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ROTORBLADE AERODYNAMIC PERFORMANCE EVALUATION

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"I declare this report is on my own work except for summary and quotes that I have mentioned its sources"

Signature :

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To my beloved family

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ABSTRACT

The goal of this project is to analyse the aerodynamics performance of rotor blade. This analysis involves aerodynamic theory and wind tunnel testing. For wind tunnel analysis, an airfoil model was developed and tested in the wind tunnel with target to assess the performance of rotor blade under almost real conditions. Data collected from the test was compared and validated with the data obtained from various sources, including from industry. The evaluated aspects on this project were coefficient of lift and drag. This project provides understanding on rotor blade performance and the characteristic of NACA 23012 rotor blade profile.

ABSTRAK

Matlamat projek ini ialah untuk menganalisa prestasi aerodinamik bilah rotor. Analisa ini melibatkan teori aerodinamik dan ujian terowong angin. Bagi ujian terowong angin, model foil udara dibangunkan dan diuji dalam terowong angin dengan tujuan untuk menilai prestasi bilah rotor di bawah keadaan yang hampir nyata. Data yang diperoleh daripada ujian dibandingkan dan disahkan dengan data yang diperoleh daripada pelbagai sumber, antaranya daripada sumber ilmiah dan industri. Aspek yang akan diuji ialah pekali angkatan dan seretan. Projek ini memberi pemahaman ke atas prestasi bilah rotor dan gayalaku profil bilah rotor NACA 23012.

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LIST OF SYMBOLS

L	=	Lift, N
D	=	Drag, N
N	=	Normal Force, N
A	=	Axial Force, N
α	=	angle of attack
M_{LE}	=	Moment on leading edge
q_{∞}	=	Freestream dynamic pressure, N/m^2
C_n	=	Normal force coefficient
C_a	=	Axial force coefficient
C_d	=	Drag coefficient
C_l	=	Lift coefficient
C_m	=	Moment coefficient
x_{cp}	=	centre of pressure
M_x	=	Pitching moment
C_p	=	Pressure coefficient
Re	=	Reynolds Number
M_{∞}	=	Mach number
V	=	Velocity, m/s
ρ	=	Density, kg/m^3
μ	=	Viscosity, kg/ms
c	=	Chord length
R	=	Gas constant
a	=	Speed of sound

p	=	pressure, N/m^2 or Pa
T	=	Temperature
AR	=	Aspect Ratio
b	=	Wingspan
S	=	Planform Area
ac	=	Aerodynamic Centre

CHAPTER I

INTRODUCTION

1.1 Project Background

Unlike fixed-wing aircraft, the aerodynamic influence on the airframe is not so significant on helicopter. According to an experienced engineers in aviation industry, the only part in helicopter which aerodynamic plays important role is usually on the rotor blade.

Airfoils designed for helicopter applications have been traditionally been obtained through a long evolutionary process which various levels of theory and experimental measurements have been combined together to find and airfoil shapes with higher maximum lift value, better lift-to-drag ratios, lower pitching moments and higher divergence Mach numbers. In general, these requirements are conflicting, making the design of general purpose rotor blade extremely challenging. Instead, various airfoil families have been developed to meet the specific needs of a rotor blade.

1.2 Concept of Aerodynamics

Aerodynamics is the branch of dynamics that treats the motion of air (and other gaseous fluids) and the resulting forces acting on solid objects moving about within such a fluid. The science of aerodynamics is the fundament of all flight.

According to Prandtl (1949), aerodynamics is generally used for problems arising from flight and other topics involving the flow of air. Literally, "aerodynamic" refers to dynamics of gases, especially atmospheric interactions with moving objects (Dictionary of the English Language, 1969).

Aerodynamic problems can be classified in a number of ways. The flow environment defines the first classification criterion. *External* aerodynamics is the study of flow around solid objects of various shapes. Evaluating the lift and drag on an airplane, the shock waves that form in front of the nose of a rocket or the flow of air over a hard drive head are examples of external aerodynamics. *Internal* aerodynamics is the study of flow through passages in solid objects. For instance, internal aerodynamics encompasses the study of the airflow through a jet engine or through an air conditioning pipe.

1.2 Rotor Airfoil Aerodynamics

The selection of airfoil sections for helicopter is more difficult than for a fixed-wing aircraft because the angle of attack and Mach number vary continuously at all blade elements. Overall, low pitching moment airfoil designs are important to maintain low torsion loads on blades and low control forces.

