INVESTIGATION ON COMPRESSOR BLADE'S PROFILE PERFORMANCE BY USING 3D CFD

NG KONG ENG

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DECLARATION

I declare that this project report entitled “The Investigation On Compressor Blade’s Profile 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).

Signature : ....

Supervisor's Name : ....

Date : ....

DEDICATION

To my beloved father and mother.

ABSTRACT

The key of determining the aerodynamics performance of compressor rotor blade is the drag and lift coefficient. Higher lift to drag coefficient indicates that less input power required for compressor blade rotation and growth in the efficiency of compressor. However, lift to drag ratio differs regarding to the profile of an airfoil. The other factor that contributes to compressor performance is the tip leakage occurrence. Tip clearance leads to the occurrence of tip vortex at suction surface side of compressor rotor and eventually forms a blockage effect that causes compressor stalling. In this study, three dimensional twisted profiles NACA 65(2)415, NACA 65(410) and NACA 65(4)221 are utilized to investigate the most suitable profile for compressor rotor of gas turbine using the method of numerical simulation (CFD). The performances of blade profiles are also determined using graphical visualization in Fluent post-processing (CFD). Profile NACA 65(2)415 has the highest lift to drag ratio of 20.9, which is 10% higher than the other profiles. The developed wake region at the trailing edge of profile NACA 65(410) raises the drag coefficient and deteriorates aerodynamic performance. However, NACA 65(4)221 does not manifest the best result in the three-dimensional visualization of tip leakage vortex (Q-Criterion). Although vortices are formed at the tip of all profiles, the vortex formed on suction side of profile NACA 65(4)221 has the lowest turbulence kinetic energy followed by NACA 65(2)415 and NACA 65(410). This finding corroborates NACA 65(2)415 is the most suitable profile for the industrial axial-flow compressor rotor application. However, the effect of tip vortex shall not be neglected. Further investigation shall be made to control the tip vortex of NACA 65(2)415 and avoid compressor stalling and reduction in compressor efficiency.

ABSTRAK

Kunci utama dalam menentukan prestasi aerodinamik bagi rotor untuk pemampat adalah daya seretan dan daya angkat. Nisbah daya angkat kepada daya seretan yang tinggi menunjukkan kuasa yang diperlukan untuk putaran bilah pemampat adala rendah dan ia dapat meningkatkan kecekapan pemampat. Walau bagaimanapun, profil bilah yang berbeza mempunyai nisbah daya angkat kepada daya seretan yang berlainan. Faktor lain yang menyumbang kepada prestasi pemampat adalah pembentukan pusaran di hujung bilah. Hal ini menyebabkan berlakunya pusaran di permukaan sedutan pemampat pemutar dan akhirnya menyebabkan kehalangan kepada gerakan bilah pemampat. Dalam kajian ini, tiga 3D profil bilah iaitu NACA 65(2)415, NACA 65(410) dan NACA 65(4)221 digunakan untuk mengkaji profil yang paling sesuai dengan mengunakan aplikasi Pengkomupteraan Dinamik Bendalir (CFD-Fluent). Prestasi profil bilah juga ditentu melalui visualisasi grafik. NACA profil 65(2)415 mempunyai daya angkat tertinggi iaitu 20.9 ataupun 10% lebih tinggi daripada profil lain. Pemisahan bendalir di belakang bilah NACA 65 (410) meningkatkan daya seretan dan menjejaskan prestasi aerodinamik bilah pemampat. Walau bagaimanapun, NACA 65 (4) 221 tidak menunjukkan hasil yang terbaik dalam visualisasi pusaran (Q-Criterion). Walaupun pusaran dibentuk di hujung profil yang dikaji, pusaran yang terbentuk di bahagian sedutan profil NACA 65(4)221 mempunyai impak pergolakan yang paling rendah diikuti oleh NACA 65(2)415 dan NACA 65(410). Penyelidikan ini menunjukkan profil NACA 65(2)415 paling sesuai bagi pemutar bagi pemampat aliran-pakai tetapi kesan pusaran tidak harus diabaikan. Penyelidikan lanjut harus dilakasanakan untuk mengawal pusaran yang berlaku di hujung bilah NACA 65(2)415 untuk mengelakkan pengurangan kecekapan pemampat.

