DESIGN AND DEVELOPMENT OF HEXACOPTER FOR HEAVY PAYLOAD

Abdul Hakim, Kamarulafizam Ismail* , Fazila Mohd Zawawi

School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
81310 UTM Johor Bahru, Johor,
Malaysia

Article history
Received
9 September 2020
Received in revised form
9 December 2020
Accepted
9 December 2020
Published
15 December 2020

*Corresponding author
kamarulafizam@utm.my

ABSTRACT

This work presents a methodology of design for heavy lifting hexacopter drones. The problem of such a drone is to overcome the stability of the structure and the blade design for the drone. The main objective for this work is to design and analyze a heavy-lifting hexacopter drone structure and to measure thrust produced by the newly designed blade. Design and analysis were conducted using SOLIDWORKS, in simulating the stress and displacement of a proposed structure of the hexacopter drone. The load applied on the structure is 350N which includes the 20kg of the payload and 10kg of the total weight of the drone. The maximum stresses (Von Mises) are obtained for 1mm and 2mm aluminium frame thickness which are 17.63MPa and 13.77MPa respectively. The displacement value for 1mm and 2mm thickness which are 0.73mm and 0.40mm respectively on the arm attached to the hexagonal hub. As for the newly designed blade, the thrust test indicated the ability to achieve a maximum of 3.4kg at 1500RPM using 105KV motor.

KEYWORDS

hexacopter, heavy-lift payload, counter-rotating, tri-blade

1.0 INTRODUCTION

Unmanned aerial vehicle (UAV) commonly known as a drone is an aircraft that flieswithout a pilot. Usually, UAV or drone consist of two main parts which are a drone and a ground- based controller unit. Basically, the fundamental of the UAV is based on the idea or invention of the tesla called 'teleautomaton' during 1898 which is the first ever remote control of an automated system as to solving the complex problem of control and feedback application (Vukobratovic, 2007). Then, the wireless transmission technology rapidly grew for the use of military purposes. The flight of the UAV normally operates in various degrees of autonomy such as under remote control by human or autonomously on-board computer. When it is remotely controlled from ground it is called RPV (Remotely Piloted Vehicle) and requires reliable wireless communication for control.

UAV usually build up from composite material and very light such as carbon fiber, plastics and aluminium for their frame which can increase the maneuverability, long endurance of flight time and can fly at high altitude. The frame must be light but strong enough to withstand the downward thrust produced by the motor and the weight on the frame such as batteries, speed controller and motors. If the frame of the drone is strong but heavy, the propellers must spin faster in order to generate more lifting thrust to allow the drone to stay hover in the air. The power drained from the batteries by the motors becomes high and more energy is wasted. Therefore, the higher the payload or weight, the lower the battery's life.

2.0 DESIGN OVERVIEW

2.1 Structure of Heavy-Lifting Drone

The structure of the drone must be lightweight but strong and rigid enough to take all the stresses due to the forces produced by the propeller and the payload during the flight. The design of the drone is considering the mechanical properties of the material and mechanics of material engineering knowledge to make sure the drone body structure can take all the stresses safely.

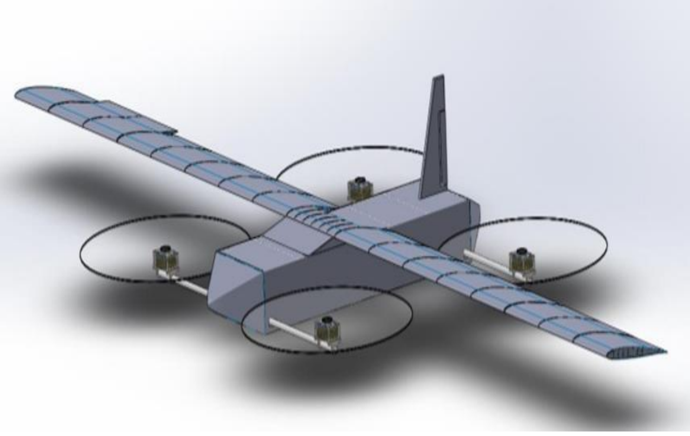


Figure 1 Tilt-wing design(Vestlund&Brynolf, n.d.)

