Sudan University of science and technology

College of engineering

Aeronautical engineering department

Design of small quad rotor helicopter

A project submitted in partial fulfillment for the requirements of the Degree of B.Sc. (Honor) in aeronautical engineering

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الآية

(والله خلق كل دابة من ماء فمنهم من يمشي على بطنه و منهم من يمشي على رجلين و منهم من يمشي على أربع يخلق الله مايشاء إن الله على كل شئ قدير)

Abstract

A quadrotor is a flying vehicle with four motors driving counter rotating propellers which are mounted in a cross pattern. It is capable of flying around and hovering like a helicopter but with the added stability and maneuverability gained from the extra motors.

The goal of this project is to create a quadrotor hovering platform, capable of carrying a metal prospective by minimized the weight of quadrotor so that it can carry the device. The CAD software has been used for drawing the model and ANSYS® program to analyses the structure statically which evaluate the ability structure for carrying the load.

This project started with the design having in mind a list of objectives to be fulfilled by it. Follow by calculation using ECALC calculator which gave the first suggestion for the requirement.

The report covers the selection component, design, analysis, manufacturing, and testing of selected component and an autonomous quad-rotor helicopter, foxing the study in; the structure manufacturing, performance and propeller aerodynamics calculation.

The most significant problems to date have been an ambitious development schedule coupled with very limited funds. These constraints have forced compromise in components selected and methods used for prototype development.

Acknowledgment

First thanks for Allah……

It is a pleasure to thank those who have contributed to the realization of this dissertation……

To our families who be at pains to build us up to face this life…

To our friends who give a helping hand to supported us ….

To our teachers who go the extra mile to armed us with knowledge….

To great Sudan university……….

To department aeronautical engineering ……

Dedication

FIRSTLY THANKS ALLAH FOR CONCILIATION US TO ACCOMPLISH THIS PROJECT

THANKS TO OUR MOTHERS WHO SUPPORT US

THANKS TO OUR FATHERS FOR THEIR UN- LIMITED ENCOURAGEMENT AND HELPING

TO DIGNIFIED TEACHERS …

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DR. SAKHER BABEKER

MS.C. RAHEEG OSAMA WAHBI
B.SC. MOHAMMED MAHMUD

TO THE PROMISES GENERATION PROMISED BY SUCCESSFUL AND CONCILIATION THE PRECIOUS BROTHERS

OMER MOHAMMED ABD- ELRAHEEM

ISRAA NASR EL-DEAN

LADEN

AND THE THANKFUL FOR VIGA SYSTEMS CENTER REPRESENT IN:

DR. MOHAMMED AD-ALAZEEZ

ENG. MOHAMMED EL-FATEH

AND TO ALL THAT CONTRIBUTE IN ACCOMPLISH THIS HUMBLE WORK

Contains

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List of Abbreviation

I	Inertia moment
M	Angular moment
Ω	Rotational (angular) speed
KV	R.P.M Per Volt
T	Thrust
Q	Drag moment
β	Pitch angle
P	Pitch of the propeller
r	Distance along the blade
d	Diameter of the propeller
x	The relative radios of blades section
R	Radius of propeller
ϕ	Angle of resultant flow
α	Angle of attack
C_L	Lift coefficient
C_D	Drag coefficient
dL	The lift
dT	The thrust
dD	The drag
V_i	Induced velocity
D	Rotor diameter
P	Power
n	R.P.M
η	Efficiency of propeller
Λ	Advanced ratio
P_i	Power induced
ρ	air Density
A	Area of propeller
v	Velocity
P_{par}	Parasite power

P_{prof}	Profile power
P_{sup}	Power supply
f	Equivalent parasite area
N	Drag and lift coefficient ratio
V_{opt}	Optimum velocity
D_{par}	Drag parasite
P_{req}	Power required
G	Weight
P_a	Power available
t	Time of climb
T_{tot}	Total time of climb
R/C	Rate of climb
Δh	Altitude change rate
V_c	Velocity of climb
$V_{C_{mean}}$	Mean climb Velocity
ΔP	Power change rate
E_{min}	flight Endurance per minute
Ran	Range of flight
V	Volt
$c.d.r$	Continues discharge rate
i	Current
W	Watt
N	Newton's
P_{mech}	Power mechanical
P_{elec}	Electrical power
P_{loss}	Power loss
K	Boundary layer coefficient
H	Altitude
m	Meter
m/s	Meter per second
s	Second
V_{C_0}	Velocity of climb at steady level

H_0	Absolute selling
L	Lift force
H_{ser}	Service ceiling
c	Battery capacity

1 Chapter one: Introduction

1.1 Overview

The helicopter is one of the most complex flying machines due to its versatility and maneuverability to perform many types of tasks. Classical helicopters are usually equipped with a main rotor and a tail rotor. However, other types exist which use a twin rotor[1].

And there is new miniature rotorcraft known as quad rotor helicopter. The quad rotor an emerging rotorcraft concept for unmanned aerial vehicle platforms, It consist of four equally size rotor with two pairs of counter rotating fixed pitch blade located at the front, rear, left and right ends of across or H frame.

The quad rotor is controlled by changing the Speed of rotation of each motor. The front and rear rotors rotate in a direction, e.g., counterclockwise, while the left and right rotors rotate In the opposite direction, to balance the torque created by the spinning Rotors. The relative speed of the front and rear rotors are varied to Control the pitch rate of the UAV. Increasing the speed of the front motor by the same amount that the speed of the rear one is decreased will keep the total thrust provided by the four rotors constant. Furthermore, the total torque created by these two rotors will remain constant. Similarly, the roll rate is controlled by varying the relative speed of the left and right rotors. The yaw rate is controlled by varying the relative speed of the clockwise (right and left) and counterclockwise (front and rear) rotors. The collective thrust is controlled by varying the speed of all the rotors simultaneously[2].

In its simplicity, the four rotor helicopter does not need any Complex mechanical controls of its rotors for vehicle control. Instead it uses Rotor blades with fixed pitch and changes the angular velocity with the same Results[3].

1.2 Aim and objectives

Aim: to design a quad rotor helicopter capable of carrying metals prospecting.

Objectives:

- Estimate the quadrotor weight
- Select the motors type and suitable propellers
- Select the battery type and speed controller
- Select the suitable materials for rods, frame and main box
- Design of outer frame first by drawing and then modeling
- Design the primary shape of the main box and rods then fabricating
- Drawing the 3D model use CAD programs and ANSYS for analysis and test the forces and moments acting on the structure.
- Make mass balancing to the propellers and quadrotor
- Manufacturing the main hub and rods by using CNC and driller
- Complex the main parts (rods, hub and cover)
- Make the various connections to the motors and ESC with battery
- Rotor aerodynamics calculation
- Calculate the quadrotor performance and estimate the endurance, rang and maximum altitude
- Make the flight Test

1.3 Problem statement

- In design there was many challenge and problems that we must asses and solved in an acceptable manor as fallowing.
- The frame must design to damping vibration and be stiff as possible to resist the damage.
- Also be light as possible to increase the flight time and permit to add various equipments.
- Helicopter must be design with smooth structure to reducing the aerodynamic drag.
- Helicopter must be design to able for flight at very harsh environments.

1.4 Proposed solution

- Choose suitable materials that make helicopter strong and stiff as possible to resist the different forces while being light weight and vibration absorbent.

- The Control electronics, rotors, motors and batteries will also be chosen bearing the weight.
- Choose suitable frame shape structure investigate better characteristics of aerodynamics

1.5 Motivations

In the last few years, small unmanned aerial vehicles (UAVs) have been developed for large-scale territorial monitoring. The commercial and civilian sectors have expressed an interest in small vertical take-off and landing (VTOL) vehicles capable of reducing take-off and landing distance, to fly over a target and complete many tasks, without the need for excess pilot workload or risk of life. For this reason, small rotary-wing UAVs has been the subject of several recent research projects. Because of the complexity in control and the intrinsic dynamics of these small-size vehicles, multicolor unmanned vehicles have been developed. Small quad rotors have many potential missions including indoor flight and operations in urban areas.

A quad rotor might achieve stable hovering and precise flight by balancing the forces produced by the four rotors.

1.6 Contributions

New design for the purpose of the prospecting about metals with the development in the design of the structure and the use of suitable materials and with a lightweight addition to using the software to analyze the aerodynamic forces and loads inflicted on the structure in addition to trying to reduce the noise caused by the rotation of the motors and rotors.

1.7 Methodology

Design the 3D model and had been drawn using CAD programs and then fabricated by CNC.

Forces acting on the structure analysis by use ANSYS program.

The report consists of five chapters the first chapter gave a brief background on the project; in chapter two evaluate the current work, history and existing work. In chapter three evaluate the project simulations; rotor aerodynamics also handles the materials, props, motor, and battery selection. In chapter four made the design and performance calculations. Chapter five has been back to the final results and concluded the work and recommendations for action in the future.

2 Chapter two: The literature review

A Quad copter is a multi copter lifted and propelled by four rotors. The initial development of quad rotor began in the early twentieth century. Throughout the 20th century not many unique rotor-craft designs have been developed the earliest workable designs for a quad-rotor were developed by

2.1 Breguet-Richet Gyroplane (1907)

A four rotor helicopter was designed by Louis Breguet. This was the first rotary wing aircraft to lift itself off the ground, although only in tethered flight at an altitude of a few feet. In 1908 it was reported as having flown 'several times', although details are sparse[4]**.**as shown in Figure 2-1.

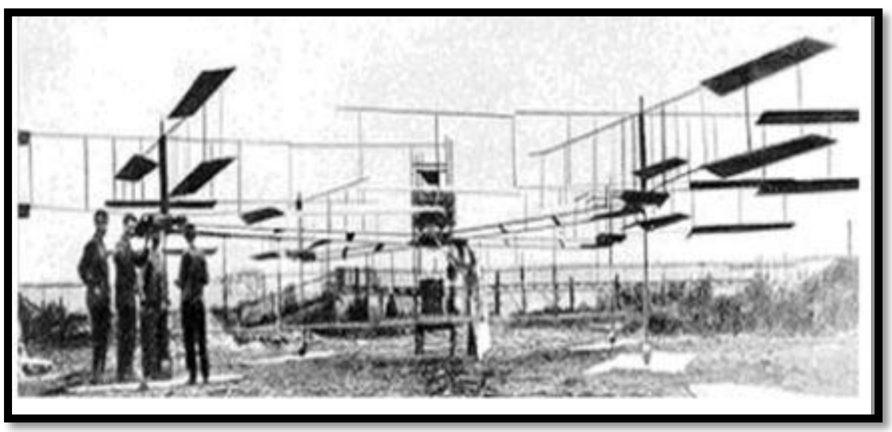


Figure 2-1: Breguet-Richet Gyroplane (1907)

2.2 Oehmichen No.2 (1920)

One of the first engineering to attempt to design a quad rotor was Etienne oemichen in 1920 his design consisted of four rotors and 25 horse power motor but it was unable to flight.

Two years later oemichen complete his second design consisted of four rotor and eight propellers with a 125 horse power motor. Five of propellers were used to achieve stable flight while two for propulsion and the final prop being used to steer the helicopter.

By 1923 it was able to remain airborne for several minutes at a time and on April 14,1924 it established the first – ever FAI distance record for helicopters of 360 m and complete a circular course and later it complete the first kilometer closed circuit flight by rotor craft[5],[1] As show in figure 2-2.

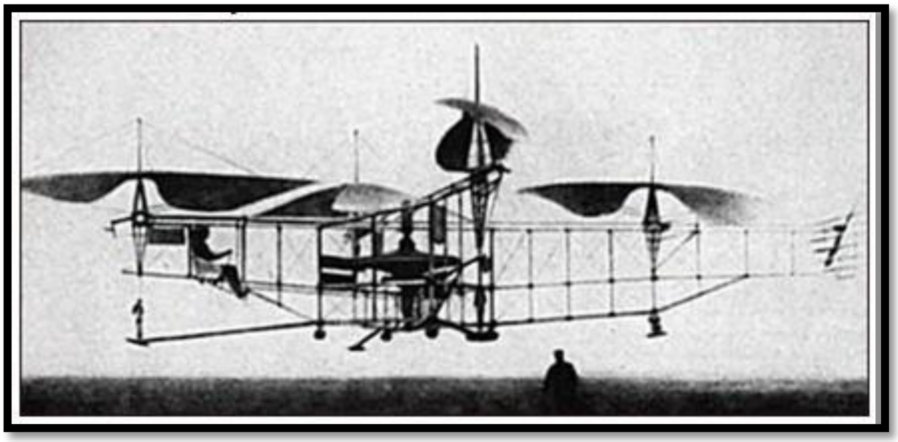


Figure 2-2: Oehmichen No.2 (1920)

2.3 De Bothezat Helicopter (1922)

In united state Dr.George debothazat and Ivanjerome began their design in mid 1922 , there design weighted around 1700 kg and consisted of four six-bladed rotor at the end of x-shaped structure along with a 220 hp motor after many tests the quad rotor was only able to achieve a maximum flight time of 1 minute 42 second and maximum height of 1.8 meters [1] as shown in figure 2-3.

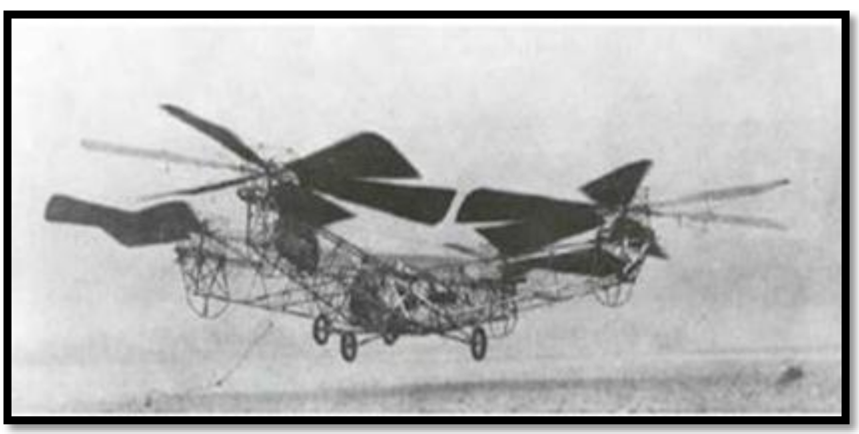


Figure 2-3: De Bothezat Helicopter (1922)

2.4 Convert wings Model "A" Quad rotor (1956)

In 1955 the convert wing model "A" quads rotor was intended to be prototype for line much larger civil and military quad rotor helicopters. The design featured it had wings added for additional lift in forward flight and also consisted of two engines driving four rotors and no tail was needed and was obtained by varying the thrust between rotors.

This helicopter provides the quad rotor design with first four rotors to demonstrate successful forward flight as shown in figure 2-4.

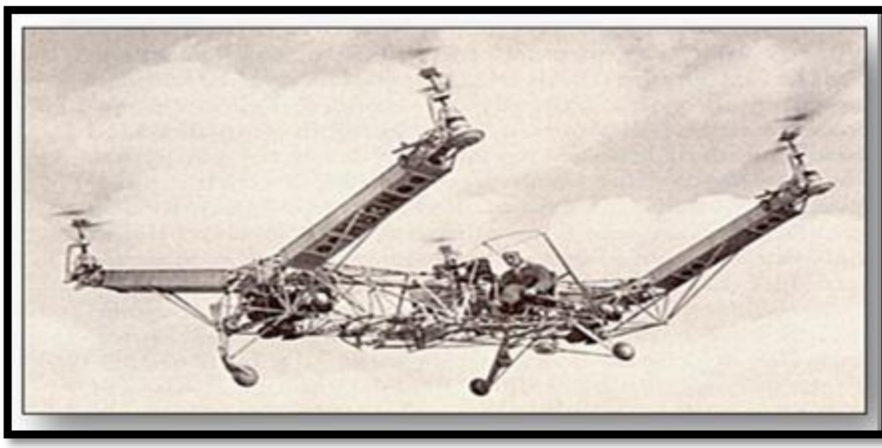


Figure 2-4: Convert wings Model A Quad rotor (1956)

2.5 Curtiss-Wright VZ-7 (1958)

In 1958 the curtiss-wright VZ-7was a VTOL designed by the curtiss-wright company to achieve military uses. It was controlled by changing the thrust of each of the four propellers as shown in figure 2-5.

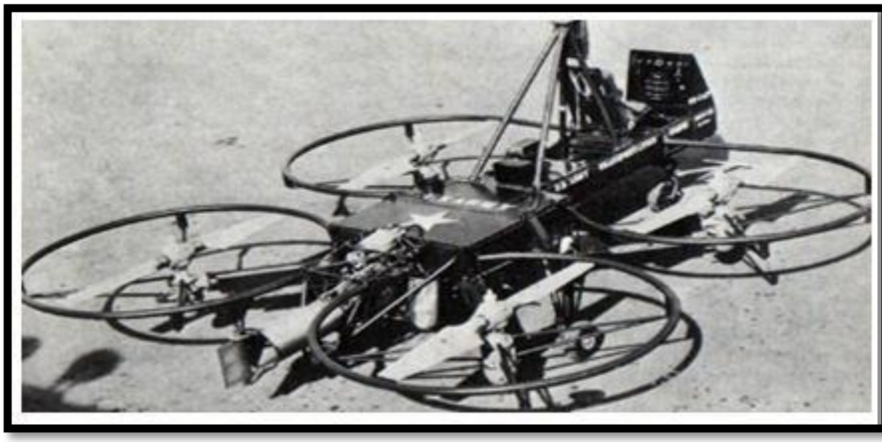


Figure 2-5 Curtiss-Wright VZ-7 (1958)

2.6 Parrot AR. Drone 2.0 (2012)

Quad Copter designs are constantly progressing as the years go on. It wasn't too long ago that designs were limited and constrained, those days are history. The number of projects being undertaken regarding the topic has considerably increased, most of which are for commercial payload, human transport and military use.

Quad copters transforms to a new form to UAV’s but they in the entry level to satisfy the flying conditions only, with one payload and it is also known as hobbyist crafts. Parrot AR. Drone is a small radio controlled quad copter with cameras attached to it built by parrot SA, designed to be controllable with by smart phones or tablet devices figure.2-6 [6].

Figure 2-6: Parrot AR. Drone 2.0 (2012)

2.7 Bell Boeing Quad Tilt Rotors

Currently Bell Helicopter Textron and Boeing Integrated Defense Systems are doing joint research and development of the Bell Boeing Quad Tilt Rotor, as depicted in Figure 2-7, the initial design consists of four 50-foot rotors powered by V-22 engines. The main role of the Bell Boeing Quad Tilt Rotor will be that of a cargo helicopter with the ability to deliver pallets of supplies or also deploy paratroopers. The first wind tunnel tests were completed in 2006 and the first prototype is expected to be built in 2012, with great anticipation [7].

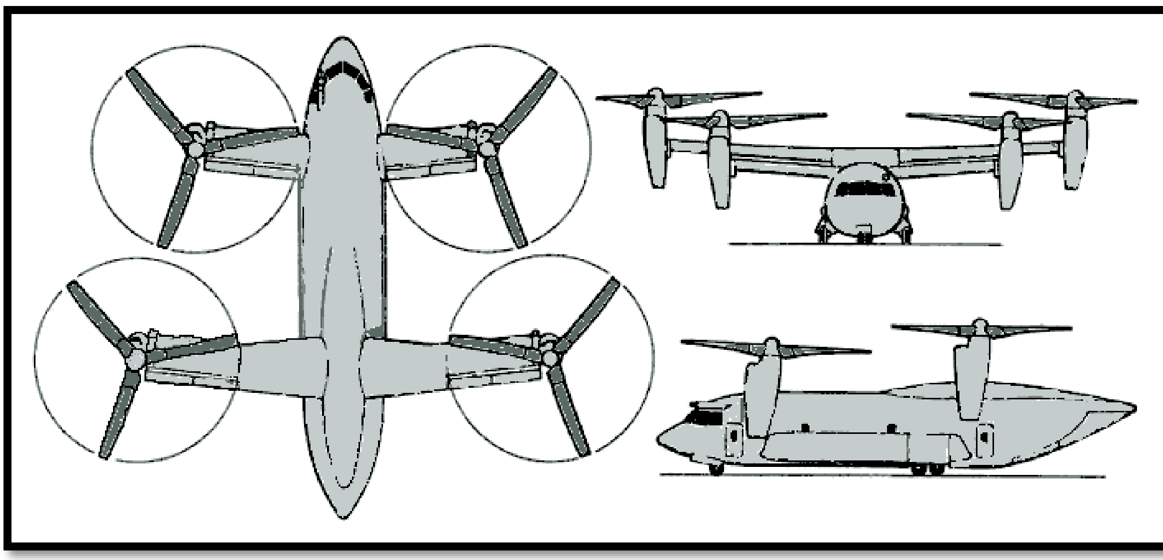


Figure 2-7: Bell Boeing Quad Tilt Rotors

In the last few decades, small unmanned Aerial vehicles (UAVs) have become used for many applications. This led to current rise on quad rotor and hence the need for A/C for greater maneuver ability and hover ability. Cutting edge research is continuing to increase the viability of quad rotor by making advances in multi-craft communications, environment exploration and maneuverability. If all of these developing qualities can be combined together, quad rotor would be capable of advanced autonomous mission that are currently not possible with any other vehicle. There are many type of quad rotor such as dragon flyer, X-UFO and MD4-200. Other researchers prefer instead to build their own structure[6].

The recent advances in micro processor capabilities and in micro electrical mechanical system inertial sensor have spawned a series of radio controlled quad rotor toy such as the

Roswell flyer and dragon flyer which include augmentation to make flight more accessible for remote control pilots[8].

2.8 Principle of operation

2.8.1 Single rotor helicopter

All the lifting thrust of the single rotor helicopter is produced by the main rotor, see figure2.8. When the main rotor is rotating it has to overcome the air resistance (drag) of the rotor blades. The torque that is applied to the rotor shaft in order to overcome the drag is directly transmitted to the helicopter body to which the rotor is attached. It is customary to treat the rotor as if it had an infinite number of blades which form a disc. This imaginary rotor disk lies in the plane of the blades with the radius equal to the length of the blades. The thrust that the rotor produces is always perpendicular to the rotor disc plane. When the helicopter is in axial flight, that is flying up, down or hovering, the lift of the rotor is symmetrical around the rotor’s axis. One of the characteristic features of the single rotor helicopter is the tail rotor. The tail rotor’s thrust generates a torque which cancels out the torque deriving from the main rotor as result of the blade drag. The pilot also exploits the tail rotor to turn the helicopter body around the rotor axis. This is done by changing the angular velocity of the tail rotor, and thereby its thrust. The tail rotor reacts immediately in a predefined way to the pilot’s controls so that the pilot does not have to think about it when he is maneuvering the helicopter.

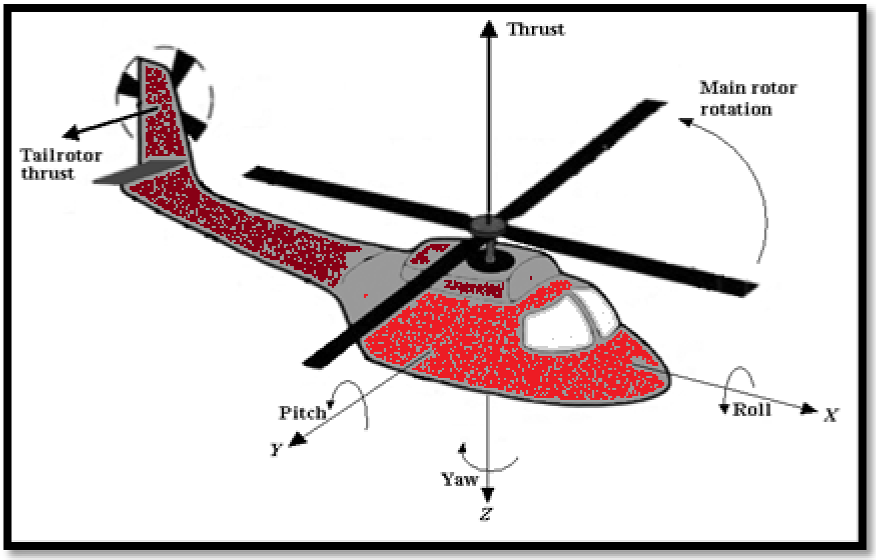


Figure 2-8: Single rotor helicopter

Besides producing the lifting thrust, the main rotor is also the primary source of propulsion and control in forward flight, the main rotor disk is effectively tilted so that the otherwise vertical thrust in axial flight is now tilted as well, see figure 2.8. The thrust in the figure is represented by two force components, the lifting force and the propulsion force. To maintain altitude, the lifting force has to overcome the gravity force. The thrust must therefore be increased when going from axial flight into forward flight in order to maintain the same altitude. Tilting the rotor disk in the direction of choice is done by adjusting the rotor blades. A rotor blade is generally attached to its hub by the means of hinges located at the root of the blade, see figure 2-8.