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LIST OF SYMBOLS

F_L	=	Lift Force, N
F_D	=	Drag Force, N
ρ	=	Density, kg/m^3
v	=	Velocity, m/s
A	=	Frontal Area, m^2
Cl	=	Lift Coefficient
Cd	=	Drag Coefficient
θ	=	Twisting angle of Blade, °

LIST OF ABBEREVATIONS

CFD	Computational Fluid Dynamics
NACA	National Advisory Committee for Aeronautics

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The history of the first invented gas turbine has never been sorted out. However, the first registered trademark of gas turbine was by a British named John Barber. from United Kingdom in 1791. Charles Parsons, set off the idea of first patented axial flow compressor in 1884 and followed by the multistage axial compressor and turbine in 1904 (Hunt, 2011). The first successful gas turbine was developed in 1930s and the first gas turbine used for electric generation was introduced in Oklahoma in 1949 (Cengel and Boles, 2014). The gas turbine has experienced historically improvement and changes over the centuries. Today the development of gas turbine is focus within the areas of increment the temperature of turbine inlet, modification to the basic thermodynamic cycle and improvement in the efficiencies of turbomachinery components.

A gas turbine is the heart of a power plant. It can be divided to three portions which are compressor, combustion chamber and turbine. An axial compressor is selected for the usage of gas turbine is due to continuous supply of high mass flow capacity and its high efficiencies air flow. Air flows into the compressor is directed by inlet guide vanes into the stages of rotor and stator blades (Boyce, 2012). Rotors rotating in high speed produce air flow with high velocity. The flowing air is then diffused by the stator which is stationary and thereby produces high pressure. The process is repeated stage by stage and raises the overall pressure ratio of the system. Rotor and stator blades are designed based on the shape of airfoil which is an aerodynamic shape that allows any blades to be lifted. The shape of airfoil divides air flow to top and bottom of a blade. The top part of a blade usually designed in a convex curve. Compared to concave curve at bottom of the blade, the fluid flow will more streamline and this indicates that the velocity flowing on top on the blade is higher. According to Bernoulli's Principle, the higher the velocity, the lower pressure on the part of the blade. Thus, an upward force is created which allows the blade to be lifted as shown in Figure 1.

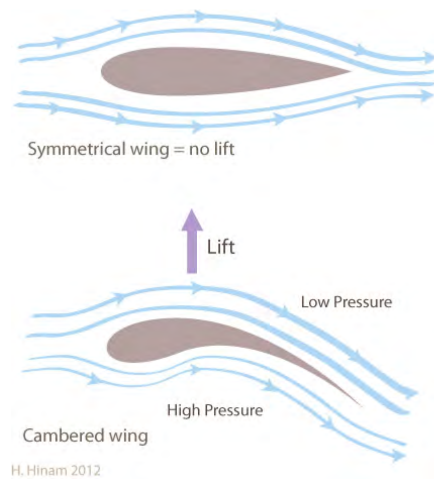

Figure 1.1 The principle behind an airfoil blade

Turbomachinery of compressor blades play an important role in the efficiencies of gas turbine. Inventors in the 1800s faced the difficulties to achieve a great performance gas turbine due to limitation knowledge in aerodynamics and financial costs. Today, with the help of advanced computational technology, simulation of turbomachinery components such as compressor blade profile and cascade are crucial in the analysis of the performance of gas turbine.

