THE APPLICATION OF COMBINED MOMENTUM AND BLADE ELEMENT THEORY FOR AERODYNAMICS PERFORMANCE ANALYSIS OF ROTATING BLADES

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ABASTRACT

Computer code for performance aerodynamics analysis of three types of rotating blade configuration had been successfully developed. The computer code which developed based on the combined Momentum and Blade Element Theory can be applied for Horizontal axis wind turbine performance analysis, rotor blade helicopter in vertical climb and forward flight and the aircraft propeller analysis. The Combined Momentum and Blade Element Theory required the detailed blade geometry involves the chord and twist angle distribution along blade span and also the aerodynamics characteristics of its airfoil section. The developed computer code allows one to obtain the detail of differential thrust coefficient, differential torque coefficient and differential power coefficient along blade span. Integrate those differential quantities will give the thrust coefficient, torque and power coefficients. The comparison result with other method or experimental result were not yet be done due to difficulties in obtaining suitable data for such purposes. Hence the comparison result with other method has been suggested for the future work.

ABSTRAK

Komputer kod untuk analisis prestasi aerodinamik untuk tiga jenis konfigurasi bilah yang berputar telah berjaya dibangunkan. Komputer kod yang dibangunkan adalah berdasarkan gabungan momentum dan teori element bilah yang boleh digunakan untuk prestasi turbin angin pada kedudukan menegak,bilah berputar bagi helikopter dalam kedudukan mendatar dan penerbangan maju dan analisis propeller pesawat. Gabungan momentum dan teori element bilah memerlukan geometri bilah secara terperinci yang melibatkan '*chord'* dan pengedaran '*twist*' sudut di sepanjang span bilah dan juga ciri-ciri aerodinamik pada bahagian Aerofoil. Komputer kod yang dibangunkan membolehkan kita untuk mendapatkan perincian daripada pekali pembezaan, pekali pembezaan kilas dan pekali kuasa pembezaan di sepanjang permukaan bilah. Mengintegrasikan jumlah pembezaan akan memberikan pekali, pembezaan, daya kilas dan pekali kuasa. Keputusan perbandingan dengan kaedah lain atau hasil eksperimen belum dilakukan kerana kesulitan dalam memperoleh data yang sesuai untuk tujuan tersebut. Maka hasil perbandingan dengan kaedah yang lain telah dicadangkan untuk kajian di masa hadapan.

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LIST OF MAIN SYMBOLS

a	axial interference or induction factor
$a^{'}$	angular induction factor
A	airfoil area (chord × span), surface area, rotor swept area
A	axial (chord) force
C_d	drag coefficient
C_l	lift confficient
C_p	pressure confficient
C_P	rotor power coefficient
C_{P_i}	induced power confficient
C_Q	torque conefficient
C_T	thrust conefficient
c	blade chord, airfoil chord
r	rotor radius
$\dot{m}$	mass flow
t	time
D	diameter, drag, propeller diameter
k	index of blade element closest to hub

L	characteristic length, lift force
F	force
Q	torque
T	thrust
N	number of blade eleament
U	characteristic velocity, velocity of undisturbed airflow
V	velocity of advance
L	characteristic length, lift force
J	propeller advance ratio
x	dummy varible
α	angle of attack
β	blade engle
ε	axial kinetic egergy factor
λ	advance ratio
λ_h	local speed ratio at the hub
λ_r	local speed ratio
λ_c	climb inflow ratio
λ_i	rotor induced inflow ratio
ρ	density of air
σ	solidity
ω	the angular velocity
θ	angular coordinate in the sestem masstransport coefficient
Ω	anguler velocity of rotor, angular velocity about spin axis

η	efficiency (electrical, meckanical) (%)
η_i	ideal efficiency
ψ	azimuh angle around a rotor, stresm function
d_r	thickness
μ	coefficient of friction, dimensionless airplan mass
γ	ratio of specific angle
φ	phase angle
ν	kinematic air viscosity
B	number of blade

Subscripts and superscripts

i	induced
∞	free stream flow condition
l	lower surface
0	reservoir conditions
0	sea level
0	midspan
w	Used as index for normal rotor average normal induction

Abbreviations

AC	alternating current
BEM	blade element theory
HAWT	horizontal axis wind turbine
rpm	rotations per minute
VAWT	vertical axis wind turbine

CHAPTER1

THE APPLICATION OF COMBINED MOMENTUM AND BLADE ELEMENT THEORY FOR AERODYNAMICS PERFORMANCE ANALYSIS OF ROTATING BLADES

1.1 Introduction

The rotating blade applications had been found in many engineering applications. This type of devices had been used for generating thrust such as for the propeller aircraft, , rotor blade helicopter and they may for extracting the kinetic energy of the airflow such as on the horizontal axis wind turbine. There are various method can be used to estimate the performance of such devices, they are namely : the Momentum Theory, Blade Element theory, the Combined Momentum-Blade Element Theory, a Prescribed wake Method, a Free Wake Method or The Method which derived from solving the governing equation of fluid motion such as a Three Dimensional Euler Equation or Three Dimensional Time Averaged Navier Stokes equation.

The simple momentum theory provides an initial idea regarding the performance of a propeller but not sufficient information for the detailed design. Detailed information can be obtained through analysis of the forces acting on a blade element like it is a wing section. The forces acting on a small section of the blade are determined and then integrated over the propeller radius in order to predict the thrust, torque and power characteristics of the propeller.

The present work will explore the implementation of the idea of Combined Momentum – Blade Element Theory for predicting the aerodynamics performance for : propeller blade of the aircraft, rotor blade helicopter in hover and forward flight and also the rotor blade of the horizontal axis wind turbine.