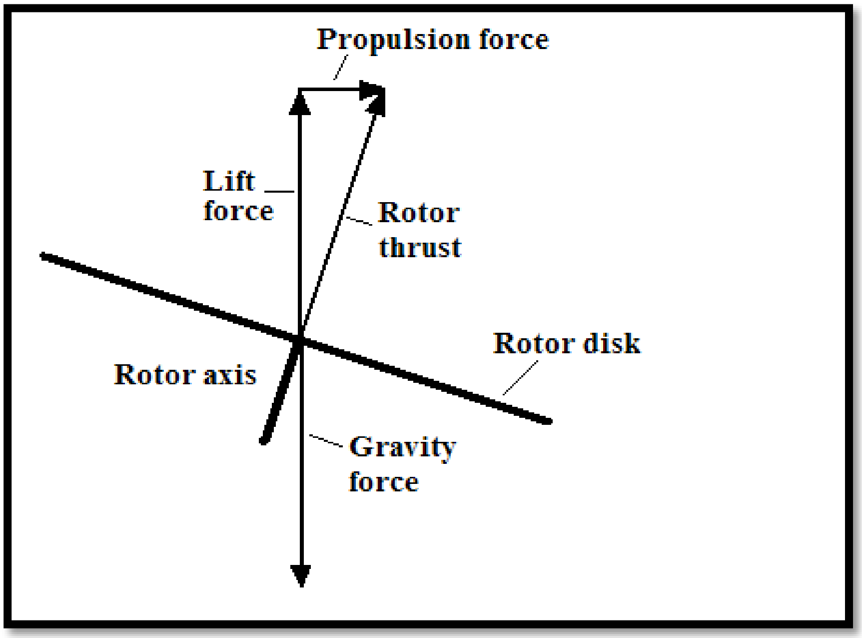


Figure 2-9: the two force components of the thrust when the rotor disk is tilted.

The hinges allow the rotor blade to flap with respect to its hub plane Flapping is the rotational motion of the blade about its flapping axis as shown in figure 2.8. The possibility of pitching the rotor blades is also incorporated into the blade design. Pitching is the rotation of the blade about its longitudinal axis. Pitching the rotor blades collectively, that is all with the same angle, while maintaining constant rotor angular velocity changes the lift of the rotor.

Changing the pitch of the rotor blades independently while they are rotating is called cyclic pitch. Cyclic pitch, which changes the distribution of forces over the rotor disk, is the key feature in tilting the rotor disk effectively in order to move the helicopter in axial flight.

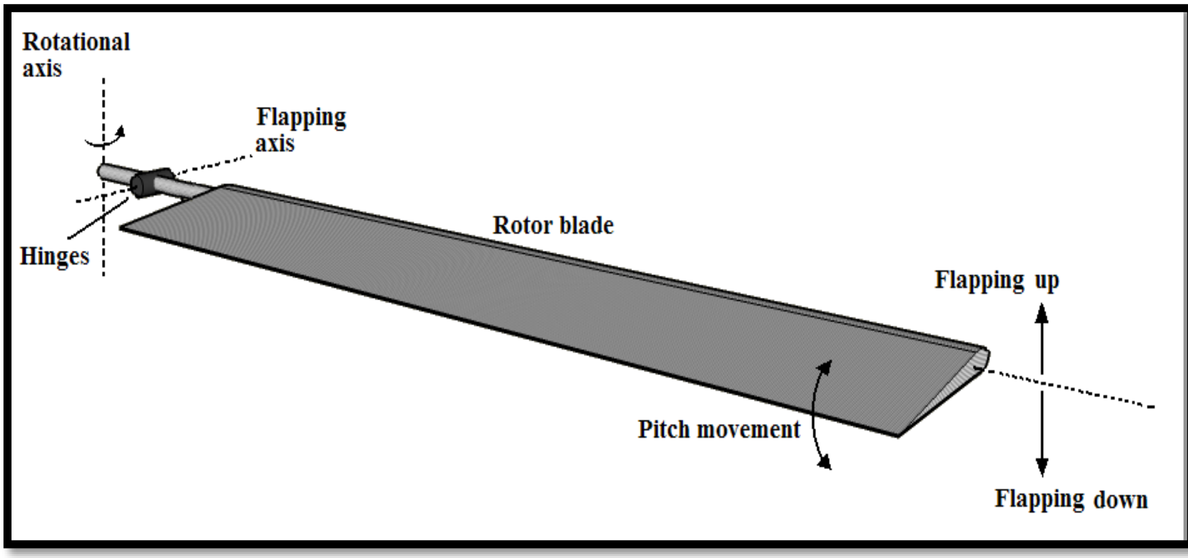


Figure 2-10: Schematics of rotor blade show the basic movements of the rotor Blade, flapping and pitch.

2.8.2 Four rotor helicopter

The four rotor concept does not seem to have been a success though, probably because it is Beyond the skills of an even a trained pilot to fly the helicopter by controlling the four rotors simultaneously. The four rotor helicopter is built as a square where rotors are mounted on each corner, see figure 2-11. All the rotors are fixed in the helicopter's $x-y$ plane see figure 2-11. Each rotor has thrust that is perpendicular to the rotor disk plane. As all the rotors are fixed in the helicopter's $x - y$ plane, the total lifting thrust is perpendicular to the helicopter's $x-y$ plane at all Times. Rotors on the opposite side of the square center rotate in the same direction.

These are considered to be a pair. In figure 2-11 the two pairs are $R1$ and $R2$, $R3$ and $R4$. The two pairs of rotors spin in opposite directions. Ideally the torque that each rotor causes on the body is cancelled out since one pair rotates in the opposite direction of the other. The function of the tail rotor on a conventional helicopter is therefore redundant in the four rotor concept. This, in fact, holds for all helicopters that incorporate rotors spinning in opposite directions, for example in the familiar Boeing CH-47 Chinook. Figure 2-11 illustrates how the transition from axial flight into horizontal flight is invoked. Starting with a hover state of the helicopter, the attitude is changed by increasing the relative angular velocity of some of the rotors and simultaneously decreasing the relative angular velocity of the others; see figure 2-11

(a) and (b). As this is done the total thrust vector angle is shifted from vertical of the body frame in the direction of the two faster spinning rotors. This will tilt the helicopter and thus have the same effect as shown in figure 2-8 for the total thrust that is it will thereby be composed of lift force and propulsion force as discussed for the single rotor helicopter. The total thrust has to be adjusted concurrently in order to maintain the helicopter altitude.

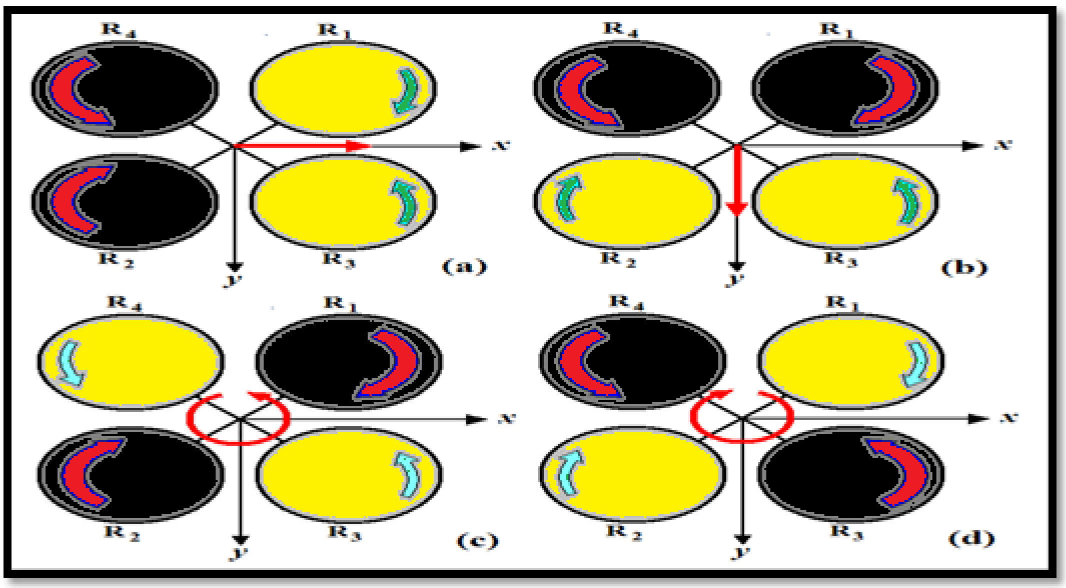


Figure 2-11: Four rotor helicopter seen from above

Starting in a hover state of the helicopter again, in order to make the helicopter revolve around its center, the angular velocity of one of the rotor pairs is increased while it is decreased for the other; see figures 2-11 (c) and (d). The resulting difference in torque applied to the body frame by each rotor pair causes the helicopter to rotate around its center. It is easy to see that with increased difference in the angular velocities of the two rotor pairs the helicopter will rotate faster[3].

This section introduces some of the work presented in recent years, on Colorado state university published the work to build a design quad rotor that contain a cam- -era and telemetry that will allow watching a live video from the quad copter on laptop this located up to two miles away. There project has verified that it is possible to build a small scale quad rotor that could be used for both military and commercial use. There quad rotor has achieved stable un tethered flight as well as autonomous altitude hold, like Matt Parker and Gerad Bottorff [9]. there design

Deal with the design, analysis, manufacturing, and testing of an autonomous quad-rotor helicopter a control system was designed and implemented through the use of an onboard microprocessor and inertial measurement system. The goal of the helicopter was to maintain a hover at a used-defined altitude while minimizing lateral drift. In addition to achieving autonomous flight, the helicopter attained a 10% weight reduction from an earlier quad-rotor design and which led to increased flight time, like Antonio DiCesare, Kyle Gustafson and Paul Lindenfelzer[1]. There objective was to deal with the design of the "Quad copter" the regular design of the quad copter is modified and the static analysis is done on frame to sustain the loads generated in these vehicles and concluded that small deformation occurred on the center plates are safe and within the limit, like Anudeep M , G Diwakar and Ravi Katukam [5].all previous researches are focusing on quad rotor as a control problems and mechanical design but in our project we will design the quad rotor as helicopter for prospecting materials that means study the aerodynamic effect and stability and control, also structural analysis and performance for the aircraft.

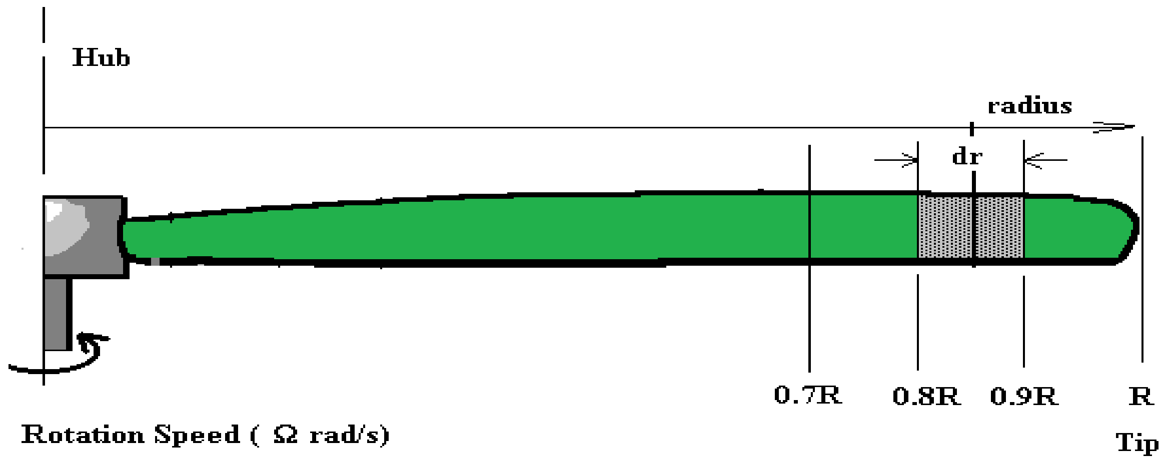
3 Chapter three: quadrotor component, simulation and fabrication

Obtaining successful flight results with the fixed-pitch quadrotor requires both accurate control and robust physical hardware. This chapter addresses the technical challenges inherent with the physical construction of the fixed-pitch quadrotor and the software required for agile flight. Also discussed is the simulation software that used to draw and design frame for the quadrotor and the material that has been used on it.

3.1 Blade Element Rotor Theory

A relatively simple method of predicting the more detailed performance of a helicopter rotor is the use of Blade Element Theory. In this method the rotor is divided into a number of independent sections along the length as show in figure 3-1.For each section the flow can be analyzed independently if the assumption is made that for each there are only axial and angular velocity components and that the induced flow input from other sections is negligible.

At each section a force balance is applied involving 2D section lift and drag with the thrust and torque produced by the section. At the same time a balance of axial momentum is applied. This produces a set of non-linear equations that can be solved for each blade section. The resulting values of section thrust and torque can be summed to predict the overall performance of the rotor.



3-1 blade section

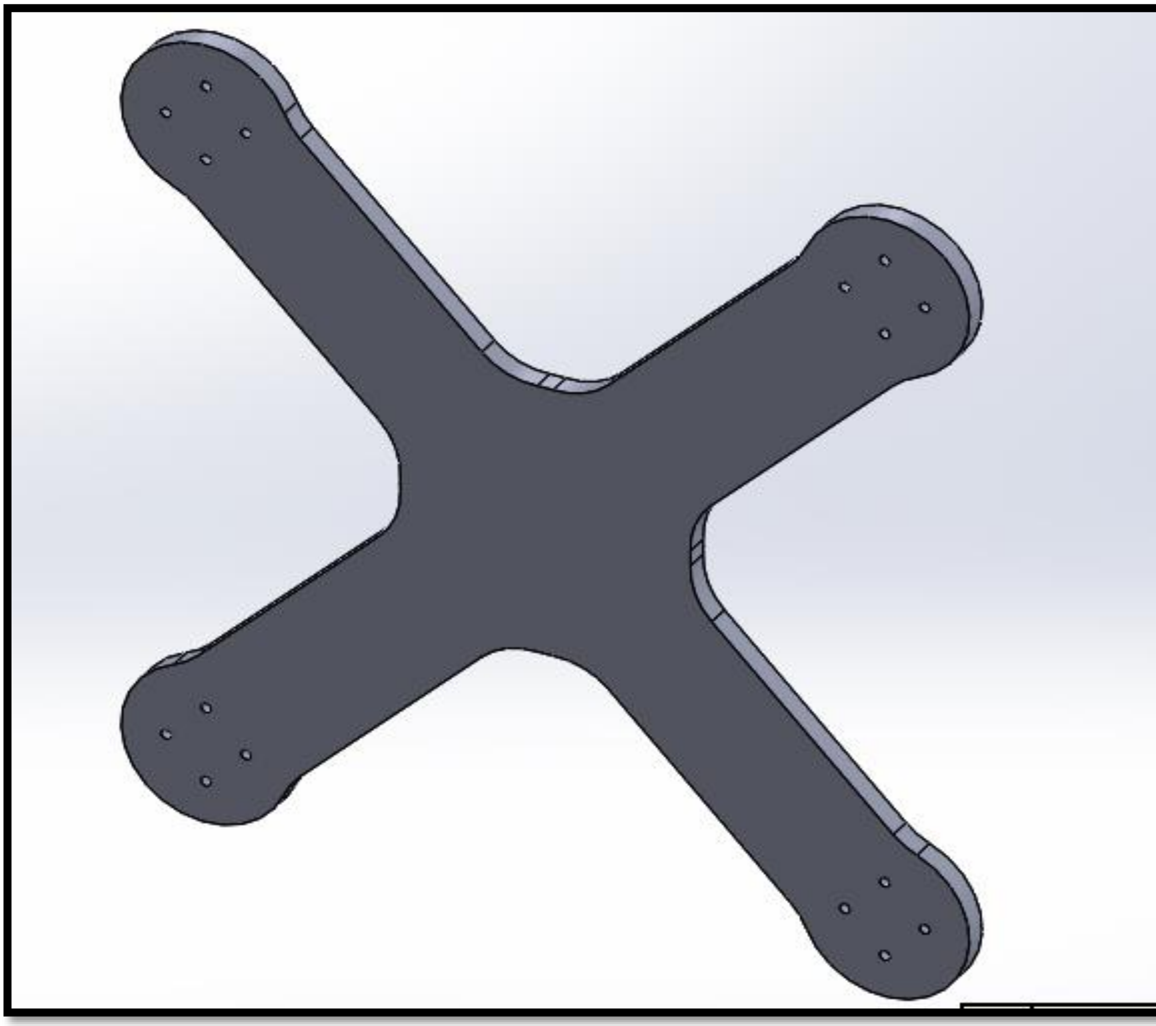
In comparison with real rotor results this theory will over-predict thrust and under-predict torque with a resulting increase in theoretical efficiency of 5% to 10% over measured performance.

The theory has been found very useful for comparative studies such as optimizing blade collective setting for a given cruise speed or in determining the optimum blade solidity for a rotor. Given the above limitations it is still the best tool available for getting good first order predictions of thrust, torque and efficiency for rotors under a large range of operating conditions.

3.2 Simulation

The base frame is designed with the aid of 3D mechanical design software named SolidWorks. SolidWorks develops efficient and quicker designs of mechanical products and components, facilitating the design tasks for the platform. This 3D software is chosen as the design and analyzing software over other mechanical design tools for the following.

Figure 3-2 and figure 3-3 shows the model of x frame and full quadrotor model



3-2 "X" frame shape

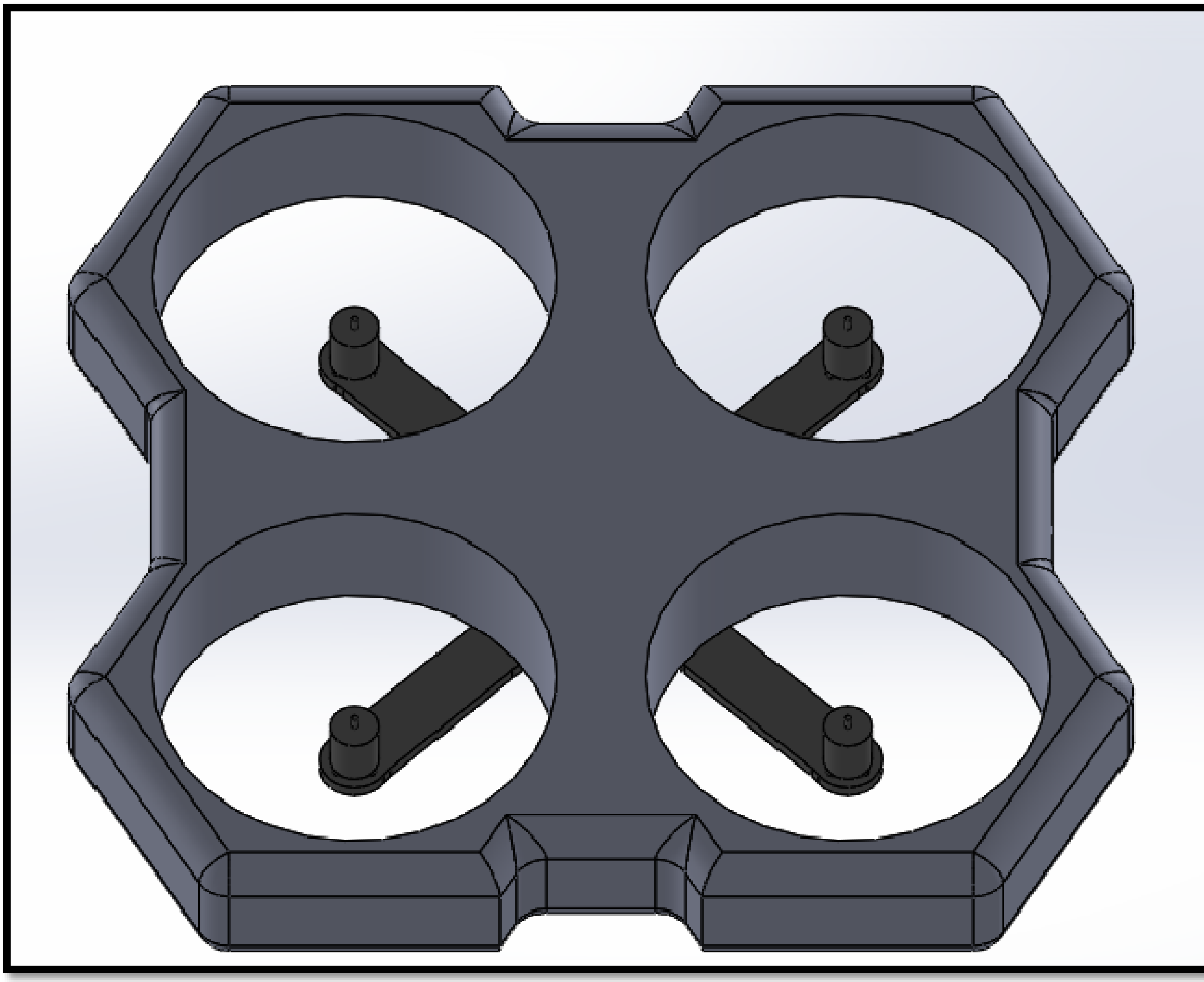


Figure 3-3 quad rotor model

3.2.1 Advantages

(1) In-built intelligence design tools increase design efficiency and minimize design error;

(2) Better visualization of the design with intuitive interaction with the 3D model;

(3) Easy one click creation of 2D drawing from 3D objects for fabricating and manufacturing;

(4) Weights, center of gravity (CG), moment of inertia and other geometric data can be obtained directly from the evaluation functions. The base frame is designed such that it is one piece frame, forming a symbolical cross shape of the quadrotor.

3.3 Analysis

The analysis was done by using ANSYS software to investigate that the carbon fiber structure is able to resist the total weight of the quad rotor, and the result shown in the figures below.