Tilt wing UAV design (figure 1) is able to shorten the vertical flight time and at the same time it can glide while in flight. Thus, the gliding can increase the time of flight and the range drastically. The material used in this thesis comes from a company which produces high-strength carbon fiber tubes and rods as well as a 3k twill weave carbon fiber prepreg for the skin, making the structure as light and strong as possible. The total weight of the UAV is 56.6 kg which is able to carry payload at 495 kg and can perform safe glide flight. (Vestlund&Brynolf, n.d.).

2.2 Power System for UAV

Lithium-ion battery technology was developed in early1990's and enabled the portable electronics revolution. The electrical vehicles (EV) and grid storage are now adapting the lithium ion battery technology because of the rapid improvement of the lithium battery as the alternative power source today is much better. For premium application and high-performance application, lithium-ion battery technology is most suitable compare to conventional lead-acid battery technology for its higher energy density which offers longer range and endurance, other than its lightweight and super-fast charging rate. (Chipade, Abhishek, Kothari, & Chaudhari, 2018). Most of the portable devices today widely use the lithium ion battery as they are small and lightweight but can provide a large of power capacity, plus they also are rechargeable.

Figure 2 Panasonic NCR-18650GA Lithium Ion Cell.

The most common batteries are the lithium ion cell base (Figure 2) and each cell can provide 3.7V, the capacity of 3500 mAh with 10A maximum continuous discharging current output. This type of battery is widely used in Electric Vehicles.

2.3 Propulsion Design of Heavy-Lifting Drone

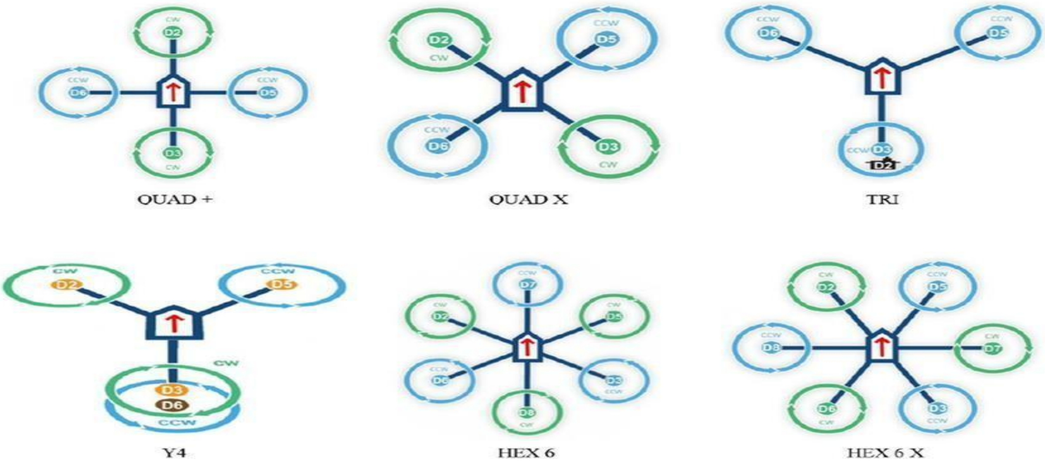


Figure 3 Basic multirotor platform configurations. (Anweiler, 2017). Multicopter platform prototype for environmental monitoring.

In this paper, HEX 6 X configuration is used for heavy lifting drone design by placing each arm with only one motor. This configuration is suitable for a single rotating propulsion system comparedto a contra-rotating propulsion system which is placing two motors on each arm. The rotation for each motor is alternated with clockwise and anticlockwise in order to eliminate the effect of the angular momentum produced from each of the motors. In HEX 6 X configuration (figure 3), the drone has 6 Degree of Freedom (DoF), where all of the 6 degrees of freedom are affected by rotational motion produced by the propeller (fixed-pitch). All six motors have different speeds in order to yaw, pitch, and roll except only for vertical hovering or during take-off.

3.1 DESIGN PROCESS AND METHODS

This section briefly explains the method that was adopted towards the design of the optimum heavy-lifting drone.

3.2 Second Moment of Area

The Second Moment of Area or Moment of Inertia about a given axis is the sum product of the area and the square of the distance from the centroid to the axis.