1.2 Research Background

There are engineering applications used a rotating blade devices to carry out a particular tasks. Rotating blade on wind turbine is designed to convert the wind kinetic energy to become a useful energy such as for generating electricity or in the form of mechanical work for water pumping. Rotating blade on propeller aircraft is designed to generate thrust through converting the mechanical power to the kinetic energy of the airflow which pass through the blade. It is similar with what occured on the flow past through a rotor blade helicopter. Considering such importance of the rotating blade devices in generating thrust as well as in the way of extracting the wind kinetic energy in the problem of wind turbine, hence understanding performance for such devices are required. One will not be able to fly the airplane if the thrust generated by the propeller blade is not sufficient to overcome the aircraft drag. Similary the helicopter will also not be able to hover if the thrust at hover is less then the helicopter weight. Through these reasons, the research work was purposed to carry out on the development of computer code for performance rotating blade analysis.

1.3 Problem Statement.

The flow pass through rotating blade can be modelled by introducing a streamtube model in order to distunguish the flow surrounding the blade can be diveded into two regions disturbed and undisturbed flow region.

Here one can applied momentum conservation along the stream tube and in the same time one can formulate the forces which work on the blade in view of blade element theory. Those two approaches will give the same forces quantatively and equoting them makes the mathematical expression for solving the unknown induced velocity can be developed. Such approach is konwn as the Combined Momentum and Blade Element Theory. This approach can be applied whether the rotating blade in the form of horizontal axis wind turbine, propeller aircraft or rotor blade helicopter.

However due to geometry differences in their configurations, the implementation of the combined Momentum and Blade element theory give a slightly different mathematical experession in the way of estimating the induced velocity. Such difference need to be clarified in order to make better understanding in implenting the combined Momentum and blade element theory for the case of rotating blade problems.

1.4 Objective

To develop computer code for the aerodynamics analysis of rotating blade by using a Combined Momentum – Blade Element Theory which applicable for propeller aircraft, and rotor blade helicopter and rotor blade of the horizontal axis wind turbine

1.5 Scope of Study

1. Overview on the progress development in the aerodynamic performance predicting method of rotating blade.
2. Identity the typical rotor blade configuration if those devices designed as propeller for the aircraft, rotor blade of the helicopter and as rotor blade for the horizontal axis wind turbine**.**
3. Develop computer code for the rotor blade aerodynamic performance analysis based on the idea of combined Momentum – Blade Element Theory.
4. Comparison result between the developed computer code for several test case of rotating blade which available in literature**.**

CHAPTER 2

THE ROTATING BLADE CONFIGURATION

2.1 Overview Various Methods for solving for aerodynamics performance analysis of rotating blade

R. Lanzafame, M. Messina (2008) [1] Horizontal axis wind turbine working at maximum power coefficient continuously. The performance of a horizontal axis wind turbine continuously operating at its maximum power coefficient was evaluated by a calculation code based on Blade Element Momentum (BEM) theory. It was then evaluated for performance and Annual Energy Production (AEP) at a constant standard rotational velocity as well as at a variable velocity but at its maximum power coefficient. The mathematical code produced a power co-efficiency curve which showed that notwithstanding further increases in rotational velocity a constant maximum power value was reached even as wind velocity increased.

This means that as wind velocity varies there will always be a rotational velocity of the turbine which maximizes its coefficient. It would be sufficient therefore to formulate the law governing the variation in rotational velocity as it varied with wind velocity to arrive at a power coefficient that is always the same and its maximum. This work produced a methodology which allows a horizontal axis wind turbine to work continuously at its maximum power coefficient. A wind turbine operating at constant rotational velocity has a maximum power coefficient for a given wind velocity which decreases as wind speed decreases.

C Siva,MSMurugan, and R Ganguli(2009)[2] Effect of uncertainty on helicopter performance predictions. The effect of uncertainties on performance predictions of a helicopter is studied in this article. The aeroelastic parameters such as the air density, blade profile drag coefficient, main rotor angular velocity, main rotor radius, and blade chord are considered as uncertain variables. The propagation of these uncertainties in the performance parameters such as thrust coefficient, figure of merit, induced velocity, and power required are studied using Monte Carlo simulation and the first-order reliability method. The Rankine–Froude momentum theory is used for performance prediction in hover, axial climb, and forward flight. The propagation of uncertainty causes large deviations from the baseline deterministic predictions, which undoubtedly affect both the achievable performance and the safety of the helicopter. The numerical results in this article provide useful bounds on helicopter power requirements. The structural and aerodynamic uncertainty effects on helicopter performance predictions are presented. The MCS is carried out with 100 000 samples of structural and aerodynamic variables with a COV ranging from 1 per cent to 5 per cent.

The power coefficient for the hover case shows a large scatter in their predictions with a COV of 8.33 per cent and extreme values ranging from −30 per cent to 45 per cent from the baseline deterministic value. The power required of an axial climb shows a COV of 2.87 per cent and has a scattering of −10 per cent to 15 per cent from the baseline deterministic prediction. The power required for forward flight at $\mu_f = 0.1$ has a COV of 3.94 per cent and a deviation of −15 per cent to 25 per cent from the baseline, whereas for forward flight at $\mu_f = 0.3$, the power required has a COV of 1.54 per cent and a deviation of −6 per cent to 10 per cent from the baseline. Although the absolute power required may differ in hover, axial climb, and forward flight, the uncertainty propagation has much more impact over the hover deterministic prediction with a large COV of 8.33 per cent. These numerical results provide useful bounds on helicopter power requirements for hover, axial climb, and forward flight. The outcome of this work clearly shows the need to incorporate randomness of structural and aerodynamic properties in the helicopter design and performance analysis. Understanding the influence of various uncertainties on the performance of a helicopter is certain to augment the design process, thereby bringing significant improvements in range, endurance, operational flexibility, and safety The results of this study will enhance confidence in the design process and will gradually pave the way for safer aerospace systems through inclusion of uncertainty analysis in computer simulations.