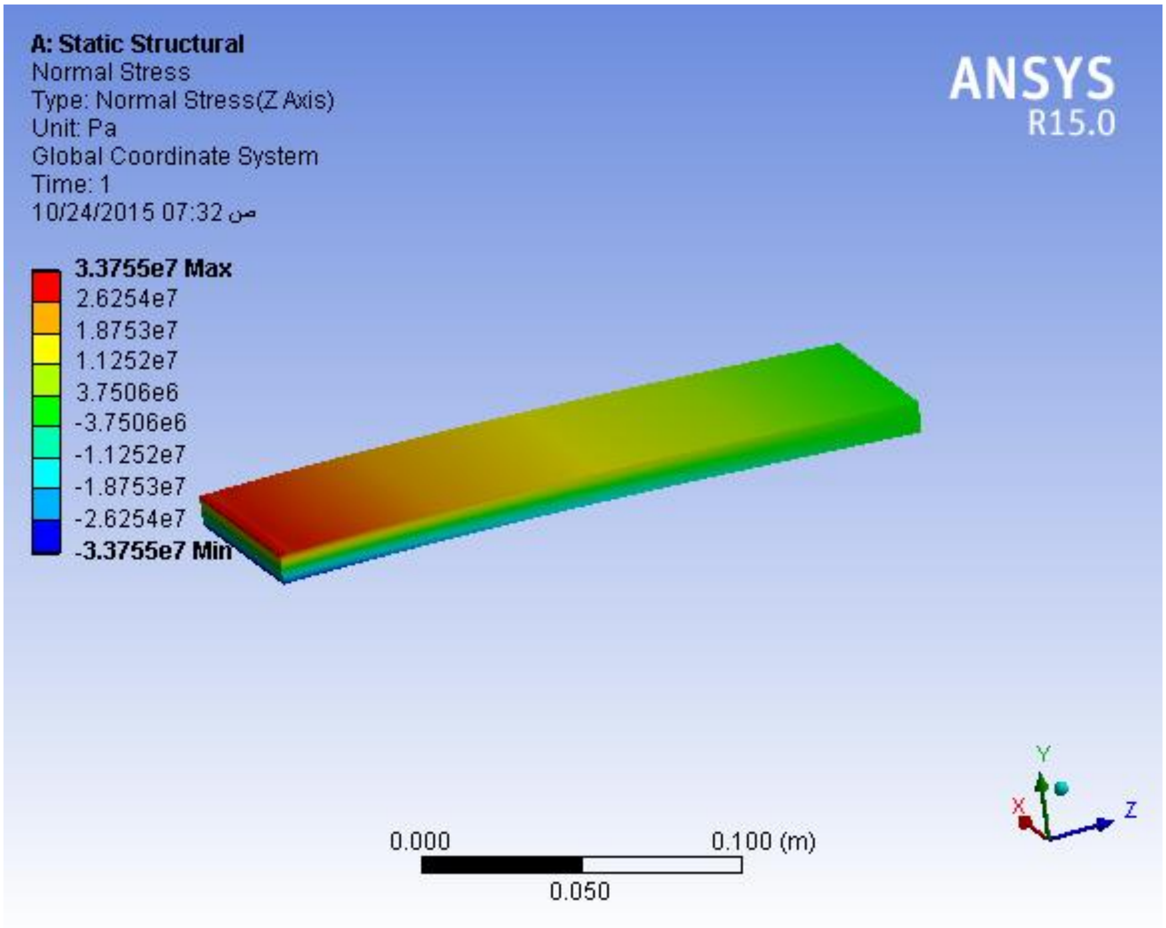


Figure 3-4 normal stress

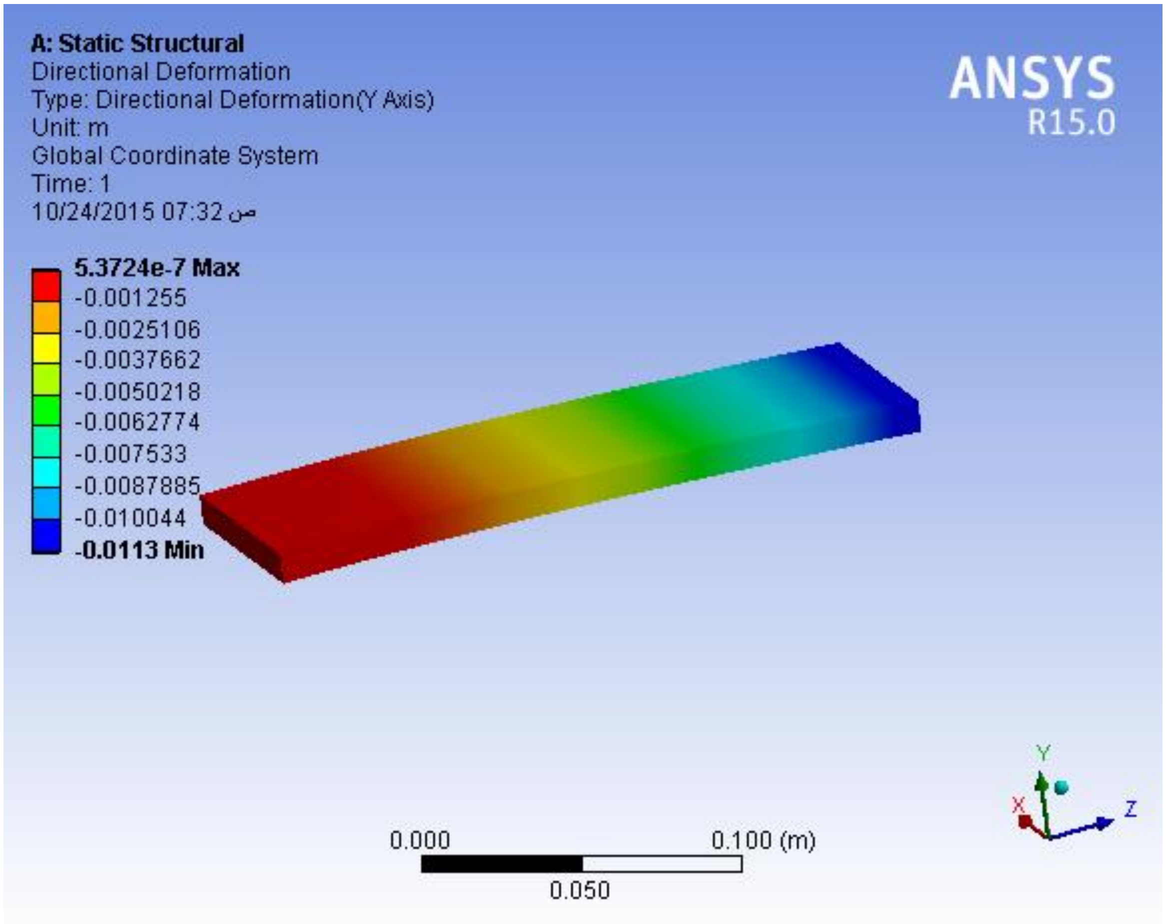


Figure 3-5 Directional deformation

Directional deformation

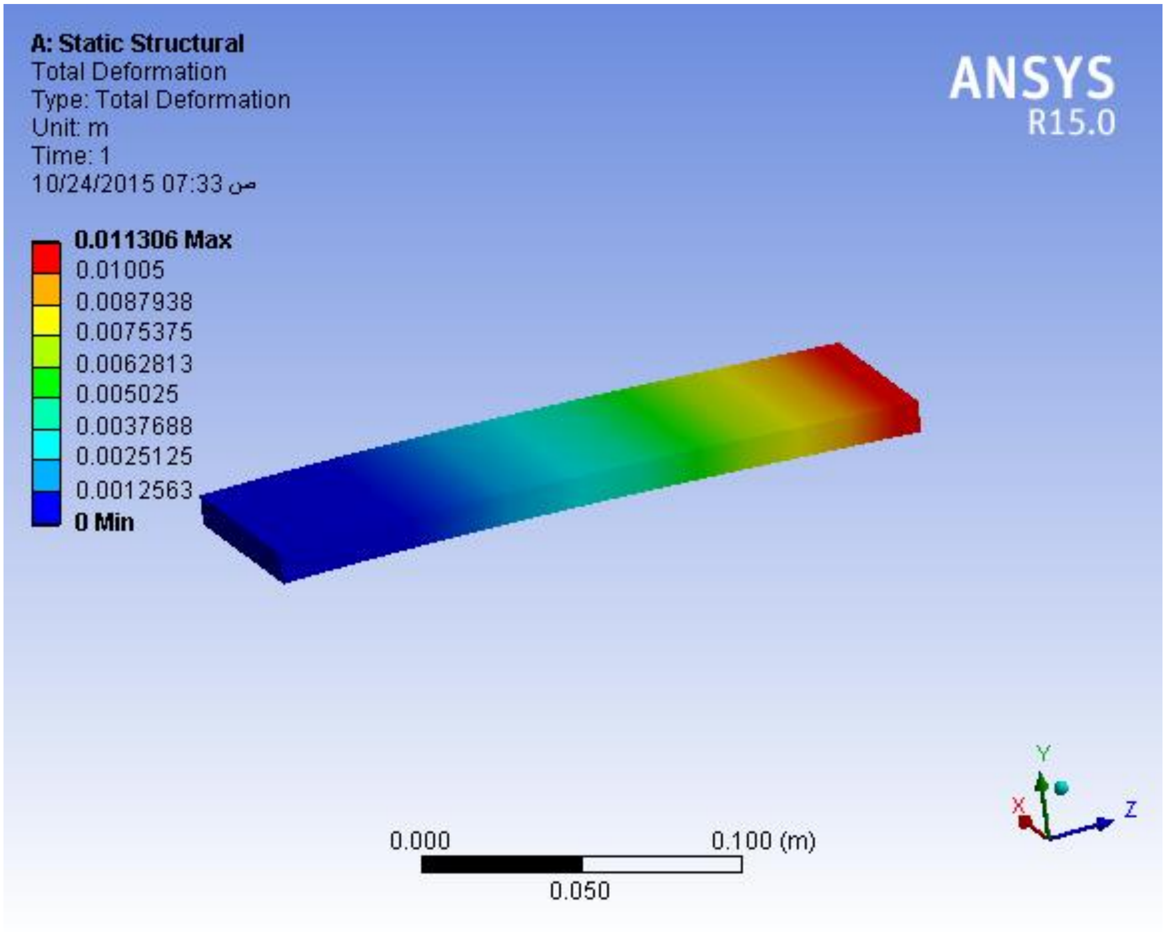


Figure 3-6 Total deformation

3.4 Frame and Material Selection

The frame is the structure that holds or houses all the components together. They are designed to be strong and lightweight. To decide the appropriate frame for the quadrotor three factors, i.e. weight, size and materials used are considered. The frame should be stiff and able to minimize the vibrations from the motors. It consists of 2-3 parts which are not necessarily of the same material: The center plate where the electronics are mounted Four arms mounted to the center plate Four motor brackets connecting the motors to the end of the arms Strong, "motor-to-motor distance" is sometimes used, meaning the distance between the center of one motor to that of another motor of the same arm. The motor to motor distance usually depends on the diameter of the propellers in order to have enough space between the propellers.

Also there is many type of frame shape, the most popular two shapes is "X" and "H" frame, An X frame of the same size tends to be lighter and stiffer than an H, giving marginally better flight characteristics.

When designing an autonomous quad-rotor, there are several material options which must be considered. Any design must consider different materials based on durability, machinability, and price. When dealing with a machine capable of flight, then one must consider weight a major factor.

The first materials was used in design is aluminum as shown in figure 3-7

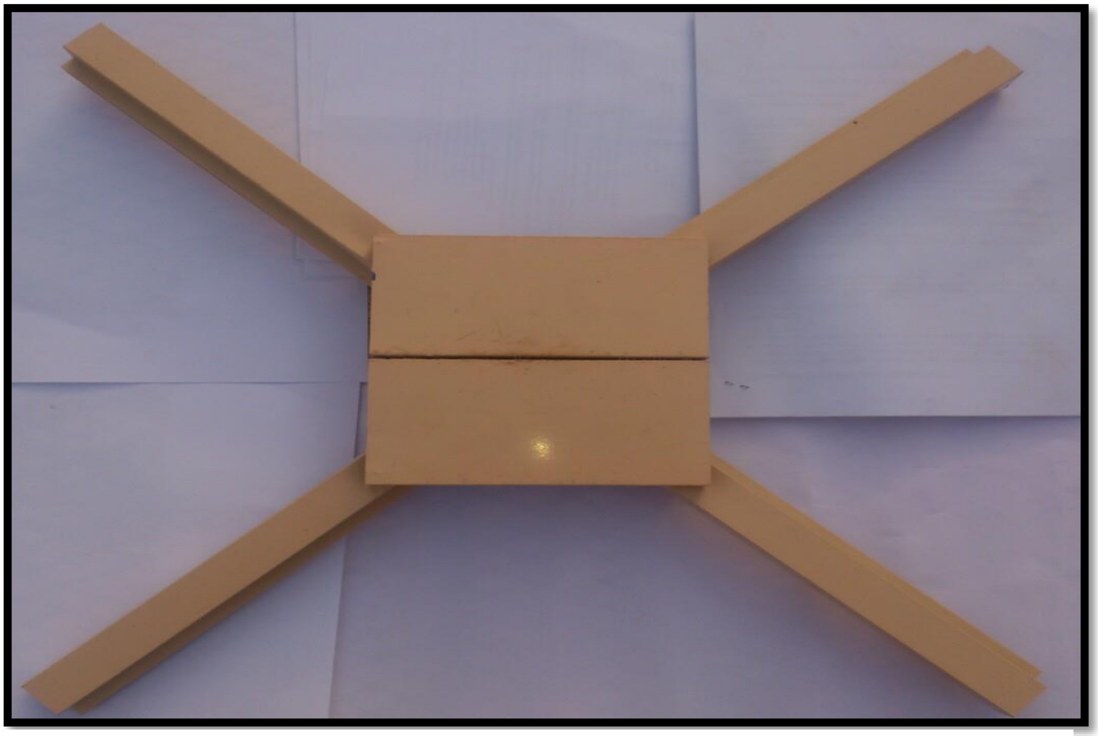


Figure 3-7 aluminum frame

Second wood and third fiber glass figure 3-8

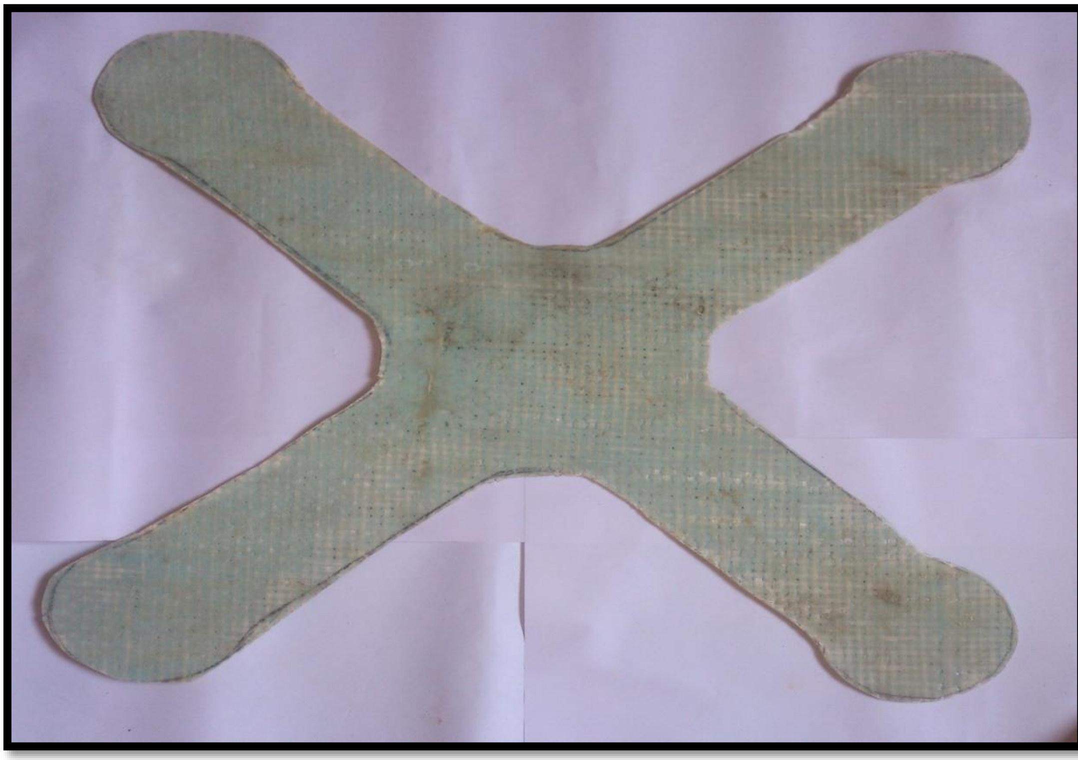


Figure 3-8: Fiber glass material with 3 layers

Last we used sandwich structure figure 3-9

Figure 3-9: Sandwich structure figure

Which consist of composed material carbon fiber, fiber glass and foam with cover from plastic cork to protect propellers from crash, reduce noise and increase thrust. Composites materials are made by combining two or more materials where one of the materials is reinforcement (fiber) and the other material is a matrix (resin). The combination of the fiber and matrix provide characteristics superior to either of the materials alone.

Composites structures (sandwich) that are made up of diverse elements, with the principle being that the sum of the whole is greater than the sum of its component parts.

Aluminum, historically, has been the material of choice for RC helicopters. Aluminum is light and strong, dissipates heat well, and is relatively inexpensive in comparison to some of the other possibilities. The negative for aluminum is that it tends to be too heavy for small aircraft models. Also, aluminum can develop cracks over time from vibrations.

wood is lighten than alum or carbon and no radio interference, it has a lower density and lower density means lower frequency waves will propagate through it easier, vice versa for the aluminum Unfortunately the wood is not a very rigid material and can break easily in quad copter crashes.

Fiber glass depends on the number of layers that used to manufacturing as it little it become flexible and we need to add more layers to be rigid enough to handle the weight of component and vibration that induce from motor and propellers, but this lead to increase in weight of frame so is not good for our project.

Carbon fiber however, will really vary on stiffness and thickness, because it's a inhomogeneous material and might have specific frequencies throughout the bandwidth that can propagate, depending arm length that can completely damping vibration, but given the law of conservation energy, might weaken the arm over time by internally breaking the carbon stands. Carbon Fiber is currently the best material available for RC helicopters. It is stronger and lighter than aluminum and absorbs vibration better. It can be molded to be super stiff in one direction and flexible in the other. But, it is also much more expansive than other materials. Also, it is difficult to machine so it would require an outside source to manufacture the required parts.

The table 3-1 shows the Mechanical Properties of Carbon Fiber, Fiber Glass and aluminum.

Table 3-1: Mechanical Properties

Materials	Longitudinal Modulus (G pa)	Tensile Strength (M pa)	Poisons ratio ν	Density (g/cm^3)
Carbon Fiber	220	760	0.74	1.7
Fiber Glass	12.3	90	0.53	1.9
Aluminum 7075	71	572	0.32	2.80

So to get the best properties for each material we use composed material (sandwich structure) which consist of carbon fiber as reinforce material with foam figure 3-10

Figure 3-10: sample of foam material

and fiberglass as matrix this in turn gives us the more stiff material that can handle the structure and more absorbent to vibration with less weight and low cost and for safety major we cover the structure using plastic cork also it can increase the lift from propeller which act to guide the air flow, the cover cutting and shape by hot wire this device is shown in figure 3-11 and figure 3-12 shows the plastic cover.

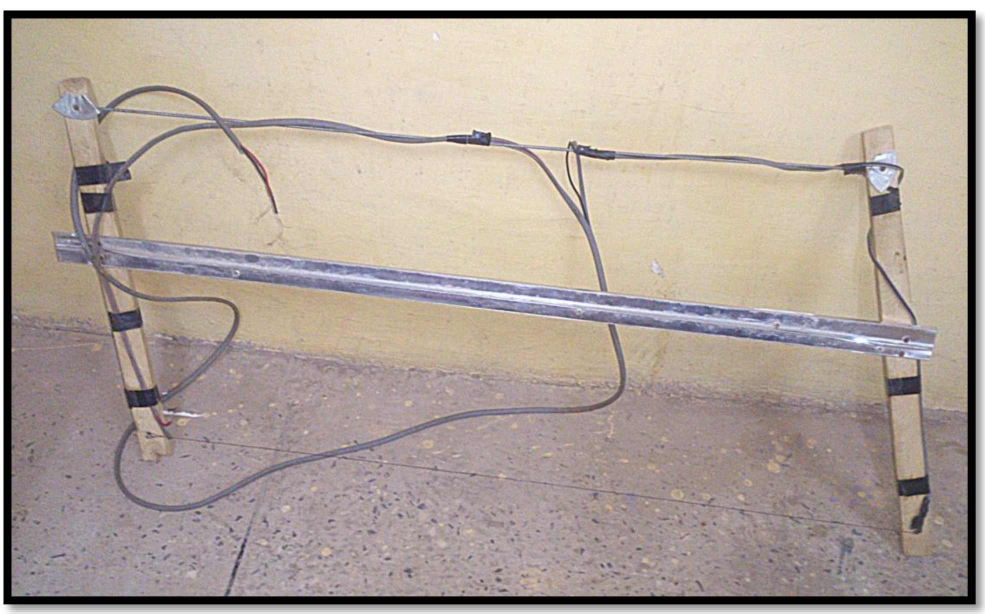


Figure 3-11: show the device use for shape the cover

Figure 3-12: cover for quadrotor

3.4.1 Quad Rotor Balancing

The quad rotor, which includes the hub, spars, and motor mounts, was carefully designed and assembled with the idea of having a helicopter which is as close to perfect in terms of its weight distribution throughout the entire aircraft. Achieving a steady and controllable flight is almost impossible to achieve unless the aircraft is as close to perfect balance. The addition of the electronic components and battery onto the frame of the quad rotor leaves its weight distribution inconsistent throughout. As a result, the group has devised a way to make sure that the frame is as balanced as possible. The way to do this is by attaching a piece of string to the center of the hub and allowing the quad rotor to float freely. If the weight is not evenly distributed, then the quad rotor will lean towards the heaviest part. The battery packs, which are mounted below the central, were then adjusted to ensure the quadrotor was balanced in the x and y axes.

3.5 Battery

Quadrotor typically uses LiPo batteries which come in a variety of sizes and configuration. We typically use 3 S1P batteries, which indicate 3 cells in parallel. Each cell is 3.7 volts, so this battery is rated at 11.1 volts. LiPo batteries also have a C rating and a power rating in mAh (which stands for milliamps per hour). The C rating describes the rate at which power can be drawn from the battery, and the power rating describes how much power the battery can supply. Larger batteries weigh more so there is always a tradeoff between flight duration and total weight. A general rule of thumb is that doubling the battery power will get you 50% more flight time, assuming your Quadrotor can lift the additional weight. For this Quadrotor[10], we choice the LiPo batteries 3S 11.1V 2600MAH 30C packs as shown in figure 3-13.

Figure 3-13: LiPo batteries 3S 11.1V 2600MAH 30C packs

This battery has higher power with lower weight; Lower IR; Can be charged with 5C when time is limited,1-2C is strongly advise for longer life cycle; Longer life cycle up to 200times under proper usage.

The table 3-2 shows the specification for LiPo batteries 3S 11.1V 2600MAH 30C packs

Table 3-2 LiPo batteries 3S 11.1V 2600MAH 30C packs

Capacity	2600mAh
Configuration	3S1P
Dimensions	116X34X26mm
Weight	200g
Constant Discharge	30C
Burst Discharge	60C
Balance connector	JST-XHR
Discharge plug	T plug
Use	Vehicles & Remote Control Toys
Material	EVA

3.6 Control board

The flight control board is the 'brain' of the quadrotor. It houses the sensors such as gyroscopes and accelerometers that determine how fast each of the quadrotor's motors spin. Flight control boards range from simple to highly complex. We use KK 2.1 Multi-Rotor Control Board figure 3-14 It is affordable, easy to set up, and has strong functionality The KK2.1 Multi-Rotor controller manages the flight of mostly multi-rotor Aircraft (Tricopters, Quadcopters, Hexcopters etc). Its purpose is to stabilize the aircraft during flight and to do this, it takes signals from on-board gyroscopes (roll, pitch and yaw) and passes these signals to the Atmega324PA processor, which in-turn processes signals according the users selected firmware (e.g. Quadrotor) and passes the control signals to the installed Electronic Speed Controllers (ESCs) and the combination of these signals instructs the ESCs to make fine adjustments to the motors rotational speeds which in-turn stabilizes the craft.

The KK2.1 Multi-Rotor control board also uses signals from your radio system via a receiver (Rx) and passes these signals together with stabilization signals to the Atmega324PA IC via the aileron; elevator; throttle and rudder user demand inputs. Once processed, this information is sent to the ESCs which in turn adjust the rotational speed of each motor to control flight orientation (up, down, backwards, forwards, left, right, yaw)[11].