The second moment of area or moment of inertia (I) is determined using the following mathematical expression:

$$I_{xx} = \sum_{i=1}^{n} \bar{I}_i + Ay^2 \tag{1}$$

The second moment of area (I_{xx}) is an important figure that is used to determine the stress in a section, to calculate the resistance to buckling, and to determine the amount of deflection in a beam.

3.3 Drone arm

The arm of the drone is designed using Aluminium 6061-T6 Grade as the material is light and sufficiently strong to withstand the load applied. The aluminium arm is designed with length of 0.75m long with the thickness of 2 mm as shown in Figure 4. The length of the drone arm is designedaccording to tip to tip clearance of the blade and the angle of 60 degree for a total of six arms. The arrangement of the drone arms is 2 inches by 1 inch to obtain a larger second moment of area which reduce the bending moment of the arm.

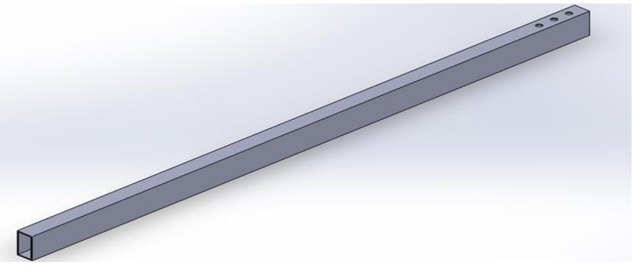


Figure 4 Drone Arm CAD Design

3.4 Rankine–Froude Theory

The propeller is designed for optimal flight endurance in both climbing and hovering modes of the drone. The design of the propeller for this research is based on the momentum theory which is well known as Rankine–Froude Theory. The propeller is modelled as the film thickness disk which is inducing a constant velocity along the axis of rotation. The drone is basically using the same concept with the helicopter which is hovering. This disc creates a flow around the rotor. Fluid relatedmathematicalmodels were used to govern the equations that connectbetween power, radius of the rotor, torque and induced velocity.

The Bernoulli Equation can be applied to the particles passed across the propeller.

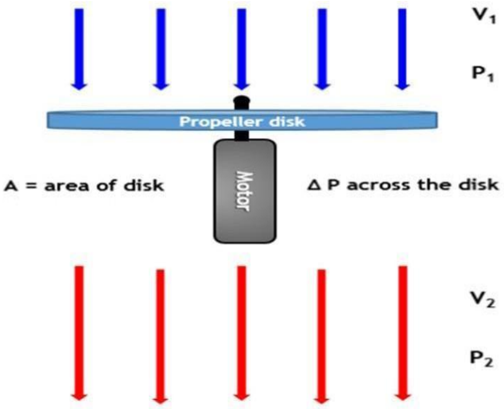


Figure 5 Diagram of air particle passing through propeller by the RC drone hub

As the Bernoulli Equation is applied between (1) to (2), the induced velocity of the air passed through the propeller can be obtained.

$$V_2 = \sqrt{\frac{T}{2\rho A}} \tag{2}$$

According to Rankine–Froude Theory, the thrust and power can be calculated through the induced velocity produced by the propeller, these two parameters are required to fly the drone. It is general analysis that links velocity of the air flow before and after the propeller to obtain thrust and power.

$$T = 2\pi R^2 \rho_{air} V^2 \tag{3}$$

Induced power is defined as the ideal power required to produce a thrust:

$$P_{ideal} = TV \tag{4}$$

The efficiency of the propeller or the Figure of Merit (FM) is a ratio between ideal power and mechanical power (actual power) consumed by the propeller during hovering:

$$FM = \frac{P_{ideal}}{P_{mec\,h}} = \frac{TV}{P_{mec\,h}} \tag{5}$$

$F_M$is range from 0 to 1, it is impossible to obtain 1 with the ideal propeller which is mean no losses. Generally, the propeller does not exceed 0.9 but all propellers are designed as close as possible to 0.9 of Figure of Merit in order to minimize losses and to maximize the power used for endurance.