Sung Nam Jung(2004)[3] Aerodynamic performance prediction of a 30 kW counter-rotating wind turbine system. The aerodynamics performance prediction of a unique 30 kw counter-rotating (C/R) wind turbine system, which consists of the main rotor and auxiliary rotor, has been investigated by using the quasi-steady strip theory. The near wake behavior of the auxiliary rotor that is located upwind of the main rotor is taken into consideration in the performance analysis of the turbine system by using the wind tunnel test data obtained for scaled model rotor. The relative size and the optimum placement of the two rotors are investigated through use of the momentum theory combined with the experimental wake model. In addition, the performance prediction results along with the full-scale field test data obtained for C/R wind turbine system are compared with those of the conventional single rotor system and demonstrated the effectiveness of the current C/R turbine system.The aerodynamics performance analysis has been carried out for a 30 kW C/R wind turbine system by using the quasi-steady strip theory along with the experimental wake model obtained based on the wind tunnel test data. The relative size and the optimum placement of the auxiliary rotor and the main rotor in the C/R system were identified. Regarding the relative dimension of the two rotors, the size of the auxiliary rotor should be smaller than one-half of the main rotor diameter. It is also, found that the power output was significantly affected by the interval remained at around one-half of the auxiliary rotor diameter. The full-scale test data for the performance of the C/R wind turbine system were compared with the present prediction results. A fairly good correlation between the two results was obtained. Based on the prediction results as well as the field test experience, the current C/R system through to be quite effective in extracting energy from the wind. The maximum power coefficient reached as high as 0.5.

2.2 Configuration of Rotating Blades

As it has mentioned in the previous chapter, the present works will conduct aerodynamics performance on three types of rotating blade.

They are namely (1) rotating blades of the propeller aircraft (2) the rotating blades of helicopter and (3) the rotating blades of the horizontal axis wind turbine.

Each of those rotating blades worked at difference operation conditions, as result there are a configuration differences among of them. The following subchapters discuss the typical of configuration for each of rotating blade as mentioned above.

2.2.1 Rotating blade configuration of Propeller Aircraft

Thrust is the force that moves the aircraft through the air. Thrust is generated by the propulsion system of the aircraft. There are different types of propulsion systems in the way to develop thrust, although it usually generated through some application of Newton's Third Law. Propeller is one of the propulsion systems. The purpose of the propeller is to move the aircraft through the air. The propellers consist of two or more blades connected together by a hub. The hub serves to attach the blades to the engine shaft [4].

The blades are made in the shape of an airfoil like wing of an aircraft. When the engine rotates the propeller blades, the blades produce lift. This lift is called thrust-and moves the aircraft forward. Most aircraft have propellers that pull the aircraft through the air. These are called ct or propellers. Some aircraft have propellers that push the aircraft. These are called pusher propellers [4].

2.2.2 Description of propeller aircraft

This section will describe some parts of propeller aircraft, the propeller part are as shown in the Figure 2.1 [5]

- **Leading Edge**

Of the airfoil is the cutting edge that slices into the air. As the leading edge cuts the air, air flows over the blade face and the camber side. [5]

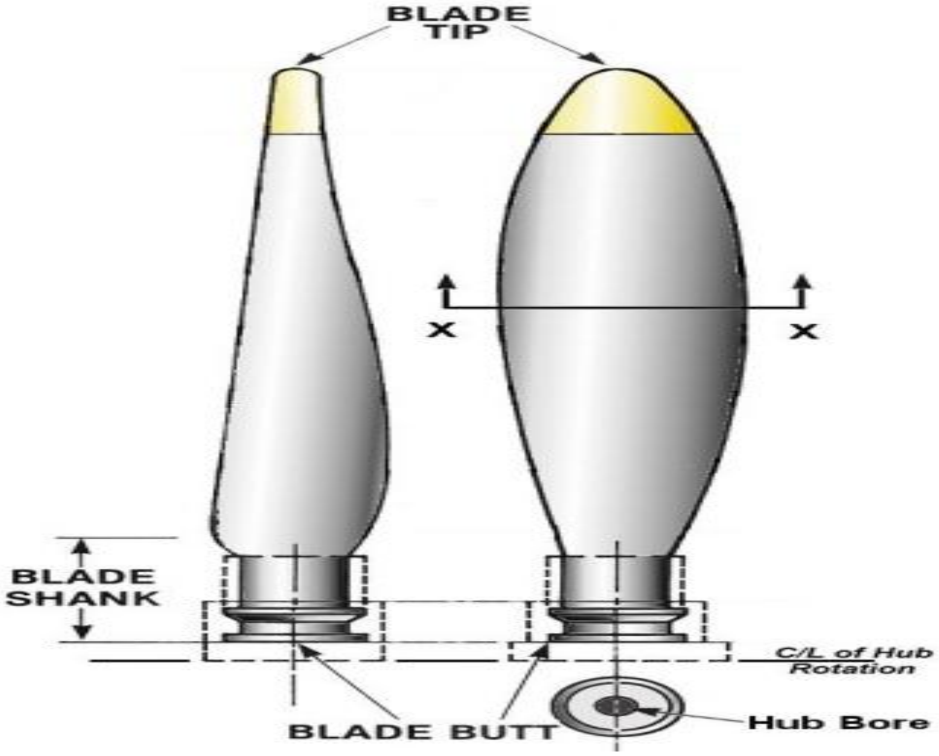

Figure 2.1 Leading Edge [5].

- **Blade face**

Is the surface of the propeller blade that corresponds to the lower surface of an airfoil or flat side, it called Blade Face.

