better result and good operating condition compare to single blade. Difference angle of blade with various angle of attack of compressor cascade have been done to obtain the variation of pressure in order to measure the efficiency of compressor cascade. However, the experimental analysis result was compared to the numerical analysis which carried out using Computational Fluid Dynamics. Both analysis shows that pressure distribution increased with increase angle of attack. Thus, efficiency increased. In future, the researches expected increasing the number of blades may be improving the efficiency.

Mohsinali and Vimal (2014) has been optimized the number of blades in high pressure compressor. In designing the compressor, three major design parameter is important including the number of stages, rotational speed and number of blades. By assumed the rotational speed 6000 to 40000 in range with same boundary condition for 2000 modules, the result shows the best module with 91 percent of efficiency and 11400 rpm for rotational speed. With help of Axstream software, number of blade has been selected in rotor and stator. This number of blades helps the researcher to understanding some parameter such as outlet pressure, enthalpy, temperature and velocity. Efficiency of compressor is measured in term of energy losses. Losses occur during the air compression in the compressor, it might be due to friction and flow separation. Heat loss created by high loaded and higher pressure ratio compressor is the main losses in this study. Thus, it is shows that increasing the number of blade in rotor would increase the efficiency as well as power requirement.

Cascade blades are defines as number of blades is assembled in parallel or annular with similar stagger angle and pitch to one another of blades. The flow is deflected through the cascade blades due to the loss in stagnation pressure. Research found that the performance of compressor cascade blade is depending on exit angle with optimum inlet angle and stagnation pressure loss across on it. Rhoden, *el.at.* (1942)has been measured the distribution of static pressure over the central cross section of the middle blade, traverse static pressure and angle inlet and outlet flow in the plane of the central cross section in experimental. The different camber angle of axial flow cascade compressor blades with same chord/pitch ratio and same stagger angle is used in the experiment to obtain the result on effect of Reynolds number on inlet and outlet air angles, efficiency of blade against Reynolds number and graph of static pressure over the surface of the middle blade. Incidence flow in cascade has been the important parameter in process of design turbomachine blades. This has been investigated by