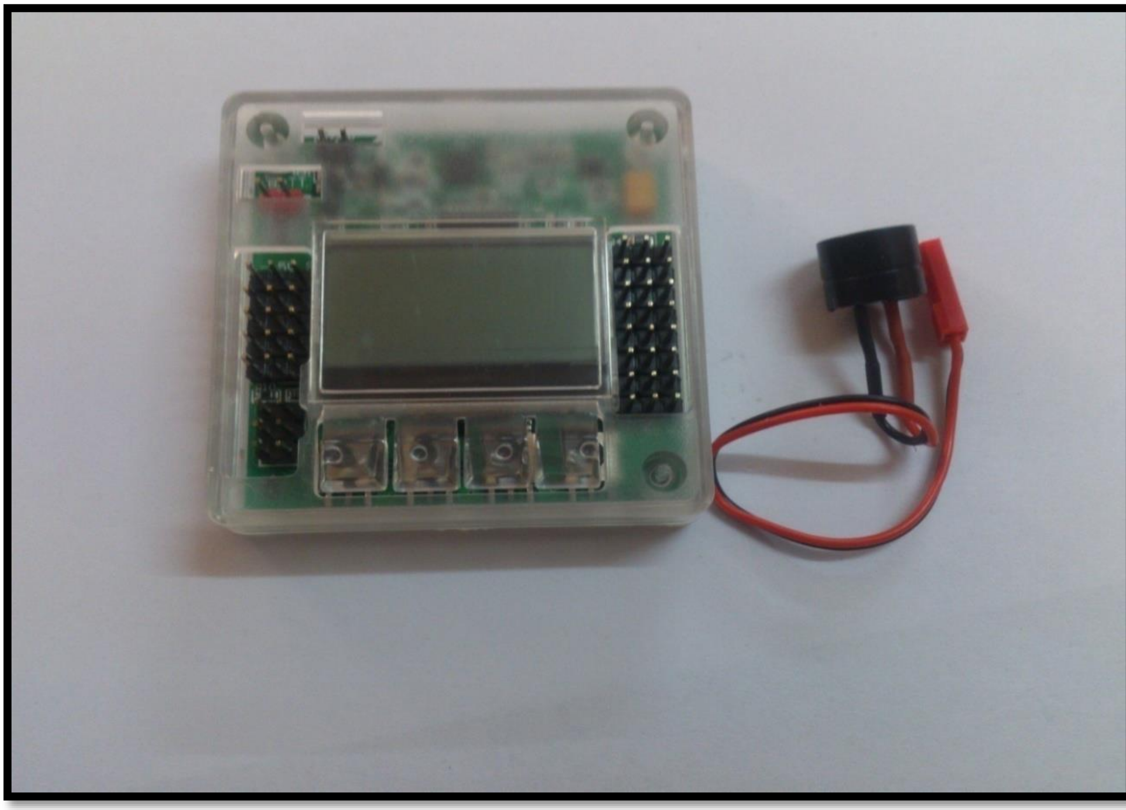


Figure 3-14: KK2.1 Multi-Rotor control board

3.7 Propellers

Propeller is a set of rotating blades design to convert the power (torque) of the engine in to thrust.

As the propeller rotate is produce forward thrust by giving a small forward acceleration to large mass of air.

Propellers are specified by their diameter and pitch. The diameter is measured length of the propeller and the pitch is how far the propeller will advanced in one revolution.

The quadrotor consists of four propellers coupled to the brushless motor. Among these four propellers, two clockwise and the remaining other two are counter clockwise. They are divided in pusher propellers and tractor propellers. Pusher propellers rotate clockwise and tractor propellers rotate anti clockwise to canceling their torque from each other.

3.7.1 Propellers selection

The primary purpose of propeller is to convert the engine power to axial thrust by torque transfer to the propeller, in order to push air it must be able to capture the air. If the blade not twisted they will not capture any air, so the twist is very important to the capturing the air and produced thrust. The blade cross-section has an airfoil shape to maximize the left and minimize drag.

Generally, increased propeller pitch and length will draw more current but produced more thrust, when deciding on length and pitch we need to find a good balance between the aircraft and propeller. a prop with low pitch can generate more torque and the motors don't need to work as hard so it pulls less current with this type of prop. Lower pitch propellers will also improve stability, a higher pitch propeller moves greater amount of air, which could create turbulence and cause the aircraft to wobble during hovering.

When it comes to the length, propeller efficiency is closely related to the contact area of a prop with air, so a small increase in prop length will increase the propeller efficiency.

A smaller prop is easier to stop or speed up while a larger prop takes longer to change speeds (inertia of movement).

$I = M/\Omega$ … (3.9)

Moment of inertia I is defined as the ratio of the angular momentum M of a system to its angular velocity Ω around a principal axis smaller prop also means it draws less current.

3.7.2 Propeller materials

When choosing multi-copter props, not only we need to consider the size and pitch but also need to choose the type of material.

There are a few different types of propellers materials like carbon fiber, nylon, fiber glass reinforced, wooden props and composed materials etc, which affect flight performance, Good props can improve helicopter's control-ability and increase the battery life.

3.7.3 Carbon Fiber Propellers

Carbon fiber props are almost twice as expensive as the common plastic props, and it's promoted to have better performance than the cheap plastic ones, also produce less vibration due to its stiffness, and it sounds quieter too when spinning, They are lighter and significantly stronger than plastic when crashed, but not indestructible though, Perform well under high RPM (work well with high KV motors),Light weight props means less inertia, thus faster motor speed change, and the control feels more responsive.

3.7.4 Wooden Propellers

Wood props are popular either in the multi-rotor world, since it’s inexpensive, but it’s heavy. And heavier weight lead to an increase in rotation momentum then wood propellers became less responsive to changes in motor speed.

3.7.5 Propeller Balance

Due to the fact that the propellers are operating at such a high RPM, it is crucial to the quad rotors performance that the propellers are balanced. Although theoretically the propellers are designed to have symmetric blades, in reality there are slight imperfections. These imperfections cause the propellers to vibrate uncontrollably, making smooth flight almost impossible. By balancing the propellers, vibrations can be significantly reduced.

The group balanced the propellers by examining the relative weight distribution of each propeller. There are several types of commercially available propeller balancing devices, but a similarly effective device was made. The method used attaching the propeller's center, allowing the propellers to rotate freely. If one of the blades is heavier than the other, the propeller will rotate towards the heavier blade figure 3-15 showing the method used for balancing propeller.

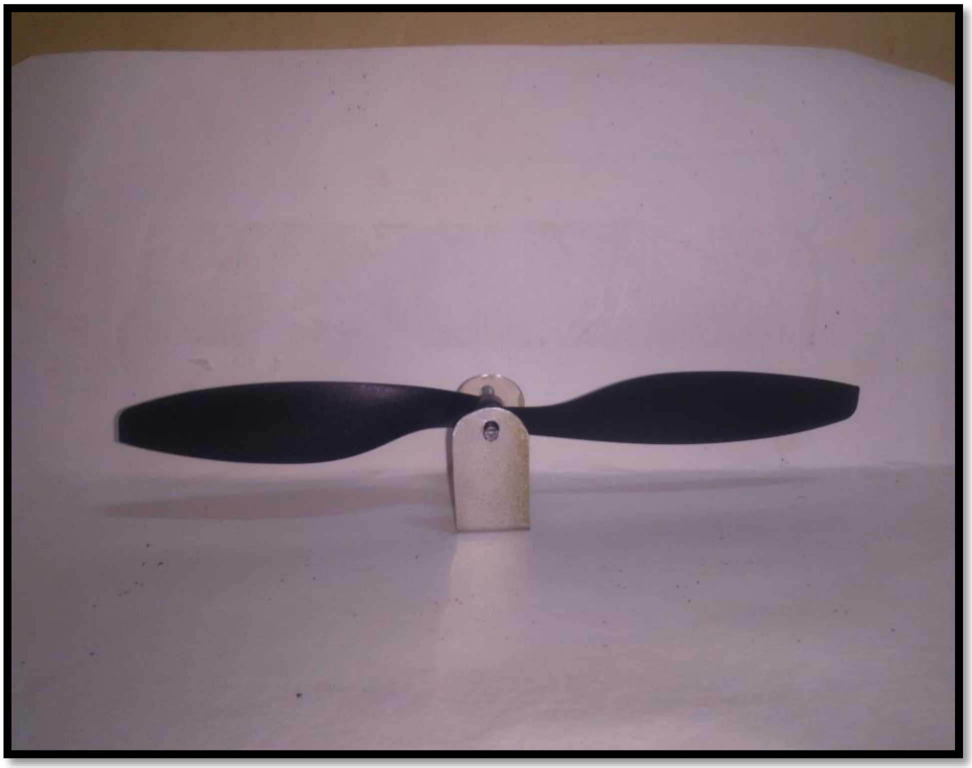


Figure 3-15: show how to balance the propeller

3.7.6 Propeller Model

The propeller we used is fixed-pitch, symmetric, tapered Normal Rotation Carbon Filled Propeller, is a High-Strength prop which made from Nylon with Carbon Fiber that will not deform under load. These props are about 10 times stiffer than the standard from nylon as shown in Figure 3-16.

Figure 3-16: show The Propellers types

3.7.7 Rotor aerodynamics

The rotor aerodynamic was simulated using the JavaProp© software package to establish the performance characteristics of the rotor. This was necessary to determine the efficiency of the rotors and possible payload capacities.

There are five aerodynamic influences which act on a rotor figure 3-17. The first is called ground effect. This refers to the variation of the thrust coefficient when the rotor is in close proximity to the ground. The second influential aerodynamic force occurs as a result of horizontal forces acting on all the blade elements, known as the hub force, and the third influence, referred to as rolling moment, is the combined moment due to the lift at each point along the radius of the rotor, The most important influences is thrust T and drag moment Q [12].

The blade used in the rotors is fixed pitch, signifying that the pitch angle β, sometimes referred to as the blade angle, remains fixed.

Propeller geometry can be complex, where the chord length c and airfoil profiles vary along the length of the blade. The pitch angle determines the pitch of the propeller p.

$p = 2\pi r tan\beta$ … (3.10)

Where r is the distance along the blade where the specific pitch angle exists. Because of the variation that exists, a ratio is commonly used known as the pitch diameter ratio

$^{p}/_{d} = \pi$xtanβ … (3.11)

Where *D* is the diameter of the propeller and *x* is the relative radios of the blade section and may be represented as,

$x = \frac{r}{R}$ … (3.12)

Because of the variation of *β* and *c* throughout the length of the radius, the angle of attack *α* is also varied to conduct an effective analysis of a propeller of this type, momentum-blade element

Theory should be used and the blade should be analyzed in sections across its radius and then integrated to determine the overall performance and characteristics.

The velocity *VE* is the induced air velocity and enters the blade at an angle *α* to the zero lift line. The velocity *V* is the advance velocity of the propeller and the velocity *ωr* is the velocity due to rotation. The angle *Φ* is the angle of resultant flow. The dimensionless co-efficient of lift *CL* is dependent on angles *α, β* and *Φ* and the co-efficient of drag *CD* is a function of *CL* and Mach and Reynolds numbers. The lift *dL* generated is always orthogonal to the line of zero lift. The thrust *dT*, which is the effective upward force Perpendicular to the plane of rotation, is a component of *dL* The drag *dD* is the force acting adjacent to the airfoil.

The local lift and drag may be expressed as,

$dL = \frac{1}{2}\ \rho\, V_E cCLdr$… (3.13)

$dD = \frac{1}{2}\ \rho\, V_E cCDdr$ … (3.14)

Where, *ρ* is the density of air. Vortex theory was analyzed to determine the thrust and drag moment. In the same manner in which a wing works, the aerodynamic lift on propeller blade can be related to a bound circulation *Γ* around the blade, this circulation may be expressed as

$\Gamma = \frac{1}{2} cC_L V_E$ … (3.15)

Using circulation changing the local thrust and drag moment are,

$dT = \rho(\Omega - \omega) r d\Gamma$… (3.16)

$dQ = \rho(V - v)$ … (3.17)

Where, P and V are the global rotational and advance velocities respectively. From this, the local efficiency of the propeller can be found,

$$\eta = \frac{\boldsymbol{VdT}}{\Omega dQ} \ldots (3.18)$$

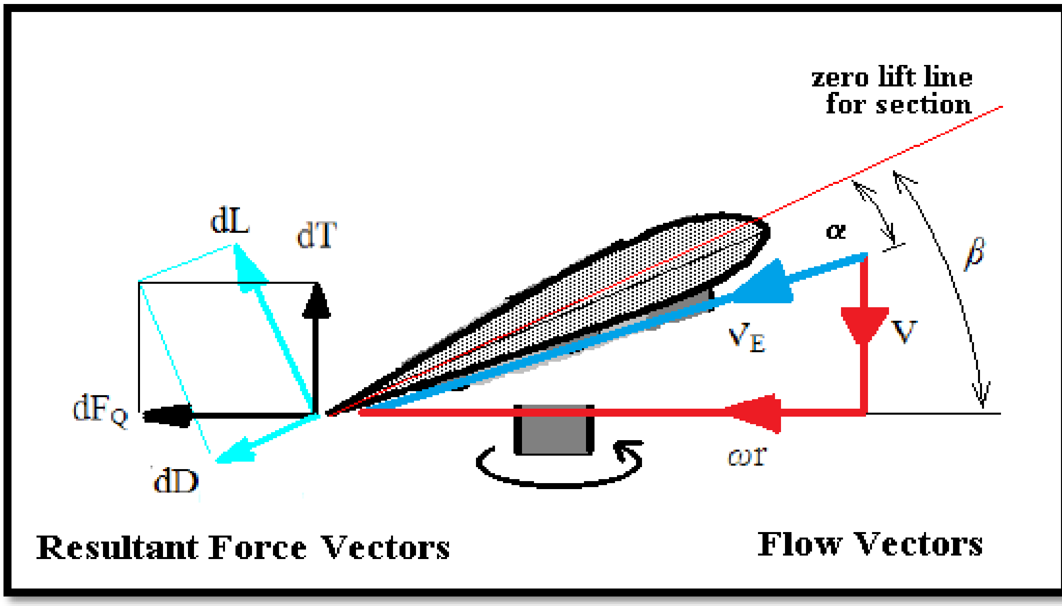


Figure 3-17: rotor aerodynamic

To determine the overall efficiency of the propeller, a ratio of the product of the thrust and advance velocity and the power P must be found,

$$L = \propto \rho n^2 D^4 \ldots (3.19)$$

$$P = \beta \rho n^3 D^5 \ldots (3.20)$$

Where the D is refer to rotor diameter and not drag and $\beta, \propto$ is power coefficient and Lift coefficient respectively and the propeller efficiency represented as,

$$\eta_p = \frac{L\,V}{P} \ldots (3.21)$$

The velocity ratio in this expression is known as the advance ratioλ,

$$\lambda = \frac{V}{nD} \dots (3.22)$$

A numerical simulation was conducted based on the above theory using the Javaprop software package .The first investigation conducted was the thrust and drag moment properties of the rotor. These results are shown in Figure 3-18 and figure 3-19

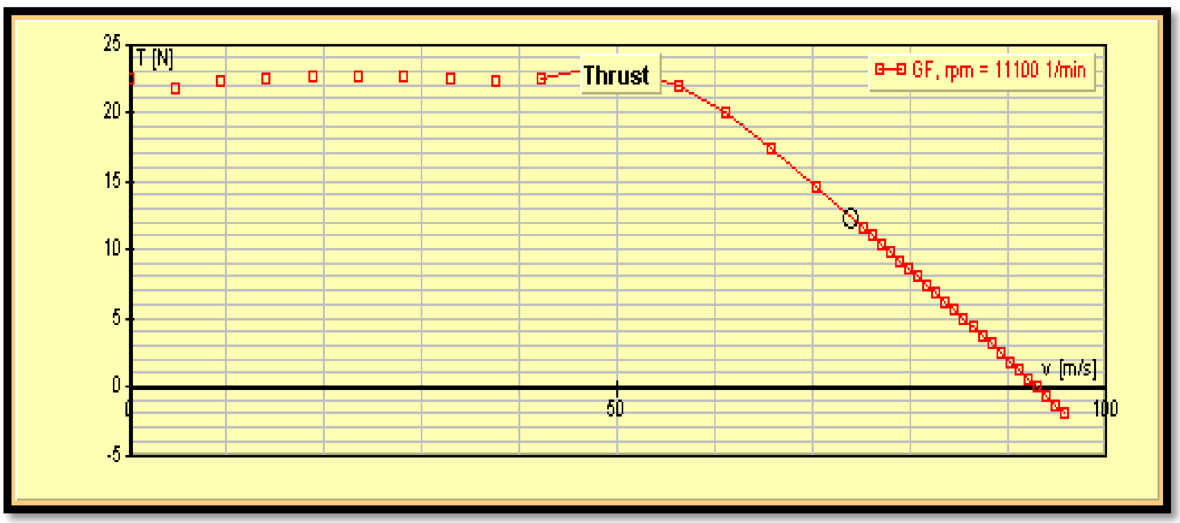


Figure 3-18: Graph of thrust VS rotor speed

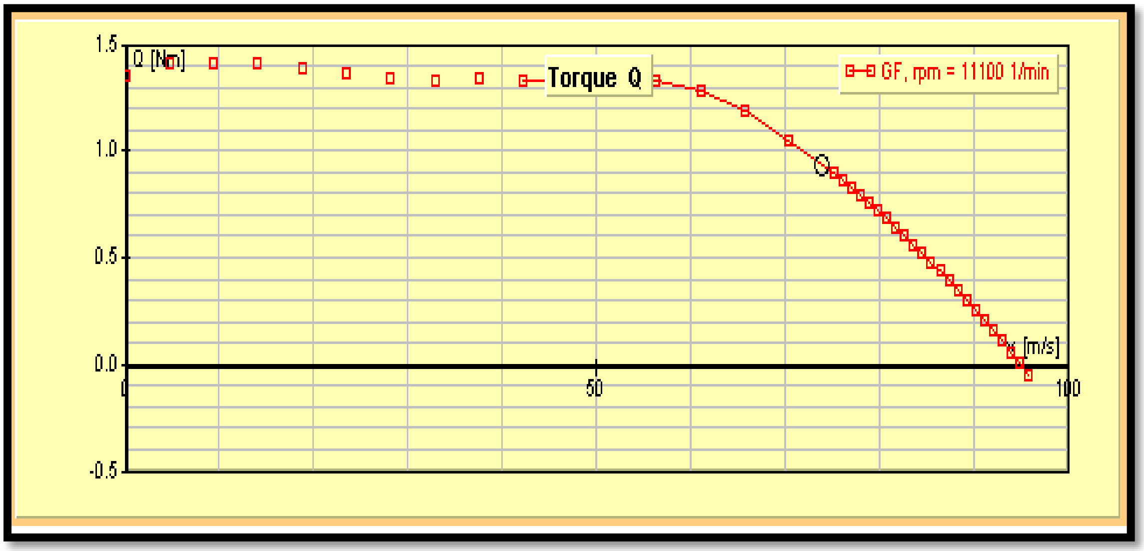


Figure 3-19: Graph of torque VS rotor speed

The coefficient of lift and drag was also investigated at all the length of the propeller blade. Figure 3-20 plot the variation of the C_l, C_d against the relative radius of the propeller.

The aerodynamics properties of the propeller were investigated. The thrust and power coefficient are represent if figure 3-21. And the changing of these properties along the length of the propeller was shown in figure 3-22. The figure 3.23 shows that the overall efficiency against the advance ratio and another plot of η^* it's for efficiency of optimal propeller.