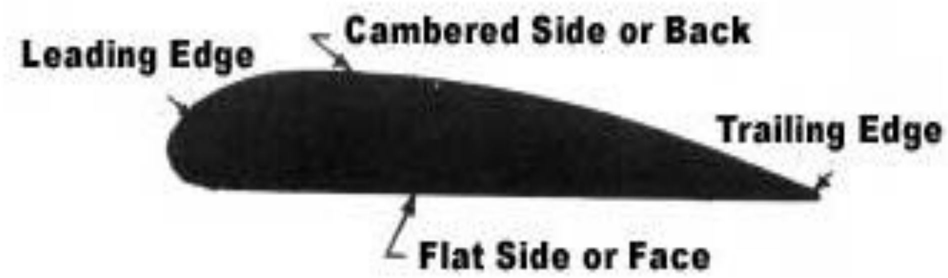

Figure 2.2 Cross section of a propeller blade [5]

- **Blade Back / Thrust Fac**e

Is the curved surface of the airfoil.

- **Blade Shank (Root)**

Is the section of the blade nearest the hub·

- **Blade Tip**

Is the outer end of the blade farthest from the hub.

- **Plane of Rotation**

This plane represents an imaginary plane perpendicular to the shaft; it is the plane that contains the circle in which the blades rotate.

- **Blade Angle**

The blade angle is formed between the face of an element and the plane of rotation .The blade angle throughout the length of the blade is not the same. The reason for placing the blade element sections at different angles is because the various sections of the blade travel at different speed. Each element must be designed as part of the blade to operate at its own best angle of attack to create thrust when revolving at its best design speed.

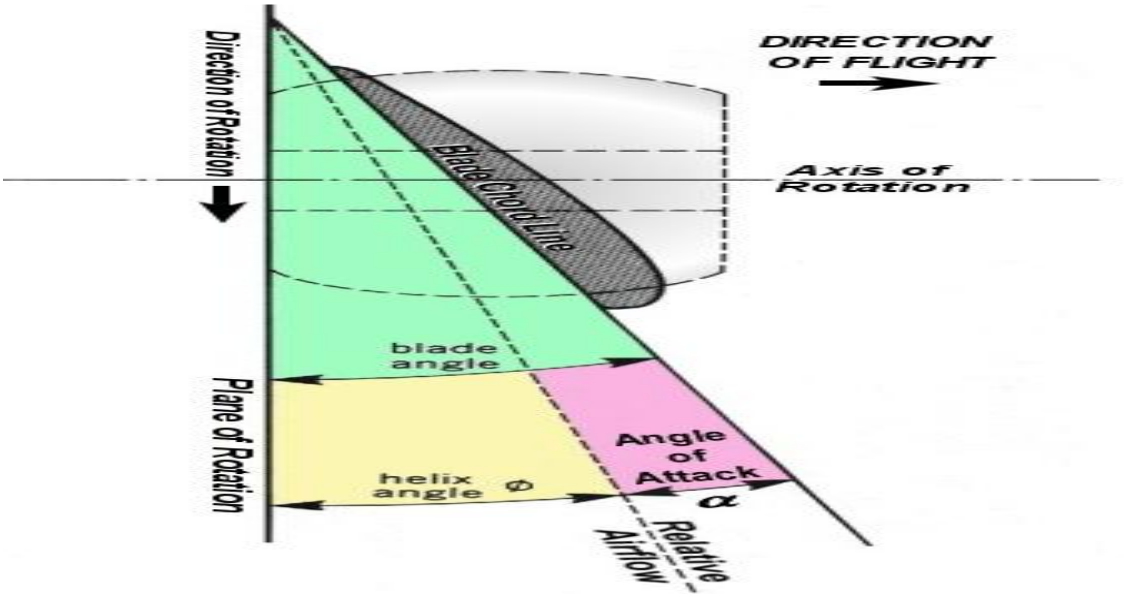

Figure 2.3 Blade Engle [5]

- **Blade Element**

Are the airfoil sections joined side by side to form the blade airfoil.

2.2.3 Type of aircraft propellers

In designing propellers, the maximum performance of the airplane for all condition of operation from takeoff, climb, cruising, and high speed. The propellers may be classified under eight general types as follows [5].

- **Fixed pitch**

The propeller is made in one piece. Only one pitch setting is possible and is usually two blades propeller and is often made of wood or metal [5].

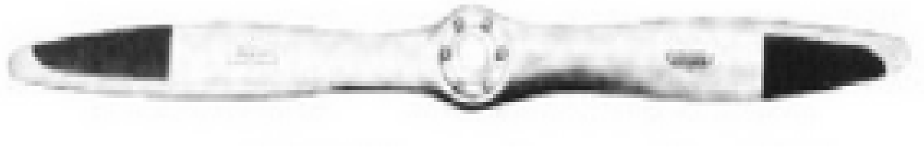

Figure 2.4 Fixed pitch one-piece wood propeller [5]

- **Wooden Propellers**

Wooden propellers were used almost exclusively on personal and business aircraft prior to World War II .A wood propeller is not cut from a solid block but is built up of a number of separate layers of carefully selected .any types of wood have been used in making propellers, but the most satisfactory are yellow birch, sugar Mable, black cherry, and black walnut. The use of lamination of wood will reduce the tendency for propeller to warp. For standard one-piece wood propellers, from five to nine separate wood laminations about 3/4 in. thick is used [5].

- **Metal Propellers**

During 1940, solid steel propellers were made for military use. Modern propellers are fabricated from high-strength, heat-treated, aluminum alloy by forging a single bar of aluminum alloy to the required shape. Metal propellers are now extensively used in the construction of propellers for all type of aircraft. The general appearance of the metal propeller is similar to the wood propeller, except that the sections are generally thinner [5].