1.2 PROBLEM STATEMENT

An axial flow compressor is important in supplying high static pressure to a gas turbine. Scientists have made efforts over the centuries in raising the overall pressure ratio of the system and firing temperature in order to increase thermal efficiency of the cycle. However, the blade profile of compressor blade also plays an important role in the criteria of smoothness of the air flowing through. Thus, the analysis of a single compressor blade is remarkable to keep the air flowing smoothly and minimize the pressure loss due to friction throughout the process. The airfoil designed blade profile holds the crucial keys to determine the drag and lift coefficient of a single blade. NACA 65 was selected in this research to study their fluid flow behavior using CFD (Herrig et al., 1957). Compressor stalling is a known issue that deteriorates the performance of a compressor. One of the factors that contributes to this instability is the vortex forming at the suction side of blade due to tip clearance. Investigation was carried out to study the effect of tip clearance vortex to a single rotor blade and how it affects the compressor performance.

1.3 OBJECTIVES

1. To investigate various profiles of single twisted compressor blade in term of parameters that affect cascade blade performance by using CFD.
2. To suggest the best blade profile by comparing the blade performance.

1.4 SCOPE OF PROJECT

The scopes of this project are

1. Focus on a single twisted blade of axial flow compressor for gas turbine engine.
2. Create 3D model by using SolidWork for twisted blade of NACA 65(410), NACA 65(2)415 and NACA 65(4)221.
3. Simulate of fluid flow for a three-dimensional twisted blade to obtain velocity and pressure distribution, coefficient of lift and drag, to observe tip leakage vortex occurs around the blade by using ANSYS.
4. Compare and suggest the blade profile with the best performance.

1.5 GENERAL METHODOLOGY

1. Identify blade profile for CFD simulation. NACA 65 is used for this research because a large number of cascade performance tests were conducted using 2D wind tunnel tests to investigate the pressure contour of blade with different angle of attack and solidities (Roland and Galison, 2000). Therefore, this database is helpful in this research and NACA 65 series blades are widely used in gas turbine industries.

2. Identify suitable parameters for angle of twisted blade and angle of attack. The range of optimum angle of attack is around 10º to 20º because lift coefficient rises to maximum whereas the drag coefficient is at minimum (Patil and Thakare, 2015).

3. Develop 3D model of twisted blade using SolidWork. The standard a single NACA 65 blade profile's coordinates is obtained and imported into SolidWork. The dimension of

blade is adjusted and extruded into a 3D aerofoil. The angle of 3D blade is then twisted using flex function available in the software.

4. Identify the suitable boundary conditions for compressor blade investigation such as inlet velocity, air properties and temperature of fluid flow.

5. Simulate fluid flow around the twisted blade. The velocity distribution, pressure distribution, lifts and drag coefficient are obtained from the result of simulation using CFD.

6. The visualization of tip leakage vortices due to tip clearance occurs around the blade tip profiles are observed using CFD.

7. Choose and suggest the best profile of among the 3D twisted blades.

CHAPTER 2

LITERATURE REVIEW

2.1 Gas Turbine

Gas turbine is employed in various power plants for electricity generation. Ambient air is drawn into compressor where the air flows through multistage of rotating and stationary blade. The air is compressed at each stage and sent to combustion chamber. The pressure and temperature of air are further increased as fuel is inject and burned with the air mixture in the combustion chamber. The hot combustion product is then directed into turbine where the volume of hot gas mixture expands to cause rotation of the shaft. The power of rotating shaft is used to drive compressor to draw in more air and electric generator to produce electricity. Gas turbine obeys the law of thermodynamics and operates with Brayton cycle. Figure 2.1 shows the actual Brayton cycle of gas turbine, stage 1-2 is the compression of fresh air drawn in by compressor. The compressed gas is heated to state 3, which has the highest temperature under constant pressure condition in the combustion chamber. In state 3-7, the hot gas mixture is expanded where the work is harvested for electricity generation. The work output in state 3-5 is relatively equal to work input of 1-2 because turbine and compressor are sharing the same shaft, part of the shaft power is used to drive compressor to draw in fresh air.