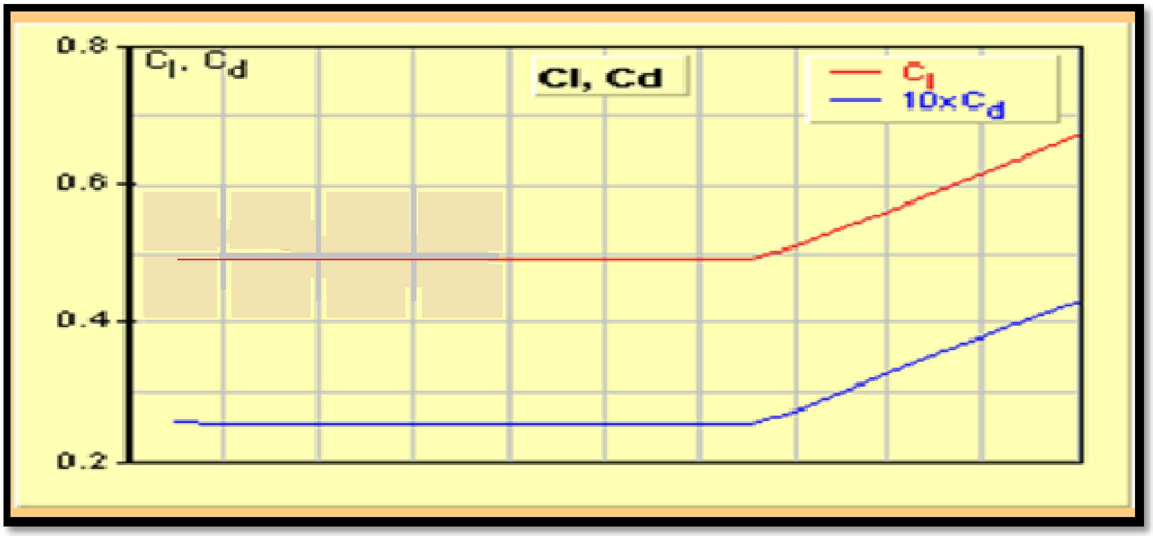


Figure 3-20: Graph of *CL* and *CD* VS relative radius

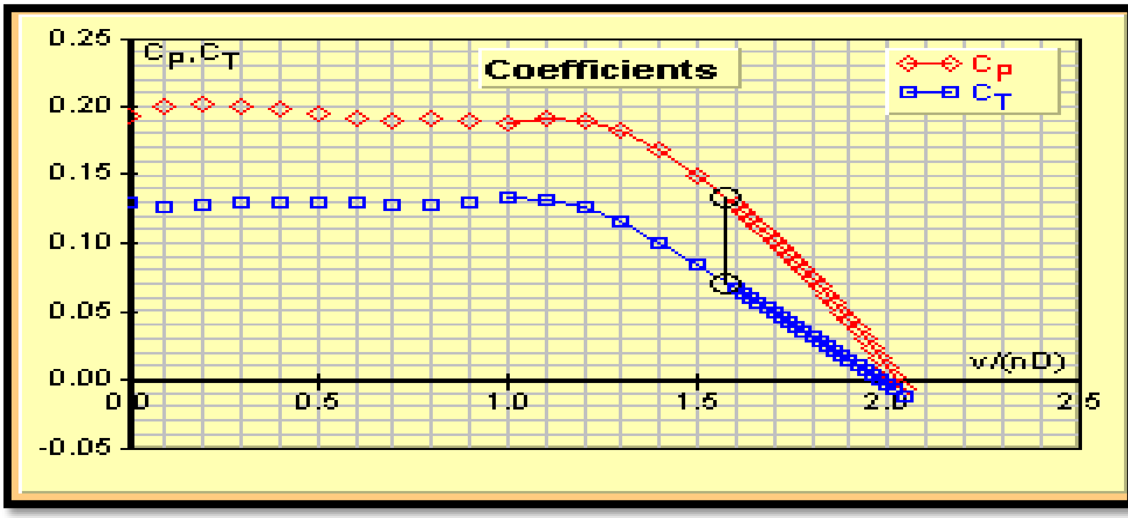


Figure 3-21 Graph of CP and CT VS advance ratio

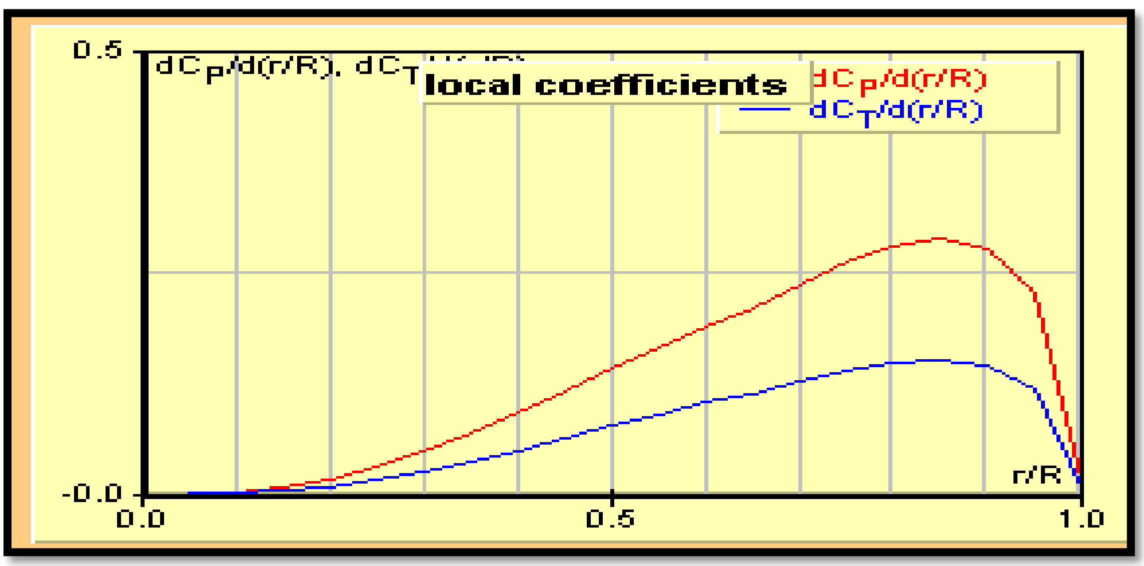


Figure 3-22 Change in CP and CT over the length of the Propeller blade

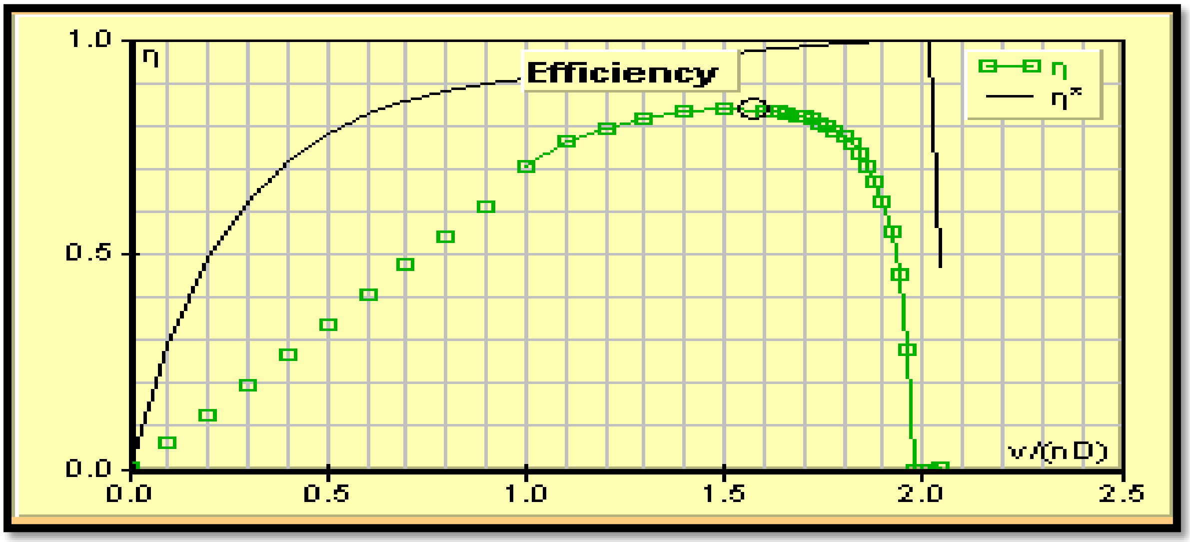


Figure 3-23 Graph of efficiency VS advance ratio

Figure 3-25 figure 3-26 illustrate the coefficient of shear force and bending moment along the blade. The last investigation is about the flow field as shown in figure 3-28 from the analysis can find that the performance of propeller is good.

The local and overall efficiency in figure 3-23 and figure 3-24 are about 82.7% and 84.62% respectively the pitch angle of the propeller was designed for best performance in cruise.

Figure 3-21 shows that the maximum thrust and power coefficient occurs at low advance ratio, it is good to know that the thrust is approximately const at low advance ratio.

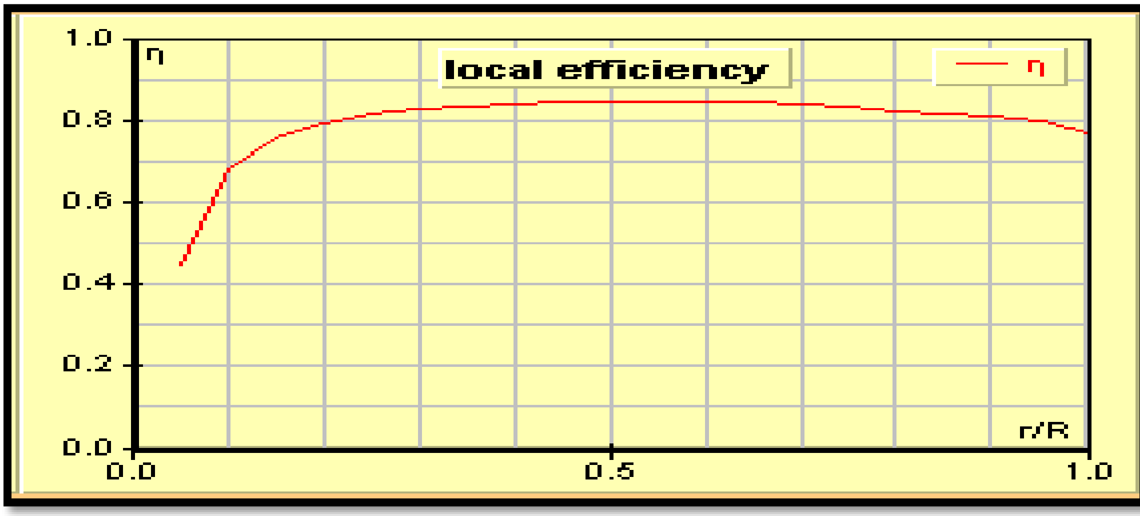


Figure 3-24 Graph of local efficiency VS relative radius

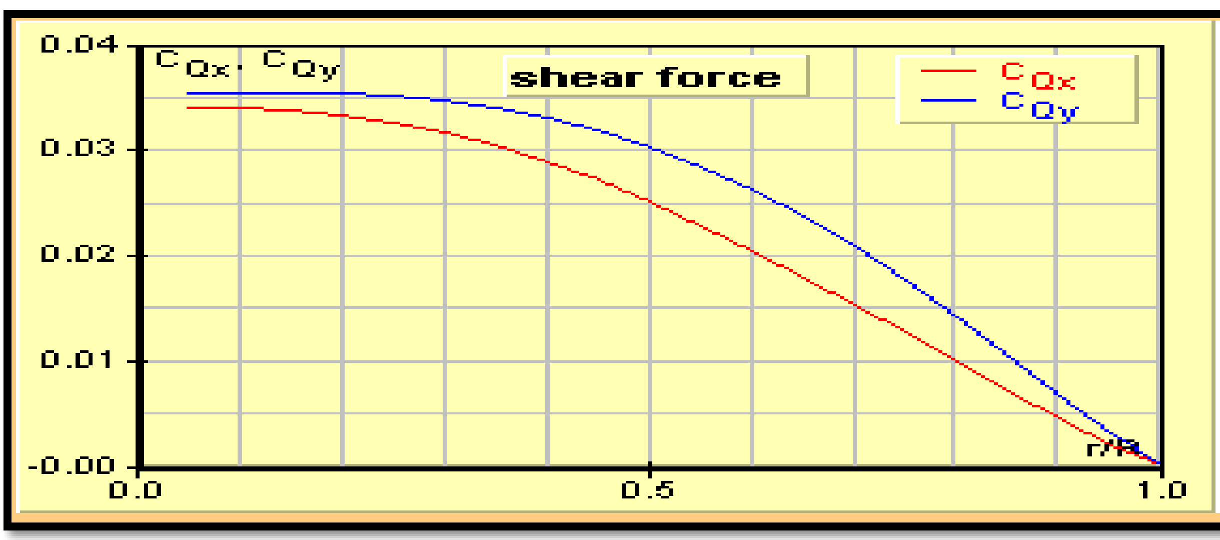


Figure 3-25 Graph of co-efficient of shear force VS relative radius

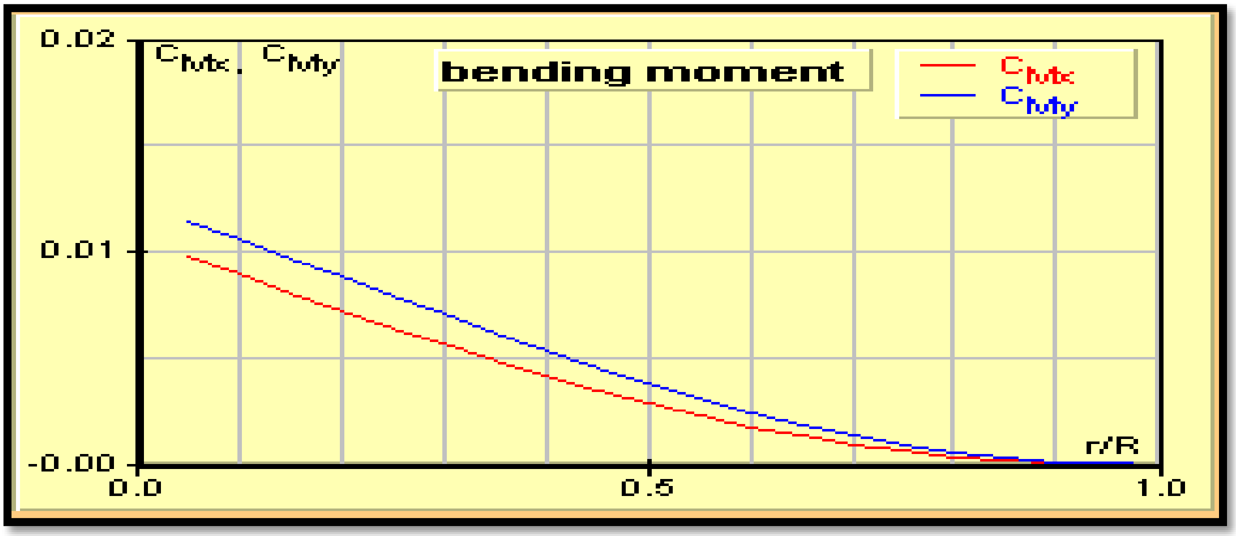


Figure 3-26 Graph of bending moment co-efficient VS relative radius

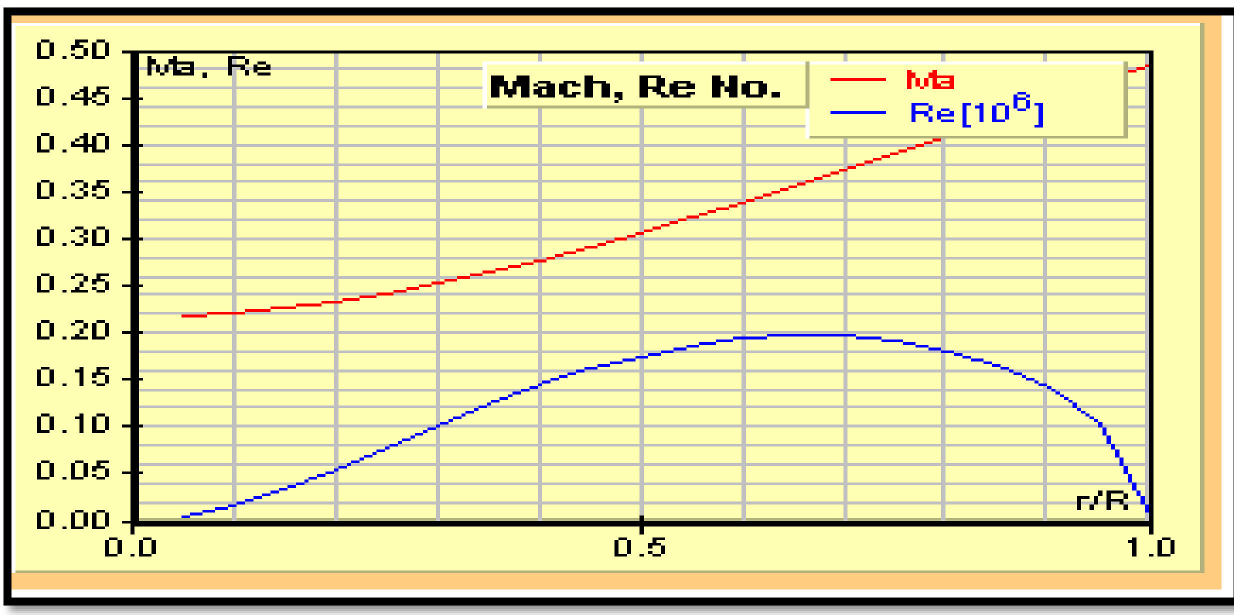


Figure 3-27 Graph Mach, Rey numbers VS relative radius

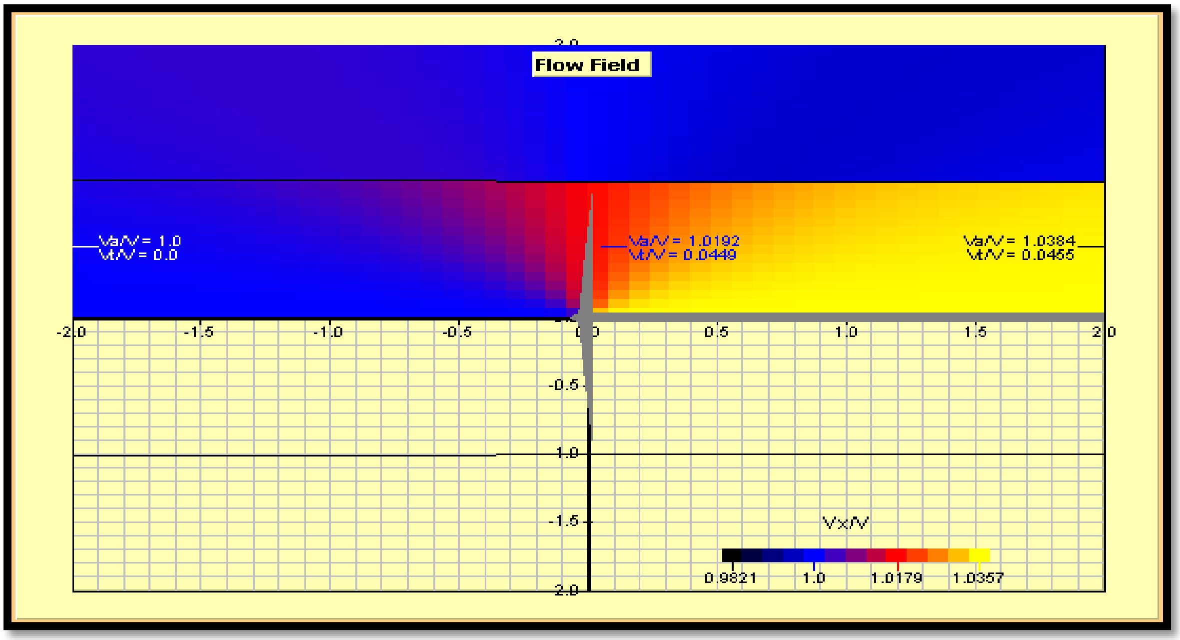


Figure 3-28 Flow field of the propeller

From figure 3-16 implies that the propeller which has diameter 10 in, and pitch 4.5 in and powered by motor with 1000KV will be approximate capable of producing the sufficient thrust and the loading along the propeller blade shown in figure 3-18 and figure 3-19 correlate with coefficient of lift and drag. The velocity of stream increase in the flow field diagram in figure 3-28 is not correlates with that was expected typical airflow through the propeller. The flow field must be convergent due to increasing in air stream velocity and to solve this problem using ducted propeller became important for satisfying the required thrust.

3.7.8 Ducted propeller

The use of ducted propeller as main propulsion units on A/C has been investigated since the end of world war II . Because theoretically a ducted propeller is more efficient in hover than a free propeller it is desirable for vertical takeoff and landing (VTOL). However losses involving friction and boundary separation decrease the efficiency gain, And the weight of the ducted often lead the using of duct was un- useful. This problem can be solved using strong light composite materials.

A method of designing a ducted propeller blade was investigated and developed to maximize the thrusting efficiency for the quadrotor by using cover from cark plastic which acts as duct for the propellers as shown in figure 3-29 [13]

3.7.9 Discussion

The duct was affected on the propeller by twofold: first inducing and increment of velocity and the second is negating tip effect if the gap between the inner wall and the propeller tip is very small.

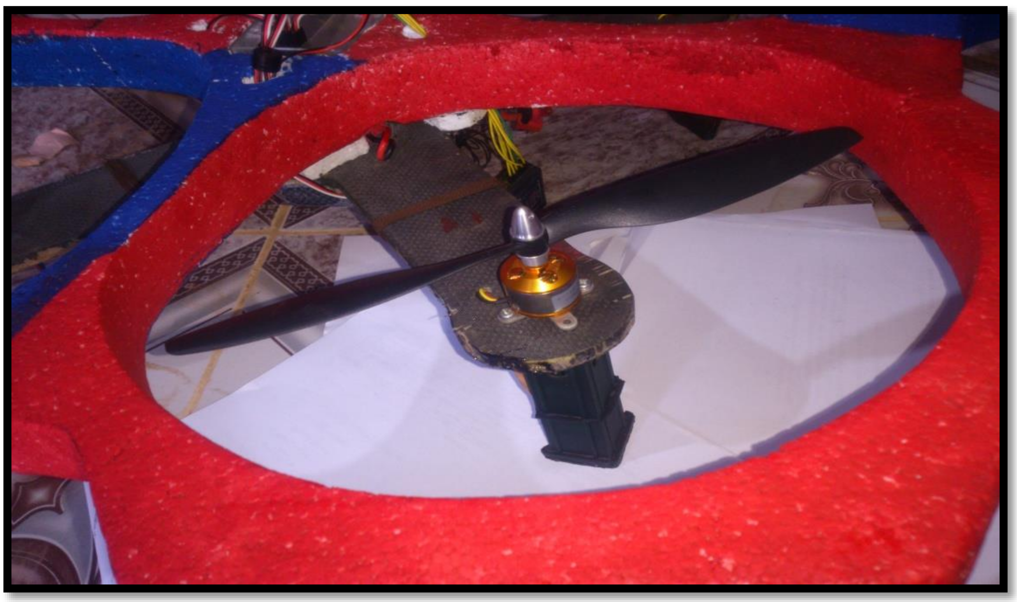


Figure3-29 Ducted propeller

3.8 Motors

Michael Faraday, a scientist and experimenter, was the first to conceive a device which would turn electrical into mechanical energy. Today, this device comes in two varieties, AC or brushless, and DC or brushed. The principal concern in motor selection was power output versus motor weight, as any weight added would require power expenditure to keep it aloft, with a secondary desire for reliable and long-term performance. A majority of quadrotor utilize brushless motors due to their high power output to weight ratio. However, driving brushless motors requires an increase in design complexity due to electrical commutation (multiphase) requirements.

In the case of the brushless quadrotor this driving circuitry is taken care of through the use of ESC modules which can variably drive each motor's speed independently.

Most electric motors operate through interacting magnetic fields and current-carrying conductors to generate force, although electrostatic motors use electrostatic forces. Here brushless motors are used these are synchronous electric motors powered by direct-current (DC) electricity and having electronic commutation systems, rather than mechanical commentators' and brushes.

3.8.1 Basic concepts when selecting Motors

First need to know how much weight you are planning to take and the thrust required to lift the quadrotor, the general rule is that you should be able to provide twice as much thrust than the weight of the quadrotor.

If the thrust provided by the motors are too little, the quadrotor will not respond well to your control, even has difficulties to take off, But if the thrust is too much, the quadrotor might become too agile and hard to control.

3.8.2 Brushless DC

Brushless DC motors consist of a permanent magnet rotor with a three-phase stator winding. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated. Typically three Hall sensors are used to detect the rotor position and commutation is based on these sensor inputs. Brushless DC (BLDC) motors are rapidly gaining popularity. They are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft. Though the brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and that's why they are called brushless, instead the brushless motors have three coils on the inner (center) of the motor, which is fixed to the mounting.

On the outer side, it contains a number of magnets mounted to a cylinder that is attached to the rotating shaft. So the coils are fixed which means wires can go directly to them and therefore there is no need for a brush.

They offer longer life and less maintenance than conventional brushed DC motors. Some other advantages over brushed DC motors and induction motors are: better speed versus torque characteristics, noiseless operation and higher speed ranges. And in addition, the ratio of torque delivered to the size of the motor is higher, making them useful in applications where space and weight are critical factors.

In a brushless DC motor, the electromagnets do not move; instead, the permanent magnets rotate and the three-phase stator windings remain static. This gets around the problem of how to transfer current to a moving rotor. In order to do this, the brush-commutator assembly is replaced by an intelligent electronic “controller”. The controller performs the same power distribution as found in a brushed DC motor, but is using a solid-state circuit rather than a commutator/brush system.

The speed and torque of the motor depend on the strength of the magnetic field generated by the energized windings of the motor, which depend on the current through them. Therefore adjusting the rotor voltage (and current) will change the motor speed.

The maximum power that can be applied to a brushless motor is limited almost exclusively by heat. Too much heat weakens the magnets and may damage the winding's insulation.

When converting electricity into mechanical power, brushless motors are more efficient than brushed motors. This improvement is largely due to the brushless motor's velocity being determined by the frequency at which the electricity is switched, not the voltage. Additional gains are due to the absence of brushes, which reduces mechanical energy loss due to friction. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve. Under high mechanical loads, brushless motors and high-quality brushed motors are comparable in efficiency.

3.8.3 Brushless outrunner motor

brushless motor primarily used in electrically propelled, radio-controlled model aircraft, This type of motor spins its outer shell around its windings, its driving electric aircraft propellers since they eliminate the extra weight, complexity, inefficiency and noise of a gearbox.

The stationary (stator) windings of an outrunner motor are excited by conventional DC brushless motor controllers. A direct current (switched on and off at high frequency for voltage modulation) is typically passed through three or more non-adjacent windings together, and the group so energized is alternated electronically based upon rotor position feedback. The number of permanent magnets in the rotor does not match the number of stator poles, however. This is to reduce Cogging torque and create a sinusoidal back emf. The number of magnet poles divided by 2 gives the ratio of magnetic field frequency to motor rotation frequency.

3.8.4 How to control a brushless DC motor Rotation

In a Brushless DC motor, two coils are energized at a time with equal and opposite polarities, one pushes the rotor away from it while the other attracting the rotor towards it. This increases the overall torque capacity of the motor and Hall effect sensors or a rotary encoder determines which two coils have to be energized to achieve this strategy

A BLDC motor is driven by voltage strokes coupled with the given rotor position. These voltage strokes must be properly applied to the active phases of the three-phase winding system so that the angle between the stator flux and the rotor flux is kept close to 90° to get the maximum generated torque. Therefore, the controller needs some means of determining the rotor's orientation/position (relative to the stator coils.)

Brushed DC motors develop a maximum torque when stationary, linearly decreasing as velocity increases. Some limitations of brushed motors can be overcome by brushless motors, they include higher efficiency and a lower susceptibility of the commutator assembly to mechanical wear. These benefits come at the cost of potentially less rugged, more complex, and more expensive control electronics.

A typical brushless motor has permanent magnets which rotate and a fixed armature, eliminating problems associated with connecting current to the moving armature. An electronic controller replaces the brush/commutator assembly of the brushed DC motor, which continually switches the phase to the windings to keep the motor turning. The controller performs similar timed power distribution by using a solid-state circuit rather than the brush/commutator system.