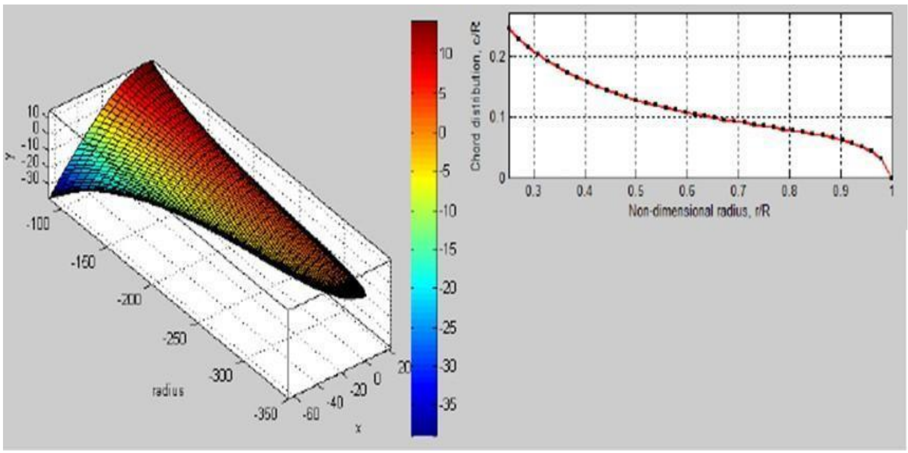


Figure 6 Blade Design Profile

The design of the blade profile was obtained from previous works of lecturer which produce through MATLAB coding as shown in Figure 6. The MATLAB-based blade design program uses the Blade Element Momentum Theory (BEMT) which requires important input parameters such as speed, diameter, angle of attack etc.

4.0 RESULTS

This section discusses the result analysis of aerodynamic performance in terms of thrust variations as well as the structural analysis in designing the optimum heavy-lifting drone.

4.1 Structure Design and Analysis

The structure of the heavy-lifting hexacopter frame consists of aluminum T-6061 material for its strength, machining ability and lightweight characteristics. A static loading analysis is done by using Finite Element Analysis (FEA) through SOLIDWORKS. The motor mount plates are fixed as rigid points (green arrow) and the hub of the drone is applied with 350 N of the load (purple arrow) as shown in Figure 7. The loading is considering the weight of the payload which is 250 N and the weight of the drone structure of 100 N.

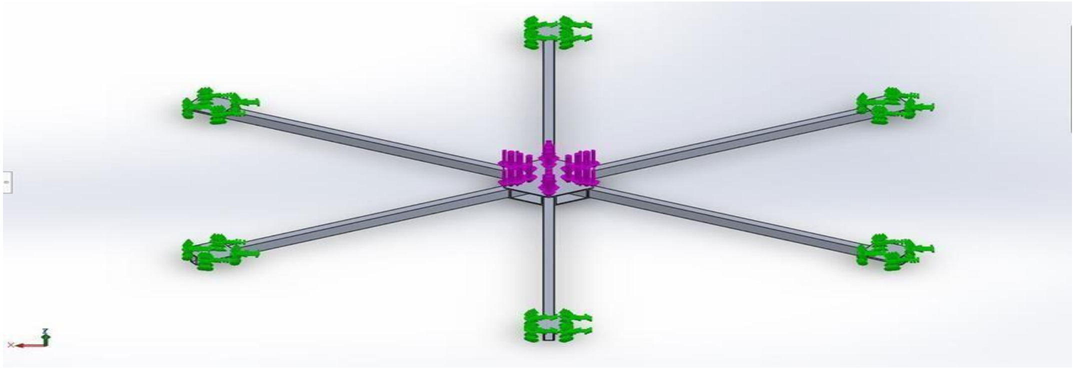
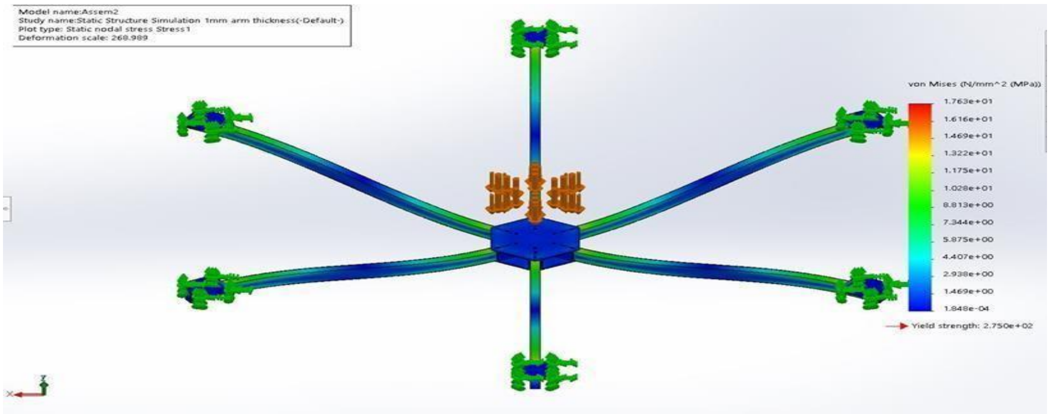