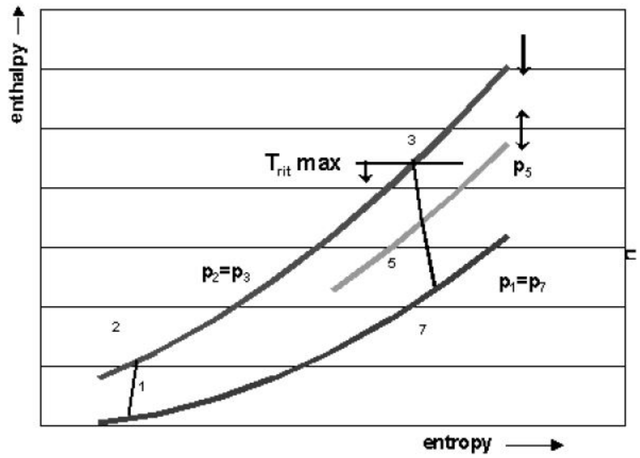

Figure 2.1 Brayton cycle of gas turbine (Brun and Kurz, 2001)

2.1.1 Compressor

Compressor is a mechanical device used to increase the pressure of flowing fluid in a certain system driven by an electric motor or combustion engine. Compressor can be divided to two categories, positive displacement and dynamic compressors. Positive displacement compressor provides continuous flow against any pressure built-up and usually employs screw, diaphragm and piston to reduce the volume of the air in the system. Dynamic compressor increases the pressure of system by converting high velocity of the air (Yusof et al., 2014). Gas turbine is in the category of dynamic compressor as it draws accelerated air into the system.

2.1.2 Centrifugal compressor

Centrifugal compressor is used in small gas turbine because it has lower flow rates compared to axial flow compressor. The fresh air is drawn in by the high speed rotating impeller and directed to its stationary diffuser. The pressure rises due to the high velocity air is forced through the impeller and diffuser. As shown in Figure 2.2, the highest efficiency of centrifugal compressor operates between the range of $90 \leq N_g \leq 850$, where N_g is the specific speed (Balje, 1964).

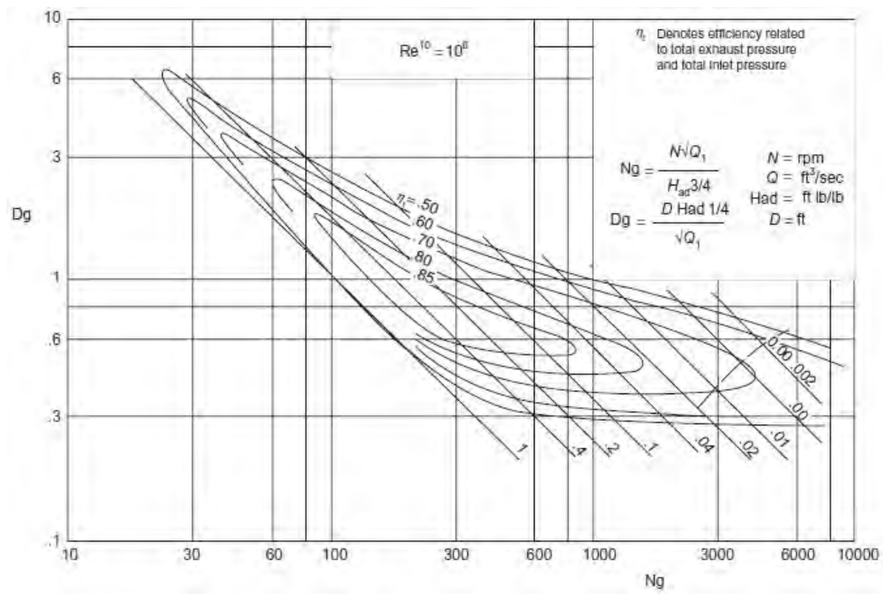

Figure 2.2 Graph of performance for typical centrifugal compressor [3]

