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DESIGN AND PERFORMANCE STUDY OF A CENTRIFUGAL COMPRESSOR USED IN HELICOPTER APPLICATION

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# DECLARATION

I hereby declare that this project report entitled

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is written by me and is my own effort and that no part has been plagiarized without citations.

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## DEDICATION

*Dedicated to my beloved family Father (Mr. Ng Chon Teck), Mother (Mrs. Chee Peck Wan), Sister (Nellie Ng Chiau Koun), Brothers (Nicholas Ng Seh Kee and Deric Ng Seh Lin) and also my friends who always be my side*

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# ABSTRAK

*Centrifugal compressor* merupakan salah satu komponen yang penting dalam enjin helikopter, ia digunakan untuk menaikkan tekanan bagi udara yang masuk sebelum ia dihantar ke *combustion burner*. *Centrifugal compressor* yang berperingkat satu banyak digunakan dalam helikopter kerana ia mempunyai berat yang ringan, size yang kecil serta dapat menghasilkan nisbah tekanan yang tinggi. Terdapat pelbagai cara yang dapat menaikan keupayaan *centrifugal compressor*, salah satu daripada faktornya adalah peranan *impeller*. *Impeller*, terkandung dalam *centrifugal compressor*, digunakan untuk menaikan tenaga bendalir dengan memutarkan bendalir itu kearah luar dari pusat, dengan itu meninggikan momentum bersudut. Kedua-dua tekanan static dan halaju dapat dinaikan dalam *impeller*. Oleh itu, satu kajian tentang peranan *impeller* akan dikaji dalam project ini. Tiga jenis sudut impeller blade yang berlainan akan direka menggunakan *Solid Work*. *Computational Fluid Dynamics (CFD)* teknik akan digunakan untuk simulate ketiga-tiga reka bentuk *impeller* itu. Perbandingan akan dibuat berdasarkan keputusan dari *CFD simulation.* Pada akhir, keputusan yang diperoleh merupakn sudut *impeller* blade yang dapat menghasilkan nisbah tekanan yang paling tinggi.

# ABSTRACT

Centrifugal compressor is an essential part that consist in the helicopter engine, it is used to increase the pressure of the incoming air before enter the combustion burner. Single stage of centrifugal compressor is used in most helicopter application are due to their weight is light, the size is small and the pressure ratio is high. There are many ways that can increase the performance of centrifugal compressor, and one of the factors is the performance of the impeller. Impeller, consists in the centrifugal compressor, is used to increase the energy level of the fluid by whirling it outwards, thereby increasing the angular momentum of the fluid. Both the static pressure and the velocity are increase within the impeller. Thus, a study about the impeller performance will study in this project. Three different angle of impeller blade are design using Solid Work drawing. Computational Fluid Dynamics (CFD) technique will used to simulate the three design impeller with different blade angle. The comparisons to verify the design were made between the CFD simulation results. In the end, the result should come out with the impeller blade angle that can produce higher pressure ratio.

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## ABREVIATIONS

| | |
|---|---|
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| APU | Axillary’s power unit |
| CAD | Computer Aided Design |
| CFD | Computational Fluid Dynamic |
| FEA | Finite Element Analysis |
| FKM | Fakulti Kejuruteraan Mekanikal |
| FOD | Foreign Object Damage |
| Re | Reynolds Number |
| MFA | Malaysia Flying Academy |

# LIST OF SYMBOLS

| SYMBOLS | DEFINITION |
|---|---|
| $A$ | Area, $m^2$ |
| $d_h$ | Hub diameter, $m$ |
| $d_i$ | Impeller diameter, $m$ |
| $c_1$ | Absolute velocity, $m/s$ |
| $c_\theta$ | Tangential component |
| $c_p$ | Specific heat at constant pressure |
| $c_r$ | Radial component |
| $l$ | Characteristic length, $m$ |
| $N$ | Angular Speed, *m/s* |
| *rpm* | Rotation per Minute |
| $w$ | Relative velocity, $m/s$ |
| $T_{01}$ | Absolute temperature, $k$ |

| GREEK | DEFINITION |
|---|---|
| $\phi$ | Flow coefficient |
| $\psi$ | Pressure coefficient |
| $\gamma$ | Specific heat ratio |
| $\alpha$ | Entry angle, $^0$ |
| $\beta$ | Exit angle, $^0$ |
| $\rho$ | Density, $kg/m^3$ |
| $\mu$ | Dynamic viscosity, $kg/ms$ |
| $v$ | Kinematics viscosity, $m^2/s$ |