According to Leishman (2000), on early helicopters the airfoil selection is not given much attention because there were a lot of other technical issues to be solved. Although NACA had developed some dedicated helicopter airfoil profile in late 1940s, only on 1960s that airfoil sections specifically suited to meet special requirements of a particular helicopter become widely used. Since then, various helicopter manufacturers and research organisations have developed various families of improved airfoil profiles for use as helicopter rotor blade. Each airfoil profile within the family will have specific aerodynamic and geometric attributes optimised for different radial positions on the blade.

While most airfoil designs have been conducted for 2-D flows, the complicated flow near the tip of helicopter blade demands 3-D prediction methods as well (Leishman, 2000). However, because of modern computational tools have not yet matured to a level that turbulent flow separation and stall can be predicted with acceptable accuracy; together with adverse operating conditions and often unsteady flow environment found in helicopters means that rotor airfoils still need to be tested in a wind tunnel to fully assess their aerodynamic performance.

1.3 Scope

The scope of this project will cover aerodynamic theory review, mainly on lift and drag aspects. This also involves theoretical calculation, comparison between theory and wind tunnel test, model development via rapid prototyping process, and wind tunnel testing and result analysis. The evaluation of rotorblade aerodynamic lift and drag performance was based under incompressible, subsonic flow regime.

1.4 Objective

The goal of this project is to evaluate the aerodynamic lift and drag performance of rotor blade under subsonic, incompressible flow regime. This take into account together theoretical calculation and results from various sources will be used to compare with the results obtained from wind tunnel test.

CHAPTER II

LITERATURE REVIEW

2.1 Airfoil Geometry Parameters

When a horizontal wing is cut by a vertical plane parallel to the centreline of the vehicle, the resultant section is called the airfoil section. The generated lift and stall characteristics of the wing will depend strongly on the geometry of the airoil section. The geometric parameters of the airfoil section that have an important effect on the aerodynamic characteristics of the airfoil section including:

a) the leading-edge radius

b) the mean camber line

c) the maximum thickness

d) The trailing-edge angle

2.1.1 Airfoil Section Nomenclature

The gradual development of wing theory tended to isolate the wing section problems from the effects of planform and led to a more systematic experimental approach. During pre-World War II, many families of wing sections were tested in various laboratories, but the work of National Advisory Committee for Aeronautics (NACA) was outstanding. The NACA investigations were further systematised by separation of the effects of camber and thickness distribution, and the experimental work was performed at higher Reynolds number than were generated elsewhere.

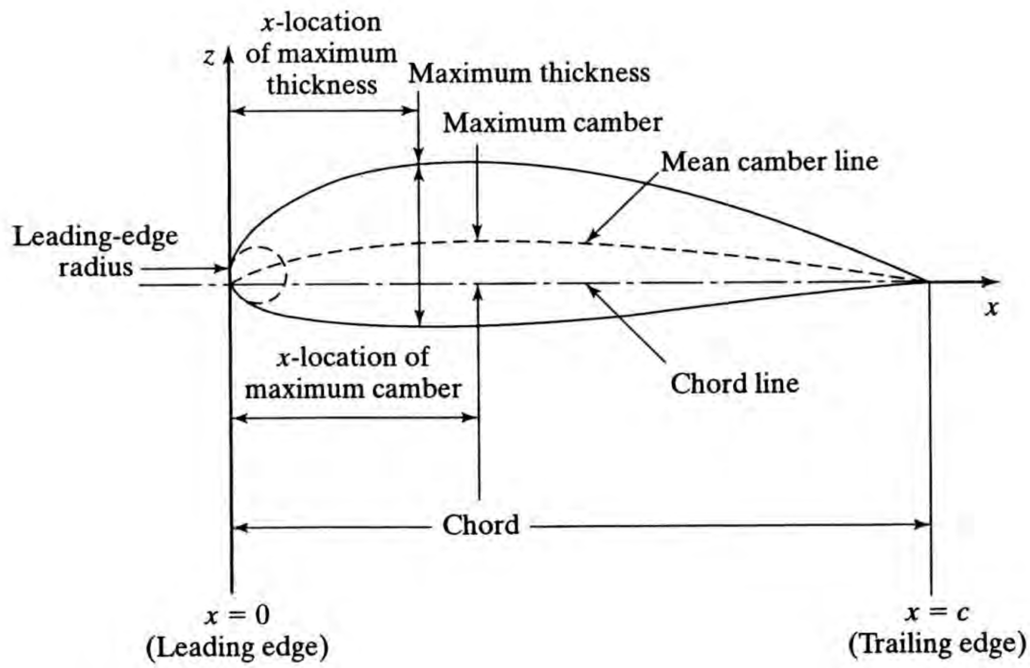

Figure 2.1: Airfoil-section geometry and its nomenclature (Source: Bertin, 2002).