2.2.4 Forces and stresses acting on a propeller in flight

The forces and stresses work on the propeller can be identified as follows:

1. **The forces acting on a propeller in flight are**

a) Thrust is the air force on the propeller which is parallel to the direction of advance and induces bending stress in the propeller.
b) Centrifugal force is caused by rotation of the propeller and tends to throw the blade out from the center.
c) Torsion or Twisting forces in the blade itself, caused by the resultant of air forces which tend to twist the blades toward a lower blade angle [6].

2. **The stress acting on a propeller in flight is**

a) Bending stresses are induced by the trust forces. These stresses tend to bend the blade forward as the airplane is moved through the air by the propeller.
b) Tensile stresses are caused by centrifugal force.
c) Torsion stresses are produced in rotating propeller blades by two twisting moments. One of these stresses is caused by the air reaction on the blades and is called the aerodynamic twisting moment. The stress is caused by centrifugal force and is called the centrifugal twisting moment [6].

2.3 Rotating blade configuration of rotor blade helicopter

Before the development of powered helicopters in the mid 20th century, autogyro pioneer Juan de la Cierva researched and developed many of the fundamentals of the rotor. Cierva is credited with successful development of multi-bladed, fully articulated rotor systems.

This type of system is widely used today in many multi-bladed helicopters. In the 1930s, Arthur Young improved the stability of two-bladed rotor systems with the introduction of a stabilizer bar. This system was used in several Bell and Hiller helicopter models. It is also used in many remote control model helicopters [7].

A helicopter is a type of rotorcraft in which lift and thrust are supplied by one or more engine driven rotors. In contrast with fixed-wing aircraft, this allows the helicopter to take off and land vertically, to hover, and to fly forwards, backwards and laterally. These attributes allow helicopters to be used in congested or isolated areas where fixed-wing aircraft would not be able to take off or land. The capability to efficiently hover for extended periods of time allows a helicopter to accomplish tasks that fixed-wing aircraft and other forms of vertical takeoff and landing aircraft cannot perform. The word 'helicopter' is adapted from the French helicopter , coined by Gustavo de Ponton Amecourt in 1861, which originates from the Greek helix 'spiral' or 'turning' and Peterson 'wing'. Helicopters were developed and built during the first half-century of flight, with the Focke-Wulf Fw 61 being the first operational helicopter in 1936[7].

Some helicopters reached limited production, but it was not until 1942 that a helicopter designed by Igor Sikorsky reached full-scale production, with 131 aircraft built. Though earlier designs used more than one main rotor, it was the single main rotor with ant torque tail rotor configuration of this design that would come to be recognized worldwide as the helicopter [7].

2.3.1 Components and their Sub-components of helicopter

The component of helicopter may be easily understood through Figure 2.5. Those figure shows that the helicopter can be divided into their components as follows:

1. Fuselage & Skid
2. Main Rotors & Rotor-head
3. Engine & Transmission
4. Tail rotor, Tail Rotor head, and Tail-boom
5. Flight Controls
6. Electrical System
7. Hydraulic System
8. Digital System
9. Instruments and Avionics.

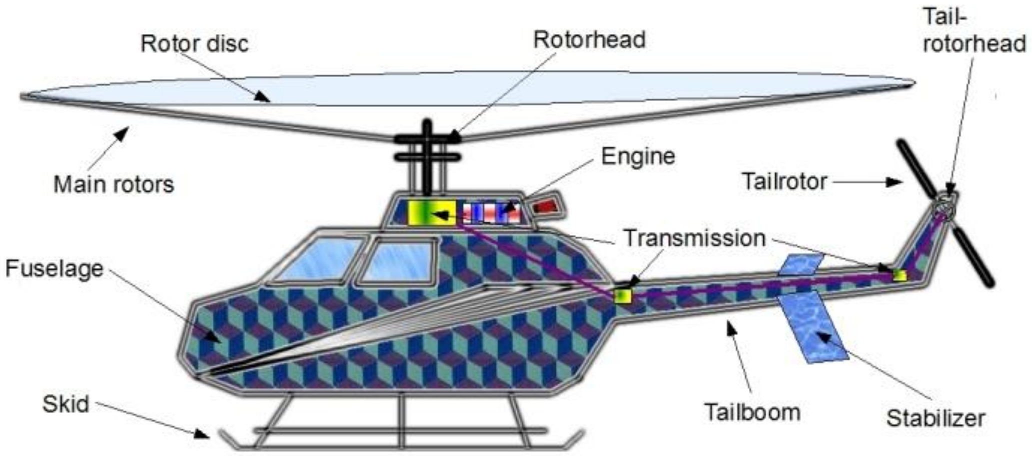

Figure 2.5a Components and their Sub-components [7]

Figure 2.5b Components and their Sub-components [7]

2.3.2 Rotor configurations

Most helicopters have a single, main rotor but require a separate rotor to overcome torque. This is accomplished through a variable pitch, ant torque rotor or tail rotor.

This is the design that Igor Sikorsky settled on for his helicopter and it has become the recognized convention for helicopter design, although designs do vary. When viewed from above, the main rotors of helicopter designs from Germany, United Kingdom and the United States rotate counter-clockwise, all others rotate clockwise. This can make it difficult when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft.

The main rotor assembly is composed of see saw (which holds the fly bar), blade holder (which holds the main rotor blades) and the rotor head which is connected to the rotor shaft. (See Fig. 2.6). Basically there are two main types of main rotor assembly. The one shown on Fig. 2.7 is a collective pitch main rotor. The blades' pitch is fixed and the only vertical flight control is dependent on the blades speed of rotation as well as the engine speed (See Fig 2.7).