2.1.3 Axial Flow Compressor

An axial flow compressor is another type of dynamic compressor. The air flow direction that enters and exits the compressor is parallel to the axis of its shaft rotation. The angle of air flowing into the compressor is directed by inlet guide vanes to the rotating rotor. A rotor or stator is a blade that has a shape of airfoil with the purpose of increasing its lift force. The velocity of air is accelerated and diffused by the stator of compressor. Thus, the pressure ratio of the gas turbine increases after passing of a few combination rotors and stators. This process is also known as multistage compression. The temperature, pressure and density inlet of air that draws into a transonic axial flow compressor has a range of 300–600K, 0.1-3.0MPa and 1.16-17.2 kg/m^3 respectively as shown in Table 2.1 (Ishizuka et al., 2010). Besides, the axial velocity used is 50m/s with an inlet angle 10 degree, the chord length of rotor is for a compressor blade is 0.0679m. These parameters are important for the setting of boundary conditions during numerical simulation.

Table 2.1 Parameters of inlet and outlet temperature, pressure and density of air drawing into industrial axial flow compressor (Ishizuka et al., 2010)

Compressor			Air
Temperature	(inlet – outlet)	K	300 – 600
Pressure	(inlet – outlet)	MPa	0.1 – 3.0
Density	(inlet – outlet)	kg/m^3	1.16 – 17.2

2.1.4 Compressor Blade

Compressor blade is made out of forming or machining process. The material used for fabrication is alloyed metal because the shape of compressor blade might require twisting and bending in order to reduce the load of driving force. Alloyed metal is a good option as they can be easily shaped by machining to the desired twisting angle or dimension. Compressor blades are fabricated to be durable and light weighted to draw in air while rotating at high revolution per minute. Compressor blades with rotation motion that are arranged in row inside an axial flow compressor are named as rotor while the stationary compressor blades arranged in row is named as stator. As the air flows through the rotor, its acceleration increases until it is directed to the stator. The air is losing its speed but with exchange of increasing pressure as shown in Figure 2.3.

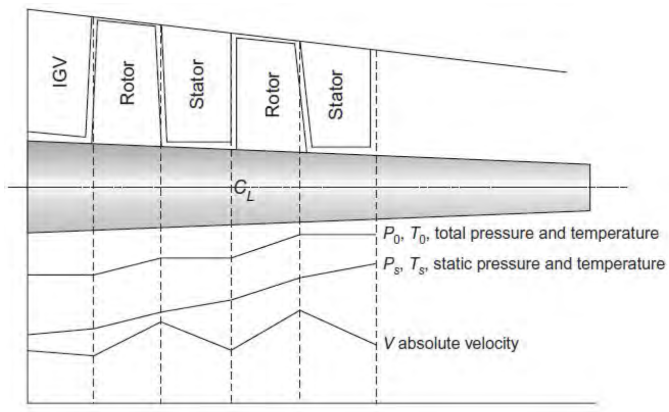

Figure 2.3 Variation of velocity and pressure plots as fluid flow through an axial compressor (Boyce, 2012)

2.2 Fluid Properties Laminar and Turbulent Flow

Laminar is well known as having a low velocity, fluid flows in highly organized compared to turbulent flow, which fluid particles flow chaotically in high velocity. There is a region where laminar or turbulent is hardly differentiate, this region is named as transition flow.

2.2.1 Separation

Separation is a phenomenon where the streamline which originally flow across a surface starting to leave the surface. According past research (Marusic et al., 2007), with the rising of angle of attack of an airfoil body, the pressure gradient will also develop and thus resulting in the formation of separation point of the airfoil. In special case, the fluid that experiences transition region where the flow rejoins to the airfoil surface after separation to form a laminar separation bubble showing in Figure 2.4 (Lian and Shyy, 2006). This transition region is difficult to simulate for all turbulence model due to indistinguishable between