Figure 7 Applied Load on the structure.



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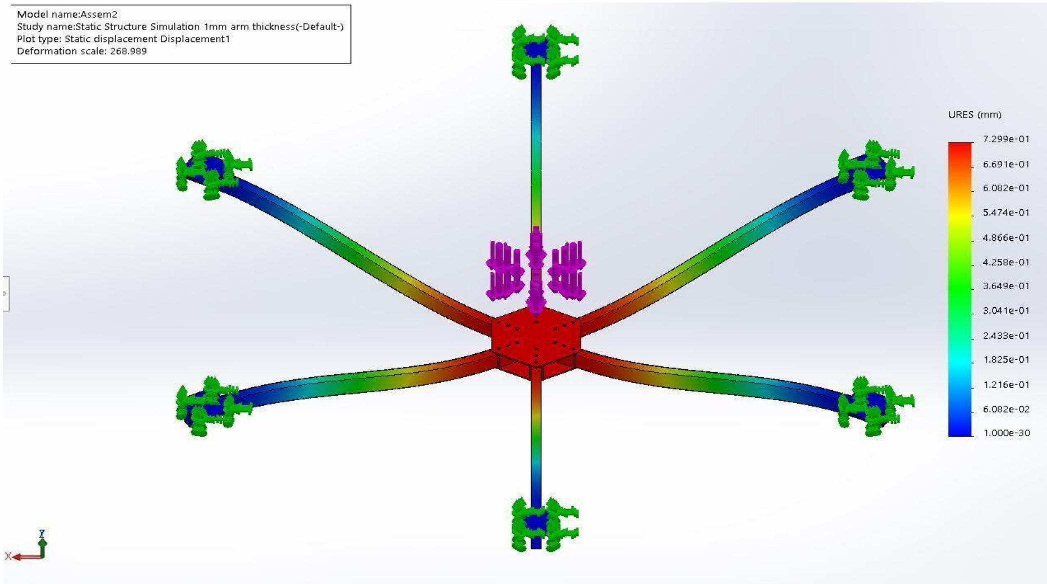
Study name:Static Structure Simulation 1mm arm thickness(-Default-)
Plot type: Static nodal stress Stress1
Deformation scale: 268.989

Figure 8 Stress Contour for 1 mm thickness arm



Model name:Assem2
Study name:Static Structure Simulation 1mm arm thickness(-Default-)
Plot type: Static displacement Displacement1
Deformation scale: 268.989

Figure 9 Displacement contour of 1 mm thickness arm.

FEA in Figure 9 indicated the value of stress and displacement of the structure. The structure of the Hexacopter is made of Aluminium 6061-T6 as designed in Figure 7. The properties of the Aluminium 6061-T6 is as shown in Table 1. The yield strength of the material is about 275 MPa. Then, Maximum von mises stress value obtained for 1mm and 2 mm thickness which are 17.63 MPa and 13.77MPa respectively. The displacement value for 1mm and 2mm thickness which are 0.73 mm and 0.40 mm respectively on the arm attached to the hexagonal hub. Thus, the structure is concluded as safe for flight with designed payload. The large difference of the maximum stress created by the loading of 350 N compared to the yield strength of the material proves that Aluminium 6061-T6 can be used safely. The stress and displacement can be seen in the color contour that there is no red region on the structure which indicates maximum stress and stress concentration point.