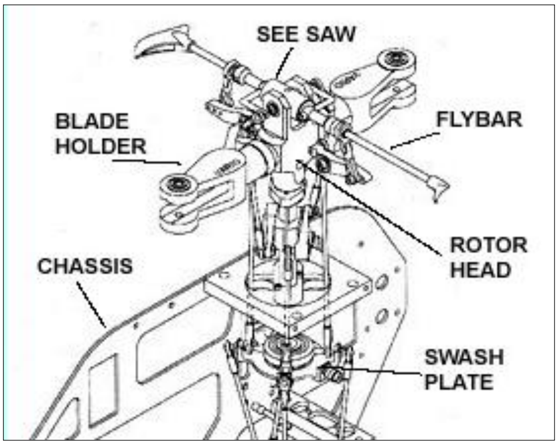

Figure 2.6 Collective Pitch [8]

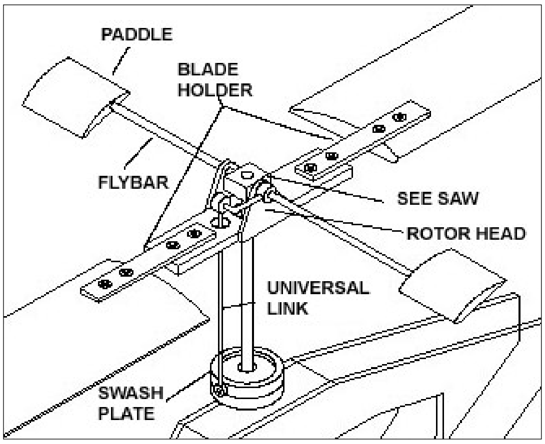

Figure 2.7 Fixed Pitch Man Rotor [8]

2.3.3 Single main rotor

With a single main rotor helicopter, the creation of torque as the engine turns the rotor creates a Angular momentum, Conservation of angular momentum torque effect that causes the body of the helicopter to turn in the opposite direction of the rotor.

To eliminate this effect, some sort of ant torque control must be used, with a sufficient margin of power available to allow the helicopter to maintain its heading and provide yaw control. The three most common controls used today are the traditional "tail rotor", Euro copter’s "Fenestron" also called a "fant [8].

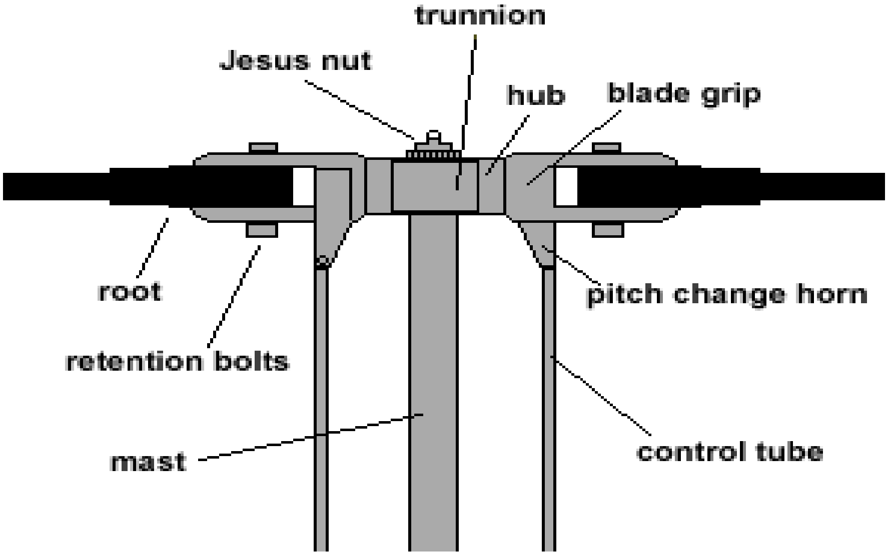

Figure 2.8a main rotor system [8]

Figure 2.8b single main rotor [8]

2.3.4 Dual rotors (counter-rotating)

Tandem rotors are two horizontal main rotor assemblies mounted one behind the other. Tandem rotors achieve pitch Aircraft attitude changes to accelerate and decelerate the helicopter through a process called differential collective pitch. To pitch forward and accelerate, the rear rotor increases collective pitch, raising the tail and the front rotor decreases collective pitch, simultaneously dipping the nose. To pitch upward while decelerating (or moving rearward), the front rotor increases collective pitch to raise the nose and the rear rotor decreases collective pitch to lower the tail. Yaw control is developed through opposing cyclic pitch in each rotor; to pivot right, the front rotor tilts right and the rear rotor tilts left, and to pivot left, the front rotor tilts left and the rear rotor tilts right. All of the rotor power contributes to lift, and it is simpler to handle changes in the center of gravity fore-aft. However, it requires the expense of two large rotors rather than the more common one large main rotor and a much smaller tail rotor [9].

Figure 2.9 Dual rotors (counter-rotating) [9]

2.3.5 Tail rotor

The tail rotor is a smaller rotor mounted so that it rotates vertically or near-vertically at the end of the tail of a traditional single-rotor helicopter. The tail rotor's position and distance from the [[center of gravity]] allow it to develop thrust in a direction opposite of the main rotor's rotation, to counter the torque effect created by the main rotor. Tail rotors are simpler than main rotors since they require only collective changes in pitch to vary thrust. The pitch of the tail rotor blades is adjustable by the pilot via the anti-torque pedals, which also provide directional control by allowing the pilot to rotate the helicopter around its vertical axis (thereby changing the direction the craft is pointed).

Figure 2.10 Tail rotor of helicopter [9]

2.4 Rotating blade configuration of the horizontal axis wind turbine

It is worthwhile to consider some of the history of wind energy. The history serves to illustrate the issues that wind energy systems still face today, and provides insight into why turbine look the way they do.