Brushless motors offer several advantages over brushed DC motors, including more torque per weight, more torque per watt (increased efficiency), increased reliability, reduced noise, longer lifetime (no brush and commutator erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI). With no windings on the rotor, they are not subjected to centrifugal forces, and because the windings are supported by the housing, they can be cooled by conduction, requiring no airflow inside the motor for cooling. This in turn means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter [14-18].

Figure 3-30 shows A2212 1000KV brushless outrunner motor: that we used.

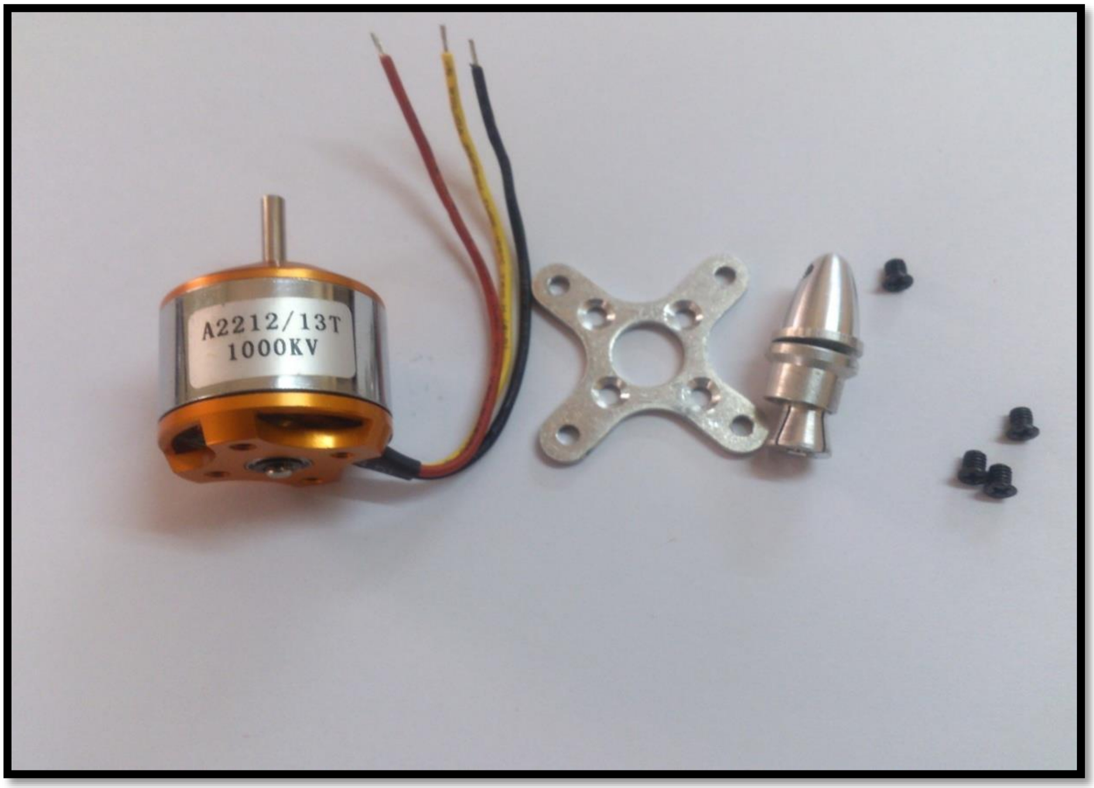


Figure 3-30 A2212 1000KV brushless outrunner motor:

The table 3-3 shows the Specifications of A2212 1000kv outrunner motor

Table 3-3 Specifications of A2212 1000kv outrunner motor

KV	1000
Max. Efficiency	80%
Max. Efficiency current:	4-10A (>75%)
Current capacity	12A/60s
No Load current	@ 10V: 0.5A
No. of cells	2-3 Li-Poly
Motor size	27.5 * 27mm / 1.1 * 1.1in
Shaft diameter	3.17mm / 0.1in
Weight	48g / 1.7oz

3.9 Electronic Speed Controller

An electronic speed control or ESC is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on electrically-powered radio controlled models.

An ESC can be a stand-alone unit which plugs into the receiver's throttle control channel or incorporated into the receiver itself, as is the case in most toy-grade R/C vehicles. Some R/C manufacturers that install proprietary hobby-grade electronics in their entry-level vehicles, vessels or aircraft use onboard electronics that combine the two on a single circuit board. ESCs are normally rated according to maximum current, for example, 25 amperes or 25 A. Generally the higher the rating, the larger and heavier the ESC tends to be which a factor when calculating mass is and balance in airplanes. Many modern ESCs support nickel metal hydride and lithium ion polymer batteries with a range of input and cut-off voltages[16], the figure 3-31 show 30A Brushless ESC that we used in our quadrotor.

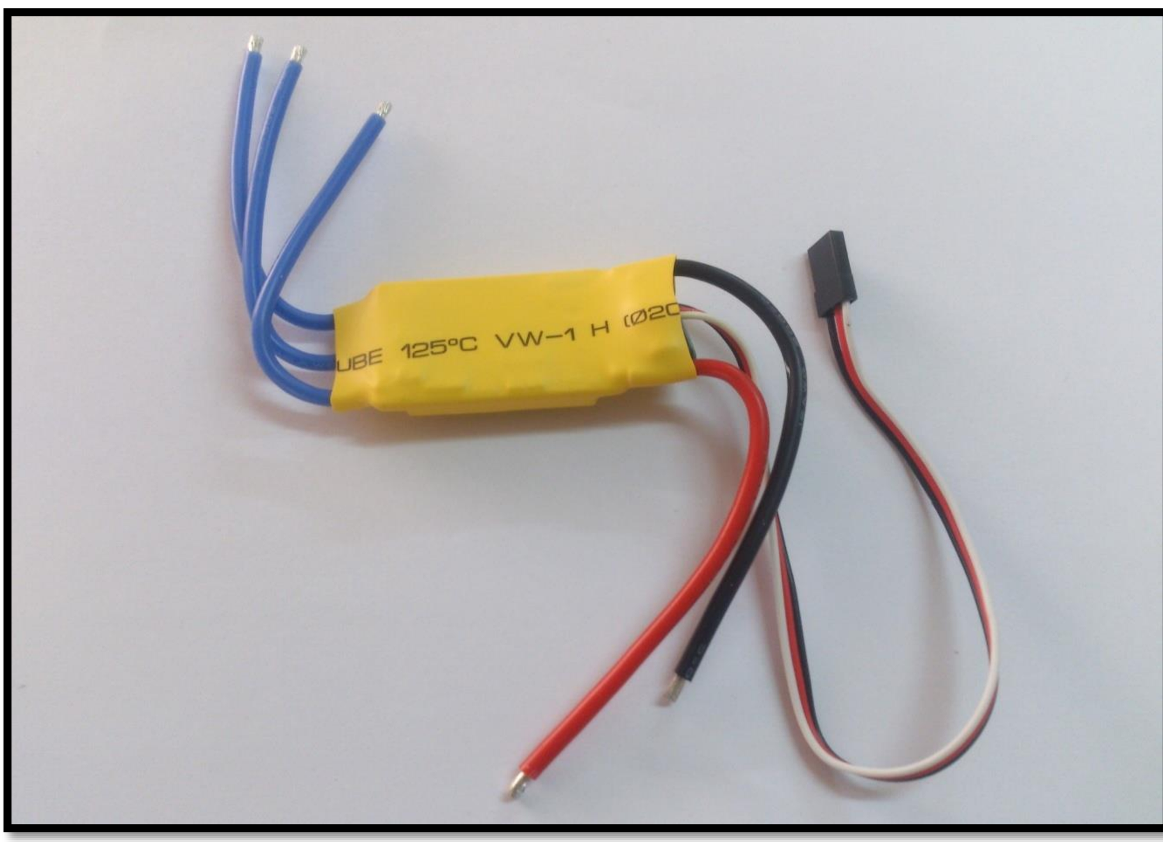


Figure 3-31 30A Brushless ESC

The table 3-4 shows the Specification for **30A Brushless ESC**

Table 3-4 Specification for 30A Brushless ESC

30A Brushless ESC Output	Continuous 30A, burst 40A up to 10 Sec
Input voltage	2-4 cells lithium battery or 5-12 cells NiCd/NIMh battery
BEC	2A / 5V (Linear mode).
Max speed	210,000rpm for 2 poles BLM, 70,000rpm for 6 poles BLM, 35,000rpm for 12 poles BLM.(BLM: Brushless Motor)
Size	45 * 24 * 11mm / 1.8 * 0.9 * 0.4in
Weight	25g / 0.9oz
Item total weight	480g / 1.06Lbs

3.10 Power distributor

Power distribution board is used to simplify the connection between batteries and, ESCs and flight controllers. Circuit board using special design, covered with copper. Signal cable uses tinned copper conductor material, strong and reliable.

It distributes power from the flight battery to ESCs to power the Quads motors with easy and safe to use.

We used T Plug APM PX4 Power Distribution Board as shown in figure3-32.

3.10.1 Features

- Color: as shown in the pictures.
- Material: durable aluminum alloy and silicone.
- 100% brand new and high quality T Plug APM PX4 Power Distribution Board / ESC Connecting Board.
- Can be used to simplify the cable connection between the battery and ESC, ESC and flight controllers.
- Suitable for quadrotor and tricopter.
- Battery interface connectors with T plug.

- It distributes power from the flight battery to ESCs to power the Quads motors.
- Now comes pre-assembled! No need to solder connectors or wires

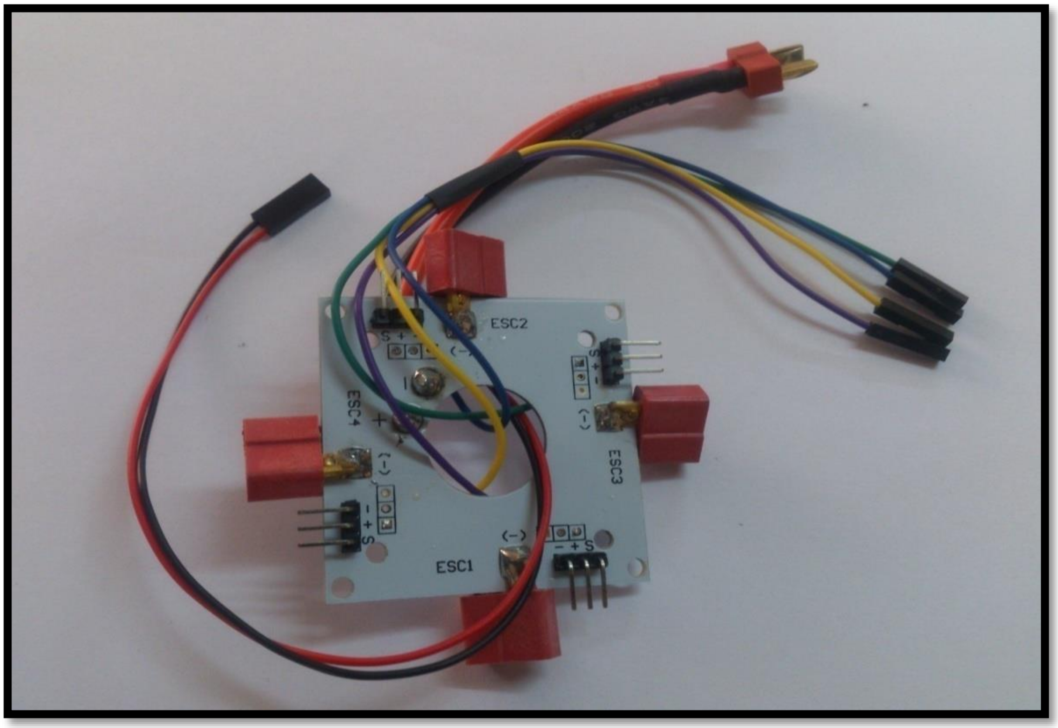


Figure 3-32 T Plug APM PX4 Power Distribution Board / ESC Connecting Board for RC Quadrotor

3.11 Transmitter and Receiver Selection

The Transmitter (Tx) and Receiver (Rx) system allows the RUAV to be remotely controlled through a wireless signal. The aircraft controls would typically include throttle, pitch, roll, yaw, and mode settings. There are two basic types of Transmitter Receiver systems currently available in the market namely, the FM system and the 2.4GHz system. Here 2.4GHz is used for its better performance, because it will not experience signal conflicts from other radio frequency (RF) controllers. [4]

Prototype

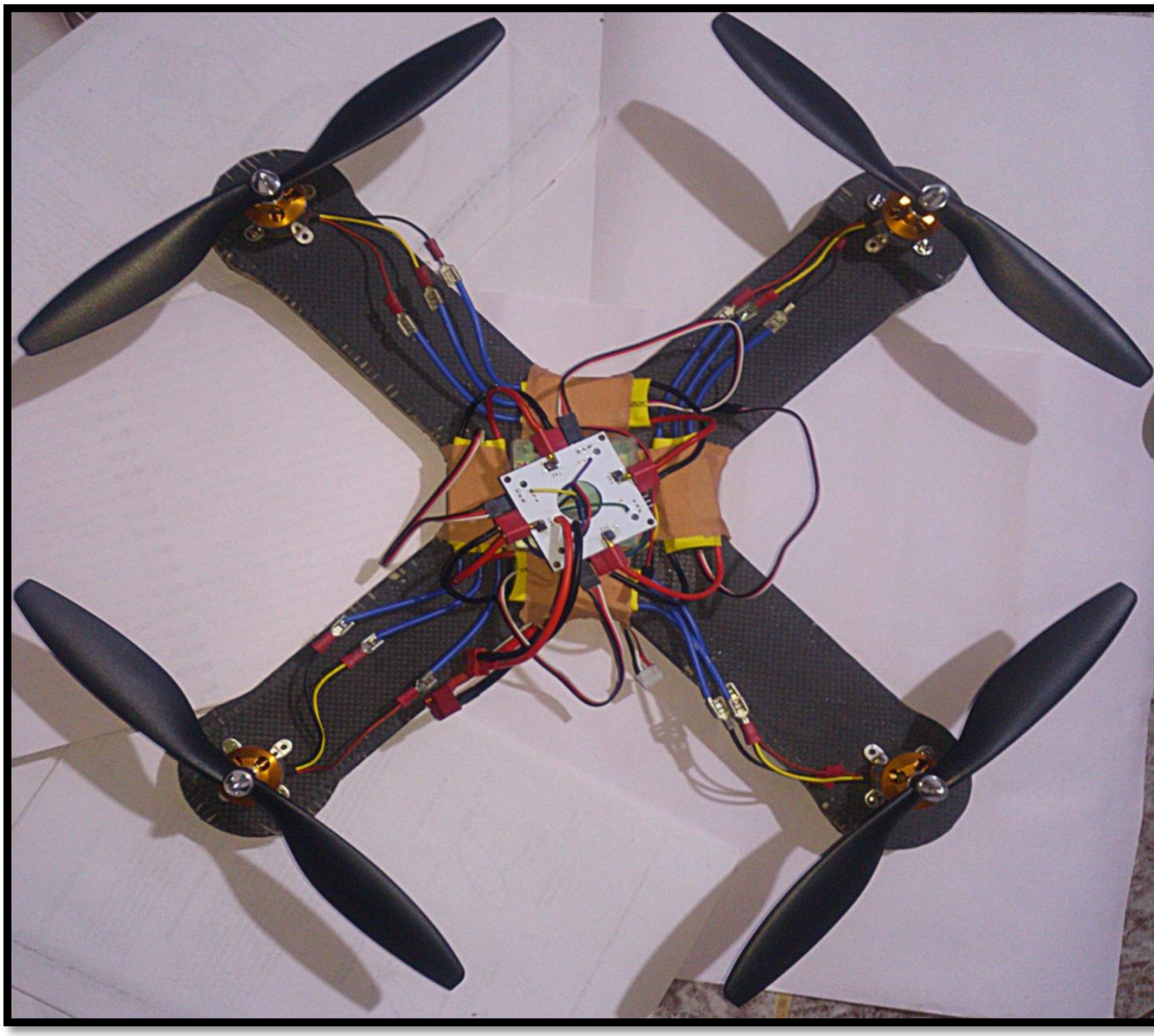


Figure 3-33 Quadrotor assembly

Figure 3-34 show the final quadrotor design

Figure 3-34 final quadrotor design

After manufacturing structure, all component assembly equally distance from CG of the frame, the total Wight calculated using the a gravity weighing (1.04 kg) as shown in figure 3-35 also the CG found it is locate at the center of the quadrotor.

Figure 3-35 weighing device

3.12 Flight test result

The quadrotor was successfully hovered as shown in figure 3-36

Figure 3-36 hovering flight

4 Chapter four: helicopter Performance calculation and Results

The problem of Complicating helicopter performance in forward flight is complicated by the many variables involved and by the length and complication of the equations that define the rotor characteristics, for this reason any exact Performance method (i.e. method that uses the most refine theory available or the main number of approximation). Necessary involves the use of tables and charts in order to facilitate the work. The Performance chart may be based upon a method utilized the fact that; A power balance exists for helicopter in steady flight (i.e. the power expended by the main rotor shaft must equal the sum of power losses expended by rotor and the fuselage; this called the energy method[19]

Performance analysis of helicopter is same like those applied in fixed wing a/c are based in curve of power required against airspeed for consider the various flight condition. In order to obtain curve of this type it is necessary to consider the various sources of power expanded by a helicopter in steady flight.

4.1 Basic Performance Equation:

- Induce power

$$P_i = \frac{G^2}{2*\rho*A*V} \dots (4.1)$$

- Parasite power

$$P_{par} = \frac{1}{2}*\rho*f*V^3 \dots (4.2)$$

- Profile power

$$p_{prof} = \frac{T[\Omega R+V]\upsilon}{100*\chi}\ (Russian) = constant \dots (4.3)$$

- Power supply

$$\mathrm{P_{sup}} = T\sqrt{\frac{T}{\rho A}} \dots (4.4)$$

- Optimum velocity

$$V_{opt} = \left[\frac{G}{\rho*A}\left(\frac{A}{3f}\right)^{0.5}\right]^{0.5} \dots (4.5)$$

- Drag parasite

$$D_{par} = \frac{1}{2}*f*\rho*V^2 \dots (4.6)$$

- power Required

$$P_{req} = P_i + P_{par} + P_{porf} \dots (4.7)$$

- Power available

$$P_a = \mathrm{P_{mech}} = P_{elec} - \mathrm{P_{loss}} \dots (4.8)$$

- Velocity of climb and service ceiling

$$V_c = \frac{P_a - P_{req}}{W} \dots (4.9)$$

- Time of climb

$$t = \frac{\Delta h}{Vcm} \dots (4.10)$$

- Rate of climb

$$R/C = V_{C_0} - kH \quad \dots (4.11)$$

- Endurance

$$E_{(min)} = \frac{\text{Battary power rating(Amp*Hr)}}{\text{current draw motors(Amp)}} * 60_{\text{min}} \dots (4.12)$$

- Range

$$Ran = Velocity * \text{Endurance} \dots (4.13)$$

For Performance calculation we have to know the following:

i. power required and Power available
ii. maximum velocity and velocity of climb
iii. time of climb
iv. range of flight
v. endurance of flight
vi. absolute and service ceiling

4.2 Calculation

4.2.1 Power

$Voltage = 11.1\ v$

$c.d.r = 25\ c$

$Capcity = 2600\ mAh$

$$i = c.d.r * c \dots (4.14)$$

$i = 25 * \frac{2600}{1000} = 65A$

$Electrical\ Power = v * \mathrm{i} \quad \dots (4.15)$

$= 11.1 * 65 = 721.5\mathrm{w}\ (\mathrm{v.A})$

$Electrical\ Power = Mech\ Power + Power\ Losses\ \dots$ (4.16)

$Power\ Losses = Electrical\ Power * \%5 \dots (4.17)$

$$\mathrm{P_{loss}} = 721.5 * \frac{5}{100} = 36.075\ w$$

$\mathrm{P_{mech}} = P_{elec} - \mathrm{P_{loss}} \dots (4.18)$

$\mathrm{P}mech = 721.5 - 36.075 = 685.425$

$R.P.M\ for\ 1000\ kv\ Motor = KV = \frac{r.p.m}{v}$ ... (4.19)

$R.P.M = KV * V \dots (4.20)$

$= 1000 * 11.1 = 11100\ \mathrm{r.p.m}$

$Prop\ Raduis = 5\ in = 0.127\ m$

$\mathrm{P_{mech}} = 685.425\ w$

$$0.75 = 0.707 * \frac{T}{P} \frac{\sqrt{T}}{\sqrt{\rho \pi R^2}} \dots (4.21)$$

$$0.75 = 0.707 * \frac{T}{685.425} \frac{\sqrt{T}}{\sqrt{1.225 * \pi * (0.127)^2}}$$

$$\Rightarrow T = 32\ N$$

$$V = \frac{P_a}{T} \ldots (4.22)$$

$$= \frac{685.425}{32} = 21.4\ m/s$$

FOR four $ROTOR = 128\ N$

$$\frac{C_d}{C_l} = [0.02 - 0.04]$$

$$L = T = 32$$

$$\Rightarrow Cl = \frac{L}{0.5 * \rho * V^2 * A} \ldots (4.23)$$

$$C_l = \frac{32}{0.5 * 1.225 * (21.4)^2 * \pi * 0.127^2} = 2.25$$

$$C_d = 2.25 * 0.02 = 0.045$$

$$F = \pi R^2 * Cd = \pi * 0.127^2 * 0.045 = 0.0023$$

$$P_{prof} = (T\ \Omega\ R\ v)/100X \ \ldots (4.24)$$

$$= \frac{32 * 147.6 * 0.02}{100 * 0.9} = 1.05W$$

4.2.2 Velocity of climb forward flight for quadrotor

Assume: T = G

$$V_{opt} = \left[\frac{G}{\rho A}\left(\frac{A}{3f}\right)^{0.5}\right]^{0.5} \quad \dots (4.25)$$

$$= \left[\frac{32}{\rho(\pi * 0.127^2)}\left(\frac{(\pi * 0.127^2)}{3(0.0023)}\right)^{0.5}\right]^{0.5} = \left[\frac{1711.38}{\rho}\right]^{0.5}$$

$$P_i = \frac{G^2}{2\rho A Vopt} \quad \dots (4.26)$$

$$= \frac{(32 * 4)^2}{2(4\pi * 0.127^2)\rho Vopt} = \frac{40417.8}{\rho Vopt}$$

$$P_{par} = 0.5\rho f Vopt^3 \quad \dots (4.27)$$

$$= 0.5 * (4 * 0.0023)\rho {V_{opt}}^3$$

$$P_{par} = 0.0046\rho {V_{opt}}^3 \quad \dots (4.28)$$

Table 4-1 Climb Speed

ALT ,m	density ,kg/m^3	V_{opt} , m/s	P_i , W	P_{par} , W	P_{prof} , W	P_{req} , W	P_a , W	ΔP , W	V_c , m/s
0	1.225	37.37706	882.7371	294.2453	4.2	1181.182	2741.7	1560.518	12.19154
100	1.2133	37.55685	886.9831	295.6606	4.2	1186.844	2741.7	1554.856	12.14732
200	1.2071	37.65317	889.2581	296.4189	4.2	1189.877	2741.7	1551.823	12.12362
300	1.1901	37.92115	895.5869	298.5285	4.2	1198.315	2741.7	1543.385	12.05769
400	1.1787	38.10409	899.907	299.9686	4.2	1204.076	2741.7	1537.624	12.0126

			4						9
500	1.167	38.2897	904.291	301.429	4.2	1209.921	2741.7	1531.779	11.967
600	1.156	38.476	908.7	302.899	4.2	1215.8	2741.7	1525.9	11.921
700	1.144	38.664	913.1343	304.377	4.2	1221.712	2741.7	1519.988	11.874
800	1.133	38.852	917.5936	305.864	4.2	1227.658	2741.7	1514.042	11.828
900	1.122	39.044	922.1189	307.372	4.2	1233.691	2741.7	1508.009	11.781
1000	1.111	39.235	926.6285	308.875	4.2	1239.704	2741.7	1501.996	11.734
1100	1.100	39.429	931.2049	310.401	4.2	1245.806	2741.7	1495.894	11.686
1200	1.09	39.624	935.8068	311.935	4.2	1251.942	2741.7	1489.758	11.638
1300	1.079	39.820	940.4341	313.477	4.2	1258.112	2741.7	1483.588	11.590
1400	1.068	40.017	945.0865	315.028	4.2	1264.315	2741.7	1477.385	11.542