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# CHAPTER ONE

# INTRODUCTION

## 1.1 Overview

Nowadays, many helicopters are powered by gas turbine engines, which are also called jet engines. There are several types of jet engine, but the engine used in helicopter is called turbo shaft engine where it is used to drive the shaft rotor to make the helicopter fly. Inside the turbo shaft engine, there is an important component, called compressor, which is used to increase the pressure of the incoming air before it enters the burner.

Basically, there are two main types of compressors. One type of the compressor is called centrifugal compressor, the flow through the compressor is turned perpendicular to the axis of rotation. Another type of compressor is an axial compressor which the flow through the compressor is in parallel direction. For turbo shaft engine, the compressor type that used is known as centrifugal compressor, and also is the compressor that will study in this project.

Compressor efficiency can used to determine the power necessary that need to create the increasing of pressure of a given flow, and it affects the temperature changes which takes place in the combustion chamber. The increased pressure of compressor will increase the efficiency of the engine; on the other hand reduce the work input to the compressor. Therefore, compressor is an important component inside the gas turbine engine because its efficient operation is the key to overall engine performance.

The topic of this project named as: Design and performance study of a centrifugal compressor that used in helicopter applications. A single stage centrifugal compressor is specified chosen to examine and study the critical performance variables.

## 1.2 Problem Statement

A good design of compressor is necessary to have high compressor efficiency, designing and manufacturing a good compressor is a difficult problem from both the engineering and material perspective. However, if correctly applied, installed and maintained, a centrifugal compressor offers a reliable, continuous source of compressed air.

Many studies have done as to how to improve the efficiency of centrifugal compressor, such as a large diameter of impeller is used, semi open design of impeller, suitable material and method to manufacture impeller and so on, but there are still don't has any study about improve the centrifugal compressor by different impeller blade angle.

In this project, there are three impellers with different blade angles will be study and design, based on forward angle ($>90^0$), radial angle ($=90^0$) and also backward angle ($<90^0$). A comparison between these three impellers will be analyzing using CFD simulation software. In the end of this project, the result should come out with the best blade angle impeller where it can help to improve the performance of centrifugal compressor. Moreover, the analyze results will also compared with the theoretical result.

## 1.3 Objectives of Project

The objectives of this project basically can divide into three, which are:

(a) To examine and study the critical performance variables involved in the design of a centrifugal compressor;

(b) To study the effect of different impeller blade angle on the performance in a centrifugal compressor.

(c) To determine the best type of impeller angle that can obtain higher pressure ratio.

## 1.4 Scopes and Limitation of the Project

The scopes of this project included:

(a) To design three impellers with different blades angle using Solid work software;

(b) To compare and analyze the performance of three different blade angle impellers result using CFD simulation software;

The limitation of this project included:

(a) The outer diameter of centrifugal compressor is set to 12” (0.3048m) and the rotating speed is set to 1800rpm;

(b) The semi open design impeller is specified chosen to design based on three different blades angle;

## 1.5 Thesis Outline

Thesis outline is a summary of every chapter was described to introduce about the chapter. Chapter one (1) introduced about the basic theory, the objectives of this project, problem encounter, and the content of the project. Chapter two (2) is about all the information about centrifugal compressor that used in helicopter engine, the design consideration of single stage centrifugal compressor, the factors that influenced the performance of centrifugal compressor and how to improve its performance, the function of impeller can how its work to improve the performance of centrifugal compressor, introduction about Solid Works software and also Computational Fluids Dynamics (CFD) software. In Chapter three (3), it will describe the whole process and method that used throughout this project. After that,

Chapter four (4) will perform all steps on mechanical geometries design start from specification definition, concept design generation, and concept designs selection up to details designs of the impeller using Solid Work software. Chapter five (5) will continue with test run the three different blade angles of impeller using CFD software and analyze the performance of each impeller, discussion about the best blade angle also will discuss in this chapter.

In chapter (6) will discuss the results that obtained from theoretical calculation and also the simulation results. In addition, the discussion about the project will also consist in this chapter. The final chapter (7) will be the conclusion for this project, where further recommendation and conclusion will explain in the end of this chapter.