The force of the wind can be very strong, as can be seen after the passage of a hurricane or a typhoon. Historically, people have harnessed this force peacefully, its most important usage probably being the propulsion of ships using sails before the invention of the steam engine and the internal combustion engine. Wind has also been used in windmills to grind grain or to pump water for irrigation or, as in The Netherlands, to prevent the ocean from flooding low-lying land. At the beginning of the twentieth century electricity came into use and windmills gradually became wind turbines as the rotor was connected to an electric generator. Small wind turbines were ideal for this purpose and in Denmark Poul la Cour, who was among the first to connect a windmill to a generator, gave a course for ‘agricultural electricians’. An example of La Cour’s great foresight was that he installed in his school one of the first wind tunnels in the world in order to investigate rotor aerodynamics. The development of more efficient wind turbines was still pursued in several countries such as Germany, the US, France, the UK and Denmark. In Denmark, this work was undertaken by Johannes Juul, who was an employee in the utility company SEAS and a former student of la Cour. In the mid 1950s Juul introduced what was later called the Danish concept by constructing the famous Gedser turbine, which had an upwind three-bladed, stall regulated rotor, connected to an AC asynchronous generator running with almost constant speed. Wind turbines suddenly became interesting again for many countries that wanted to be less dependent on oil imports; many national research programmers’ were initiated to investigate the possibilities of utilizing wind energy. Large non-commercial prototypes were built to evaluate the economics of wind produced electricity and to measure the loads on big wind turbines [9].

2.4.1 Type of wind turbine

Many different types of wind turbine machines were designed and constructed during the course of windmills history. The major categories of wind machines are:

1. **Horizontal axis rotor**

The most common type of wind turbine is the horizontal axis turbine. It has two or three blades that spin around a horizontal shaft. The blades are joined in the center by a hub. Together, the blades and the hub are called the rotor. The rotor is mounted on top of a tall tower, where the wind blows freely without obstacles to slow it down. The rotor is attached to a compartment called the nacelle, which contains the gearbox, the generator, and a computer. The computer tracks the wind's speed and direction. The computer activates a motor to turn the nacelle, if the wind's direction changes, and moves the rotor into the wind. The rotor will only spin when it is facing into the wind.

The Horizontal Axis Wind Turbine (HAWT) is the most efficient design for turning wind into electricity. The basic design allows two or more rotor blades to face into the wind.

Since they are all being simultaneously moved, they form the least possible resistance to wind forces. The rotor blades of a Horizontal Axis Wind Turbine usually have an aerodynamic design. On a wing or rotor blade, the top side of the blade has a longer surface area than the bottom. When the air moves over the top of the blade, the air must move faster than the air going under the bottom of the blade. This higher speed creates lift because the denser underside air pushes against the blade. The blades are hooked to a shaft so the lift on the blade forces the shaft to spin [9].

Figure 2.11 Horizontal Axis Wind Turbines [9]

2. Vertical-axis rotors

A vertical axis wind turbine (VAWT) has a shaft that spins vertical to the ground. Because of its orientation, the turbine never needs to be reoriented to face the wind. This generally means that it requires fewer moving parts and safety devices than the horizontal axis wind turbine (HAWT).

Most modern designs make use of special rotor blades that rely on lift. One side of the blade has a longer, more curved, surface than the other side of the rotor. This creates less pressure on one side which results in "lift".

This lift can actually cause the blades to move at speeds faster than the wind. But not too much faster.

This is one of the disadvantages of the vertical axis wind turbines in producing electricity; seldom do the speeds of the shafts exceed 100 revolutions per minute. Electrical generators like speeds in the range of 1000 rpms. Gearing can be used to equalize these speeds, but the introduction of every gear brings with it the concomitant loss of efficiency [10].

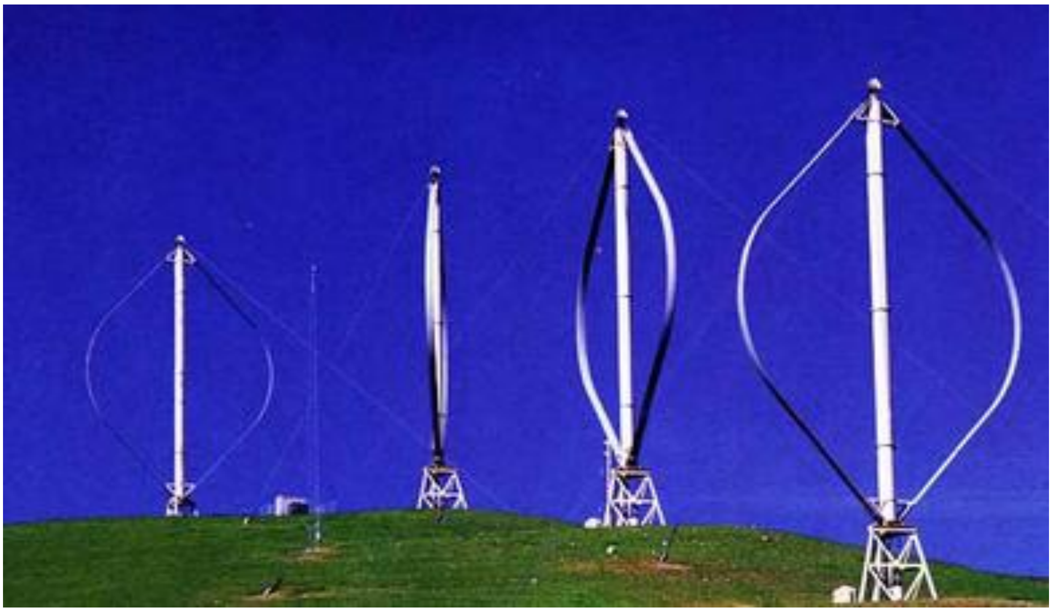

Figure 2.12 vertical axis wind turbine [9]

2.4.2 Part of a wind turbine

The simplest possible wind-energy turbine consists of three crucial parts:

1-Rotor blades

The blades are basically the sails of the system; in their simplest form, they act as barriers to the wind (more modern blade designs go beyond the barrier method).