Table 4-2 Time necessary of climb into altitudes

ALT ,m	V_c , m/s	$V_{c_{mean}}$, m/s	$\Delta t = \frac{100}{V_{c_{mean}}}$, S	T_{tot} , S
0	12.191	0	0	
100	12.147	12.169	8.217	
200	12.123	12.135	8.240	
300	12.057	12.09	8.270	
400	12.012	12.035	8.308	
500	11.967	11.989	8.340	

600	11.921	11.944	8.37	
700	11.874	11.898	8.404	
800	11.828	11.851	8.437	
900	11.781	11.804	8.471	
1000	11.734	11.757	8.504	
1100	11.686	11.710	8.539	
1200	11.63874	11.662705	8.574340172	
1300	11.59053	11.614635	8.609827171	
1400	11.54207	11.5663	8.645807216	
				117.9379

Table 4-3 The relation between Power required & Power Available

ALT, m	density ,kg/m^3	V, m/s	P_i , W	P_{par} , W	P_{pro}	P_{req} , W	P_a , W
0	1.225	13	2538.009	12.3801	4.2	2554.59	2741.7
100	1.2133	18	1850.683	32.54944	4.2	1887.432	2741.7
200	1.2071	23	1455.8	67.55921	4.2	1527.559	2741.7
300	1.1901	28	1212.917	120.1753	4.2	1337.293	2741.7
400	1.1787	33	1039.095	194.8511	4.2	1238.147	2741.7
500	1.1673	38	911.1851	294.6396	4.2	1210.025	2741.7
600	1.156	43	813.1045	422.7864	4.2	1240.091	2741.7
700	1.1448	48	735.5324	582.3863	4.2	1322.119	2741.7
800	1.1337	53	672.6647	776.3965	4.2	1453.261	2741.7
900	1.1226	58	620.7542	1007.551	4.2	1632.505	2741.7
1000	1.1117	63	577.0913	1278.695	4.2	1859.987	2741.7
1100	1.1008	68	539.9522	1592.183	4.2	2136.335	2741.7
1200	1.09	73	507.9527	1950.531	4.2	2462.684	2741.7
1300	1.0793	78	480.1046	2356.046	4.2	2840.351	2741.7
1400	1.0687	83	455.6578	2810.916	4.2	3270.774	2741.7

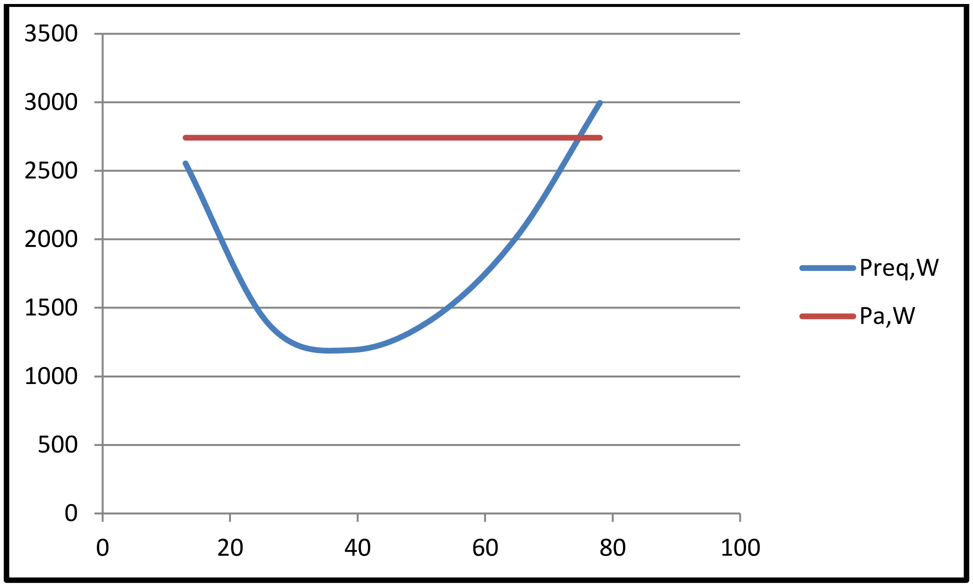


Figure 4-1 power available and power reuired VS flight speed

4.2.3 Power supply

$$\mathrm{P_{sup}} = T\sqrt{\frac{T}{\rho A}} \ \dots (4.29)$$

$$P_{sup} = 128 * \sqrt{\frac{128}{1.225 * \pi * 0.127^2}} = 5812.57\ w$$

$$\mathrm{P_{sup}} = 5.812\ kw$$

4.2.4 Absolute and service ceiling

$$R/C = V_{C_0} - K * H \ \dots (4.30)$$

At absolute ceiling (R/C=0)

$$0 = 12.19154 - (0.008846 * H)$$

$$H_0 = 1378.198\ m = 1.378\ km$$

Service ceiling (R/C =0.5 m)

$$0.5 = 12.19154 - (0.008846 * H)$$

$H_{ser} = 1321.67\ m = 1.321 km$

4.2.5 Endurance

$$E_{minute} = \frac{2.600}{65} * 60 = 2.4\ min$$

$$E_{minute} = 2.4 * min = 2.4 * 60 = 144\ sec$$

4.2.6 Range

$$R_{max} = 74 * 144 = 10565\ m$$

$$= 10.565\ km$$

5 Chapter five: Results and discussions

5.1 Results

$\mathrm{P_{mech}} = 685.425\ w$

$T = 32\ N$

$\mathrm{C_d} = 2.25 * 0.02 = 0.045$

$\mathrm{P_{sup}} = 5.812\ kw$

$R/C = V_{C_0} - K * H$ ... (4.30)

$H_0 = 1378.198\ m = 1.378\ km$

$H_{ser} = 1321.67\ m = 1.321 km$

$$E_{minute} = \frac{2.600}{65} * 60 = 2.4\ min$$

$R_{max} = 74 * 144 = 10565\ m$

$P_{prof} = 1.05W$

V_c=11.590

5.2 Discussions

From calculation at table 4-1 the optimum flight speed will increase with altitude and hence to improve the flight efficiency must increase the speed with increasing of altitude.

the climb speeds of quadrotor are found adversely proportional with the altitude and continues decrease as altitude increase until reach to (11.5 m/s) this speed is high due to the helicopter has four rotor which gives high speed to climb and the altitude at this speed equal service ceiling (1.321 km).

From table 4-2 the time necessary to climb at the service ceiling is about (117.9 s)
From table 4-3 the value of the power required and power available agents the flight speed Was plotted in figure 4-1 as shown if figure the value of the power required start from maximum value then decrease as flight speed increase until reach the point of minimum power which the speed equal to the best endurance speed. After this point the power required curve start to increase again due to increasing in parasite drag.

6 Chapter six: Conclusion and Recommendations

6.1 Conclusion

We have successfully met our design goal which is design a quadrotor capable of carrying a metal prospective; we would have liked to progress further, such as having the ability to fly to a destination.

The material has selected for structure of the quadrotor based on the most effective factor to be rigid and light weight by using appropriate method of fabrication and selection the right material for manufacturing, CNC has used to manufacturing the structure which has an accurate moving of cutting the part and give a good product in manufacturing, carbon fiber used on structure and cork plastic for cover which achieve the requirement of design.

All components has selected by ECALC calculator which give the first suggestion for requirement.

The conventional method used to achieve the propeller balance which has significant role in quadrotor stability and damping vibration.

The CAD software has used for drawing the model and ANSYS® program to analyses the structure statically which evaluate the ability structure for carrying the load.

The performance calculation has done by using the rotor theories and numerical method also the result investigated and compared with that from the ecalc.

The quadrotor weight has estimated about 1000 g by using electronic calculator (ECALC) the motor and ESC has selected according to power and R.P.M require to carry the equipment with take the main effective parameter like battery power, voltage and discharge rate .

The rotor aerodynamic has calculated by using javaprop software to establish the performance characteristic and efficiency of rotor by using the vortex and blade element theory

6.2 Recommendations

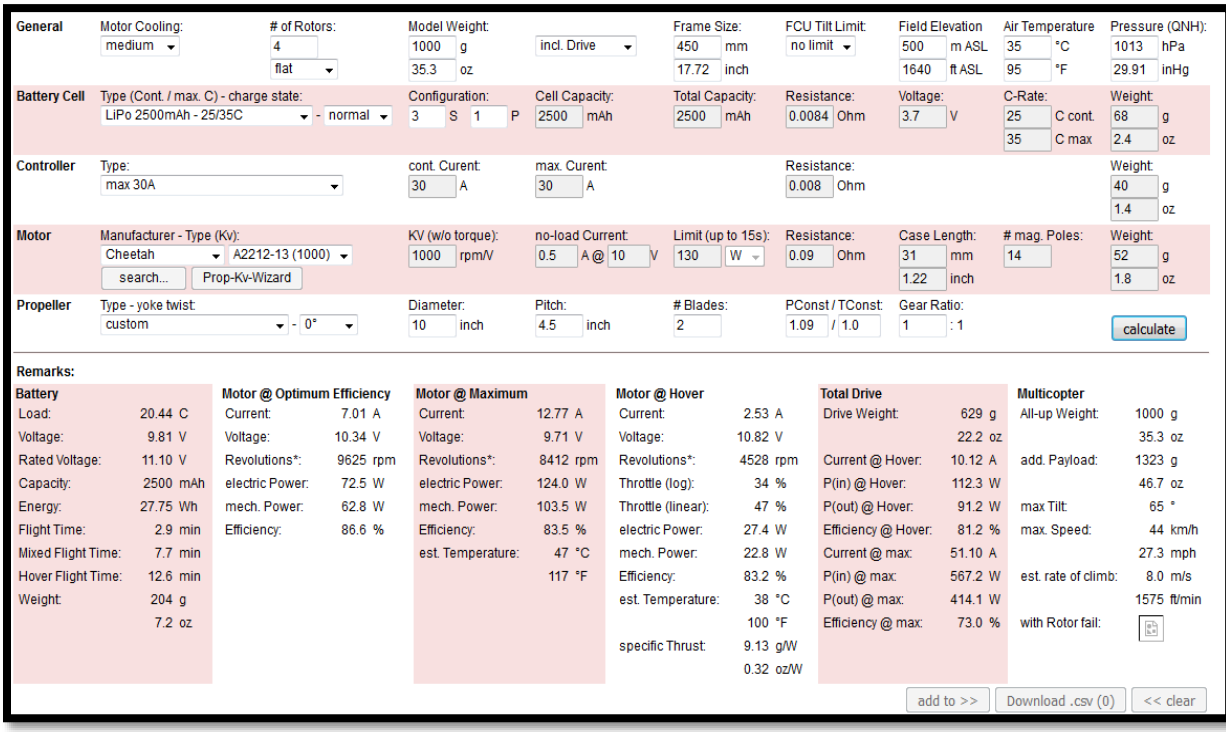
- The material selected for cover had small margin of safety and regi it should change with stiffer light weight material. A composed material should be used for cover and duct
- Increase the quadrotor range and endurance by increase the capacity of the battery
- To achieve more stability for the quadrotor as the distance from the quadrotor CG to the motor center increase the stability increase and agile decrease.
- The CFD analysis should be done for the propeller to estimate accurate result of performance for rotor aerodynamic
- Test everything as soon as possible
- The flight test must be done by an experience person or pilot
- This type of research must be done not only by power plant and structure student but also by avionics students or student with good electrical and control background
- For more specific calculation of propeller and quadrotor balance, a commercial balance device should be used.
- ANSYS and SOLIDWORKS software for analysis and simulation is better to be train before starting project so that it can offer more time.

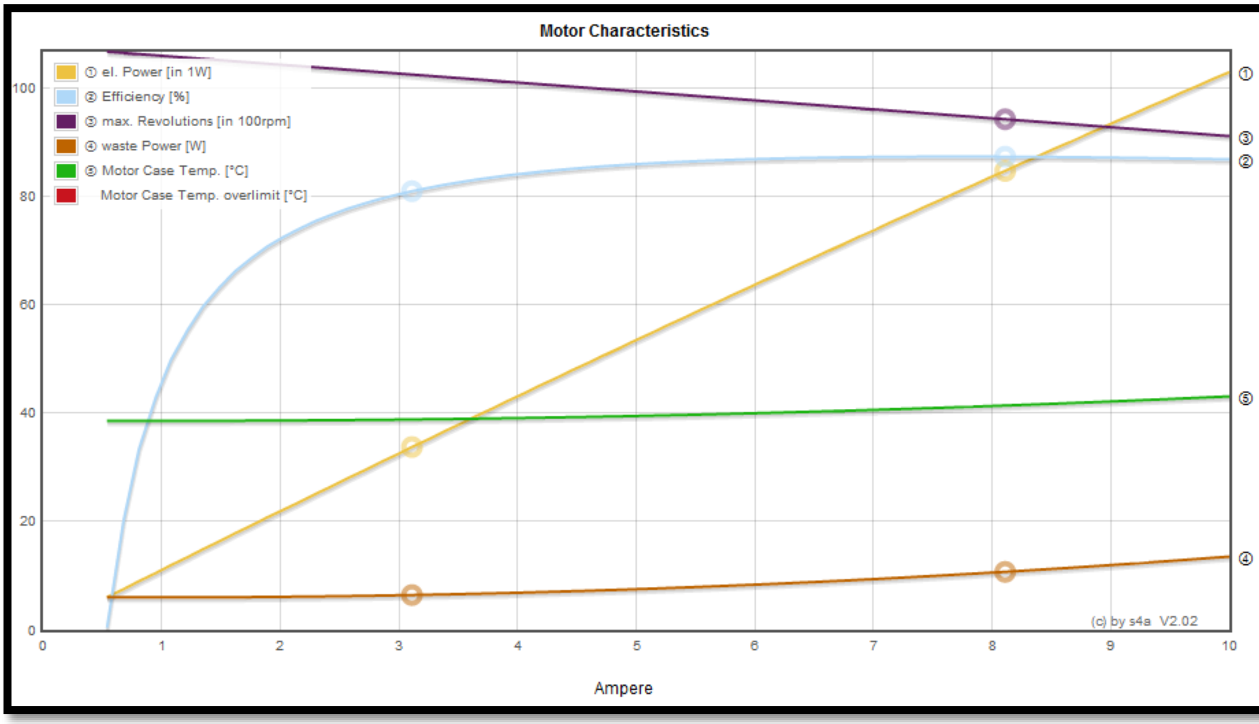
6.3 Future works

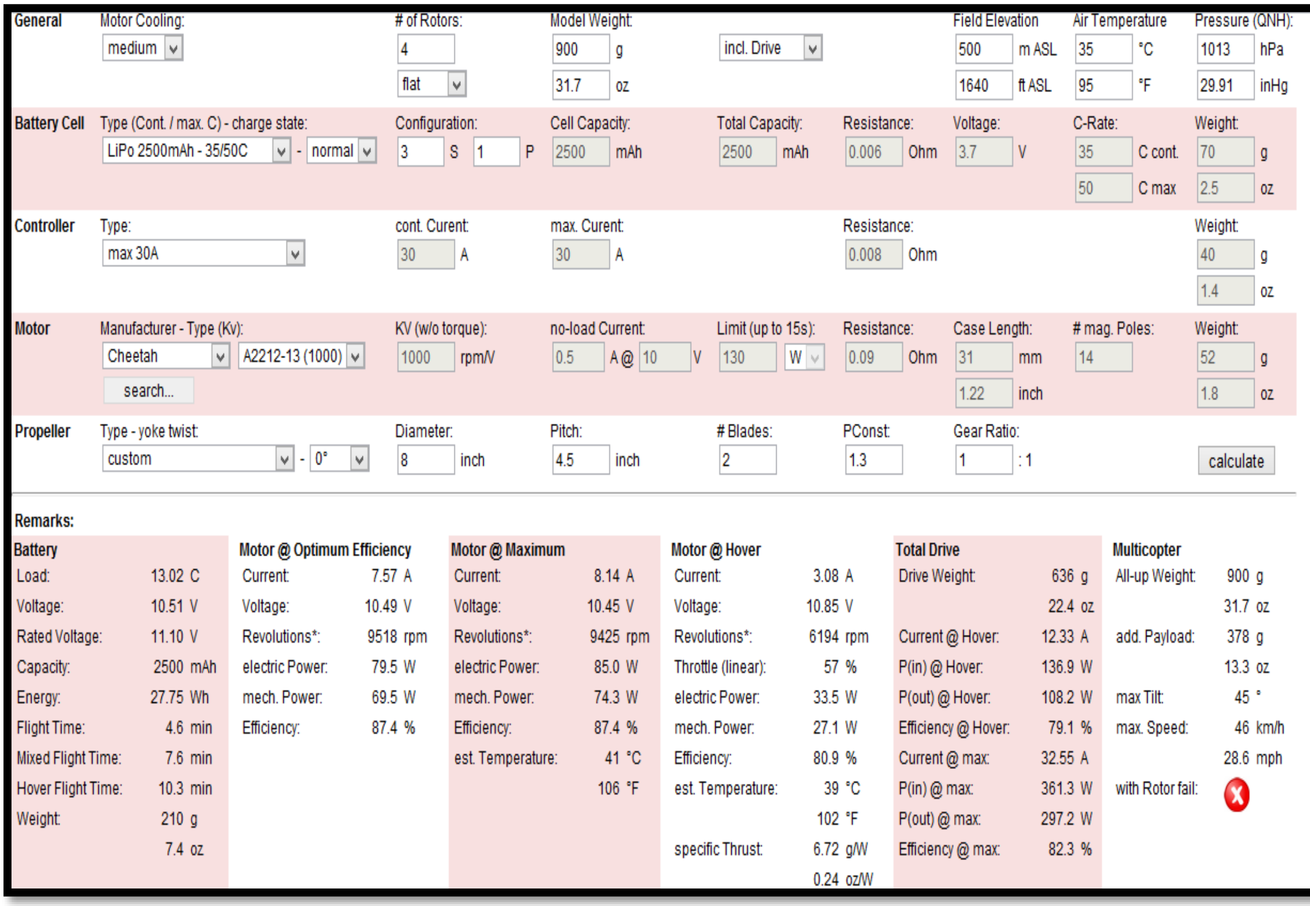
- Study the flight dynamics and control for UAV quadrotor.
- Design a metal prospective devise capable to work at quadrotor and sending a signal from metal sensor to receiver using a WIFI instead of direct wire signals.

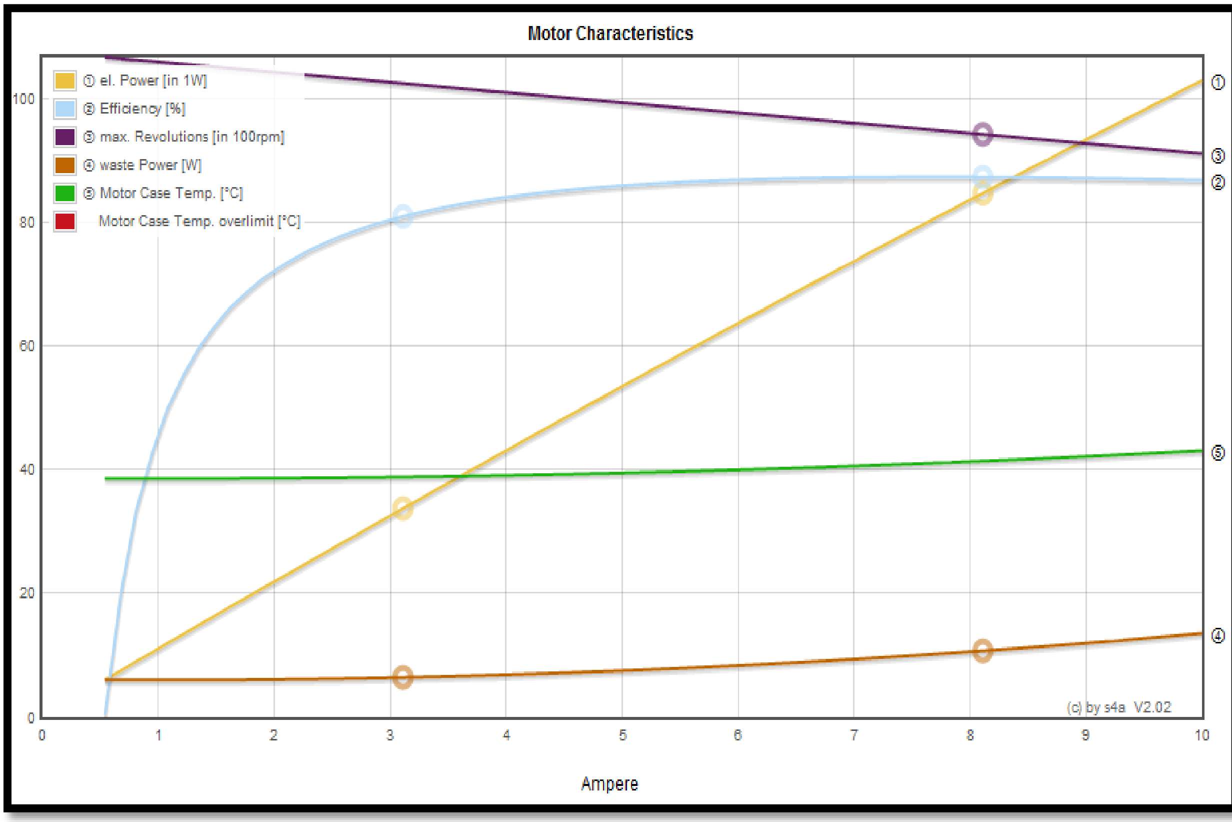
Appendixes:

Appendix A: ECALC Calculator result




Motor Characteristics
① el. Power [in 1W]
② Efficiency [%]
③ max. Revolutions [in 100rpm]
④ waste Power [W]
⑤ Motor Case Temp. [°C]
Motor Case Temp. overlimit [°C]
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
①
③
②
⑤
④
(c) by s4a V2.02
Ampere


General
Motor Cooling: medium
# of Rotors: 4
flat
Model Weight: 900 g
31.7 oz
incl. Drive
Field Elevation: 500 m ASL
1640 ft ASL
Air Temperature: 35 °C
95 °F
Pressure (QNH): 1013 hPa
29.91 inHg
Battery Cell
Type (Cont. / max. C) - charge state: LiPo 2500mAh - 35/50C - normal
Configuration: 3 S 1 P
Cell Capacity: 2500 mAh
Total Capacity: 2500 mAh
Resistance: 0.006 Ohm
Voltage: 3.7 V
C-Rate: 35 C cont.
50 C max
Weight: 70 g
2.5 oz
Controller
Type: max 30A
cont. Curent: 30 A
max. Curent: 30 A
Resistance: 0.008 Ohm
Weight: 40 g
1.4 oz
Motor
Manufacturer - Type (Kv): Cheetah A2212-13 (1000)
search...
KV (w/o torque): 1000 rpm/V
no-load Current: 0.5 A @ 10 V
Limit (up to 15s): 130 W
Resistance: 0.09 Ohm
Case Length: 31 mm
1.22 inch
mag. Poles: 14
Weight: 52 g
1.8 oz
Propeller
Type - yoke twist: custom - 0°
Diameter: 8 inch
Pitch: 4.5 inch
Blades: 2
PConst: 1.3
Gear Ratio: 1 : 1
calculate
Remarks:
Battery
Load: 13.02 C
Voltage: 10.51 V
Rated Voltage: 11.10 V
Capacity: 2500 mAh
Energy: 27.75 Wh
Flight Time: 4.6 min
Mixed Flight Time: 7.6 min
Hover Flight Time: 10.3 min
Weight: 210 g
7.4 oz
Motor @ Optimum Efficiency
Current: 7.57 A
Voltage: 10.49 V
Revolutions*: 9518 rpm
electric Power: 79.5 W
mech. Power: 69.5 W
Efficiency: 87.4 %
Motor @ Maximum
Current: 8.14 A
Voltage: 10.45 V
Revolutions*: 9425 rpm
electric Power: 85.0 W
mech. Power: 74.3 W
Efficiency: 87.4 %
est. Temperature: 41 °C
106 °F
Motor @ Hover
Current: 3.08 A
Voltage: 10.85 V
Revolutions*: 6194 rpm
Throttle (linear): 57 %
electric Power: 33.5 W
mech. Power: 27.1 W
Efficiency: 80.9 %
est. Temperature: 39 °C
102 °F
specific Thrust: 6.72 g/W
0.24 oz/W
Total Drive
Drive Weight: 636 g
22.4 oz
Current @ Hover: 12.33 A
P(in) @ Hover: 136.9 W
P(out) @ Hover: 108.2 W
Efficiency @ Hover: 79.1 %
Current @ max: 32.55 A
P(in) @ max: 361.3 W
P(out) @ max: 297.2 W
Efficiency @ max: 82.3 %
Multicopter
All-up Weight: 900 g
31.7 oz
add. Payload: 378 g
13.3 oz
max Tilt: 45 °
max. Speed: 46 km/h
28.6 mph
with Rotor fail:

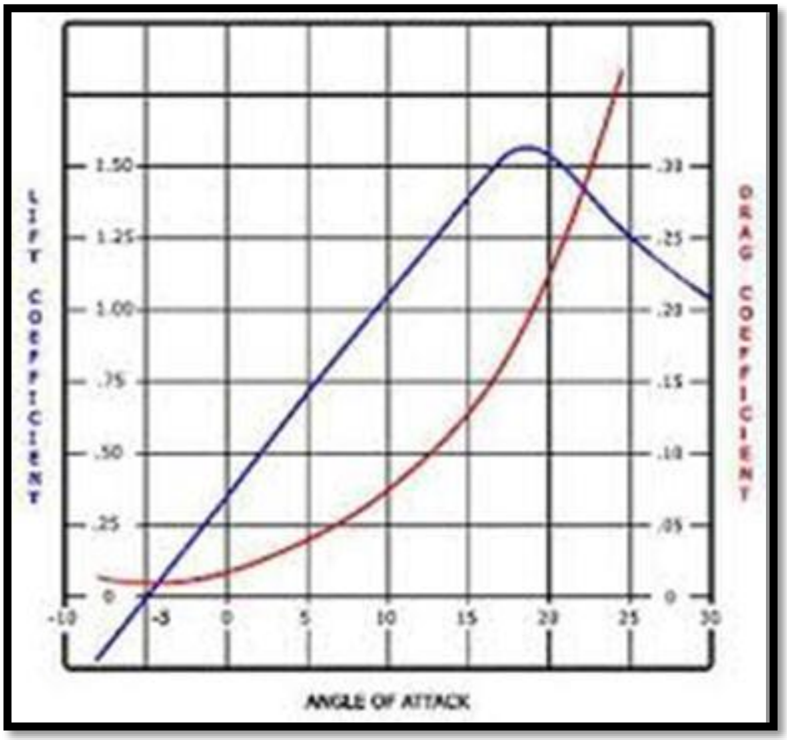


Motor Characteristics
① el. Power [in 1W]
② Efficiency [%]
③ max. Revolutions [in 100rpm]
④ waste Power [W]
⑤ Motor Case Temp. [°C]
Motor Case Temp. overlimit [°C]
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
(c) by s4a V2.02
Ampere

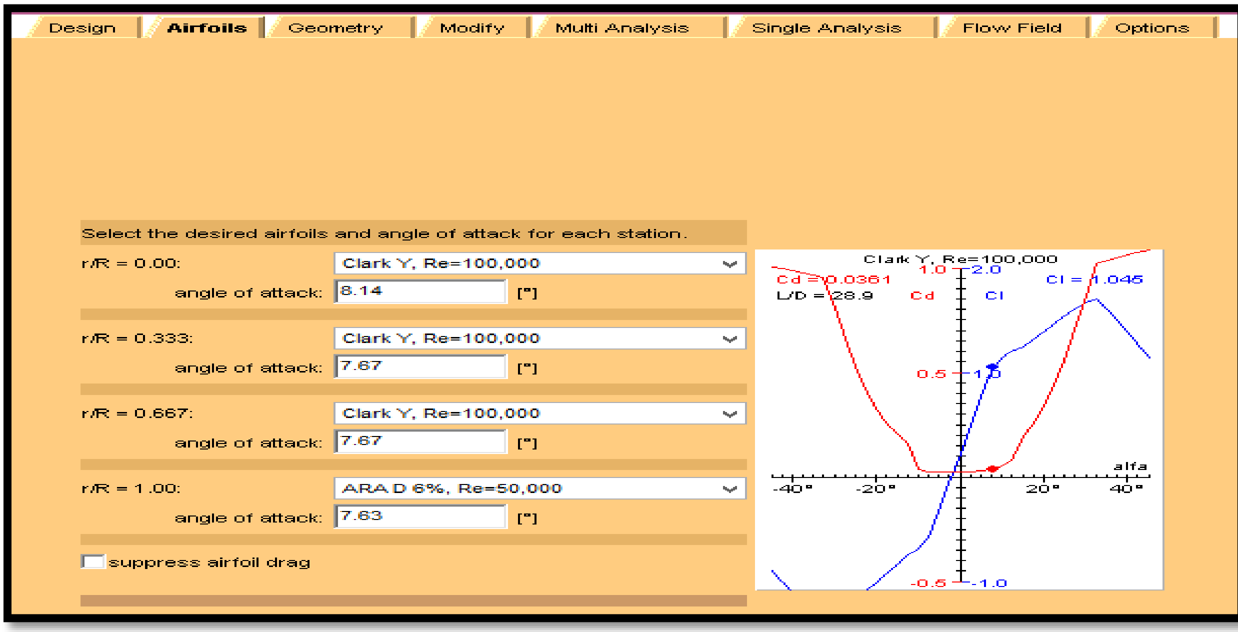
Appendix B: angle of attack matlab code

```
a=0.1182; % inflow factor
b=0.00013044; %inflow factor
b1=2; % number of blades
vinf=74; % inflow velocity
cl=1.1; %lift cofficient
cd=0.075; %drag cofficient
roh=1.225; %air density
omga=1162.4; %angular velocity
dr=0.0127;%propeller radius
pi=3.1416;
r=0.127; %propeller radius
theta=8.15; %pitch angle
vo=vinf*(1+a); %airflow Velocity
v2=omga*r*(1-b); %outlet velocity
phai=atan(vo/v2); %flow angle
dt=32;
dq=0.59;
z=dt/(4*pi*roh*vinf^2*dr);%
x=[1 1 -z];
an=roots(x); %new inflow factor
bn=dq/(4*pi*r^3*vinf^2*(1+a)*omga*dr); %new inflow factor
alpha=theta-phai;
```

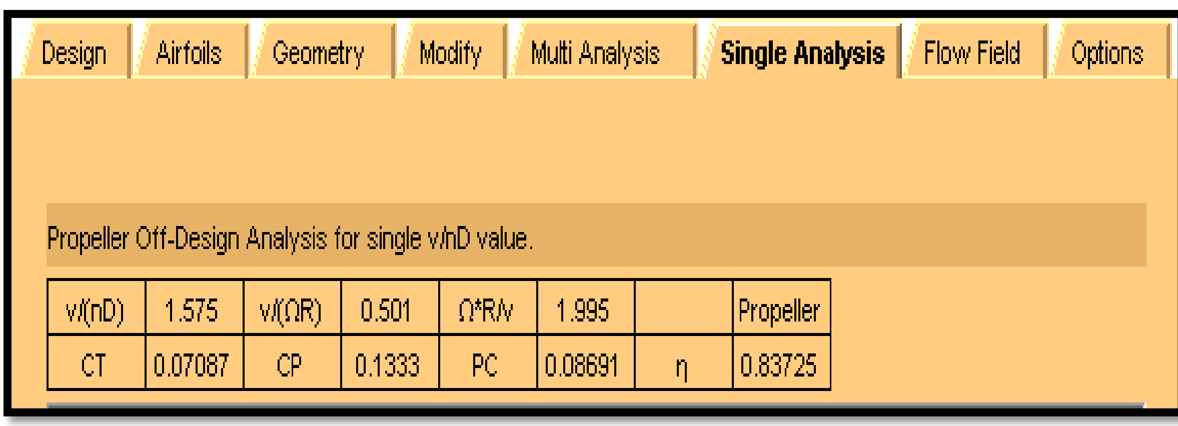
Appendix C: Clark-y lift and drag curve



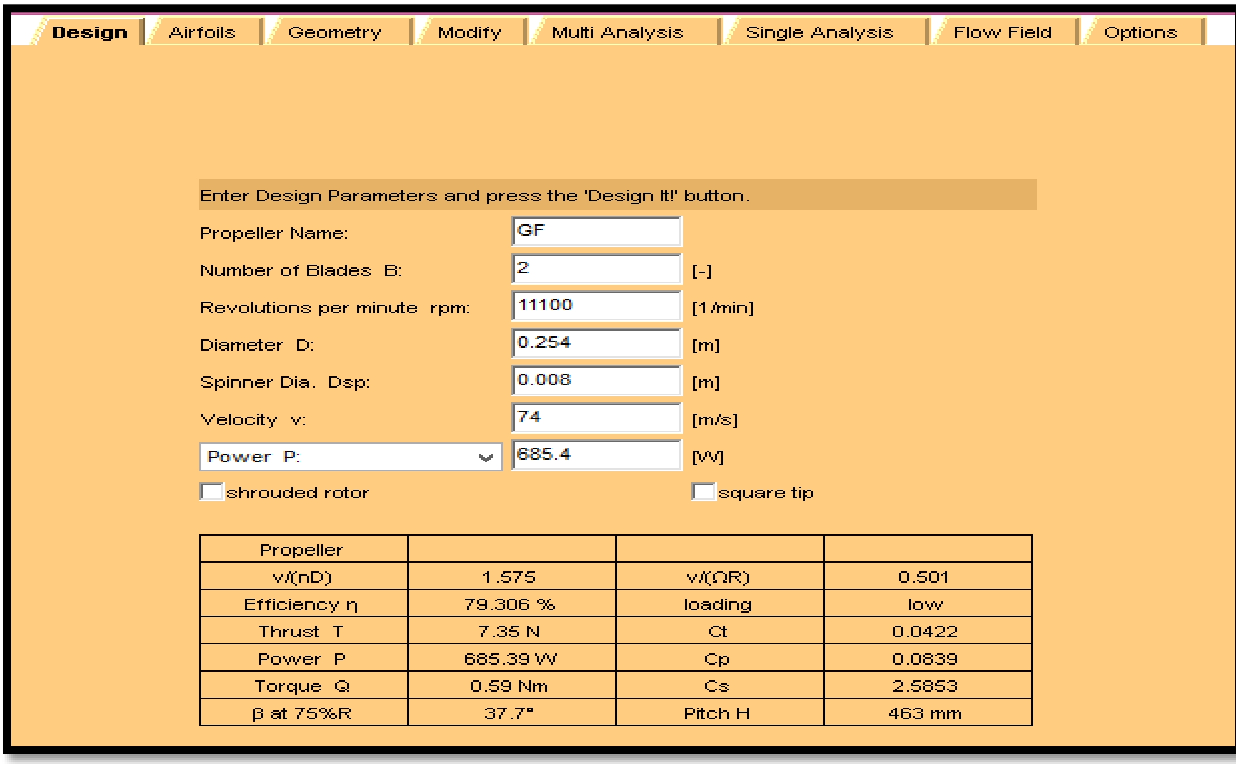
Appendix E: javaprop software

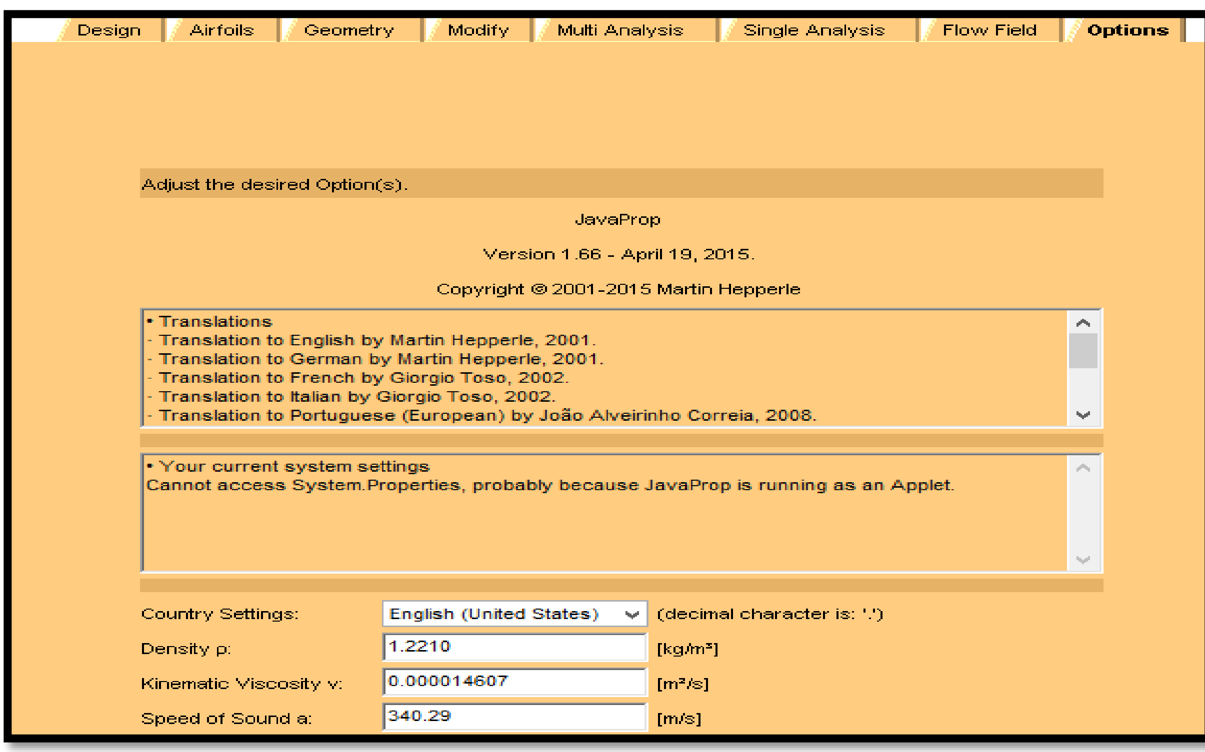


Propeller Off-design condition



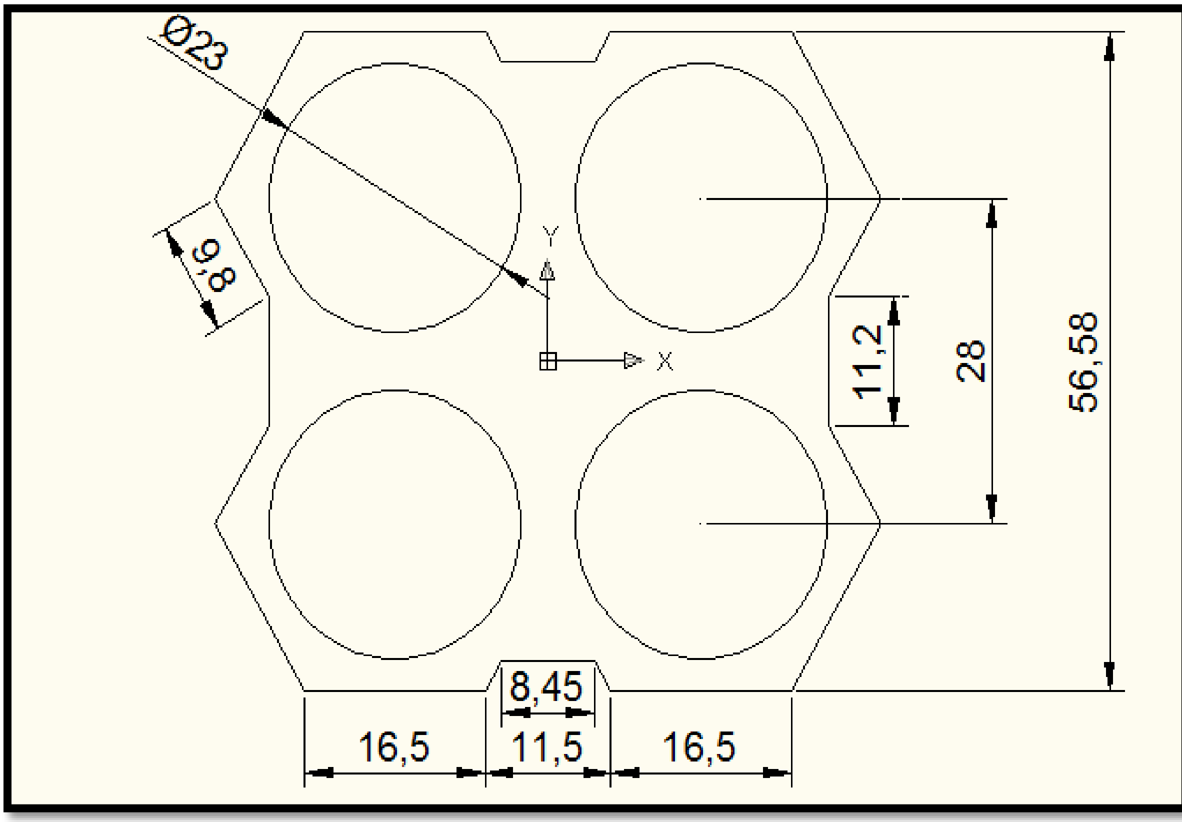
v/(nD)	1.575	v/(ΩR)	0.501	Ω*R/v	1.995		Propeller
CT	0.07087	CP	0.1333	PC	0.08691	η	0.83725


Design
Airfoils
Geometry
Modify
Multi Analysis
Single Analysis
Flow Field
Options
Enter Design Parameters and press the 'Design It!' button.
Propeller Name: GF
Number of Blades B: 2 [-]
Revolutions per minute rpm: 11100 [1/min]
Diameter D: 0.254 [m]
Spinner Dia. Dsp: 0.008 [m]
Velocity v: 74 [m/s]
Power P: 685.4 [W]
shrouded rotor
square tip
Propeller
v/(nD) 1.575 v/(ΩR) 0.501
Efficiency η 79.306 % loading low
Thrust T 7.35 N Ct 0.0422
Power P 685.39 W Cp 0.0839
Torque Q 0.59 Nm Cs 2.5853
β at 75%R 37.7° Pitch H 463 mm

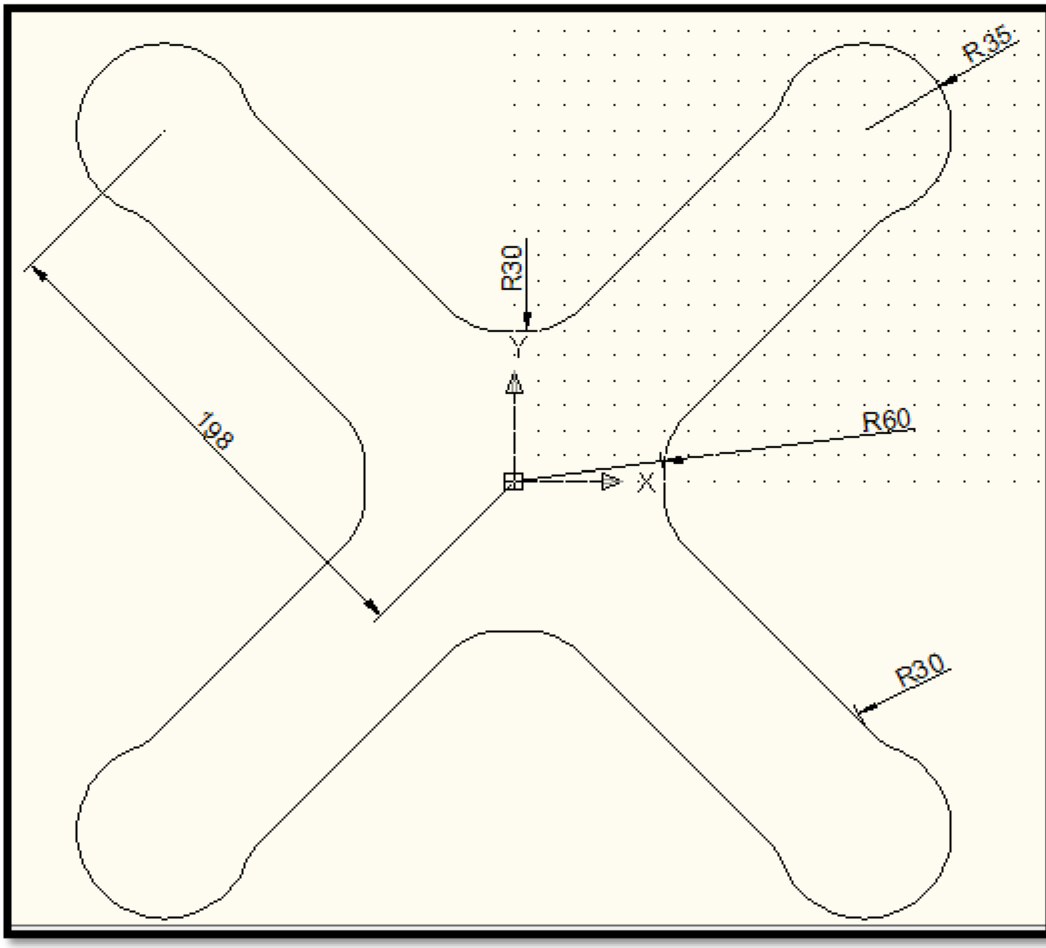

Design
Airfoils
Geometry
Modify
Multi Analysis
Single Analysis
Flow Field
Options
Adjust the desired Option(s).
JavaProp
Version 1.66 - April 19, 2015.
Copyright © 2001-2015 Martin Hepperle
• Translations
- Translation to English by Martin Hepperle, 2001.
- Translation to German by Martin Hepperle, 2001.
- Translation to French by Giorgio Toso, 2002.
- Translation to Italian by Giorgio Toso, 2002.
- Translation to Portuguese (European) by João Alveirinho Correia, 2008.
• Your current system settings
Cannot access System.Properties, probably because JavaProp is running as an Applet.
Country Settings: English (United States) (decimal character is: '.')
Density ρ: 1.2210 [kg/m³]
Kinematic Viscosity ν: 0.000014607 [m²/s]
Speed of Sound a: 340.29 [m/s]

Appendix F: AutoCAD drawing

Cover drawing



“X” frame AutoCAD drawing



Appendix G: stander atmosphere table

ALT	ALT	Temperature T, K	Pressure p, N/m2	Density ρ , kg/m3
HG , m	H, m			
0	0	288.16	1.01325 + 5	1.2250 + 0
100	100	287.51	1.0013	1.2133
200	200	286.21	9.8945 + 4	1.2071
300	300	285.56	9.7773	1.1901
400	400	284.91	9.6611	1.1787
500	500	283.61	9.5461	1.1673
600	600	282.96	9.4322	1.1560
700	700	282.31	9.3194	1.1448
800	800	281.66	9.2077	1.1337
900	900	281.01	9.0971	1.1226
1000	1000	280.36	8.9876 + 4	1.1117 + 0
1100	1100	279.71	8.8792	1.1008
1200	1200	279.06	8.7718	1.0900
1300	1300	278.41	8.6655	1.0793
1400	1400	277.76	8.5602	1.0687
1500	1500	277.11	8.4560	1.0581
1600	1600	276.46	8.3527	1.0476
1700	1700	275.81	8.2506	1.0373
1800	1800	288.16	8.1494	1.0269
1900	1900	287.51	8.0493	1.0167

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