4.2 Thrust Test

A blade thrust test bench was developed using 10Kg rated load cells and calibrated using APC 9-inch blade. The data from the test rig is obtained and plotted show the trend of the blade performance according to the designed speed and thrust as shown in Table 1 and Figure 10: -

Table 1 Blade Performance Parameters

Speed (RPM)	Thrust (g)	Current (A)
209	131	0
408	285	0.23
629	627	0.99
811	1110	2.2
1003	2229	4.2
1200	2880	7.9
1458	3400	15

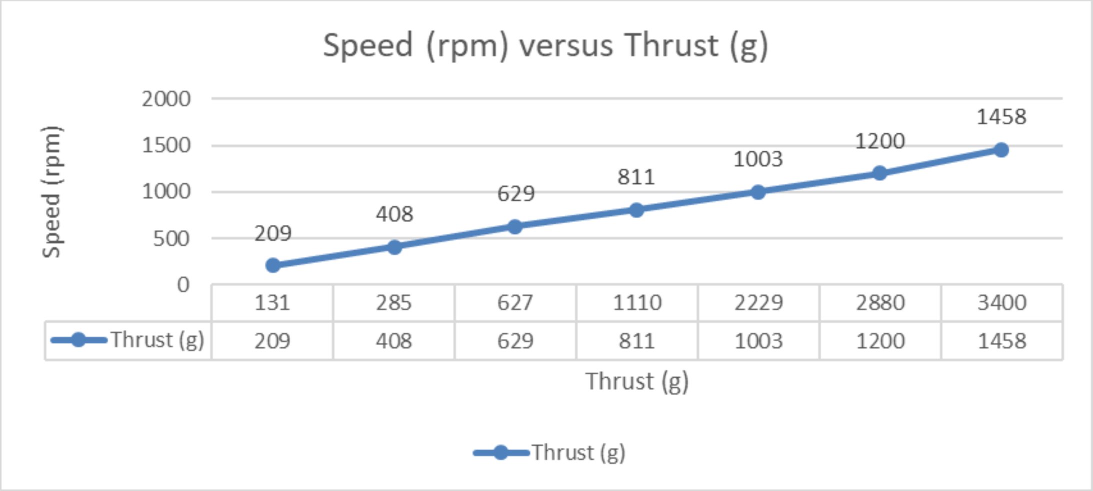


Figure 10 Speed (rpm) - Thrust (g) result

The blade is designed to produce approximately 10 kg of thrust at the designed speed of 3000 rpm. In Figure 10, the maximum speed achieved is 1500rpm using 6S LiPo batteries and the maximum thrust is 3.4 kg. Although the data of the blade performance does not achieve 10 kg of thrust at 3000 rpm, the trend of the plotted graph projected that the blade performance is according to the designed speed and thrust.

The balancing of the blade is off due to difference weight ranging from 2 grams to 4 grams each of the blade. This imbalance blade causes the rotor to vibrate during the test and the reading of the load cell is fluctuating. The hub rotor also is not perfectly concentric with the motors causing the rotor start wobbling during the high rpm testing. These problems lead to huge thrust loss during the test and can cause damage to the motor if the test is continued with the higher speed of rotation.

The voltage drops across ESC from 24 V to only 16.5 V had caused the motor to spin slower than expected which is 2520 rpm. In order to obtain the designed speed, 12S LiPo batteryis recommended which will give approximately 45 V. The motor needs about 29 V of power supply in order to achieve 3000 rpm and only then the thrust measurement of 3,000 rpm rotor can be performed.

5.0 CONCLUSION

A design and development of the hexacopter drone for heavy lifting payload with specifically designed blades was presented. The thrust gain from a single rotor is 3.4 kg of thrust. The hexacopter drone with6 rotors in total will give the maximum lifting capability at 1500 rpm is 20.4 kg including the weight of the drone. The lifting capability can be increased as the power source provided at 29 V to achieve the designed speed 3000 rpm and thrust 10 kg for each rotor which give the total of 60 kg of thrust.

Acknowledgement

This research was funded by a grant from the Ministry of Higher Education of Malaysia (GUP UTMTDR Grant Q.J130000.3551.06G08).

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