When the wind forces the blades to move, it has transferred some of its energy to the rotor.

2- Shaft

The wind-turbine shaft is connected to the center of the rotor. When the rotor spins, the shaft spins as well. In this way, the rotor transfers its mechanical, rotational energy to the shaft, which enters an electrical generator on the other end.

3- Generator

At its most basic, a generator is a pretty simple device. It uses the properties of electromagnetic induction to produce electrical voltage difference in electrical charge. Voltage is essentially electrical pressure it is the force that moves electricity, or electrical current, from one point to another.

So generating voltage is the generating current effects. A simple generator consists of magnets and a conductor. The conductor is typically a coiled wire. Inside the generator, the shaft connects to an assembly of permanent magnets that surrounds the coil of wire. In electromagnetic induction, if you have a conductor surrounded by magnets, and one of those parts is rotating relative to the other, it induces voltage in the conductor. When the rotor spins the shaft, the shaft spins assembly of magnets, generating voltage in the coil of wire. That voltage drives electrical current (typically alternating current, or AC power) out through power lines for distribution.

2.4.3 Components horizontal-axis wind turbine

Figure 2.13 shows the schematic arrangement of a horizontal-axis wind turbine. The components and their configuration are typical of a large modern wind turbine. Naturally, designs differing from this standard concept are also possible and constructional simplifications such as the absence of pith control can be found, particularly in small wind turbine [10].

Although most parts are interchangeable between horizontal and vertical axis wind turbines, here is a breakdown of a horizontal-axis wind turbine for reference:

1- Blades

Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.

2- Brake

A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

3- Controller

The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

4- Gear box

Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

5- Generator

Usually an off-the-shelf induction generator that produces 60-cycle AC electricity.

6- High-speed shaft.

Drives the generator

7-Low-speed shaft:

The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.

8- Nacelle

The nacelle sits atop the tower and contains the gear box, low- and high- speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

9- Pitch

Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

10- Rotor

The blades and the hub together are called the rotor.

11- Tower

Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

12- Wind direction

This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.

13- Wind vane

Measures wind direction and communicate with the yaw drive to orient the turbine properly with respect to the wind.

14- Yaw drive

Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.

15- Yaw motor

Powers the yaw drive. This is a general overview of the horizontal-axis wind turbine.

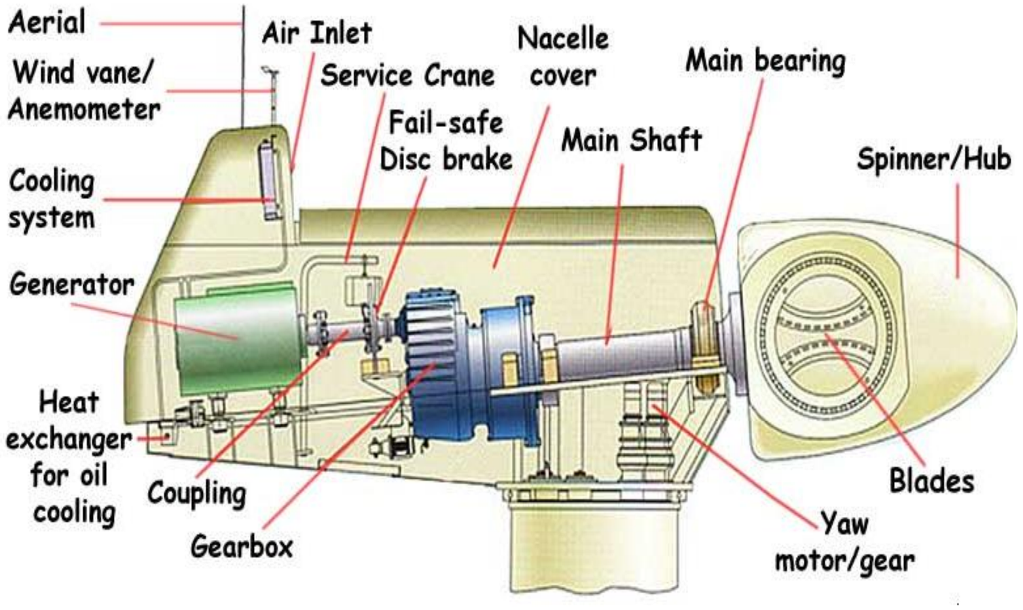

Figure 2.13 Components horizontal-axis wind turbine [10].

CHAPTER3

THE COMBINED MOMENTUM AND BLADE ELEMENT THEORY

3.1 The Overview of Aerodynamics Performance Analysis of the rotating blade configuration

There are various methods had been developed in the way how to carry out the aerodynamic performance analysis of the rotating blade. Here one may use the method which derived from the way of how to solve the governing equation of fluid motion around rotating blade, such as the model of governing equation in the form of Potential Flow model, Compressible Euler Equation or Time Average Navier Stokes Equation and etc. Each of governing equation has its own method in the way how to solve it. As the flow problem considered as the problem of potential flow problem, then, the flow problem around rotating blade need to be solved by singularity method such as Panel Method. In other hand if one considered that the flow problem can be treated as the flow problem governed by the compressible Euler Equation, so the flow problem need to be solved numerically by use Euler solver such as McCormack Scheme[Anderson J.D.Jr] , Runge Kutta – TVD Scheme[Hoffman] , Eno scheme[Hirsch] etc. Other methods in the way how to solve the rotating blade flow problems may not use directly from the governing equation of fluid motion.

This method may use assumption that the flow problem in hand can be classified as the flow problem of vortex dominated flow phenomena. If it so, one can use the method which developed from a Vortex theory. There are two methods had been introduced in solving the flow problem based on a vortex theory, they are

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