As a result, the geometry of many airfoil sections is uniquely defined by the NACA designation. There are varieties of classifications, including NACA four-digit series, Five-digit series, and 6-series airfoil sections. However, because of rapid improvements in both computer hardware and software, plus the broad use of sophisticated numerical codes, there are possiblities that one often ecounters airfoil sections being developed that are not described by the NACA geometries.

2.1.2 Leading-Edge Radius and Chord Line

The *chord line* is defined as the straight line connecting the leading and trailing edges. The leading-edge radius of the airfoil section is the radius of a circle centred on a line tangent to the leading edge camber connecting tangency points of the upper and lower surfaces with the leading edge. The magnitude of the leading-edge radius has a significant effect on the stall characteristics of the airfoil section.

The geometric angle of attack is the angle between the chord line and the direction of the free stream flow.

2.1.3 Mean Camber Line

Mean camber line is defined as the locus of the points midway between the upper surface and the lower surface as measured perpendicular to the chord line. The shape of mean camber line is important in determining aerodynamic characteristics of an airfoil section.

Furthermore, camber has beneficial effect on the maximum value of the section lift coefficient. When the maximum lift coefficient is high, the stall speed will be low with all other factors being the same. However, high thickness and camber necessary for high maximum values for section lift coefficient will produce low critical Mach number and high twisting moments at high speeds.

2.1.4 Maximum Thickness and Thickness Distribution

The maximum thickness and thickness distribution strongly influence the aerodynamic characteristics of the airfoil section as well. The maximum local velocity to which a fluid particle accelerates as it flows around an airfoil section increases as the maximum thickness increases. As a result, the adverse pressure gradient associated with the deceleration of the flow fron the location of this pressure minimum to the trailing edge is greatest for the thickest airfoil. As the adverse pressure gradient becomes larger, the boundry layer becomes thicker. Thus, the beneficial effect of increasing the maximum thickness are limited.

The thickness distribution affects the pressure distribution and the character of the boundary layer. As the location of the maximum thickness moves aft, the velocity and pressure gradient in the midchord region decreases. The resultant favourable pressure gradient in the midchord region promotes boundry-layerstability and increases the possibility that the boundry layer remains laminar.

2.1.5 Trailing-Edge Angle

The trailing-edge angle affects the location of the aerodynamic centre.Theoretically, the aerodynamic centre of thin airfoil sections in a subsonic stream is located at the quarter-chord.

2.2 Aerodynamic Forces And Moments

According to Anderson (2004), the aerodynamic forces and moments on the body are due to only two basic sources:

a) Pressure distribution over the body surface

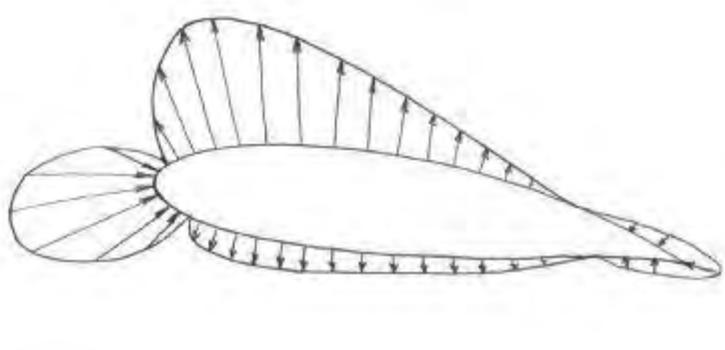

Figure 2.2: Static Pressure Distribution (Source: Bray, 2003)

b) Shear stress distribution over the body surface

Figure 2.3: Shear Stress Distribution (Source: Bray, 2003)

Pressure acts normal to the surface and shear stress acts tangential to the surface. The net effect of both distributions over the complete body surface is a resultant aerodynamic force, R; and moment, M; on the body. In turn, the resultant R can be split into two sets of components, which is:

a) Lift, L ≡ component of R perpendicular to freestream velocity, V_∞
b) Drag, D ≡ component of R parallel to freestream velocity, V_∞

2.2.1 What is Lift?

Lift is the aerodynamic force acting at right angles to the direction of motion of the object. It is produced by the interaction of the moving object and the fluid. This interaction typically leads to a pressure differential being set up between upper surface and lower surface of the object. The net effect of high pressure below and low pressure above will produce a force which sustains the object against descent due to gravity. The physical mechanisms in the fluid/body interaction that create lift are very complex. The laws of conservation of mass and momentum (including the effect of fluid rotation) result in fluid flow paths, velocity and pressure distributions which can significantly change the magnitude of lift due to small changes in flow angle or surface curvature.

2.2.2 What is Drag?