## 1.6 Summary

The project title as design and performance study the centrifugal compressor used in helicopter application. The project objective is to examine and performance study the critical performance variables of centrifugal compressor. Besides, it also involves the design which can increase the performance of centrifugal compressor. In order to complete this project, many journals have to go through, Solid work design study and CFD simulation study need to be done.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Introduction

A literature review is a body of text that aims to review the critical points of current knowledge on a particular topic. The objectives of this project involve the design and performance study about the centrifugal compressor that used in turbo shaft (helicopter engine) applications.

This project also involved the study about the critical performance variables involved in the design of a single stage centrifugal compressor, such as the factors that can improve the performance or efficiency of the centrifugal compressor, the function of impeller and how the angle of the impeller influenced the performance of the centrifugal compressor. Thus, at the end of this chapter, the result should comes out with the suitable type of method or a suitable design that can used to improve the performance of the centrifugal compressor.

Literature review will go through those topics related the functions and advantages of compressor used in helicopter (turbo shaft) engine, the type of compressor that used, the essential component part in centrifugal compressor, the losses in centrifugal compressor, the performance characteristics of the centrifugal compressor and also the related software that used to complete this project, such as Solid Work and also Computational Fluid Dynamics (CFD). Base on the literature review, it provided general up to date ideals, theoretical concepts and applications related to this project to everyone.

### 2.1.1 Helicopter

The helicopter is a type of aircraft in which lift is obtained by means of one or more power driven horizontal propellers called rotors. When the rotors of a helicopter turn it produce reaction torque which tends to make the craft to spin and fly [1].

The helicopter contains a large number of system and components, but these can generally be broken down into a smaller number of major areas. **Figure 2.1** shows a cutaway drawing of a conventional tail rotor type helicopter. The main systems to consider in a helicopter are the hull or airframe, the engine and transmission, the fuel system, the landing gear, the rotors, the controls, electrical and hydraulic power, instrumentation and avionics [1].

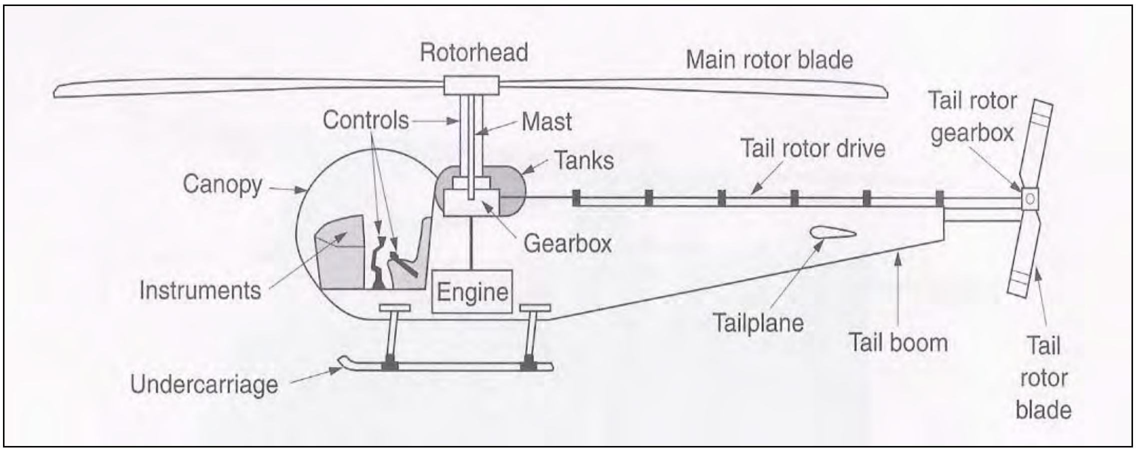


**Figure 2.1: Essential Parts of Helicopter [1]**

Nowadays, most of the aircraft and helicopter are powered by gas turbine engines, which are also called jet engines. There are many types of jet engines, such as turbojet, turbofan, turbofan, turboprop, and turbo-shaft. Different types of jet engines come out in different shapes and sizes and also different applications. The only thing that is same among these engines is the common parts inside them, which are compressor, combustion chamber and also turbine. Moreover, their operation cycle also is the same among each others [1].